AECOM

FINAL REPORT
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Assessment of Extreme Rainfall Events in 2021

Report to Ad Hoc Committee and Board of GLWA

Great Lakes Water Authority

Project number: 60665544

June 20, 2022

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Quality information

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Revision History

Revision	Revision date	Details	Authorized	Name	Position
0	18 November 2021	Phase 1 Interim Report Released for Independent Panel Review	[signature]	Molly Page	Vice President, US West Water
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EXECUTIVE SUMMARY

In 2021, Southeast Michigan experienced two extreme rainfall events, on June 25-26 (the "June 25/26 Rainfall Event") and July 16 (the "July 16 Rainfall Event, collectively the June 25/26 Rainfall Event and July 16 Rainfall Event, are called the "June/July 2021 Rainfall Events.") The June 25/26 Rainfall Event resulted in widespread surface flooding and reported basement backups (i.e., water-in-basement) across Dearborn in the west, the southern portion of the City of Detroit, and the Grosse Pointe communities in the east. Although more localized, the July 16 Rainfall Event resulted in hundreds of basement backups. For both the June/July 2021 Rainfall Events, the preparation and response of the Great Lakes Water Authority (GLWA) was scrutinized. Particularly for the June 25/26 Rainfall Event, as it was reported that failures of some of GLWA's stormwater Pumping Station (PS) had occurred.

GLWA engaged the engineering consulting firms of Wade Trim and Brown and Caldwell on June 28 to conduct an internal investigation into the June 25/26 Rainfall Event. That investigation was later expanded to include an investigation of the July 16 Rainfall Event as well. Recognizing the need to be transparent and respond to concerns of the member communities and their residents, the Board of Directors (BoD) of GLWA engaged the engineering firms of AECOM Technical Services, Inc. (AECOM) and Applied Science, Inc. (ASI) on July 28 to conduct an independent investigation of the June/July 2021 Rainfall Events. The AECOM team was led by an Independent Panel of experts from industry and academia who directed the investigation. On December 3, 2021, the Independent Panel presented its initial findings to the BoD. That report presented the factual account of both rainfall events, GLWA's state of readiness and their operational response. The findings of both the internal and external investigations were essentially the same; therefore, the BoD directed the investigations to collaborate and develop a single Final Report. This report includes the results of the investigations; factual accounts of what occurred; and provides conclusions and recommendations to improve the reliability of the stormwater infrastructure and chart a course for future improvements.

The investigation of the June 25/26 Rainfall Event yielded several observations and conclusions. A summary of these actions is provided in Table ES-1:

Table ES-1: Observations and Conclusions for the June 25/26 Rainfall Event

Charge	Observation/Conclusion
Characterization of Rainfall Event and Extent of Flooding	• The June 25/26 Rainfall Event was a large, high-intensity storm that covered much of the GLWA wastewater service area but was most intense in a band from Inkster in the west, across the southern portions of Dearborn, the city of Detroit, and the Grosse Pointe communities generally intensifying farther to the east. • The most intense areas of rainfall received more than 6 inches of rain with some areas receiving over 8 inches of rainfall over a 24-hour period. Based on historical rainfall records, this equates to a rainfall return period of 200 years to over 1000 years. • While areas to the north and west received significant rainfall with return periods between 5 and 10 years, the rainfall event across the southern portions of the service area, particularly in the east, produced combined sewer flow rates that far exceeded the designed capacity of the wastewater system. As such, extensive surface flooding and basement backups are considered inevitable. • The City of Detroit received thousands of reported water-in-basement complaints following the June 25/26 Rainfall Event. Complaints were concentrated in areas with the highest rainfall intensities in the west bordering Dearborn and on the east side. Extensive hydraulic modeling was performed, and results of high flood risk generally coincided with the location of basement flooding complaints in Detroit. Similarly, surface flooding analyses for Detroit coincided well with observed high-water marks.

Charge	Observation/Conclusion

Operational readiness	• Following the 2016 rainfalls events, GLWA implemented several measures to improve the reliability and performance of the wastewater system. Operators were deployed to the PS and CSO facilities prior to the June 25/26 Rainfall Event in accordance with measures implemented after rainfall events in 2016. Electrical technicians floated between Freud PS and Connors Creek PS due to their proximity.
	• Wastewater operations historically evaluate their readiness level based on predicted daily rainfall. In the case of the June 25/26 Rainfall Event, the actual rainfall far exceeded weather forecasts creating a false sense of readiness. This assessment of readiness was communicated to the BoD in response to an inquiry by the BoD prior to the June 25/26 Rainfall Event.
	• At the Freud PS, electrical power supply was compromised.
	  o Prior to the June 25/26 Rainfall Event, GLWA was a DTE customer, but GLWA's power supply to this PS was provided by Detroit's PLD distribution system. Since 2014, DTE has been working with its customers, including GLWA, to convert the power supply from PLD's distribution system to DTE's distribution system.
	  o In 2017, PLD abandoned one of the three independent electrical feeds and spliced one electrical feed to power transformers 1 and 3 at the PS.
	  o On June 22, 2021, a utility contractor accidentally hit the utility service #1 distribution line (Ludden Feeder No. 208) feeding primary transformers 1 and 3 (removing them from service). The energy supplier attempted a repair of the utility service #1 but was unable to complete the repairs before the June 25/26 Rainfall Event. With two of three transformers out of service, the PS's peak pumping capacity was only approximately 43% of the overall capacity during the event (three of seven duty storm pumps available). This was considered sufficient for the forecasted rainfall.
	  o Consistent with SOP, the hit line was communicated to the SCC supervisor. The supervisor did not communicate the damaged line to GLWA executive leadership nor the BoD.
	  o With only one primary transformer available, there was enough electrical capacity to operate three storm pumps and two sanitary pumps.
	• At the Connors Creek PS, all storm pump systems, except Storm Pump 5, checked out available prior to the June 25/26 Rainfall Event.
	• At the Bluehill PS:
	  o Under normal conditions, the PS is operated remotely by the operators at the SCC. Operators visit the PS to perform routine preventive maintenance duties. During storm events, staff operators are dispatched if the automated systems indicate a fault at the PS.
	  o All equipment was available for service; however, Storm Pump #4 was marked for emergency use only.
	  o At the time of the June 25/26 Rainfall Event, electrical power was supplied through PLD's distribution system and provided via two separate 24kV utility services to provide a level of utility redundancy. The PS has two GLWA-operated primary transformers, each sized to power any three of the four storm pumps. Therefore, the capacity of the primary transformers prevents full electrical redundancy. One of the power sources is backed up by three 1,825 kW emergency generators. There are no provisions to connect the emergency generators to back up utility service 2.
	  o According to the current O&M manual, hydraulic restrictions downstream of the PS limit operation to only three of four pumps. The investigation noted that four pumps did operate briefly, so further investigation is recommended.

Charge	Observation/Conclusion
System response	• At the Freud PS: ○ Power issues related to only one transformer being available resulted in only two pumps operating consistently. Attempting to start a third pump tripped out the operating two pumps. High normal wet well levels were exceeded before 11 p.m. and continued to rise. Operators were eventually able to start three pumps and, with five pumps then operating at Connors Creek PS (see below), wet well levels gradually subsided. • At the Connors Creek PS: ○ The elevation and configuration of the storm pumps requires the operation of a vacuum priming system prior to starting the storm pumps. This system has historically been complex to operate; vacuum priming takes 15 to 20 minutes per pump, and the seal water capacity allows only two storm pumps to be started simultaneously. The stormwater pumping system response does not keep pace with rapid increases in wet well levels, due to the time required for priming prior to starting pumps. ○ For the June 25/26 Rainfall Event, the rate of rise of wet well levels was fast and the operators could not start additional pumps fast enough to respond. ○ Operators were able to initially start two pumps, but a leak from the vacuum priming system sprayed on an electrical panel causing a loss of house power, including the lighting system. Electrical supply to the PS was not impacted and the two pumps continued to operate, but additional pumps could not be started. The wet well elevation before midnight was already above 86 feet (i.e., the maximum recordable level). ○ Electricians dispatched to the Freud PS were recalled to Connors Creek PS to perform repairs, but street flooding and lack of lighting or ability to access the site (security gates operate on house power) hampered these efforts. This delay is estimated at 15 to 30 minutes with the wet well level remaining above 86 feet. When house power was restored, five pumps were able to operate and began to reduce wet well levels and shortly after 2 a.m., dropped to within recordable range. • At the Bluehill PS: ○ Experienced power quality issues from PLD's distribution system. Voltages plus/minus 10% of rated voltage will cause a pump not to start. The PS operated with two of the four available storm pumps during the peak of the June 25/26 Rainfall Event and the wet well level reached the maximum recordable level (approximately 86 feet). • Local System Response: ○ Detailed reviews of the response of member communities was beyond the scope of this investigation; however, the investigation found: ▪ Peak flow measurements of discharges suggest that most communities were at or below their contracted discharges limits within the exception of the Cities of Grosse Pointe Park and Grosse Pointe, which significantly exceeded their contract limits. ▪ SEMSD operated for extended periods beyond their contract capacity, Dearborn, Grosse Pointe Farms and the flow in other districts were impacted by the surcharged condition of the GLWA system during the height of the storm. ▪ Accounts of local system response are included in the ASI report (Appendix A9)

Charge	Observation/Conclusion
System Response if Everything had worked as intended	• The intensity of the rainfall far exceeded the designed capacity of the wastewater system and, as a result, some level of both surface flooding and basement backups was unavoidable. • Modeling suggests an additional 336 MG (or 26%) of total flow could have been pumped had everything operated as intended and wet well levels at the Connors and Freud PS would have been approximately 7 feet lower. • An analysis of risk of basement backups did not show an appreciable reduction in risk if everything had worked as intended. • Surface flooding would have been reduced, but not eliminated. For example, the areas that experienced surface flooding greater than 2 feet could have been reduced by approximately 110 acres. • GLWA customer contract limit exceedances that occurred during the June 25/26 Rainfall Event did not significantly affect basement backup flooding. • The above suggests that conveyance capacity in the collection system, not pumping, was the primary cause of flood risk and additional pumping capacity would not appreciably reduce the risk of surface flooding and basement backups. Rather, a strategic assessment of conveyance improvements, inlet controls and in-system storage is warranted.

Notes:
BoD = Board of Directors
DTE = DTE Energy
kV = kilovolt
kW = kilowatt
MG = million gallons
O&M = operations and maintenance
PLD = Public Lighting Department
PS = Pumping Station
SCC = Systems Control Center
SEMSD = Southeast Macomb Sanitary District
SOP = Standard Operating Procedure

The investigation of the July 16 Rainfall Event yielded several observations and conclusions. A summary of these conclusions is provided in Table ES-2:

Table ES-2: Observations and Conclusions for the July 16 Rainfall Event

Charge	Observation/Conclusion
Characterization of Rainfall Event and Extent of Flooding	• While smaller than the June 25/26 Rainfall Event, the July 16 Rainfall Event was still a large, high-intensity storm that covered much of the GLWA wastewater service area. The storm was most concentrated in the southeast portions of Dearborn, the city of Detroit, and the Grosse Pointe communities and generally intensified farther to the east. • Maximum accumulated depth of 4.7 inches over 12 hours was observed, representing a rainfall return period of 100 years to 300 years. • Areas to the north generally experienced less than 5-year rainfall, while Dearborn and the south-central part of Detroit saw rainfall in the 10 to 50 year range. Because the storm exceeded the designed capacity of the wastewater system, localized surface flooding and risk of basement backups could be expected. Areas experiencing greater than 100 year intensities would certainly incur flooding and basement backups based on local hydraulic conditions. • The City of Detroit received hundreds of water-in-basement complaints following the July 16 Rainfall Event; however, the number of complaints was far fewer than the June 25/26 Rainfall Event. Complaints in Detroit were concentrated in the east and south, including the neighborhoods of Jefferson Chalmers and Cornerstone Village.

Charge	Observation/Conclusion

Operational readiness	• Operators were deployed to the PS and CSO facilities prior to the July 16 Rainfall Event.
	• At the Freud PS, three storm pumps were not available (one with warranty issues and two with electrical issues) leaving five pumps available for service.
	• At the Connors Creek PS, all storm pump systems, except Storm Pump 1, checked out available prior to the July 16 Rainfall Event.
	• At the Bluehill PS:
	  ○ Under normal conditions, the PS is operated remotely by the operators at the SCC. Operators visit the PS to perform routine preventive maintenance duties.
	  ○ The Bluehill PS was staffed prior to the July 16 Rainfall Event.
	  ○ Based on the operator logbook, all systems appear to have been available at the time, however, Storm Pump #4 was marked for emergency use only.

System response	• At the Freud PS:
	  ○ External power quality issues were observed but did not significantly impact operations. Repairs to the main electrical feed lines to the Freud PS were completed prior to the July 16 Rainfall Event.
	  ○ Four storm pumps were operated continuously over the event and a fifth pump was started and ran for approximately 2 hours from 2 p.m. to 4 p.m.
	  ○ Wet well levels peaked slightly above the maximum normal wet well elevation, but quickly subsided and wet well levels continued to drop during the normal pump shutdown process.
	• At the Connors Creek PS:
	  ○ The investigation did not reveal any equipment issues and up to six storm pumps were operated simultaneously during the event.
	  ○ Water levels in the wet well remained well below the normal maximum wet well elevation.
	• The Bluehill PS experienced power quality issues that did not allow all available pumps to operate or delayed their operation as operators attempted to supplement with on-site generators:
	  ○ Throughout most of the July 16 Rainfall Event only one pump operated, and wet well levels surpassed the normal high water level between approximately 10:30 a.m. and 2:00 p.m. During this time, wet well levels remained above the maximum recordable level of about 86 feet.
	  ○ By 2 p.m., operators were able to first start one small pump and then an additional large pump resulting in water levels in the wet well quickly dropping within range.
	  ○ Operational issues continued, but wet well levels remained within normal limits.
	  ○ While detailed analysis and modeling of DWSD's local collection system was beyond the scope of this investigation, it is reasonable to anticipate that surcharging of the local collection system would have occurred.
	• Modeling results did not indicate any areas in Detroit with significant surface flooding during the July 16, 2021 Rainfall Event.
	• 350 basement backup complaints provided by GLWA were reviewed and none of those reported significant surface flooding.
	• Surface flooding in Dearborn and areas of the Grosse Pointe communities could not be simulated because those sewer systems are not included in sufficient detail in the model.
	• The GLWA PC SWMM model was used to assess the risk of basement backup and over 6900 acres was estimated as having significant flood risk.
	• There are reports of basement flooding in locations in Detroit where the model results show low probability of basement backups. These instances of basement backups may have been caused by issues in the local and/or property owners sewer systems not included in the PC SWMM model.

Charge	Observation/Conclusion
System Response if Everything had worked as intended	• The intensity of the rainfall exceeded the designed capacity of the wastewater system in some areas and, in those areas, basement backups were reported. • The Connors Creek and Freud PSs operated as intended and no surface flooding was observed. Despite this, numerous basement backups were reported in the Jefferson Chalmers area, suggesting local conveyance issues/restrictions may be present. • Power quality issues at the Bluehill PS delayed the necessary starting of storm pumps, which resulted in high water levels in the PS and likely surcharge of the local upstream collection system. It is not known whether local basement flooding complaints could have been reduced if the system has operated as intended.

Notes:
CSO = Combined Sewer Overflow
DWSD = Detroit Water and Sewerage Department
GLWA = Great Lakes Water Authority
PS = Pumping Station
SCC = Systems Control Center

A summary of the following recommendations is provided in Table ES-3 and detailed in Section 4. Recommendations are structured in short-/medium-/long-term timeframes with short-term recommendations generally focused on measures to improve availability and reliability of existing infrastructure, medium term measures to retrofit and improve infrastructure performance, and long-term measures to investigate and develop policies and direction to maximize level of service. Many measures can be undertaken by GLWA internally; a preliminary cost estimate is provided for recommended capital works. It should be noted that significant detail has been omitted from this table; therefore, the reader is encouraged to review the appropriate report section (Section 4.1.2) to better understand each recommendation.

Table ES-3: Summary of Recommendations and Estimated Capital Cost

Category (Subheading)	Summary	Preliminary Cost Estimate
Short Term (approximately 12 to 18 months)		
General (4.1.1)	Take measures to reduce basement backups. Maintain a level of service of at least 14 of 16 storm pumps at Connors Creek and Freud PS and at least 3 of 4 storm pumps at Bluehill PS. Be ready for extreme storms at all times not just when predicted.	
PS (4.1.2)	Conduct tests on vacuum priming system and pump starting at Connors Creek PS to improve system reliability and to provide operator training opportunities. Develop, improve and document operational measures. Regularly use Connors Creek PS in wet weather and maintain the vacuum priming systems after a large storm events to improve system readiness and enhance operator training.	
Electrical Systems (4.1.3)	Transfer power sources to DTE. Provide capability for emergency generators to be connected to any section of the switchgear to enable generators to power any group of pumps. Develop protocols to operate generators at no-load prior to expected events to enable the pumps to be quickly switched to generator power if there is an outage.	
Mechanical Systems (4.1.4)	Make improvements to seal water and vacuum priming systems. Keep the Connors Creek storage gates and relief gates at the CSO Basins in good working order.	

Category (Subheading)	Summary	Preliminary Cost Estimate
Medium Term (approximately 2 to 5 years)		
General (4.2.1)	Define level of service objectives with respect to flooding and water quality and implications of water quality requirements. Investigate how those objectives have been achieved previously.	
PS (4.2.2)	Implement modifications to the “Freud Pump Station Improvements – DRAFT” report prepared by Arcadis/Brown and Caldwell for GLWA project number CS-120 in August 2020	
Electrical Systems (4.2.3)	Provide for a policy for redundant PS power sources and perform studies to understand existing and potential power source redundancy.	
Mechanical Systems (4.2.4)	Implement intake flow conditioning devices at Connors Creek PS and Freud PS wet wells based on testing and recommendations from the February 2018 Clemson Engineering Hydraulics, Inc. study. Also, replace two storm pumps with vertically suspended pumps at Connors Creek PS. Expand and improve the Connors Creek PS seal water system.	$16M for IFC devices $19.5M for VS3i pumps
Operational Measures (4.2.5)	Operate and inspect IFC devices. Regularly clean the Connors Creek Storm wet well and IFC devices.	
Additional Investigation/Studies (4.2.6)	Review existing studies with consideration of flooding and water quality objectives. Conduct additional studies to understand flooding and water quality level of service and optimize system operations using “real-time” data. Consider different operating procedures for extreme storms that maximizes conveyance but may increase CSOs.	
Long Term (more than 5 years)		
General (4.3.1)	Consider implementing comprehensive policies and practices that address the frequency and extent of flood losses.	
PS (4.3.2)	Make additional PS modifications at the Connors Creek PS based on performance of medium-term recommendations, including replacing the remaining six storm pumps and constructing access and screening improvements in lieu of building a new pumping station.	
Regional Coordination		
General (4.4)	Foster regional coordination. Various recommendations generally intended to reduce future flood damages and requiring regional coordination to implement.	

Notes:
CSO = Combined Sewer Overflow
DTE = DTE Energy
IFC = intake flow conditioning
PS = Pumping Station

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Figures

Tables

Acronyms and Abbreviations

1D	one-dimensional
2D	two-dimensional
AACE	American Association of Cost Engineering
ADA	Americans with Disabilites Act
AECOM	AECOM Technical Services, Inc.
ANSI	American National Standards Institute
AOI	Area of Interest
ASI	Applied Science, Inc.
BoD	Board of Directors
CCE	Connors Creek Enclosure
CEH	Clemson Engineering Hydraulics, Inc.
cfs	cubic feet per second
CSO	combined sewer overflow
CWA	Clean Water Act
CWSRF	Clean Water State Revolving Fund
DRI	Detroit River Interceptor
DTE	DTE Energy
DWSD	Detroit Water and Sewerage Department
DWSRF	Drinking Water State Revolving Fund
EGLE	Department of Environment, Great Lakes, and Energy
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FY	fiscal year
GDRSS	Greater Detroit Regional Sewer System
GLWA	Great Lakes Water Authority
gpm	gallons per minute
HI	Hydraulic Institute
IDF	Intensity, Duration, and Frequency
IFC	intake flow conditioning
IIJA	Infrastructure Investment and Jobs Act
ITA	intent to apply
Lidar	light detection and ranging
MCC	motor control center
MDI	Mersino Dewatering, Inc.
MDOT	Michigan Department of Transportation
MG	million gallons
MRIDDD	Milk River Intercounty Drain Drainage District
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PLD	Public Lighting Department
RFQ	Request for Quotation
RTB	retention treatment basin
RWCS	Regional Wastewater Collection System
SCADA	supervisory control and data acquisition

SCC	Systems Control Center
SEMSD	Southeast Macomb Sanitary District
SOP	Standard Operating Procedure
SRF	State Revolving Fund
SWIFIA	State Water Infrastructure Finance Innovation Act
US	United States
USACE	US Army Corps of Engineers
V	volt(s)
WIFIA	Water Infrastructure Finance and Innovation Act
WRRF	Water Resource Recovery Facility

1. Introduction

1.1 Background

The Great Lakes Water Authority (GLWA) provides water supply and sewerage disposal wastewater services to wholesale customers in much of Southeast Michigan. GLWA operates and maintains the major wastewater conveyance system including relief sewers, pumping stations (PSs), combined sewer overflow (CSO) facilities, outfalls, and large interceptors leading to the Water Resource Recovery Facility (WRRF).

On the evening of June 25, 2021, an extreme rainfall event occurred over parts of Southeast Michigan (the June 25/26 Rainfall Event). The June 25/26 Rainfall Event resulted in electrical power interruptions, localized surface flooding and basement backups and posed challenges to operating agencies responsible for delivering essential services. While previous extreme rainfall events have occurred in the area (including storms in 2016), these events are suspected of becoming more frequent and more intense. In fact, a storm on July 16, 2021 resulted in flooding and additional basement flooding reports (the July 16 Rainfall Event; collectively the June 25/26 Rainfall Event and July 16 Rainfall Event, [i.e., the June/July 2021 Rainfall Events]). Detailed information regarding these rainfall events is provided in this report.

1.2 Investigative Team

On June 28, 2021, Sue McCormick, GLWA's Chief Executive Officer (now retired), launched an internal investigation into the June 25/26 Rainfall Event and investigation was subsequently expanded to include the July 16 Rainfall Event (the June/July 2021 Rain Events). GLWA retained Wade Trim and Brown and Caldwell to complete that investigation.

On July 28, 2021, the GLWA Board of Directors (BoD) selected AECOM Technical Services, Inc. (AECOM) and Jeffery G. Collins, Esq. to conduct an independent investigation of the June/July 2021 Rainfall Events. The AECOM Technical Services, Inc. (AECOM) team was directed by an Independent Panel of relevant subject matter experts who established the overall direction for the assessment, with technical support provided by AECOM. Professor Glen T. Daigger, Ph.D., P.E. of the University of Michigan was selected to serve as principal investigator and chair of the Independent Panel. Devan Thomas, P.Eng., M. ASCE, of AECOM served as team manager, while Beverley Stinson, Ph.D. of AECOM served as executive advisor. The firm of Applied Science, Inc. (ASI)—specifically Karen E. Ridgeway, P.E., president—was retained by GLWA at the request of BoD to: (1) assemble background information for AECOM; (2) request, review and provide data to AECOM; (3) assist in GLWA staff interviews; and (4) review findings and recommendations. The AECOM team and the Independent Panel reported to the GLWA BoD through outside attorney Jeffrey G. Collins, collinslegal.

The following individuals were selected to serve on the Independent Panel:

- Glen T. Daigger, Ph.D., P.E., University of Michigan, Chair
- Paul W. Behnke, P.E., Behnke Pump Technologies, LLC, Pumping Systems
- Jonathan Jones, P.E., P.H., D.WRE, Wright Water Engineers, Flooding. Mr. Jones was supported by Chris Olson, Ph.D., PE.
- Salil Kharkar, P.E., CMRP, DC Water, Senior Technical Advisor to Chief Operating Officer
- Melanie Kueber Watkins, Ph.D., P.E. Michigan Technological University, Flooding and System Modeling
- Johanna Mathieu, Ph.D., University of Michigan, Electrical and Controls

Resumes for the Independent Panel members are provided in Appendix E.

On November 18, 2021, the GLWA BoD passed a Resolution authorizing the independent investigation team and the internal investigation team to collaborate on a report related to the June/July 2021 Rainfall Events. Since the directive, the teams completed a series of meetings. During these meetings, the parties discussed their respective findings. While the investigations were conducted separately, both internal and external investigations arrived at essentially the same conclusions and Sections 2 and 3 of this report represent that collaborative effort. The findings of the AECOM team, Wade Trim, and Brown and Caldwell were then reviewed and compiled by the Independent Panel in developing the final version of this report. Section 4, Recommendations and Funding Sources, was prepared by the Independent Panel.

1.3 Organization of Report

Following their July 28, 2021 meeting, GLWA provided a high-level scope of work to AECOM. This scope was combined with the strategy proposed by AECOM a presentation on July 26, 2021 and a series of key charges (i.e., key questions to be answered by the investigation) were formulated and formed the basis of the investigation. The key charges of the BoD are as follows:

1. Determine the operational readiness of the Connors Creek, Freud, and Bluehill PS leading up to and through the June/July 2021 Rainfall Events.
2. Determine the sequence of events occurring during the June/July 2021 Rainfall Events.
3. Determine the status of recommendations made to GLWA in response to earlier flooding events.
4. Determine the interrelationship between the operation of the local collection systems tributary to the Connors Creek, Freud, and Bluehill PSs and their impact on those PSs.
5. Identify physical and operational improvements that can be made to the Connors Creek, Freud, Bluehill, and Fairview PSs to increase their performance reliability and resilience in response to extreme weather events.
6. Identify methods to maximize the performance of existing and currently planned GLWA infrastructure during extreme weather events.
7. In general, determine the extent of flooding associated with the GLWA and DWSD collection systems during the June/July 2021 Rainfall Events.
8. In general, determine the reduction in flooding associated with the GLWA and DWSD collections systems during the June/July 2021 Rainfall Events if the Connors Creek, Freud, and Bluehill PSs had functioned as intended.
9. Identify steps that GLWA can take in addition to those to be identified above to increase the level of flood protection service provided, including not only those by GLWA but also other regional partners.
10. Identify sources of funding for actions such as those to be identified above.

This report presents the key findings per the above-noted charges for the June 25/26 Rainfall Event (Section 2), the July 16 Rainfall Event (Section 3), and the resulting conclusions, recommendations and funding sources (Section 4). The report includes several appendices that provide details of the investigation and analyses performed.

This is the Final Report on the June/July 2021 Rainfall Events and includes recommendations to make the regional sewer system more resilient.

2. June 25/26 Rainfall Event

2.1 Summary of June 25/26 Rainfall Event

The intensity and duration of the rainfall made basement and surface flooding inevitable during the June 25/26 Rainfall Event in Southeast Michigan.

The size of the June 25/26 Rainfall Event created peak wet weather flows that exceeded the design capacities of the regional wastewater collection system, local sewer systems and individual property owner's sewerage and drainage systems.

Except for in limited areas in the city of Detroit, GLWA's investigation did not focus on the rain event's impact on the local sewerage and drainage systems or that of property owners.

For the eastern portion of GLWA's system, the investigations revealed the reduced number of storm pumps available to operate during the June 25/26 Rainfall Event at the Freud PS and the temporary loss of house power at the Connors Creek PS may have exacerbated the flooding in the upstream tributary areas.

For the western portion of GLWA's system, the Baby Creek Enclosure Sewer downstream of the CSO Screening/Disinfection facility, reduced outfall capacity due to sludge deposition has been identified as an issue that increased upstream wastewater levels during peak flow conditions and exacerbated flooding.

Flooding was so widespread that President Joe Biden declared a major disaster in Wayne, Oakland, Macomb, and Washtenaw counties. As of June 17, 2022, the major disaster declaration resulted in the Federal Emergency Management Agency (FEMA) approving over 56,437 applications for assistance, totaling $191,985,161.90 in aid.

The size of the June 25/26 Rain Event was larger than the design capacity of the regional system, and likely the design capacities of local systems and individual property owner's drainage systems. Except for limited instances in the city of Detroit, GLWA's investigation did not focus on the rain event's impact on the local systems or that of property owners. It is quite possible that conditions in local systems and/or on specific parcels also exacerbated the inevitable flooding.

For GLWA's system, the investigations revealed the availability of storm pumps at the Freud PS and the temporary loss of house power at the Connors Creek PS, out of service In-System Gates in the Connors Creek Sewer, and solids deposits at Baby Creek CSO facility may have exacerbated flooding in their tributary areas but was not the primary cause of the flooding.

2.2 Operational Readiness

This section details the findings of what equipment was available to be operated as a matter of fact and provides an account of the operational preparation and the operators' perceived level of readiness for the June 25/26 Rainfall Event. In addition, the section provides a broad overview of the East Side System and three PSs (Connors Creek, Freud, and Bluehill PSs), along with the operational readiness of the facilities in terms of personnel and equipment. This section establishes what equipment was available to be operated. In addition, this section provides an account of the operational preparation and the operators' perceived level of readiness for the anticipated wet weather event.

2.2.1 East Side System

The GLWA provides wastewater collection and treatment services to 79 communities in southeast Michigan. The GLWA service area is shown in Figure 1 and covers communities in Wayne, Oakland, and Macomb counties.

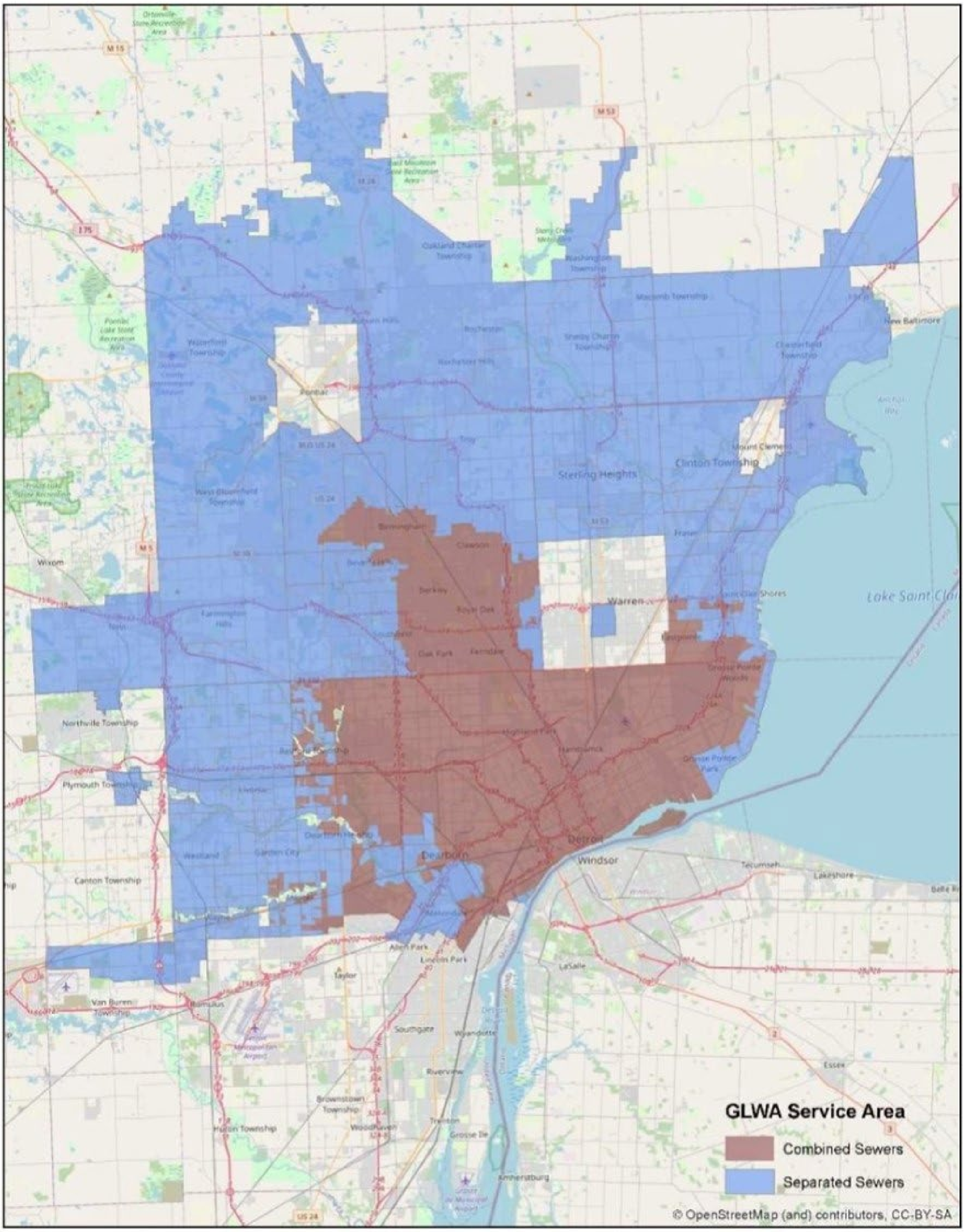


Figure 1: GLWA Wastewater Service Area

In general, GLWA leases, operates, and maintains the larger downstream assets; the upstream smaller assets are maintained by the communities. Improvements to the GLWA assets may not reduce surcharging or flooding without comparable improvements to the local assets.

The portion of the GLWA system that is a tributary to the Connors Creek, Freud, and Bluehill PSs[1] is referred to as the "East Side" System. Customers to the East Side System include Detroit; the Southeast Macomb Sanitary District (SEMSD); the Grosse Pointe communities; Grosse Pointe Farms and Grosse Pointe Park; and Milk River Intercounty Drain Drainage District (MRIDDD.

While some customers convey combined flows to the GLWA system, most customers have separate storm and sanitary sewers that only discharge sanitary flows to the GLWA system. Flows are conveyed from those customers to the GLWA PSs through several different GLWA sewers and interceptors. Some customers' system flows are conveyed to the GLWA system via gravity and others are pumped into the GLWA system via non-GLWA owned/operated PS. GLWA has contract limits with some customers to limit the rate of pumped discharges into the GLWA system. In addition, some customers with combined sewer systems also have retention/treatment basins that are used to control the discharge of wet weather flows to receiving waters. For these customers, the retained wastewater is dewatered to GLWA with flow rates within their contract limits.

To better understand the operational readiness, an illustration of the East Side System and the interconnections between these PSs is shown schematically in Figure 2 and Figure 3.

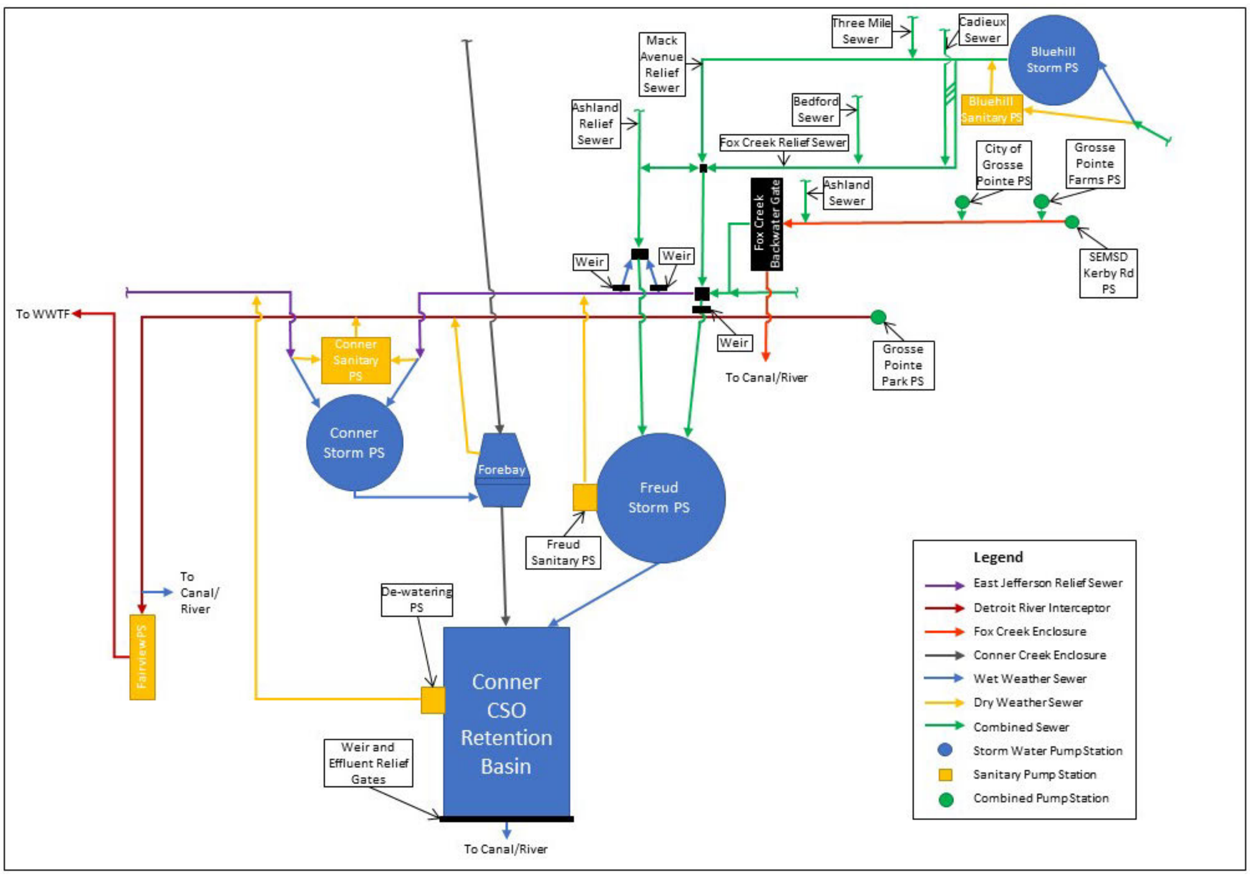


Figure 2: East Side Detroit Collection System Facilities Schematic

[1] Bluehill is a DWSD PS that GLWA operates and maintains pursuant to the Shared Services Agreement.

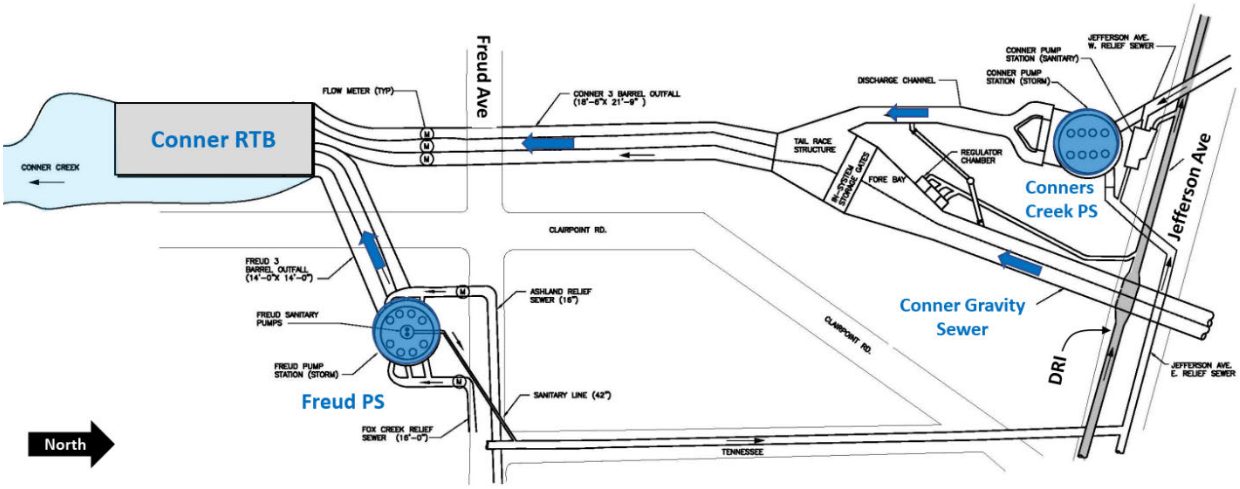


Figure 3: Connors Creek CSO Control Facility Influent System

The operational readiness of each station for the June 25/26 Rainfall Event is discussed in the following sections.

2.2.2 Connors Creek PS (GLWA)

System Description

The Connors Creek PS receives combined sewage from the East Jefferson Relief Sewer. Dry weather flow is pumped via four sanitary pumps to the Detroit River Interceptor (DRI). Wet weather flow is pumped via eight storm pumps rated at 500 cubic feet per second (cfs) each to the Connors Creek CSO Control Facility. The stormwater PS was constructed in 1929; the sanitary PS was added in around 1960.

The stormwater pumps at the Connors Creek PS require vacuum priming to operate. The stormwater pumps provide lift to a syphon and the discharged stormwater then flows by gravity to the Connors Creek CSO Facility.

The stormwater pumps have been rarely operated and generally have low run times (the last impeller rehabilitation was in 1987). Based on operator interviews, storm pumps 3, 5, and 8 are most frequently used due to being easier to prime and initiate operation.

Electrical power at the Connors Creek PS is provided via two separate DTE Energy (DTE) 24 kilovolt (kV) trunk line utility services to provide a level of utility redundancy. The two DTE services power two GLWA-operated primary transformers; each transformer is sized to power four of the eight storm pumps. Therefore, the capacity of the primary transformers prevents full redundancy to power all storm pumps from a single transformer. The two services allow the PS to operate at half capacity if one transformer is down (and the emergency generators are not running or are not connected to the downed service).

Four emergency generators are connected to one utility service. The generators are not configured to power both primary transformers; only transformer 2. The emergency generators start automatically during a utility power outage to transformer 2 and are sized to power a maximum of two storm pumps. Therefore, if power is lost to transformer 1, the generators will not automatically start and cannot power additional pumps over the capacity of the transformer 2, even if the generators are started manually since they do not have synchronizing equipment to allow both generators and utility to power bus no. 2.

The operational readiness of the stormwater pumps with different scenarios of transformer/utility and generator system availability is shown in Figure 4.

Scenarios No.	Description	Transformer No.1	Transformer No.2	Generator System	Maximum Storm Pumps That Can Be Operated
1	Two transformers are powered ON (Generator not Needed)	✓	✓	Not Needed	All Pumps
2	Only transformer 1 is powered ON (Generator Offline)	✓	✗	✗	4
3	Only transformer 1 is powered ON (Generator Online)	✓	✗	✓	6
4	Only transformer 2 is powered ON	✗	✓	N/A	4
5	Two transformers are powered OFF (Generator Online)	✗	✗	✓	2

Notes:
1. *Each transformer is sized at 10 MVA.*
2. *Generator system consists of four 2 MW units.*
3. *Each single transformer can only run a maximum of four storm pumps.*
4. *The generator system configured and connected to only backup the loss of transformer 2.*
5. *The generator system can only run a maximum of two storm pumps.*

Legend: ✓ *Powered ON* ✗ *Powered OFF*

Figure 4: Connors Creek PS Electrical Power Failure/Operational Scenarios

Under normal conditions, the sanitary pumps at the PS are operated remotely by the operators at the Systems Control Center [SCC]. During storms that are forecasted to have at least 1.5 inches of rain, the field operations staff are scheduled to be on site and local manual operation is performed. Based on their experience, GLWA reports that for rainfall events smaller than 1.5 inches, there has been no need to operate the Connors Creek PS storm pumps because the Freud PS storm pumps have been sufficient to handle wet weather flow rates. Additional details about the Connors Creek PS are provided in Appendix A3.3.1.

Operational Readiness—June 25/26 Rainfall Event

The Connors Creek PS was staffed prior to the June 25/26 Rainfall Event. A mechanical team was on-site prior to the June 25/26 Rainfall Event and checked out the mechanical systems, including the vacuum priming systems. All systems (except Storm Pump 5) checked out available at the time. A summary of the operational readiness of major system components at the Connors Creek PS prior to the June 25/26 Rainfall Event is provided in Table 1.

Table 1: Equipment Availability at Connors Creek PS prior to the June 25/26 Rainfall Event

Major System	Component	Availability Yes	No	Comments
Mechanical	Storm Pump 1	X		
	Storm Pump 2	X		
	Storm Pump 3	X		
	Storm Pump 4	X		
	Storm Pump 5		X	“Malfunctioning 4-way on vacuum prime valve #1. Instrumentation is going to address. Also – Allen-Bradly display panels are displaying “????” instead of values.’[1]
	Storm Pump 6	X		
	Storm Pump 7	X		
	Storm Pump 8	X		
	Sanitary Pump 9	X		
	Sanitary Pump 10		X	SN10: Packing gland[1,2]
	Sanitary Pump 11	X		SN11: Local operation only[2,3]

Major System	Component	Availability Yes	No	Comments
	Sanitary Pump 12	X		SN12: Emergency use only[2,3]
Electrical	Utility Service 1	X		
	Utility Service 2	X		
	Transformer 1	X		
	Transformer 2	X		
	Emergency Generator 1	X		
	Emergency Generator 2	X		
	Emergency Generator 3	X		
	Emergency Generator 4	X		
Controls	Wet Well Sensors	X		
	SCADA System	X		

Notes:
[1]Operator logbook, Connors Creek PS
[2]GLWA Red Tag Report, June 22, 2021 (Appendix A4.1)
[3]GLWA Red Tag Report, June 29, 2021 (Appendix A4.1)
SCADA = supervisory control and data acquisition

2.2.3 Freud PS (GLWA)

System Description

The Freud PS receives combined sewage from the Ashland and Mack Fox Creek Avenue Relief Sewers. Dry weather flow is pumped via two sanitary pumps to the Tennessee Sewer that discharges to the East Jefferson Relief Sewer and then delivered to the Connors Creek PS. Wet weather flow is pumped via eight storm pumps rated at 450 cfs each to the Connors Creek CSO Control Facility. The Freud PS was constructed in the 1950s to work together with the Connors Creek PS and supply additional wet weather pumping capacity.

Like the Connors Creek PS, the Freud PS is operated remotely by the operators at the SCC under normal conditions. During storms that are forecasted to have at least 1.5 inches of rain, field operations staff are scheduled to be on site and local manual operation is performed.

At the time of the June/July 2021 Rainfall Events, electrical power at the Freud PS was provided via two separate 24kV utility services to provide a level of utility redundancy (a third independent feed was abandoned by PLD in 2017). The PS has three GLWA-owned primary transformers, each sized to power three of the eight storm pumps. Therefore, the capacity of the primary transformers prevents full redundancy to power all storm pumps. Primary transformers 1 and 3 were powered from one service, and primary transformer 2 was powered from the other utility service. Because two transformers were connected to a single service (additional details provided below), a single service outage could bring down two-thirds of the PS transformers.

In addition to these electrical supply issues, the Freud PS has historically had issues with the quality of the power supplied (e.g., inconsistent line voltages supplying the PS) by PLD. The voltage drop when one storm pump is operational is about 7 percent. When two storm pumps are operational on the same transformer, the voltage drop is about 11 percent. To prevent motors faulting on low voltage during starting, the transformer tap settings are set to about 4600 volts (V), well above the 4160 V nominal rating. Any higher voltage will cause the switchgear breakers to trip on high voltage. As a result, a third pump powered on a single transformer may trip on low voltage and may not be available (Figure 5).

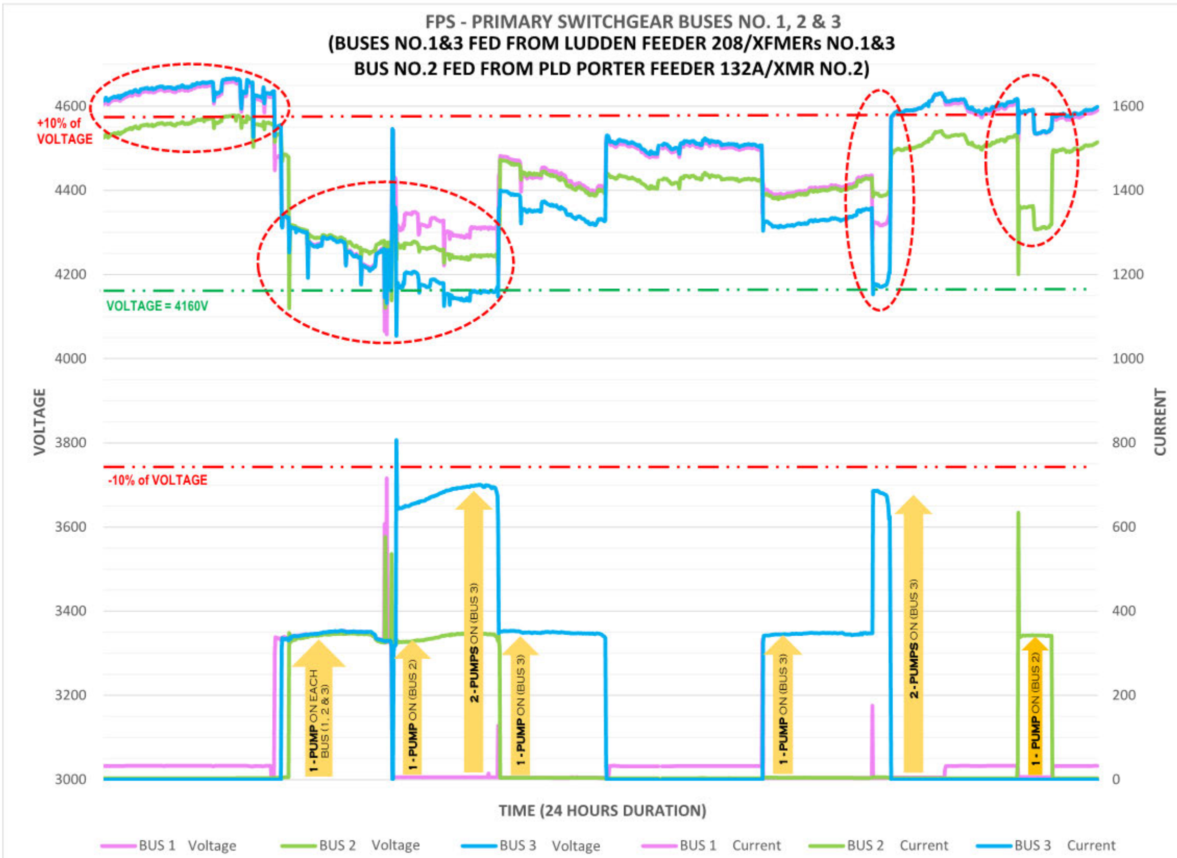


Figure 5: Observed Power Quality Issues at Freud PS

Four emergency generators are connected to utility service #2, which is the service feeding primary transformer 2. The generators are not configured to power primary transformers 1 and 3. The emergency generators start automatically during a power outage of service #2 or its associated primary transformer.

The operational readiness of the Freud PS stormwater pumps with different scenarios of utility/transformer and generator system availability is shown in Figure 6.

Scenarios		Transformer No.1	Transformer No.2	Transformer No.3	Generator System	Maximum Storm Pumps That Can Be Operated
No.	Description					
1	Three transformers are powered ON (Generator not Needed)	✓	✓	✓	Not Needed	7
2	Only transformers 1 & 2 are powered ON	✓	✓	✗	N/A	6
3	Only transformers 2 & 3 are powered ON	✗	✓	✓	N/A	6
4	Only transformers 1 & 3 are powered ON (Generator Offline)	✓	✗	✓	✗	6
5	Only transformers 1 & 3 are powered ON (Generator Online)	✓	✗	✓	✓	7
6	Only transformer 1 is powered ON (Generator Offline)	✓	✗	✗	✗	3
7	Only transformer 1 is powered ON (Generator Online)	✓	✗	✗	✓	5
8	Only transformer 2 is powered ON (Generator Not Applicable)	✗	✓	✗	N/A	3

Scenarios No.	Description	Transformer No.1	Transformer No.2	Transformer No.3	Generator System	Maximum Storm Pumps That Can Be Operated
9	Only transformer 3 is powered ON (Generator Offline)	✗	✗	✓	✗	3
10	Only transformer 3 is powered ON (Generator Online)	✗	✗	✓	✓	5
11	Three transformers are powered OFF (Generator Online)	✗	✗	✗	✓	2

Notes:

1. *Each transformer is sized at 6 MVA (air-cooled mode) /7.5 MVA (fan-cooled mode).*
2. *Generator system consists of four 2281 kW units.*
3. *Each single transformer can only run a maximum of three storm pumps (with the transformer running in the fan cooled mode).*
4. *The generator system configured and connected to only backup the loss of transformer 2.*
5. *The generator system can only run a maximum of two storm pumps.*

Legend: ✓ *Powered ON* ✗ *Powered OFF*

Figure 6: Freud PS Electrical Power Failure/Operating Scenarios

To address the known issues related to having only two primary electrical feeders supplying the three transformers and inconsistent power quality, and pursuant to an agreement between DTE and PLD, DTE initiated an electrical upgrade for the Freud PS. Construction was completed for the transfer conversion of utility services from PLD to DTE in 2022. The DTE services are from three separate DTE transformers that are powered from three independent 120kV feeds in the DTE Essex Substation. Therefore, the issue with the then-present PLD service creating a power outage for two primary transformers because of a single utility service outage (as occurred during the June 25/26 Rainfall Event) has been rectified. However, the issue of not being able to provide power via emergency generators to any of the three primary transformer loads remains. Additional details about the Freud PS are provided in Appendix A3.3.2.

Operational Readiness—June 25/26 Rainfall Event

The investigations revealed that GLWA's energy supplier abandoned one of the three independent electrical feeds and spliced one electrical feed to power transformers 1 and 3 in 2017.

On June 22, 2021, a utility contractor accidentially hit PLD's utility service #1 distribution line (Ludden Feeder No. 208) feeding primary transformers 1 and 3 (removing them from service) for the Freud PS. The energy supplier attempted a repair of the utility service #1 but was unable to complete the repairs before the June 25/26 Rainfall Event. With two of three transformers out of service, the PS peak pumping capacity was only approximately 43 percent of the overall capacity during the event (three of seven duty storm pumps available).

Consistent with Standard Operating Procedure (SOP), the hit line was communicated to the SCC supervisor. The supervisor did not communicate the damaged line to GLWA executive leadership.

With only one primary transformer available, there was enough electrical capacity to operate three storm pumps and two sanitary pumps. Transformer 2 typically provided power to storm pumps 1 and 7 and Sanitary Pump 10. Due to the distribution line outage, electrical interconnections (tie breakers) were manually opened/closed to connect multiple storm pumps to transformer 2, shown schematically in Figure 7.

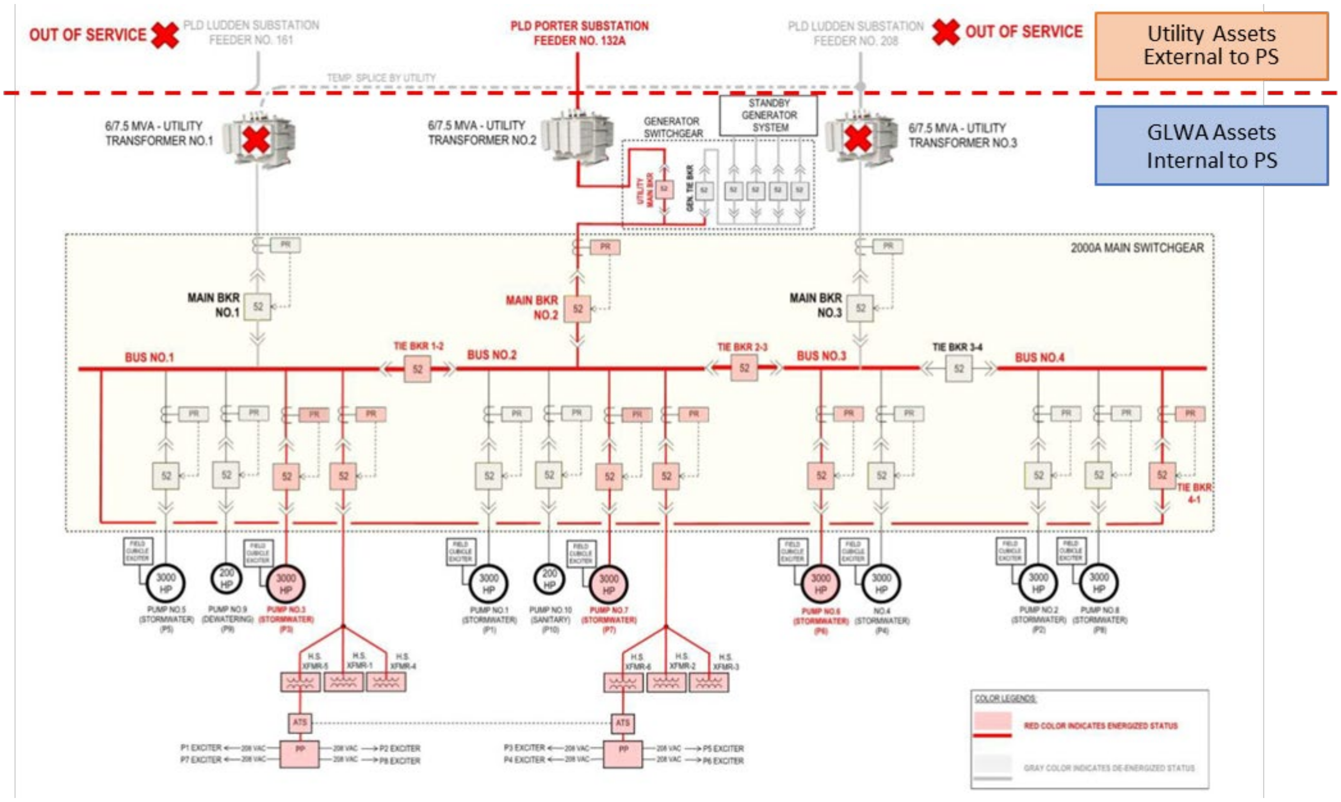


Figure 7: Freud PS Electrical Availability during the June 25/26 Rainfall Event

On June 25, the Freud PS was staffed on-site and checked out prior to the June 25/26 Rainfall Event. A summary of the operational readiness of major system components at the Freud PS prior to the event is provided in Table 2.

Table 2: Equipment Availability at Freud PS prior to June 25/26 Rainfall Event

Major System	Component	Availability: Yes	Availability: No	Comments
Mechanical	Storm Pump 1		X	ST1: Warranty Issue (motor protection)[2,3]
	Storm Pump 2	X		7 of 8 storm pumps were mechanically available, but a maximum of three storm pumps could be operated due to utility feed issue[1,3]
	Storm Pump 3	X		
	Storm Pump 4	X		
	Storm Pump 5	X		
	Storm Pump 6	X		
	Storm Pump 7	X		
	Storm Pump 8	X		
	Sanitary Pump 9	X		
	Sanitary Pump 10	X		
Electrical	Utility Service 1		X	Unavailable due to severed cables
	Utility Service 2	X		
	Transformer 1		X	Unavailable due to utility feed issue

Major System	Component	Availability Yes	Availability No	Comments
	Transformer 2	X		
	Transformer 3		X	Unavailable due to utility feed issue
	Emergency Generator 1	X		
	Emergency Generator 2	X		
	Emergency Generator 3	X		
	Emergency Generator 4	X		
Controls	Wet Well Sensors	X		
	SCADA System	X		

Notes:
[1]Operator logbook, Freud PS
[2]GLWA Red Tag Report, June 22, 2021
[3]GLWA Red Tag Report, June 29, 2021
SCADA = supervisory control and data acquisition

2.2.4 Bluehill PS (DWSD)

The Bluehill PS is a local system PS and receives combined sewage from the Rivard/Marseille Sewer. Dry weather flow is pumped via two sanitary pumps to the Cadieux Sewer, then delivered to the Fox Creek Relief sewer, and finally to the East Jefferson Relief Sewer and Connors Creek PS. Wet weather flow is pumped via four storm pumps to the Fox Creek Relief and Mack Avenue Relief sewers. Three of the stormwater pumps have constant-speed motors and have a rated capacity of 387 cfs; the fourth is a variable speed pump with a maximum rated capacity of 177 cfs.

Under normal conditions and pursuant to a Shared Services Agreement with DWSD, the PS is operated remotely by the GLWA operators at the SCC. Operators visit the PS to perform routine preventive maintenance duties. During storm events, operators check on the PS and are dispatched if the automated systems indicate a fault at the PS.

Electrical power at the Bluehill PS is provided via two separate 24kV utility services to provide a level of utility redundancy. The PS has two GLWA-operated primary transformers, each sized to power any three of the four storm pumps. Therefore, the capacity of the primary transformers prevents full redundancy. One of the power sources is backed up by three 1,825-kilowatt (kW) emergency generators. There are no provisions to connect the emergency generators to back up utility service 2.

The operational readiness of the stormwater pumps at the Bluehill PS with different scenarios of utility/transformer and generator system availability is shown in Figure 8.

Scenarios No.	Description	Transformer No.1	Transformer No.2	Generator System	Maximum Storm Pumps That Can Be Operated
1	Two transformers are powered ON (Generator not Needed)	✓	✓	Not Needed	All pumps
2	Only transformer 1 is powered ON	✓	✗	N/A	3
3	Only transformer 2 is powered ON (Generator Offline)	✗	✓	✗	3
4	Only transformer 2 is powered ON (Generator Online)	✗	✓	✓	All pumps
5	Two transformers are powered OFF (Generator Online)	✗	✗	✓	2

Notes:
1. *Each transformer is sized at 5 MVA (air-cooled mode) /6.7 MVA (fan-cooled mode).*
2. *Generator system consists of three 2281 kW units.*
3. *Each single transformer can only run a maximum of three storm pumps.*
4. *The generator system configured and connected to only backup the loss of transformer 1.*
5. *The generator system can only run a maximum of two storm pumps.*
6. *O&M manual advises that hydraulic restrictions limit maximum storm pumps that can be operated to 3, but this investigation did not confirm these restrictions.*

Legend: ✓ *Powered ON* ✗ *Powered OFF*

Figure 8: Bluehill PS Electrical Power Failure/Operating Scenarios

Like the Freud PS, the Bluehill PS was connected to PLD's power supply and at the time of the June/July 2021 Rainfall Events, suffered from external power quality issues. Voltages varying more than 10 percent of design would cause a pump to not start.

To address the power issues at Bluehill PS, DTE initiated an electrical upgrade for the Bluehill PS. Construction was completed for the transfer conversion of utility services from PLD to DTE in 2022. The DTE services are from two separate buses from two separate DTE transformers that are powered from two independent 120kV feeds in the DTE Mack Substation. The two existing primary transformers were also replaced in 2022 with new 5MVA transformers by DTE. This should resolve the issue with the high voltage in the existing system. Additional details about the Bluehill PS are provided in Appendix A3.3.3.

Operational Readiness—June 25/26 Rainfall Event

The Bluehill PS was checked out prior to the June 25/26 Rainfall Event and operators checked on the PS during the June 25/26 Rainfall Event. Based on the operator logbook, all systems appear to have been available at the time. A summary of the operational readiness of major system components at the Bluehill PS prior to the June 25/26 Rainfall Event is provided in Table 3.

Table 3: Equipment Availability at Bluehill PS prior to the June 25/26 Rainfall Event

Major System	Component	Availability Yes	Availability No	Comments
Mechanical	Storm Pump 1	X		
	Storm Pump 2	X		
	Storm Pump 3	X		
	Storm Pump 4	X		ST4: Emergency use only [1,2]
	Sanitary Pump 5	X		
	Sanitary Pump 6	X		
Electrical	Utility Service 1	X		
	Utility Service 2	X		

Major System	Component	Availability Yes	No	Comments
	Transformer 1	X		
	Transformer 2	X		
	Transformer 3	X		
	Emergency Generator 1	X		
	Emergency Generator 2	X		
	Emergency Generator 3	X		
Controls	Wet Well Sensors	X		2 in storm wet well (1 connected to SCADA system)
	SCADA System	X		

Notes:
[1]GLWA Red Tag Report, June 22, 2021
[2]GLWA Red Tag Report, June 29, 2021
SCADA = supervisory control and data acquisition

The investigations did not reveal significant equipment issues at the Bluehill PS.

2.2.5 Other PS

The internal investigation did not reveal significant equipment issues at other PSs.

2.2.6 Connors Creek Sewer

The internal investigation revealed that three of the nine in-system gates were out of service for mechanical repair. In addition, GLWA's interceptor inspection program identified solids deposition in the Sewer. At the time of the June 25/26 Rainfall Event, the removal of the solids deposition was in the design phase of the improvement project.

2.3 Sequence of Events

2.3.1 Weather Reports, Actual Rainfall versus Predicted

On June 24, the National Weather Service (NWS) and Weather Sentry subscription weather services forecasted 1.5 inches of rain over a 3-day period from Friday, June 25 through Sunday, June 27. NWS's probabilistic forecast noted a greater than 50 percent likelihood that total rainfall depth will be 0.5-inch for this 3-day period.

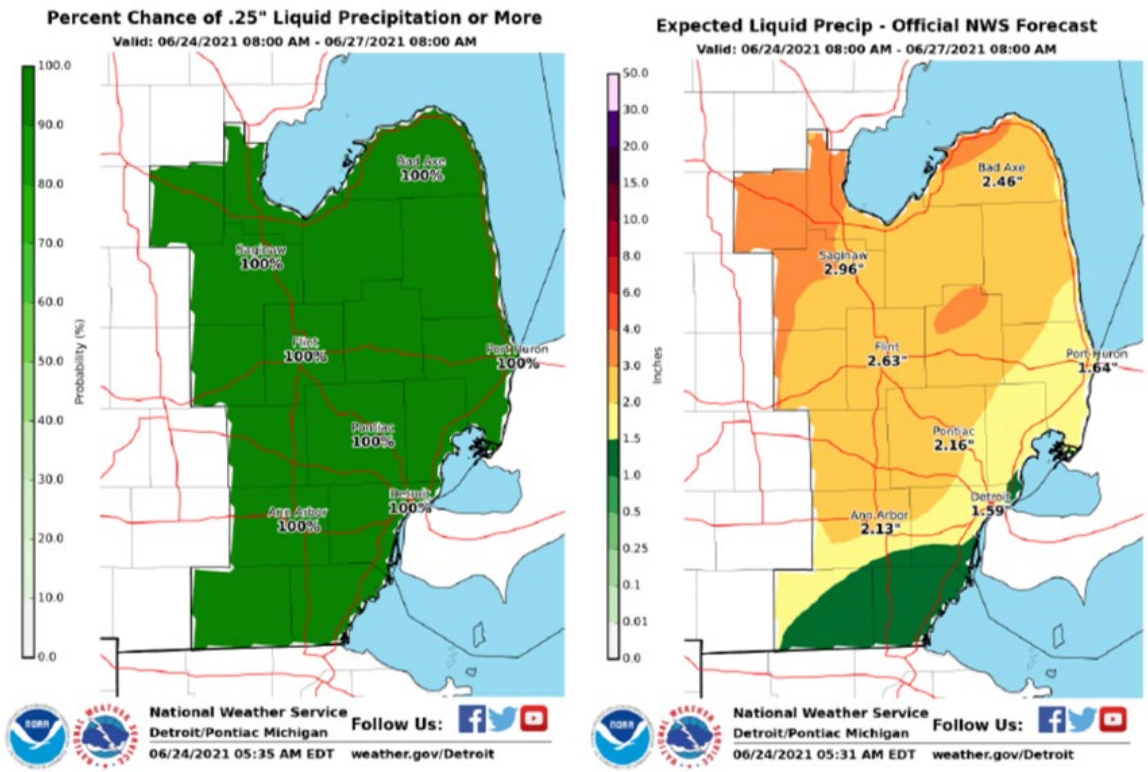


Figure 9: National Weather Service Forecasts for the June 25/26 Rainfall Event

The June 25/26 Rainfall Event was a high intensity storm starting at approximately 3 a.m. on June 25 and ending at approximately 3 a.m. on June 26 situated over areas of Oakland and Wayne counties with a peak intensity of 15.5 inches per hour over a 5-minute duration and a maximum accumulated depth of 7.8 inches over 12 hours and 8.1 inches over 24 hours as shown in Figure 10. The rainfall hyetograph shows that three intense bursts of rainfall occurred within the June 25/26 Rainfall Event. The main observations from the hyetograph include:

- The first burst of rain fell from approximately 9 a.m. to 12 p.m. with the most intense rain falling at 11 a.m. on June 25.
- The second burst of rain fell from about 6 p.m. to 8 p.m. on June 25. By this time, approximately 1 to 2 inches of rain had fallen over GLWA's Service Area. This burst of rain caused flooding north of the city of Detroit, but conveyed flow to the GLWA's interceptors, resulting in near capacity conditions within the regional system.
- The final and most intense burst began about 10 p.m. on June 25 and ended at about 4 a.m. on June 26 with the most intense rainfall occurring between 12 a.m. and 2 a.m. on June 26. This burst of rain caused flooding primarily in communities closer to the Detroit River.

When the third burst of rainfall began, the collection and treatment systems were at or near capacity due to wet weather inflows from the first and second rainfall bursts. This is evidenced by observations and data from levels sensors within main sewers, CSO facilities, in-system storage devices, and the WRRF. At 10 p.m., when the third and most intense rainfall burst began:

- Some sewers were surcharged (some of these had been surcharged since the afternoon of June 25).
- The Connors Creek CSO facility was full and already discharging.
- The WRRF was operating at full capacity, processing more than 1,750 MGD.

The June 25/26 Rain Event was preceded by a 2-inch rainfall within an 8-hour period on June 21, 2021 approximating a 2-year storm. This preceding rain likely caused wet antecedent soil moisture conditions that would contribute to increased runoff from the June 25/26 Rain Event, thus increasing flow rates in the collection system.

The investigations revealed that the actual rainfall produced more than 8 inches of rain along a 25-mile stretch from Inkster across Dearborn and Detroit, and to the Grosse Pointe communities; a storm event with a predicted reoccurrence of 1 in 1,000 years. The combined sewer system is designed to convey flows for a 10-year, 1-hour return frequency storm event. Widespread flooding was inevitable. Power limitations detailed above at the Freud and Connors Creek PSs may have exacerbated the depth and duration of surface flood and basement flooding.

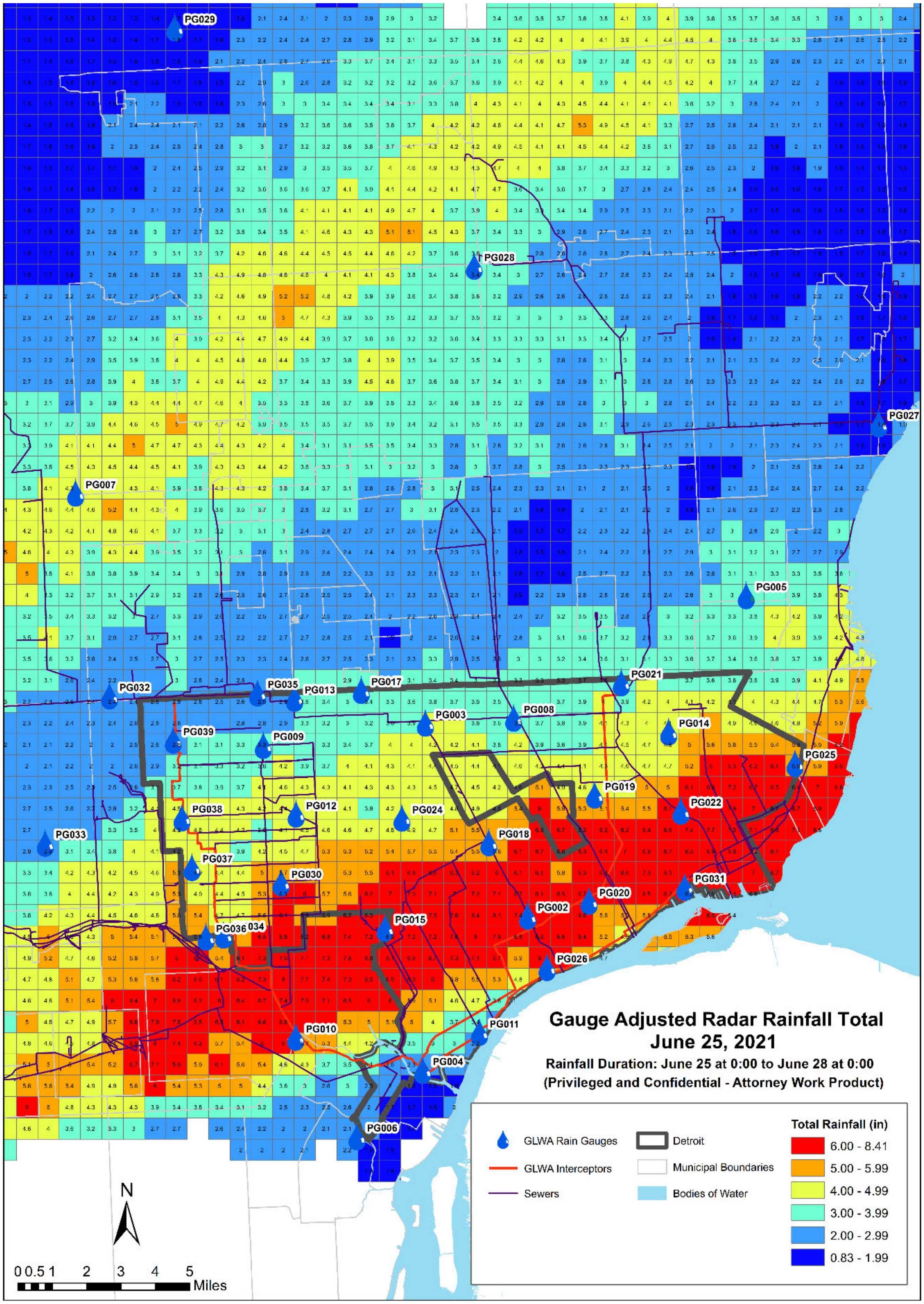


Figure 10: Total Rainfall Depths for the June 25/26 Rainfall Event

The return period and severity of the June 25/26 Rainfall Event as a whole can be generally represented by the spatial distribution of observed precipitation depths and associated return periods for the 12-hour duration, as shown in Figure 11. The largest 12-hour precipitation depths were observed, and the greatest return periods occurred in the areas along I-94 near the south-central Detroit and the Grosse Pointe area, along or near the northern shores of the Detroit River and Lake St. Clair.

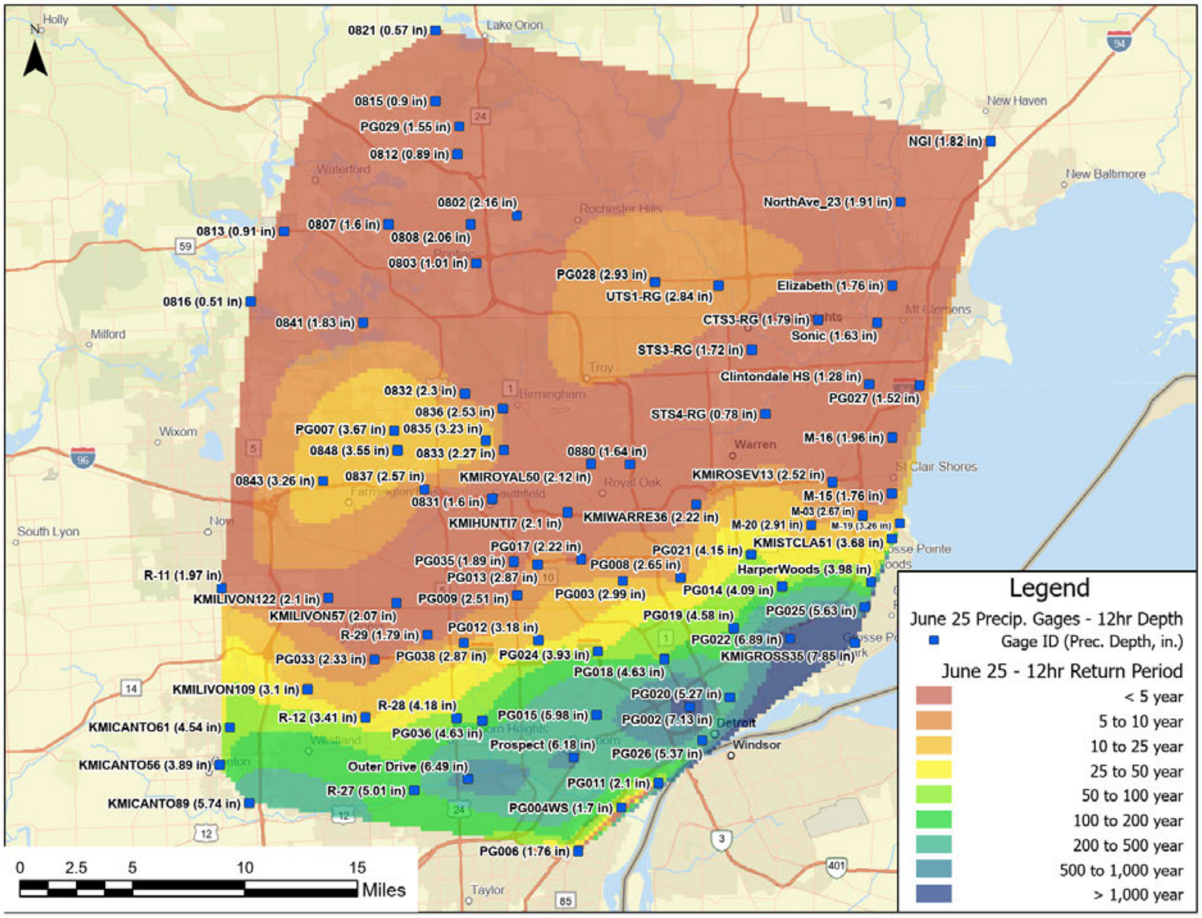


Figure 11: June 25/26 Rainfall Event 12-hour Precipitation Depth and Return Period

2.4 System Response

2.4.1 Connors Creek PS (GLWA)

Five of the seven storm pumps available were operated during the June 25/26 Rainfall Event. Power to the storm pumps was never interrupted. However, because the PS requires the storm pumps to have a suction lift, a vacuum priming system is required to start the pumps unless wet well levels get very high. This adds time and complexity to the pump starts. During the June 25/26 Rainfall Event, a leak from a vacuum priming line sprayed onto the motor control center (MCC) panel adjacent to Storm Pump 2. The MCC breaker opened resulting in the vacuum priming system, ovation control system and lights/environmental systems being temporarily out of service. Despite the loss of control, storm pumps remained in a run state throughout the house power outage. The loss of house power resulted in security gate failures as well. On returning to Connors Creek PS from the Freud PS, the electrician assigned to these PSs had to get another team member to cut the lock at the pedestrian gate because the vehicular gate would not open due to the house power issue, momentarily delaying the electrician's ability to restore the house power. Surface flooding also delayed the electrician's return to the Connors Creek PS. Once the MCC breaker issue was identified, the electrician responded to the issue and then closed the breaker to restore house power and the vacuum priming system, ovation control system, and lights/environmental systems. Despite the loss of control, storm pumps remained in a run state throughout the house power outage.

Plots of storm pumping versus time at the Connors Creek, Freud, and Bluehill PSs for the June 25/26 Rainfall Event, are shown in Figure 12 through Figure 14, and for the July 16 Rainfall Event in Figure 26 through Figure 28. The respective PS wet well levels also are shown on the plots. At times, the wet well levels reached the mximum recordable level by the sensor. When operating out of range, the sensor continues to report its maximum readable level (the horizonal lines on the plots) until water level drops back into the readable range. In these cases, the actual water level can be considered higher than the recorded level.

The Connors Creek PS wet well reached the level sensor top of range at about elevation 86 feet. During the June 25/26 Rainfall Event, the wet well rose quickly from 67 to 86 feet in about 45 minutes. It takes about 15 to 20 minutes to vacuum prime each storm pump and the seal water system is sufficient to only start two storm pumps at a time. Therefore, the storm pumps at the PS could not be started quickly enough to respond to the rising wet well.

During the June 25/26 Rainfall Event, the Connors Creek PS did not experience flooding in the PS; however, and as noted above, flooding around the PS did interfere with operators dispatched between the Freud and Connors Creek PS.

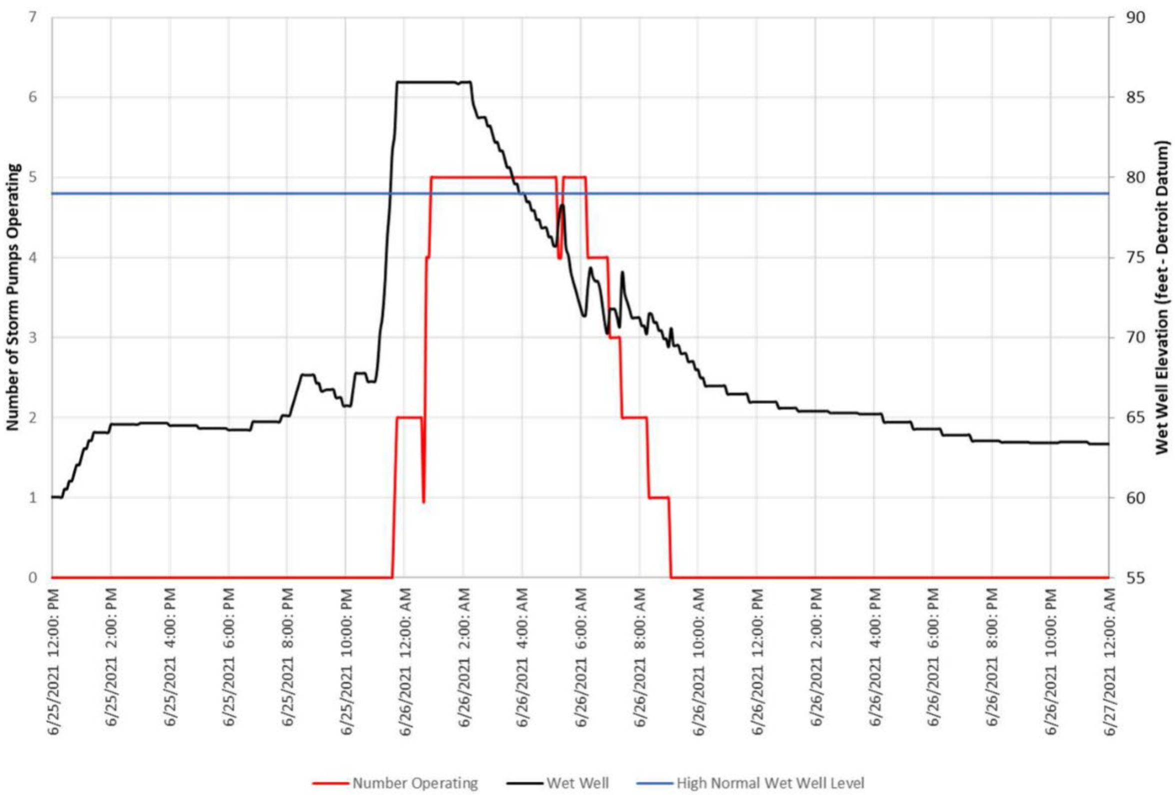


Figure 12: Storm Pump Operations at Connors Creek PS during the June 25/26 Rainfall Event

2.4.2 Freud PS (GLWA)

The operators at the station were not aware that there was insufficient available power due to the transformer issues prior to the storm event. Although they became aware that there were power issues due to transformer outages, when they attempted to operate more than two storm pumps they continued to have trouble starting a third pump with only one available transformer (due to incoming power quality issues). However, a third pump was brought online at approximately 2 a.m. on June 26 during the peak of the June 25/26 Rainfall Event. During the peak of the Event, three of seven duty pumps (the maximum that could operate from one transformer) were operating at the Freud PS; these pumps were able to operate continuously for approximately 12 hours.

The Freud PS wet well is hydraulically interconnected with the Connors Creek PS wet well above elevation 68 feet and it reached a maximum level of about 100 feet.

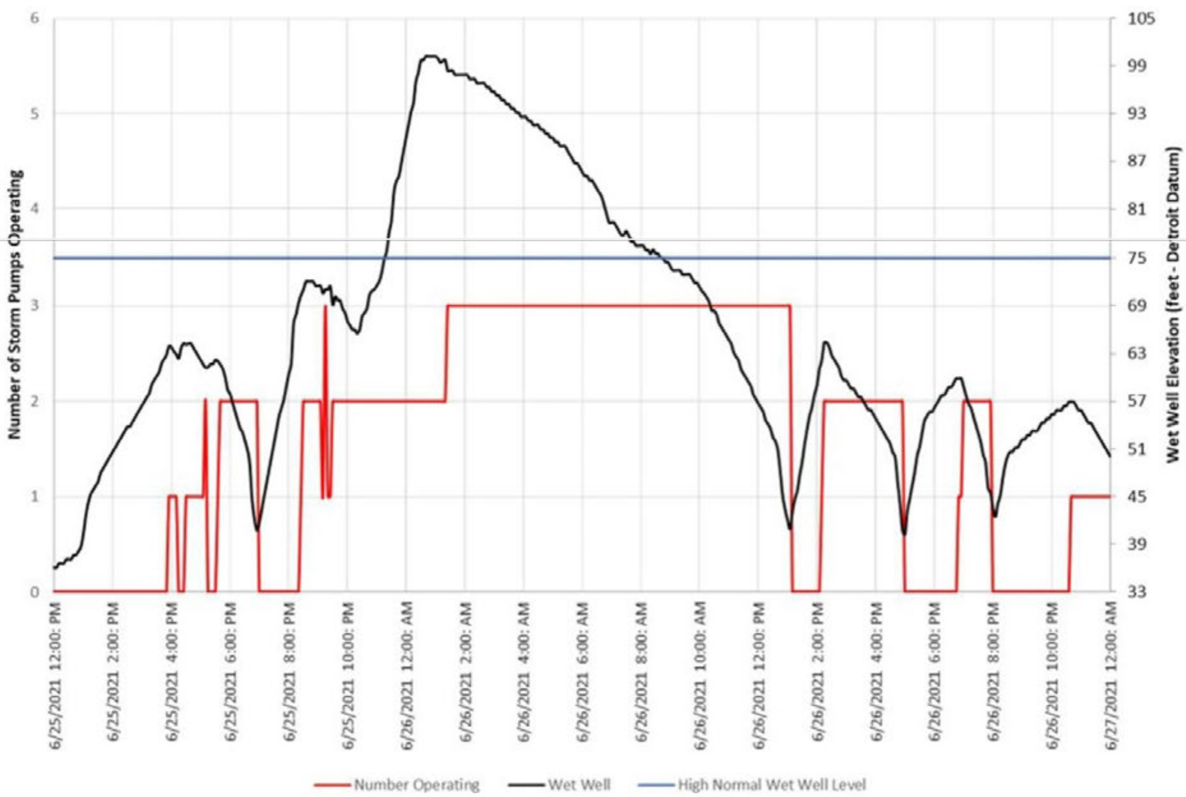


Figure 13: Storm Pump Operations at Freud PS during the June 25/26 Rainfall Event

2.4.3 Bluehill PS (DWSD)

The Bluehill PS experienced power quality issues during the June 25/26 Rainfall Event like those experienced at the Freud PS. This PS operated with two of the four available storm pumps during the peak of the June 25/26 Rainfall Event and the wet well level reached the level sensor top of range at about 86 feet (Figure 14).

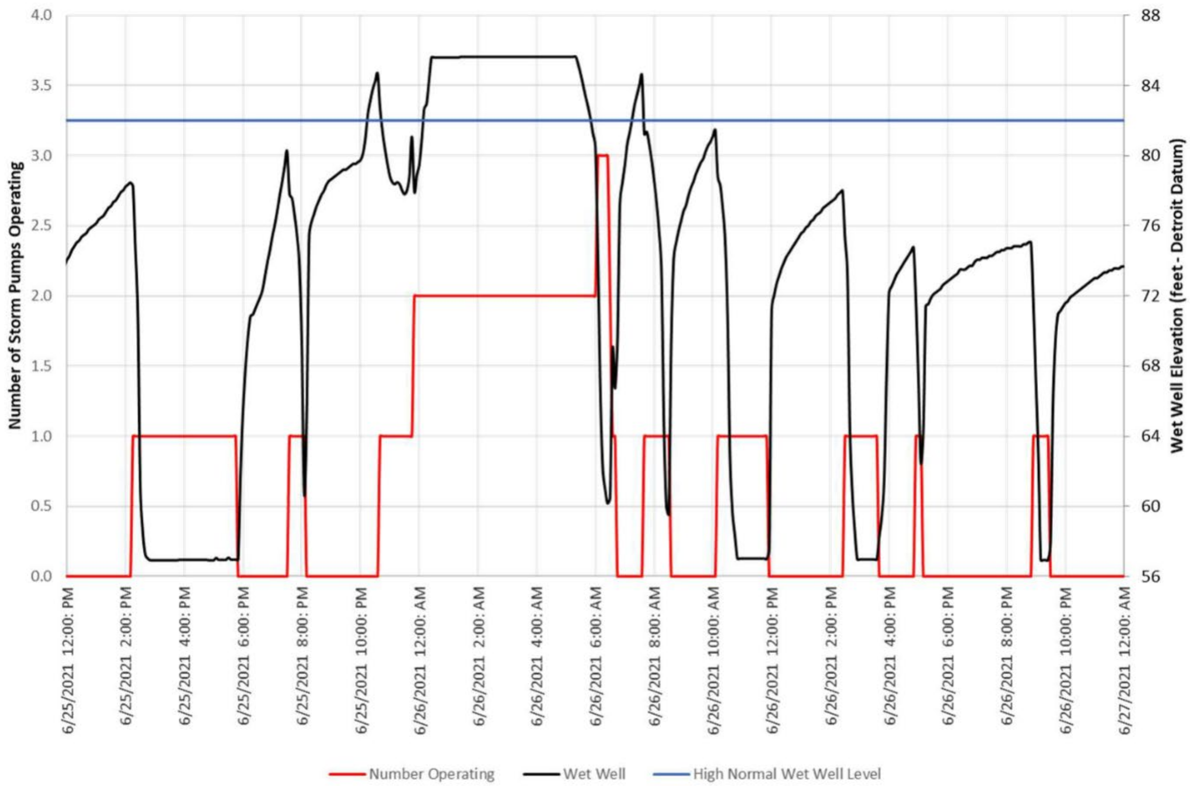


Figure 14: Storm Pump Operations at Bluehill PS on during the June 25/26 Rainfall Event, 2021

2.4.4 Other Pumping Stations

The GLWA internal investigation found that the other PSs operated as intended

2.4.5 Connors Creek Sewer

The internal investigation revealed six in-system gates were sufficient to convey flow to the Connors Creek CSO Control Facility with only marginal increase in the velocity and hydraulic gradient. Further, sediment deposition had only a minor increase in hydraulic gradient that dissipated quickly.

2.4.6 Personnel

The investigations revealed that during the storm events, the PSs did not experience flooding; however, flooding around the station interfered with the ability of staff dispatched to Freud PS to access the station.

Operators maintain 12-hour shifts and normal shift changes occur at 11:30 a.m./p.m. (every 12 hours). Staffing decisions for the PS are made by team leaders based on weather forecasts. Current practice is to staff each PS when storms are predicted to have rainfall equal to or greater than 1.5 inches.

The PSs were staffed prior to the storms on June 25/26 and July 16 Rainfall Event; however, the existing *All Events Over Time* sheets that log alarms and gate entries/exits are not effective to identify the personnel that are working at the facilities and assignments/tasks they are working on. This is magnified during rainfall events that had personnel moving between locations, and as provided in Appendix A4.2.

2.5 Interactions Between Systems

2.5.1 East Side System

As noted above, GLWA's East Side customers to the East Side System include DWSD, the Grosse Pointe communities; MRIDDD; and the SEMSD. Each of these customers have different opportunities and requirements of operating their systems to control impacts to the broader GLWA system.

The DWSD is the only tributary system that discharges combined flows without any flow rate limit. DWSD does not have any alternative discharge points other than the GLWA system.

The other tributary systems to the East Side System require flows to be pumped into the GLWA system through Wayne County's Fox Creek Enclosure. Those systems have contract limits on the maximum rate of discharges that are allowed to be pumped into the Fox Creek Enclosure.

There are three CSO facilities within the MRIDDD and SEMSD that provide operating flexibility to those districts when inflows exceed the contract limits. The customers in the cities of Grosse Pointe and Grosse Pointe Farms that do not have CSO control facilities with alternative discharge points have less operating flexibility. Without alternative discharge points, these customers can face the decision to either exceed the pumping limits into the GLWA system or risk flooding within their local system during significant runoff events.

A summary of the type and location of flows from each customer into the GLWA system as well as contract limits and maximum discharges to the GLWA system during the June/July 2021 Rainfall Events are provided in Table 4. The estimates of maximum discharges were developed by ASI using flow meter and pumping records data obtained from the customers Greater Detroit Regional Sewer System (GDRSS) website (Appendix A9).

Maximum discharges from DWSD were not estimated due to the large extent and various locations that flows enter the GLWA system.

Maximum discharges from the SEMSD into the Fox Creek Enclosure were only slightly above the contract limits during both the June/July 2021 Rainfall Events. The MRIDDD and SEMSD discharged significant amounts of CSO to Lake St. Clair.

The City of Grosse Pointe Farms pumped at or below its contract limit during both events, while the cities of Grosse Pointe Park and Grosse Pointe both exceeded their contract limits during the storm events. As noted in the ASI Report (Appendix A9), both cities also experienced significant flooding even with the additional pumping to the GLWA system.

Table 4: Summary of East Side Local Collection Systems with Contract Limits and Measured Discharges during the June/July 2021 Rainfall Events Storm Events

GLWA Customer	Description	Contract Limit (cfs)	June 25/26, 2021 Maximum Discharge (cfs)	July 16, 2021 Maximum Discharge (cfs)
DWSD	Combined flows via various sewers	None	n/a	n/a
City of Grosse Pointe Park	Sanitary flows only, via Detroit River Interceptor	84	114	114
City of Grosse Pointe	Partial combined, partial sanitary flows, via Fox Creek Enclosure	192	346	306
City of Grosse Pointe Farms	Partial combined, partial sanitary flows, via Fox Creek Enclosure	554	552	385

GLWA Customer	Description	Contract Limit (cfs)	June 25/26, 2021 Maximum Discharge (cfs)	July 16, 2021 Maximum Discharge (cfs)
SEMSD* (St. Clair Shores, Eastpointe, Roseville)	Combined flows via Fox Creek Enclosure	127	133	134

Notes:
*SEMSD contract limits and maximum discharges include contributions from Grosse Pointe Shores and MRIDDD
cfs = cubic feet per second
SEMSD = Southeast Macomb Sanitary District

Some context to the impacts of these flows on the GLWA system can be provided by comparing the various flows to GLWA system capacity. The capacity of the East Side PS, with the firm capacity assuming one of the largest pumps is out of service, is provided in Table 5. If each customer pumped at the maximum discharge rate at the same time, the flows into the Fox Creek Enclosure would have been approximately 15 percent of the total Freud and Connors Creek PS pumping capacities combined. However, it is likely that the maximum flow rate that ultimately reached the PS was less than the sum of the maximum pumping rates due to the timing of pumping, design capacity of the Fox Creek Enclosure (approximately 500 to 800 cfs depending on location), flooding, and/or discharges from the Fox Creek Enclosure via the B001 CSO outfall.

Table 5: East Side Pump Station Capacity

Pumping Station	Rated Firm Capacity (cfs)	Rated Total Capacity (cfs)
Connors Creek	3,724	4,333
Freud	3,350	4,150
Total: Connors Creek + Freud	7,074	8,483
Bluehill	971	1,538

Notes:
cfs = cubic feet per second

To evaluate the impacts further, the AECOM team performed modeling simulations of the June 25/26 Rainfall 2021 Events using both the contract limits and the actual pumping rates. The modeling approach and results are provided in Section 2.6.

2.5.2 West Side System

The West Side System is generally considered to be areas tributary to the Oakwood-Northwest Interceptor and the Baby Creek Sewer. The primary customers in the West Side System include Rouge Valley Sewer Disposal System, City of Farmington, City of Dearborn, Allen Park, Melvindale, and DWSD (Rouge River, Hubbell, Southfield, Oakwood and Baby Creek sewer districts). Major CSO facilities include 7 Mile, Puritan-Fenkell, Hubbell-Southfield, Oakwood, and Baby Creek CSO Control Facilities. PSs include Oakwood and Woodmere, the latter of which is a local system PS with the Baby Creek CSO Facility.

Several customers have contract limits established with GLWA to limit the rate of flows discharged into the GLWA system. Those contract limits along with the maximum discharge rate measured during the June/July 2021 Rainfall Events are provided in Table 6.

Table 6: Summary of West Side Local Customers with Contract Limits and Measured Discharges during the June/July 2021 Rainfall Events

GLWA Customer	Contract Limit (cfs)	June 25/26, 2021 Maximum Discharge (cfs)	July 16, 2021 Maximum Discharge (cfs)
DWSD	n/a	n/a	n/a
Allen Park	10.6	3.7	13.8
City of Dearborn	120	122	118
Melvindale	15	13.1	13.1
City of Farmington	7.9	5.8	5.7
Rouge Valley Sewage Disposal System	390	307	318
Totals	544	452	469

Notes:
cfs = cubic feet per second
DWSD = Detroit Water and Sewerage Department

Because the scope of the AECOM investigation was focused on the East Side System, the panel and teams did not perform a detailed analysis of the West Side System. GLWA and the internal investigative team advises that the PSs operated as intended. The following summaries are based on data and analysis included in the ASI Report (Appendix A9).

June 25/26, Rainfall Event

All customers with contract limits discharged into the GLWA system near or below their contract limit, with the exception of City of Dearborn, which exceeded its contract limit by approximately 2 cfs. However, a sanitary sewer overflow occurred downstream of Meter DN-S-2 and total peak flow estimate does not account for the sanitary sewer overflow.

Inflows into the Baby Creek CSO Facility were significantly less than the maximum design, headloss across the screens was within design range and Rouge River water levels were within the design range. However, upstream water levels exceeded the design level by about 2 feet indicating that headloss in the Baby Creek Enclosure downstream was greater than expected. A follow up investigation performed in February 2022 found no blockages in the Baby Creek Enclosure and accumulated sediment was approximately 4 percent of the total Baby Creek Enclosure storage volume. Therefore, it is concluded that the flow rate measurements on the influent conduits to the Baby Creek CSO Facility are significantly underreporting inflows.

The Hubbell-Southfield CSO Facility has a maximum operating capacity (including shunt bypass) of 5,100 cfs, however no estimates of inflows were provided. During this event, the Rouge River water level rose quickly and exceeded the maximum design level by about 1 foot. Leading up to the peak rainfall, the gates were managed to provide treatment/disinfection because upstream water levels were still below their top of range. Once the peak rainfall occurred, upstream water levels rose quickly (reaching the ground surface at the DT-S-3 flow sensor) and the emergency relief gates (ERGs) started opening approximately 90 minutes later. While opening the ERGs reduced upstream water levels at the facility almost immediately, water levels at the DT-S-3 flow sensor farther upstream remained at ground surface for another 3 hours.

2.6 Extent of Flooding

The extent of flooding associated with the GLWA and DWSD collection systems during the June 25/26, Rainfall Event is discussed in this section. The AECOM team modeled the GLWA and DWSD combined sewer collection systems and pumps to determine the extent of flooding during the June 25/26 Rainfall

Event. To do this, AECOM obtained an Environmental Protection Agency (EPA) SWMM model of the GLWA collection system from ASI.

EPA SWMM is an open-source modeling package developed by the EPA and is used to simulate flooding due to the combined sewer conveyance systems and associated pumps and to show capacity limitations. The AECOM team used PCSWMM, which is a proprietary software based on the EPA SWMM source code, so that surface flooding could be evaluated with the two-dimensional (2D) capabilities of the proprietary version.

Environmental Protection Agency SWMM Model

The EPA SWMM model represents the WRRF, interceptors, PSs, CSO Control outfalls and facilities that are operated by GLWA. Large trunk sewers in Detroit are also represented. The model flows include tributary hydrology (overland storm water flow) and sanitary inflows that are discharged into the sewers. The EPA SWMM model belongs to GLWA and it includes relevant GLWA infrastructure.

The following updates, performed by ASI, were made to the model prior to AECOM's modeling effort.

- The temporary Fairview PS was represented to match the operation while the PS was being upgraded.
- Hydrographs representing the flows over time from most of the customer communities' connections to the GLWA conveyance system were set as model inputs from flow meter data. For Dearborn and SEMSD, their sewer systems models were more detailed and used in place of billing flow meter data.
- When the manufacturer's pump performance curves were used at the Connors Creek and Freud PS with actual pumping operations, the wet wells were predicted to run dry. Therefore, the manufacturer's pump curves at Connors Creek and Freud PS were reduced by 20 percent so that the predicted wet well levels matched the actual during the wet weather.
- CSO outfall B-001 to the Fox Creek canal was represented with a head discharge curve in the model that did not account for any head loss through the canal. The head discharge curve was revised to account for head loss through the canal.

It also should be noted that Wade Trim setup to the West Side section of this model under a separate project.

PCSWMM Model

The one-dimensional (1D) elements of the PCSWMM model were imported directly from the EPA SWMM model. The 2D surface flooding capabilities were developed based on 2017-2018 SEMCOG light detection and ranging (Lidar) data. The extent of the 2D modeling was limited to areas tributary to the Fairview PS in Wayne County.

Pumping Station Information

The PCSWMM model can simulate pumping operations. The analysis provided in this section generally refers to two different pumping scenarios, the "ACTUAL" scenario, and the "IDEAL" scenario.

The ACTUAL scenario simulates the pumping operations that occurred during the June 25/26 Rainfall Event. The pumping information was obtained from GLWA's Supervisory Control and Data Acquisition (SCADA) system.

The IDEAL scenario simulates the pumping operations based on the standard operating wet well levels and assumed on and off levels for each pump. In other words, this scenario assumes all pumps were operated as intended with firm capacity. Firm capacity means that only one pump was out of service at the Connors Creek, Freud, and Bluehill PSs. In addition, at Connors Creek PS, the model reflects the pumps turning on faster than what was possible under ACTUAL conditions.

PCSWMM Limitations

Models are tools to represent reality, but it is important to note that every model has limitations. This model was deemed the most practicable to determine the extent of flooding associated with the June 25/26 Rainfall Event; however, it has limitations due to original purpose and data availability. The limitations include:

Local sewers not included: The PCSWMM model (and the EPA SWMM model) does not include local smaller diameter sewers in Detroit (private sewers, smaller diameter lateral sewers). These sewers can be a primary constraint within the overall collection system, particularly during large rainfall events. This limitation means that some areas may have experienced surface flooding or basement backups due to local sewer constraints, however those areas would not necessarily be identified in the PCSWMM model results.

Some collection systems not included: Some collection systems are not represented in PCSWMM model because data were not available. These include Grosse Pointe Park, Grosse Pointe, and Grosse Pointe Farms combined, sanitary, and storm systems.

Michigan Department of Transportation (MDOT) Pumps and data not included: The model includes representations of MDOT PS that are tributary to the combined sewer system in Detroit/Hamtramack and Highland Park. News accounts noted that a number of MDOT pumps failed to operate during the June 25/26 Rainfall Event; however, data were not available to determine which pumps were operated. Therefore, the PCSWMM model simulated all MDOT pumps operating as designed.

Unknown Debris Blockages: There are possible unknown field conditions, such as sediment depths or other temporary blockages that may slow flow or impede its entrance in the collection system that may not be represented. This includes clogged catch basins in combined sewer areas.

Model Validation (ACTUAL Scenario)

Model validation is the process by which modeling results are compared to measured/estimated data to provide a level of confidence that the model is reasonably representative of the real-world.

The PCSWMM model was validated by comparing the model results to estimates of high-water marks. The high-water mark estimates were made using information contained within DWSD’s flood complaint database. The database contained nearly 5,000 complaints for the June/July Rainfall Events; however, the vast majority of complaints were for basement backups and not surface flooding. AECOM staff reviewed the database to identify relevant information pertaining to surface flooding and ultimately found 11 reports with information suitable for model validation. These reports generally provided information on how deep the water was outside their homes (Figure 15).

The results of the model validation process are provided in Table 7. These results show very good agreement between the predicted surface water levels and the citizen-reported water depths, meaning that there is a high level of confidence that the model reasonably represents the GLWA collection system.

Table 7: Selected Locations with High Water Elevations during the June 25/26 Rainfall Event

Location of High Water Observation	Nearest Cross Street	Ground Elevation (ft-DD)	High Water Level (ft)	Model Predicted Flooding Levels (ft)
500 block of Marquette Drive	Freud Street	95.9	4	4.0
600 block of Connor Street	Freud Street	95.2	3	3.1
1400 block of Manistique Street	Kercheval Avenue	100.2	1	0.9
1400 block of Manistique Street	Kercheval Avenue	100.1	1	0.9
500 block of New Town Street	Victoria Park Drive S	96.0	1.5	1.1
500 block of Ashland Street	Essex Drive	95.1	0.8	2.2
500 block of Chalmers Avenue	Essex Drive	95.1	0.8	1.1
400 block of Ashland Street	Essex Drive	97.7	4	4.0
800 block of Chalmers Street	E Jefferson Avenue	96.1	1.3	1.1
500 block of S Park Street	Victoria Park Drive S	91.9	3	4.0
1300 block of Lakewood Street	Kercheval Avenue	98.6	2	1.7

Notes:
DD = Detroit Datum
ft = foot/feet

Figure 15: High Water Mark Locations from the DWSD Flood Complaint Database for the June 25/26 Rainfall Event

Locations where citizens reported water in their basements during the June 25/26 Rainfall Event are shown in Figure 16 and Figure 17. The maps show the highest density of basement flooding reports were in the Cornerstone Village, East English Village and Jefferson-Chalmers neighborhoods. No data were provided for the areas outside of the city of Detroit.

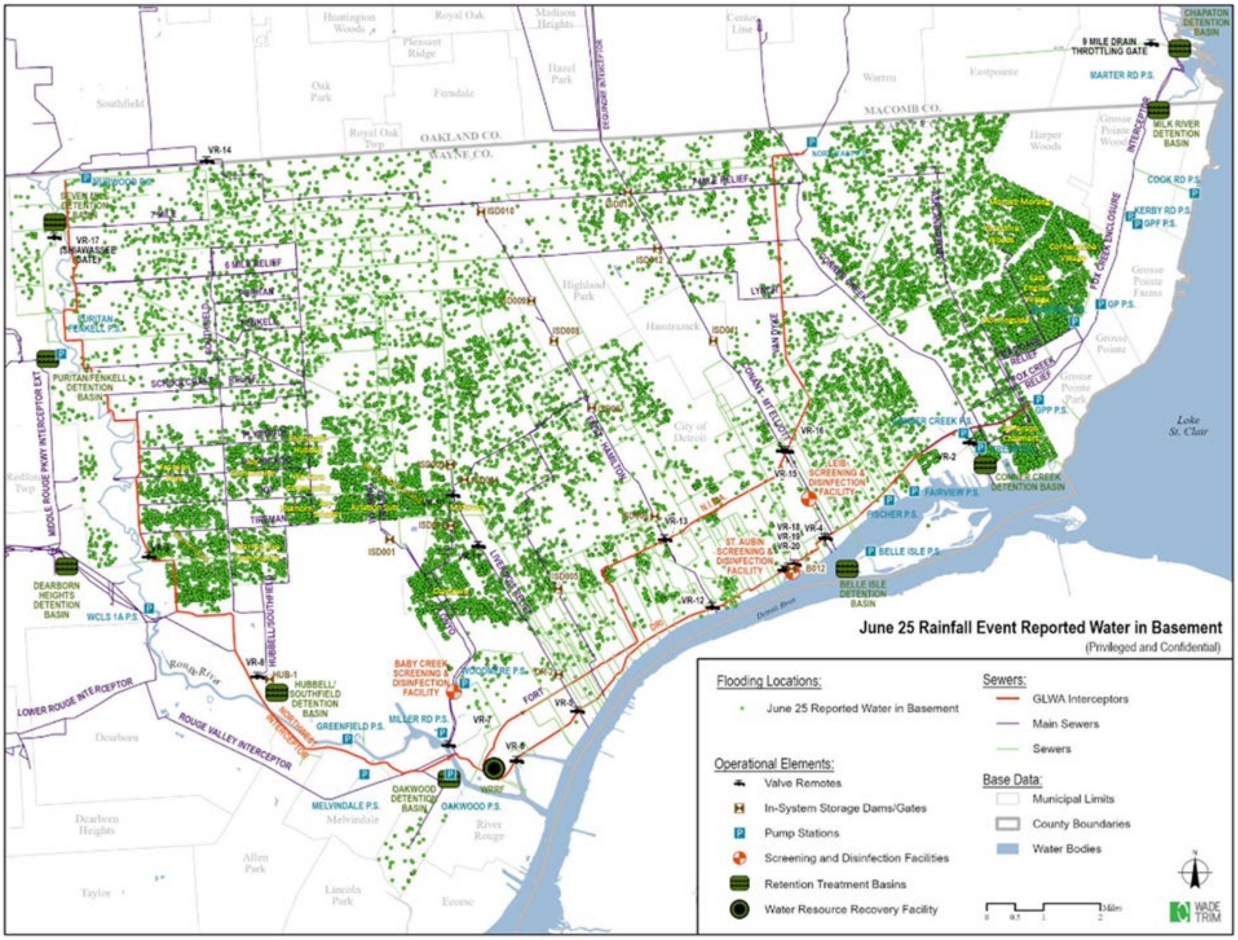


Figure 16: City of Detroit Reported Water in Basement for the June 25/26 Rainfall Event

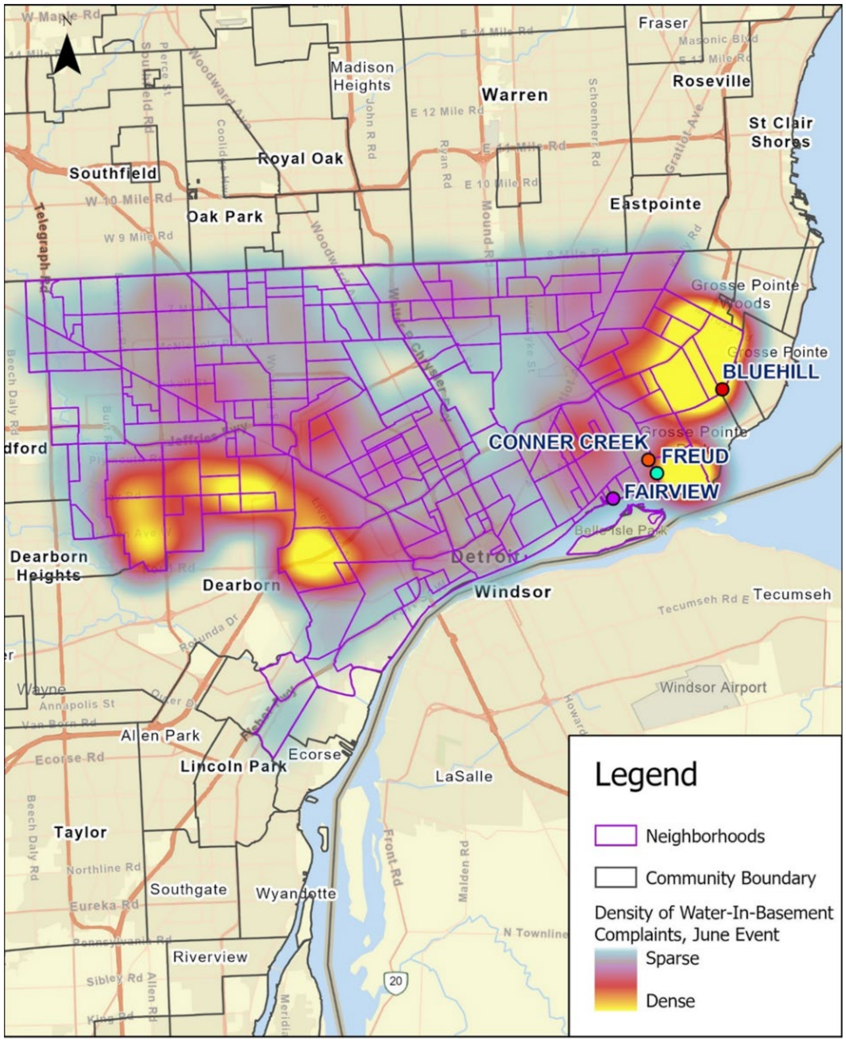


Figure 17: Heat Map of City of Detroit Basement Backup Reports for June 25/26 Rainfall Event based on DWSD flooding complaint database

PCSWMM Simulation of Actual Conditions of June 25/26 Rainfall Event

Basement Backup Potential

The validated PCSWMM model was used to estimate areas where basement backups were likely to have occurred during the June 25/26 Rainfall Event by extrapolating system-wide hydraulic grade lines. These modeling results were generated using the "ACTUAL" pumping operations. Results based on the modeled "freeboard" in the sewer system are shown in Figure 18. The freeboard represents the distance between the ground surface and the maximum water level in the sewer system. The areas in red are those where the freeboard was 4 feet or less (i.e., the water surface in the sewer system reached within 4 feet of the ground surface). The orange-shaded areas indicate a freeboard between 4 and 8 feet. It is generally assumed that the potential for basement backups is highest in areas where the freeboard is less than 8 feet. The areas shaded in red and orange in Figure 18 equal 48,295 acres or almost half of Detroit, Hamtramack, and Highland Park.

It is important to reiterate that these results are based solely on the PCSWMM model. There are clearly reports of basement flooding (Figure 16) in locations where the model results show low probability of basement backups (i.e., green-shaded areas). These instances of basement backups may have been caused by issues in the local sewer systems, not system-wide backups.

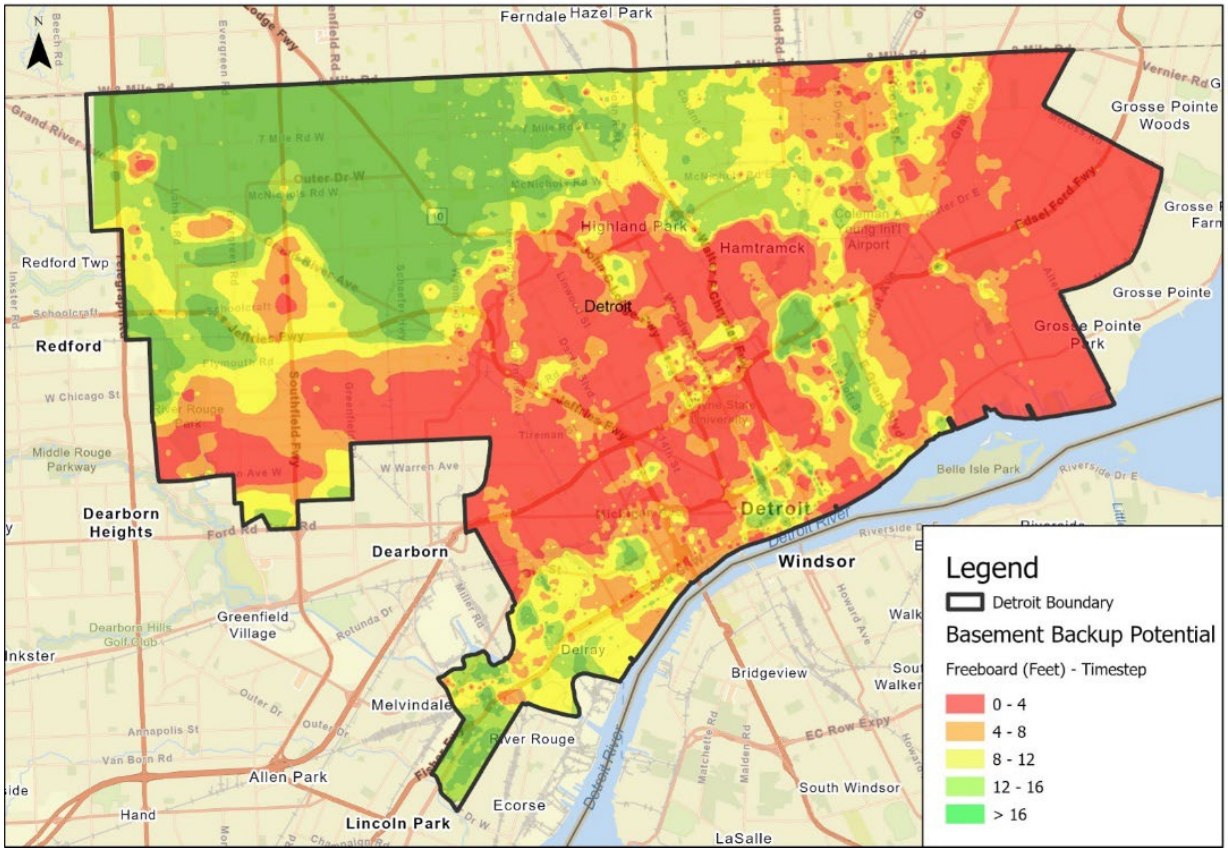


Figure 18: Predicted Risk of Water in Basement for Detroit, Hamtramck, and Highland Park in PCSWMM ACTUAL Scenario during the June 25/26 Rainfall Event (levels within 8 feet of the ground or less increase risk of basement backups)

Surface Flooding

Locations where surface flooding is predicted and the depths of that flooding with the ACTUAL scenario are shown in Figure 19. This simulation predicts approximately 3,800 acres of surface flooding during the June 25/26 Rainfall Event. The surface flooding shown here is solely the result of the sizing and operation of the GLWA sewer system. Additional surface flooding likely occurred during the June 25/26 Rainfall Event, which was not directly caused by constraints within the GLWA system. For example, storm sewer inlets can often become clogged and in some areas inlet restrictions have been installed to limit the amount of storm runoff that can enter the sewer system.

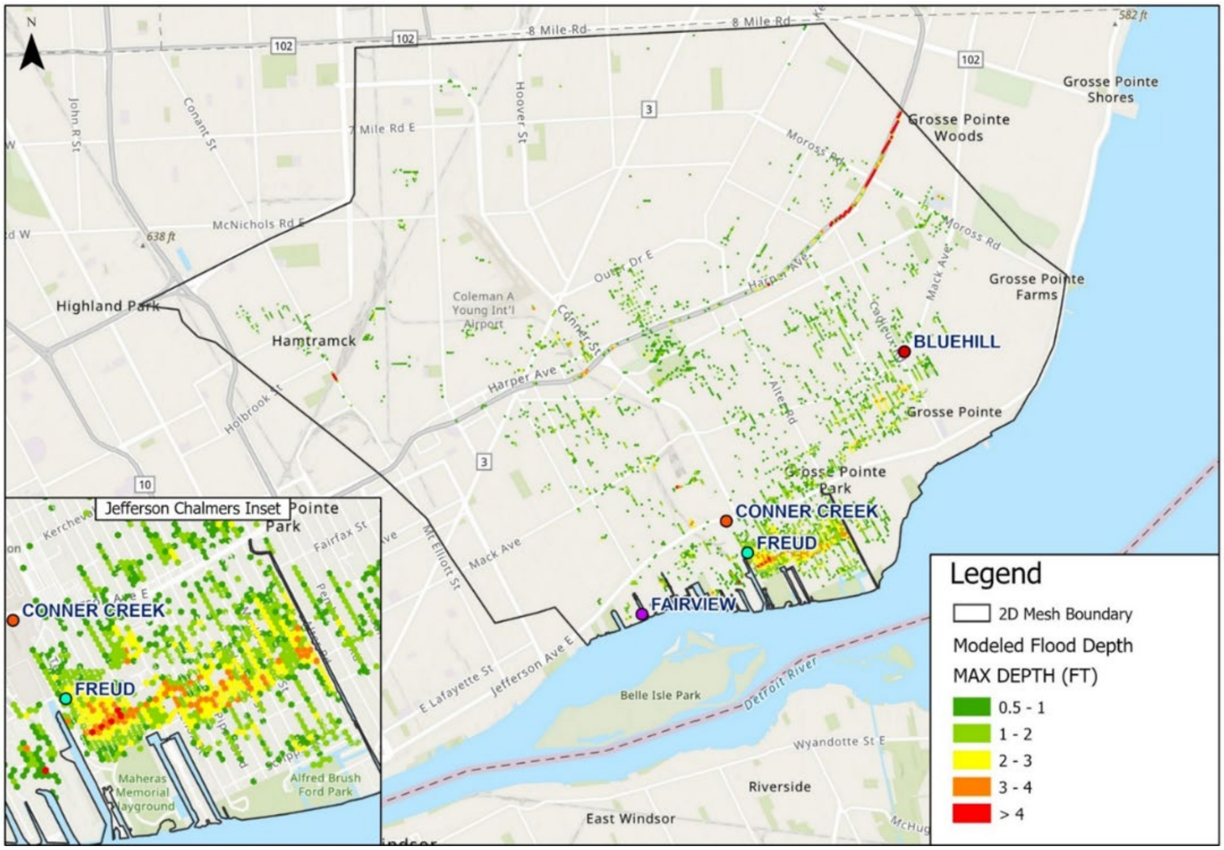


Figure 19: Predicted Surface Flooding in the ACTUAL Model Simulation during the June 25/26 Rainfall Event

The full extent of flooding in the Grosse Pointe communities east and north of the city of Detroit is not shown in the model results because data detail for those sewer systems were not included in the SWMM model or provided to GLWA.

PCSWMM Simulation of Potential Conditions of June 25/26 Rainfall Event

A similar analysis of potential basement backups and surface flooding was performed assuming the Connors Creek, Freud, and Bluehill PSs operated as intended. This scenario is referred to as the “IDEAL” scenario and uses pumping rules and operations based on the SOPs identified for each PS. This scenario is representative of what might have occurred if the PS problems discussed in Section 2.4 had not been encountered.

Pumped Volumes and Wet Well Level Comparison: PCSWMM ACTUAL Scenario versus PCSWMM IDEAL Scenario Results

A summary of the volumes pumped at the PSs under both the ACTUAL and IDEAL model scenarios is provided in Table 17 The Connors Creek and Freud pumping volumes are also totaled together since they are hydraulically interconnected when the Connors Creek wet well is above 68 feet elevation.

Table 8: Comparison of Pumped Volumes Had Stations Operated as Intended

	June ACTUAL	June IDEAL	Difference	% Change
	Volume (MG)	Volume (MG)	June Event	June Event
Connors Creek PS	429	574	145	25%
Freud PS	509	699	191	27%
Total - Connors Creek PS + Freud PS	938	1274	336	26%
Bluehill PS	155	152	-3	-2%

Notes:
MG = million gallons

The results show that GLWA could have pumped an additional 336 million gallons (MG), equal to 1,031 acre-feet, in the June 25/26 Rainfall Event if the Connors Creek and Freud PS operated as intended. This is a 26 percent increase over the actual pumping volume. In the ACTUAL model, the water that was not pumped was removed from the model as either CSO or surface flooding to areas not tributary to the PS.

The results for the Bluehill PS show a negligible difference in pumping volumes for the IDEAL and ACTUAL scenarios. These results suggest the power quality issues that were experienced and represented in the ACTUAL scenario did not result in water being removed from system, instead the water was temporarily stored upstream of the PS within the conveyance system or as surface flooding. The effects of the power quality issues are better represented by the wet well level results presented below.

It is noted that the models (both ACTUAL and IDEAL) do not account for water potentially removed from the conveyance system due to basement backups.

A summary of the maximum wet well levels under both the ACTUAL and IDEAL model scenarios is provided in Table 9. The results show that wet well levels at all three PSs would have been lower if the PS had been operated as intended.

Table 9: Comparison of Wet Well Levels Had Stations Operated as Intended

	June ACTUAL	June IDEAL	Difference
	Level* (ft)	Level* (ft)	June Event
Connors Creek	96.7	89.5	7.2
Freud	95.4	88.8	6.7
Bluehill	92.3	87.7	4.6

Notes:
* Levels reported as elevations on Detroit Datum
ft = foot/feet

Basement Backup Potential Comparison

The areas of basement backup potential under the IDEAL pumping conditions scenario are shown in Figure 20. Visually, it is difficult to discern any significant differences compared to the ACTUAL pumping conditions scenario results shown in Figure 18. The total area where freeboard is equal to or less than 8 feet is 48,105 acres, which is approximately 190 acres less than the ACTUAL scenario. This is a relatively insignificant difference that is within the range of uncertainty of the modeling results and analysis methodology. In other words, it is not possible to definitively conclude that basement backups would have been reduced under the IDEAL pumping conditions.

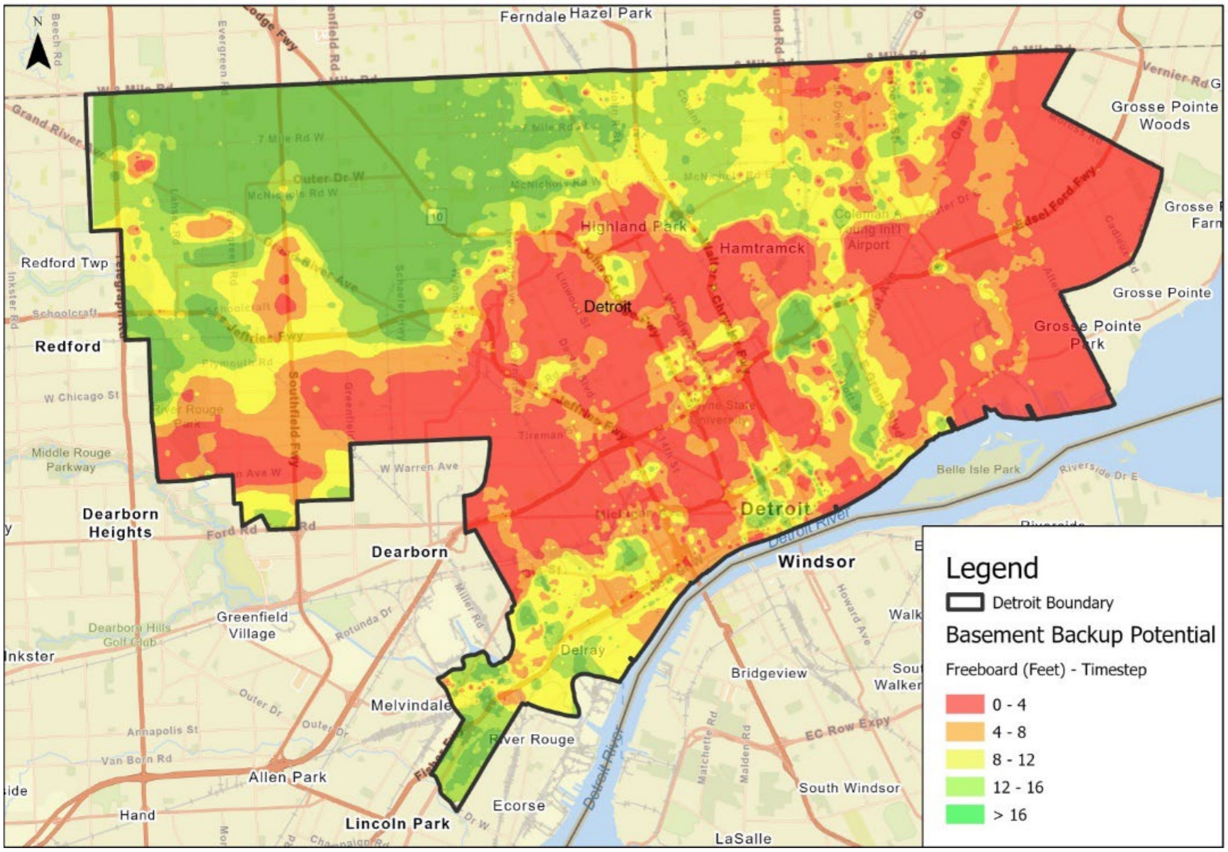


Figure 20: Predicted Risk of Water In Basement in PCSWMM IDEAL Scenario Simulation during the June 25/26 Rainfall Event (levels within 8 feet of the ground or less are expected to cause basement backups)

Surface Flooding Comparison

The predicted extent and depth of surface flooding for the IDEAL pumping conditions scenario is shown in Figure 21. Again, it is difficult to discern significant differences from the results shown in Figure 19; however, the Jefferson-Chalmers inset figure does show less red-colored dots under the IDEAL scenario. The red dots in Figure 19 represent areas with the deepest surface flooding (i.e., greater than 4 feet depth).

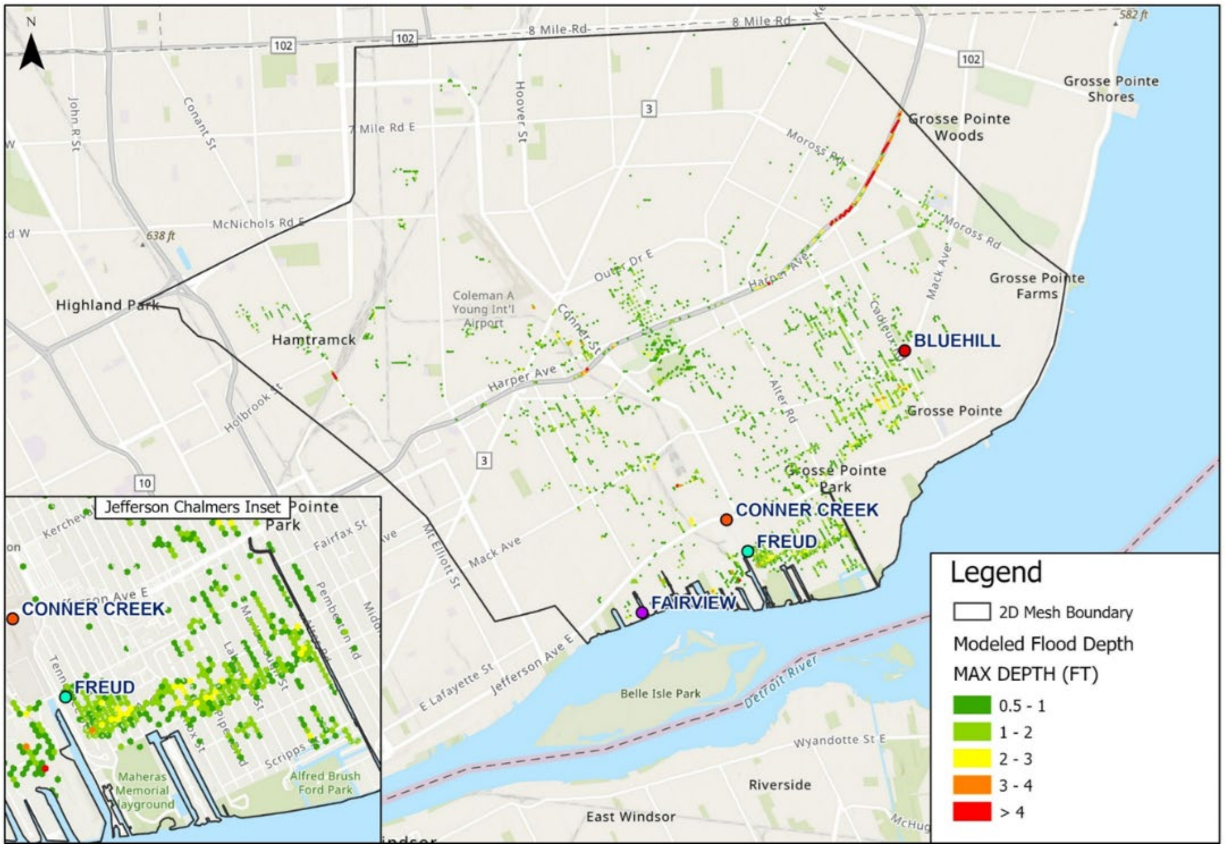


Figure 21: Predicted Surface Flooding for the PCSWMM IDEAL Simulation during the June 25/26 Rainfall Event

The surface flooding differences between the IDEAL and ACTUAL scenarios is shown in Figure 22. The areas colored in orange and yellow represent areas where the surface flooding depths would have been at least 1.25 feet (16 inches) lower had the Connors Creek and Freud PSs operated as intended. The blue, purple, and magenta areas would have also had lower surface flooding depths.

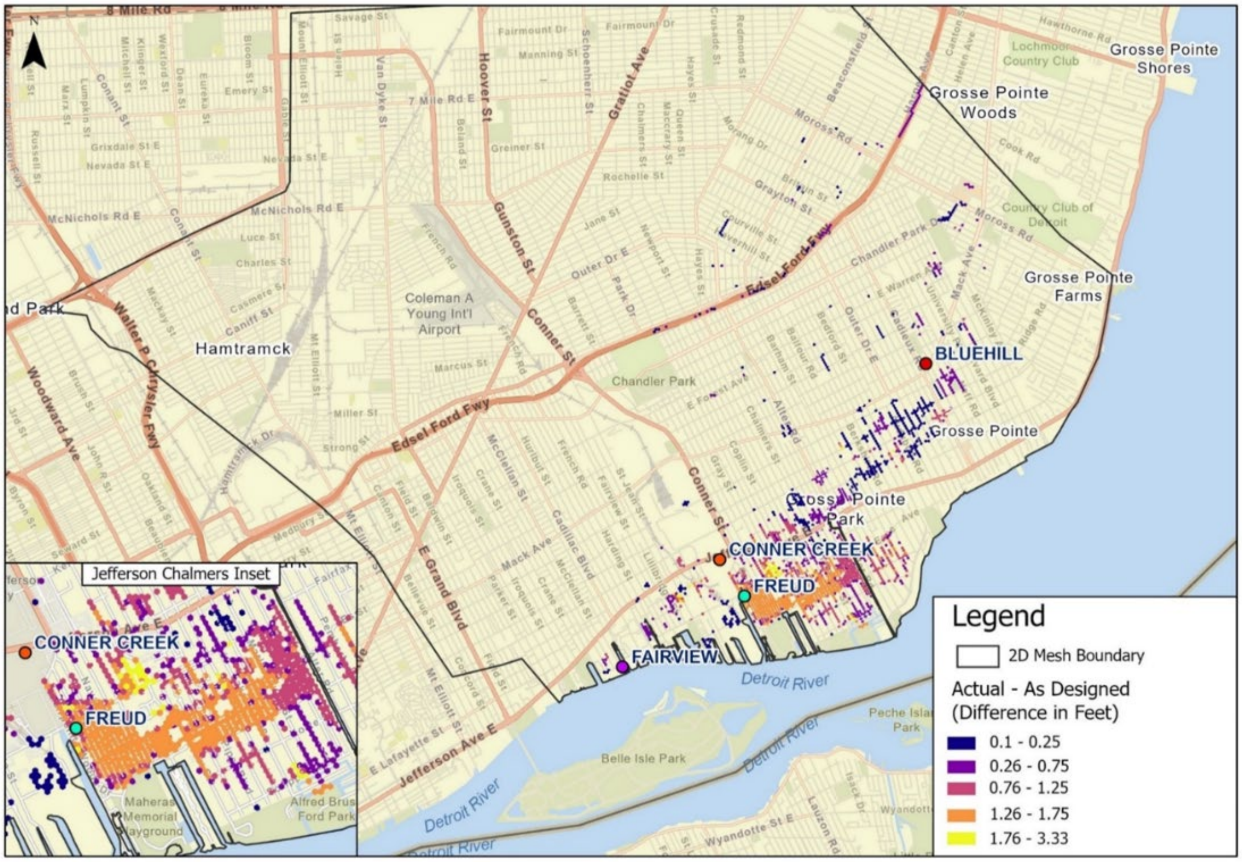


Figure 22: Surface Flooding Comparison between the PCSWMM ACTUAL and PCSWMM IDEAL model simulations during the June 25/26 Rainfall Event using the 2D mesh boundary using Lidar data

Another presentation of surface flooding results is provided in Table 10, which includes the total areas that experienced surface flooding at various depths. Again, it is clear that surface flooding would have been less under the IDEAL pumping scenario, however the differences diminish with greater depth and it is important to consider the consequences of surface flooding with respect to depth. Even though the area that may have experienced surface flooding up to 0.5 foot may have been reduced by over 350 acres, that depth of flooding generally does not result in significant damages. Depths greater than 2 feet do generally pose a greater risk of damages and these results show approximately 110 acres of area could have experienced 2 feet less surface flooding had the Connors Creek and Freud PSs operated as intended.

Table 10: Comparison of PCSWMM Simulation Results

	ACTUAL Simulation (acres)	IDEAL Simulation (acres)
Greater than or equal to 0.5 ft	1,204	866
Greater than 1 ft	602	362
Greater than 2 ft	183	73
Greater than 3 ft	59	29
Greater than 4 ft	20	16

Notes:
ft = foot/feet

PCSWMM "Contract Limits" Simulation of June 25/26 Rainfall Event

Discussion on GLWA customers that have contract limits on the maximum rate of flow that can enter the GLWA system is provided in Section 2.5. During this event, a few customers exceeded their contract limits (Table 4 and Table 6). To assess the potential impacts of these exceedances, AECOM modified the ACTUAL scenario model with inflows from those customers being limited to contract limits.

The basement backup potential for this scenario is shown in Figure 23. Again, the differences compared to Figure 18 (which simulated the ACTUAL discharges from those customers) are not discernable visually. In fact, the total area with freeboard equal to or less than 8 feet is 48,286 acres, only 9 acres less than the ACTUAL scenario results. This suggests that the contract limit exceedances that occurred during the June 25/26 Rainfall Event did not significantly affect exacerbate basement backup flooding. Due to these findings, AECOM did not produce a comparison of surface flooding.

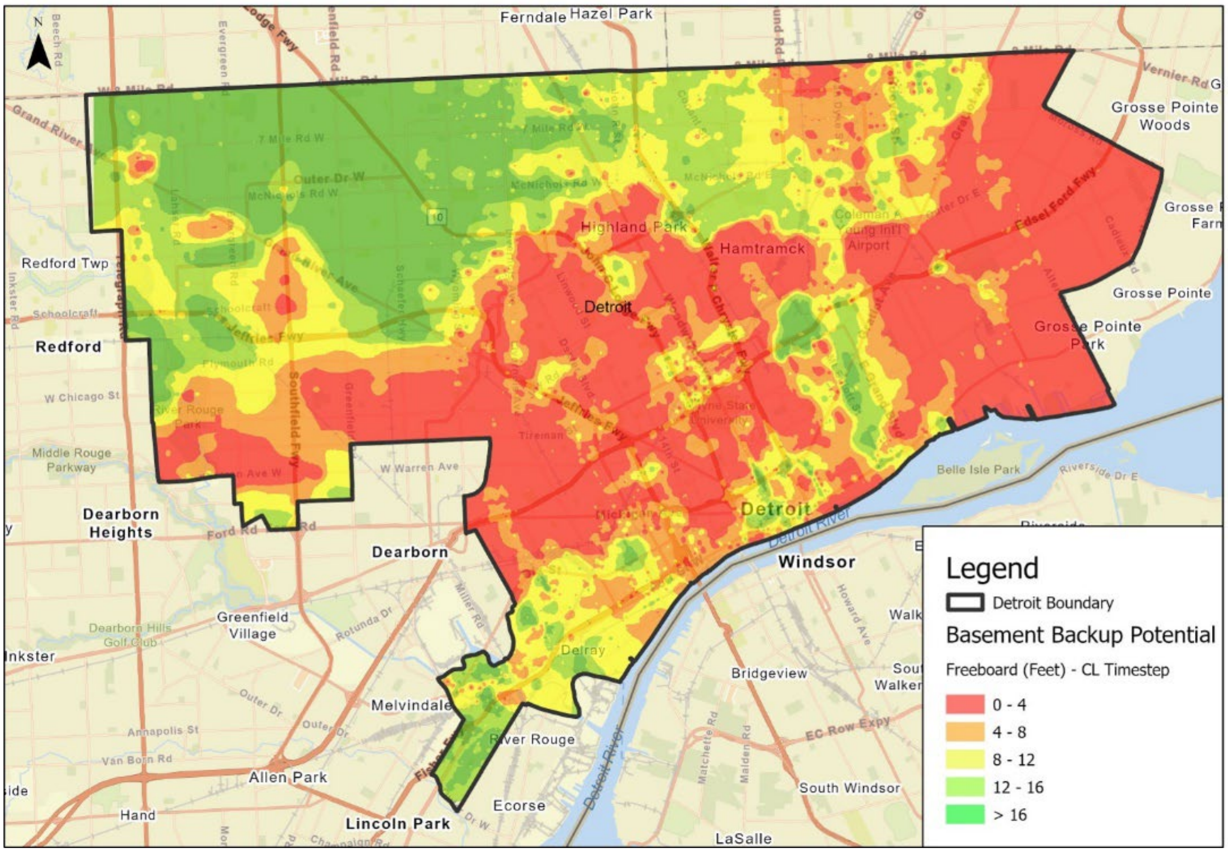


Figure 23: Predicted Risk of Water in Basement in PCSWMM CONTRACT LIMITS Scenario Simulation during the June 25/26 Rainfall Events (levels within 8 feet of the ground or less increase risk of basement backups)

Table 11: Predicted Risk of Water in Basements for all Simulations (Acres)

Scenario	Area within Basement Backup Potential (Acres)
June IDEAL	48,105
June CONTRACT LIMITS	48,286
June ACTUAL (SCADA System)	48,295

Notes:
SCADA = supervisory control and data acquisition

2.7 Observations and Conclusions

The investigation of the June 25/26 rainfall event yielded several observations and conclusions by the Independent Panel. A summary of these observations and conclusions is provided in Table 12:

Table 12: Observations and Conclusions for June 25/26 Rainfall Event

Charge	Observation/Conclusion
Characterization of Rainfall Event and Extent of Flooding	• The June 25/26 event was a large, high-intensity storm that covered much of the GLWA wastewater service area, but was most intense in the southern portions of Dearborn, the city of Detroit, and Grosse Pointe generally intensifying farther to the east. • The most intense areas of rainfall received in excess of 6 inches of rain with some areas receiving over 8 inches of rainfall over a 24-hour period. Based on historical rainfall records, this equates to a rainfall return period of 200 years to over 1000 years. • While areas to the north and west received significant rainfall with return periods between 5 and 10 years, the rainfall event across the southern portions of the service area—particularly in the east—far exceeded the designed capacity of the wastewater system. As such, extensive surface flooding and basement backups is considered inevitable. • The City of Detroit received thousands of reported water-in-basement complaints following the rain event. Complaints were concentrated in the west bordering Dearborn and the east side. Extensive hydraulic modeling was performed, and results of high flood risk generally coincided with the location of basement flooding complaints. Similarly, surface flooding analyses coincided well with observed high water marks.
Operational readiness	• Following the 2016 rainfalls events, GLWA implemented several measures to improve the reliability and performance of the wastewater system. Operations staff were deployed to PS and CSO facilities in accordance implemented measures prior to the rain event. • Wastewater operations historically evaluate their readiness level based on predicted rainfall. In the case of the June 25/26 event, actual rainfall far exceeded weather forecasts creating a false sense of readiness that was communicated to the BoD. • At the Freud PS, electrical power supply was compromised ○ In 2017, GLWA's energy supplier abandoned one of the three independent electrical feeds and spliced one electrical feed to power transformers 1 and 3. ○ On June 22, 2021, an electrical contractor for GLWA's energy supplier accidentally hit the utility service #1 distribution line (Ludden Feeder No. 208) feeding primary transformers 1 and 3 (removing them from service). The energy supplier attempted a repair of the utility service #1 but was unable to complete the repairs before the June 25/26 Rain Event. With two of three transformers out of service, the PS's peak pumping capacity was only approximately 43% of the overall capacity during the event (three of seven duty storm pumps available). This was considered sufficient for the forecasted rainfall. ○ Consistent with SOP, the hit line was communicated to the SCC supervisor. The supervisor did not communicate the damaged line to GLWA executive leadership nor the BoD. ○ With only one primary transformer available, there was enough electrical capacity to operate three storm pumps and two sanitary pumps. • At the Connors Creek PS, all systems except Storm Pump 5 checked out available prior to the June 25/26 rainfall event and operations and mechanical staff were on site prior to the rainfall event. Electrical technicians floated between Freud and Connors Creek PSs due to their proximity. • At the Bluehill PS: ○ Under normal conditions the station is operated remotely by the operators at the SCC. Operations staff visit the PS to perform routine preventive maintenance duties. During storm events, staff are dispatched if the automated systems indicate a fault at the station.

Charge	Observation/Conclusion
	◦ All equipment was available for service; however, storm pump #4 was marked for emergency used only ◦ At the time of the June 25/26 rainfall event, electrical power was supplied by Detroit's PLD and provided via two separate 24kV utility services to provide a level of utility redundancy. The station has two GLWA-owned primary transformers, each sized to power any three of the four storm pumps. Therefore, the capacity of the primary transformers prevents full redundancy. One of the power sources is backed up by three 1,825 kW emergency generators. There are no provisions to connect the emergency generators to back up utility service 2.
System response	• At the Freud PS: ◦ Power issues related to only one transformer being available resulted in only two pumps operating consistently. Attempting to start a third pump tripped out the operating two pumps. High normal wet well levels were exceeded before 11 p.m. and continued to rise. Operators were eventually able to start three pumps and, with five pumps then operating at Connors Creek (more details provided below), wet well levels gradually subsided. • At the Connors Creek PS: ◦ The elevation and configuration of the storm pumps requires the operation of a vacuum priming system prior to starting the storm pumps. This system has been historically complex to operate, and operators prefer to allow wet well levels to increase so that pumps can start without the aid of the vacuum priming system. The rate of rise of wet well levels likely exceeded the operators' ability to start additional pumps. ◦ Operators were able to initially start two pumps, but a leak from the vacuum priming system sprayed on an electrical panel causing a loss of house power. Electrical supply to the station was not impacted and the two pumps continued to operate, but additional pumps could not be started. The wet well elevation before midnight was already above 86 feet (i.e., the maximum recordable level). ◦ Electricians in route to Freud PS were recalled to Connors Creek to effect repairs, but street flooding and lack of lighting or ability to access the site (security gates operate on house power) hampered these efforts. This delay is estimated at 15 to 30 minutes with the wet well level remaining above 86 feet. When house power was restored, five pumps were able to operate and began to reduce wet well levels and shortly after 2 a.m., dropped to within recordable range. • The Bluehill PS, which like Freud PS was supplied from Detroit PLD, experienced power quality issues. Voltages plus/minus 10% of rated voltage will cause a pump not to start. Bluehill operated with two of the four available storm pumps during the peak of the event and the wet well level reached the maximum recordable level of about 86 feet. • Detailed reviews of the response of member communities was beyond the scope of this investigation, but peak flow measurements of discharges suggest that most communities were at or below their contracted discharges limits within the exception of the cities of Gross Pointe Park and Gross Pointe, which significantly exceeded their contract limits.

Charge	Observation/Conclusion

System Response if Everything had worked as intended	• The intensity of the rainfall far exceeded the designed capacity of the wastewater system and, as a result, some level of both surface flooding and basement backup was unavoidable.
	• Operational problems during the storm event likely exacerbated flooding and basement backup:
	  ○ Approximately 110 acres of area could have experienced less than 2 feet of surface flooding had the Connors Creek and Freud PSs operated as intended
	  ○ Modeling suggests an additional 336 MG or 26% of total flow could have been pumped and the PS wet well levels would have been 5 to 7 feet lower had everything worked as intended
	• An analysis of risk of basement backup did not show an appreciable reduction in risk should everything had worked an intended.
	• Contract limit exceedances that occurred during the June 25/26 Rainfall Event did not significantly affect basement backup flooding.
	• The above suggests that conveyance capacity in the collection system, not pumping, is the primary cause of flood risk and additional pumping capacity would not appreciably reduce the risk of basement backups. Rather, a strategic assessment of conveyance improvements, inlet controls and in-system storage is warranted

Notes:
BoD = Board of Directors
CSO = combined sewer overflow
MG = million gallons
PLD = Public Lighting Department
PS = Pumping Station
SCC = System Control Center
SOP = standard operating procedure

3. July 16 Rainfall Event

3.1 Summary of Rainfall Event

The July 16 Rainfall Event was a high intensity storm that started at approximately 6 a.m. on July 16 and ended at approximately 6 p.m. on July 16. The storm was situated over areas of Oakland and Wayne counties and had a peak intensity of 11.8 inches per hour over a 5-minute duration, with maximum accumulated depths of 4.5 inches over 6 hours and 4.7 inches over 12 hours. Based on an analysis of rainfall records, this storm would have a maximum return period of between 100 and 300 years in some locations.

The return period and severity of the July 16 Rainfall Event can be generally represented by the spatial distribution of observed precipitation depths and associated return periods for the 12-hour duration, as shown in Figure 24. The largest 12-hour precipitation depths were observed, and the greatest return periods occurred in the areas northeast of the center of Detroit along the north bank of the Detroit River near Belle Isle, and at the City of Dearborn Outer Drive gage in western Wayne County near the intersection of Michigan Avenue and Outer Drive. Comparison of the 12-hour precipitation depths and associated return periods for the June 25/26 Rainfall Event (Figure 11) to those for the July 16 Rainfall Event (Figure 24) show that the July 16 Rainfall Event was less severe.

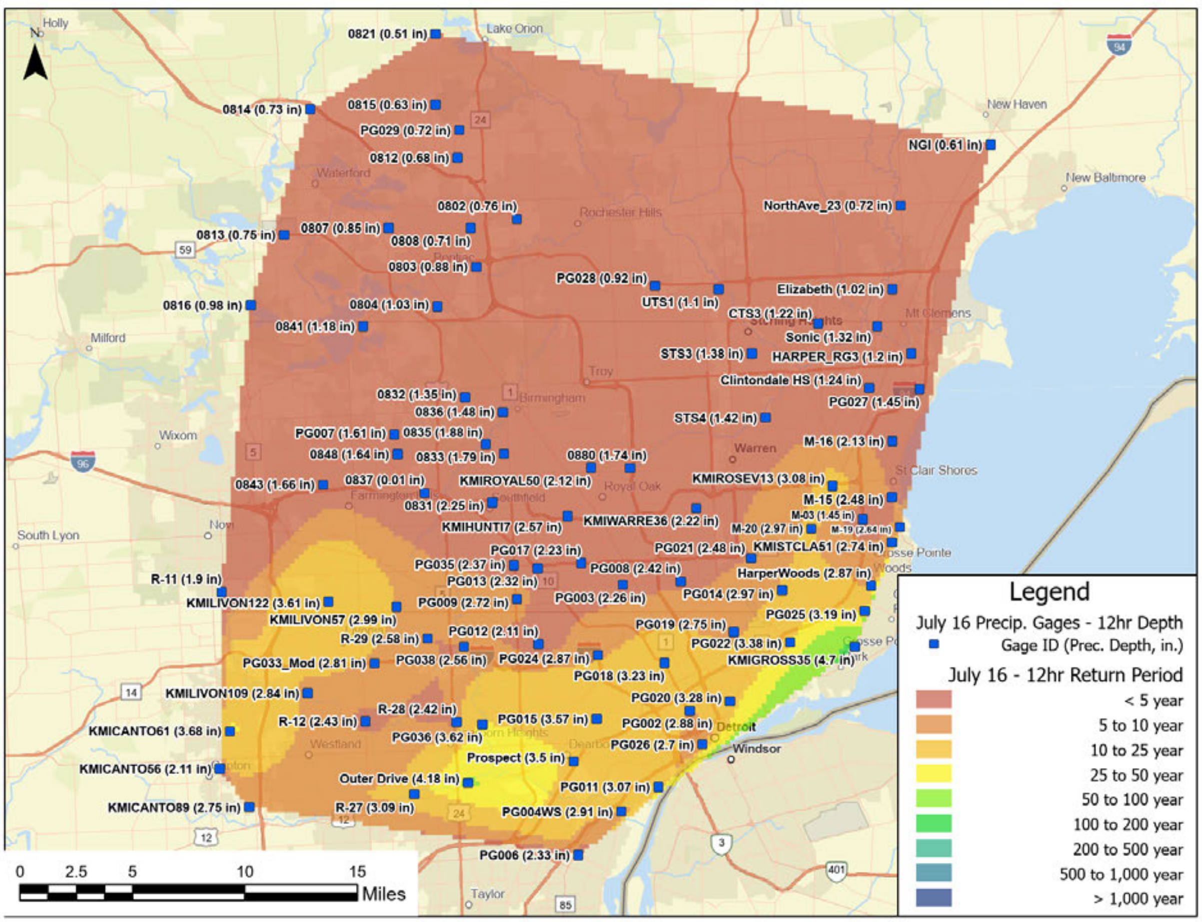


Figure 24: July 16 12-hour Precipitation Depth and Return Period

3.2 Operational Readiness

This section details the operational readiness of the PS and operators. This section details the findings of what equipment was available to be operated and provides an account of the operational preparation and the operators' perceived level of readiness for the July 16 Rainfall Event.

3.2.1 Connors Creek PS (GLWA)

The Connors Creek PS was staffed prior to the July 16 Rainfall Event. A mechanical team was on site prior to the storm and checked out the mechanical systems, including the vacuum priming system. All systems (except Storm Pump 1) checked out available at the time. A summary of the operational readiness of major system components at the Connors Creek PS prior to the July 16 Rainfall Event is provided in Table 13.

Table 13: Equipment Availability at Connors Creek PS on prior to the July 16 Rainfall Event

		Availability		
Major System	Component	Yes	No	Comments
Mechanical	Storm Pump 1		X	ST1: Protective relay out for repair[1,2]
	Storm Pump 2	X		
	Storm Pump 3	X		
	Storm Pump 4	X		
	Storm Pump 5	X		
	Storm Pump 6	X		
	Storm Pump 7	X		
	Storm Pump 8	X		
	Sanitary Pump 9	X		
	Sanitary Pump 10	X		
	Sanitary Pump 11	X		SN11: Local operation only[2]
	Sanitary Pump 12	X		SN12: Emergency use only[2]
Electrical	Utility Service 1	X		
	Utility Service 2	X		
	Transformer 1	X		
	Transformer 2	X		
	Emergency Generator 1	X		
	Emergency Generator 2	X		
	Emergency Generator 3	X		
	Emergency Generator 4	X		
Controls	Wet Well Sensors	X		
	SCADA System	X		

Notes:
[1]Operator logbook, Connors Creek PS
[2]GLWA Red Tag Report, July 7, 2021
SCADA = supervisory control and data acquisition

3.2.2 Freud PS (GLWA)

Power quality issues were observed but did not significantly impact operations.

On June 30, 2021, repairs to the main cut electrical feed lines to the Freud PS were completed. The Freud PS was staffed on site and checked out prior to July 16 Rainfall Event. A summary of the operational readiness of major system components at the Freud PS prior to the July 16 Rainfall Event is provided in Table 14.

Table 14: Equipment Availability at Freud PS prior to the July 16 Rainfall Event

Major System	Component	Availability		Comments
		Yes	No	
Mechanical	Storm Pump 1		X	ST1: Warranty Issue (motor protection) [1,2]
	Storm Pump 2	X		
	Storm Pump 3	X		
	Storm Pump 4	X		
	Storm Pump 5		X	ST5: Tripped on start [1], PLD Power Outage [2]
	Storm Pump 6	X		
	Storm Pump 7	X		
	Storm Pump 8		X	ST8: Out of service; electrical issue [1]
	Sanitary Pump 9	X		
	Sanitary Pump 10	X		
Electrical	Utility Service 1 (from PLD)	X		
	Utility Service 2 (from DTE)	X		
	Transformer 1	X		
	Transformer 2	X		
	Transformer 3	X		
	Emergency Generator 1	X		
	Emergency Generator 2	X		
	Emergency Generator 3	X		
	Emergency Generator 4	X		
Controls	Wet Well Sensors	X		2 in storm wet well (1 connected to SCADA system)
	SCADA System	X		

Notes:
[1]Operator logbook, Freud PS
[2]GLWA Red Tag Report, July 7, 2021
PLD = Public Lighting Department
SCADA = supervisory control and data acquisition

3.2.3 Bluehill PS (DWSD)

The Bluehill PS is operated remotely from the SCC. Operators are dispatched if any faults or equipment issues are identified. Based on the operator logbook, all systems appear to have been available at the time of the July 16 Rainfall Event. A summary of the operational readiness of major system components at the Bluehill PS prior to the July 16 Rainfall Event is provided in Table 15.

Table 15: Equipment Availability at Bluehill PS prior to the July 16 Rainfall Event

Major System	Component	Availability Yes	Availability No	Comments
Mechanical	Storm Pump 1	X		
	Storm Pump 2	X		
	Storm Pump 3	X		
	Storm Pump 4	X		ST4: Emergency use only [1]
	Sanitary Pump 5	X		
	Sanitary Pump 6	X		
Electrical	Utility Service 1	X		
	Utility Service 2	X		
	Transformer 1	X		
	Transformer 2	X		
	Transformer 3	X		
	Emergency Generator 1	X		
	Emergency Generator 2	X		
	Emergency Generator 3	X		
Controls	Wet Well Sensors	X		2 in storm wet well (1 connected to SCADA System)
	SCADA System	X		

Notes:
[1]GLWA Red Tag Report, July 6, 2021
PLD = Public Lighting Department
SCADA = supervisory control and data acquisition

3.2.4 Other Pumping Stations

The investigations revealed no significant equipment issues.

3.2.5 Connors Creek Sewer

The internal investigation revealed that three of the nine in-system gates were out of service for mechanical repair. The internal investigation revealed six in-system gates were sufficient to convey flow to the Connors Creek CSO Control Facility with only marginal increase in the velocity and hydraulic gradient. Further, sediment deposition had only a minor increase in hydraulic gradient, which dissipated quickly.

3.2.6 Personnel

The investigations reveal that GLWA staffed the Connors Creek PS and Freud PS for the rain event. GLWA dispatched team members to the Bluehill PS, as needed, during the rain events. GLWA staff believed they were prepared and operationally ready for the July 16 Rainfall Event.

A list of key GLWA staff members interviewed during this investigation is appended to this report. Staff consistently stated that they believed they were prepared and operationally ready for the anticipated for the June/July Rainfall Events. That belief of readiness was founded on two key factors: 1) the equipment they believed to be available; and 2) the size/amount of the storm or wet weather period that had been forecasted relative to their understanding of what the system had been designed for. However, both components were not entirely true in reality; the equipment operators believed to be ready was not fully available and the rainfall events—particularly the June 25/26 Rainfall Event—produced far higher flows than was ever planned for. In summary, a snapshot of the Operational Readiness Staffing at the three PSs for the 2021 Rainfall Events is provided in Table 16**.**

Table 16: Staffing Summary During Rainfall Event

Pumping Station	June 25/26 Event	July 16 Event
Connors Creek PS	Fully staffed prior to the storm event	Fully staffed prior to the storm event
Freud PS	Staffed on site and checked out prior to the storm event	Staffed on site and checked out prior to the storm event
Bluehill PS	Remote Operation Staff were dispatched prior to and during the event	Remote Operation Staff were dispatched prior to and during the event

Notes:
PS = Pumping Station

3.3 Sequence of Events

3.3.1 Connors Creek PS (GLWA)

During the peak of the July 16 Rainfall Event, six of the eight available storm pumps were running at the Connors Creek PS and wet well reached about elevation 73 feet. The investigations did not reveal significant equipment issues.

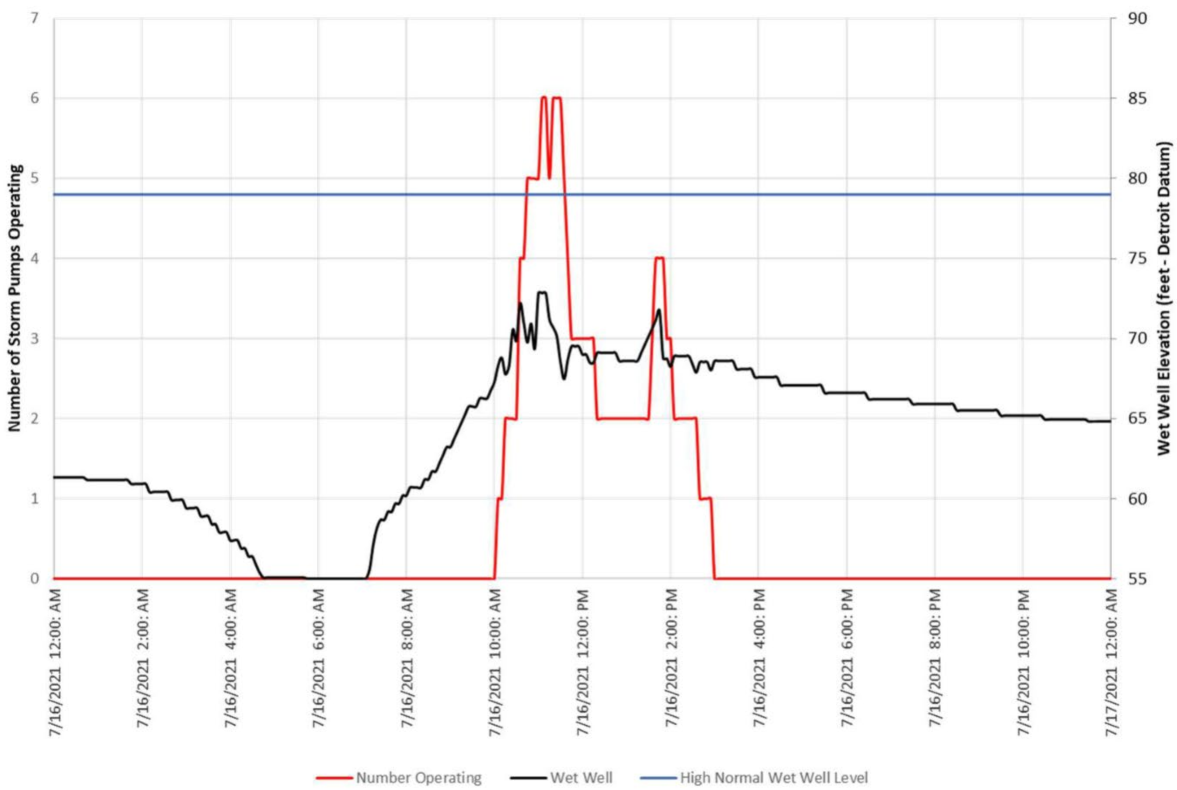


Figure 25: Storm Pump Operations at Connors Creek PS during the July 16 Rainfall Event

3.3.2 Freud PS (GLWA)

During the peak of the July 16 Rainfall Event, all five of the available storm pumps (three pumps were unavailable as shown in Table 14) were running at the Freud PS and the wet well reached a maximum level of about 78 feet. The investigations did not reveal significant equipment issues. Before the start of this rain event, the power to the cut power feed had been restored.

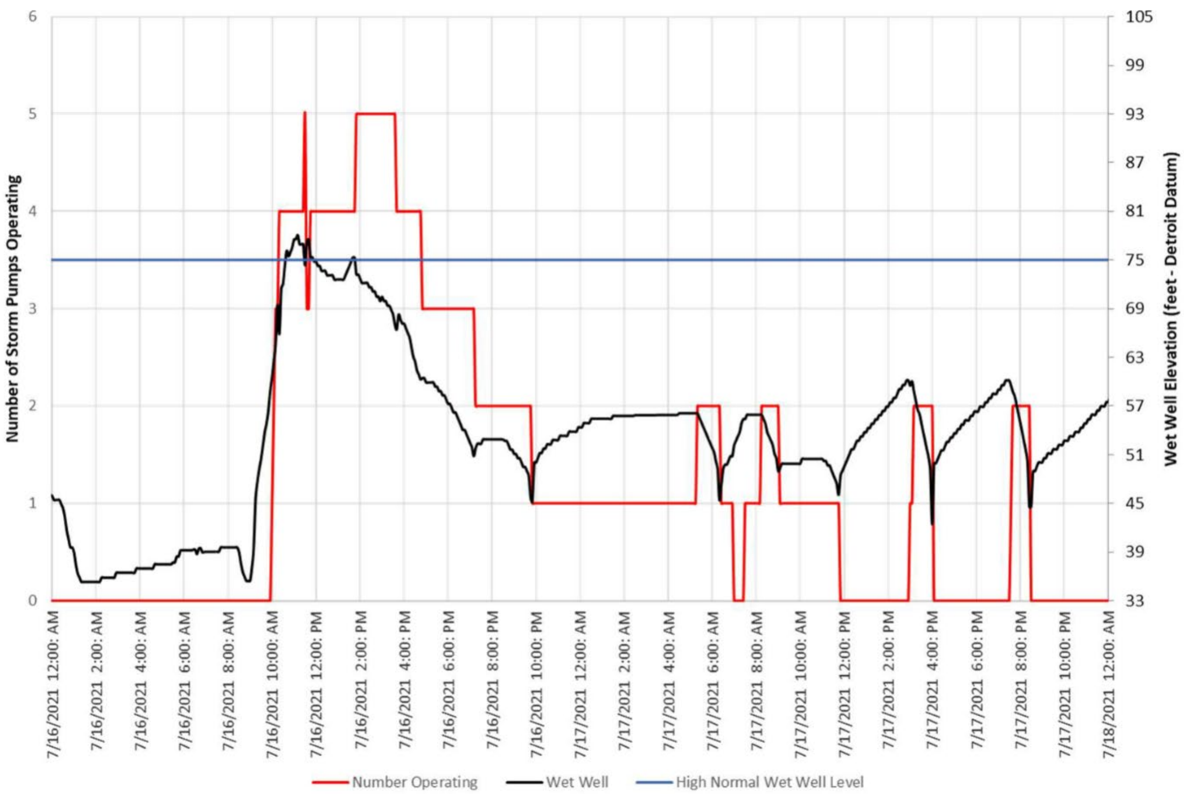


Figure 26: Storm Pump Operations at Freud PS during the July 16 Rainfall Event

3.3.3 Bluehill PS (DWSD)

The Bluehill PS has three large storm pumps: one smaller storm pump and two sanitary pumps. In the plots, the smaller storm pump has half of the capacity of the large pumps. This is exhibited for the July 16 Rainfall Event when the number of pumps equaled 0.5, 1.5, 2.5, and 3.5 as shown in Figure 27. During the peak of the July 16 Rainfall Event all four storm pumps operated (although not concurrently) and the wet well level reached the level sensor top of range at about 86 feet.

The station is normally operated remotely from the SCC. During the July 16 Rainfall Event, operators were dispatched to the PS for manual operations—if needed—between 4 p.m. and midnight. At 8:15 p.m. during the July 16 Rainfall Event, one of the utility main breakers tripped on overvoltage, which disabled two of the large storm pumps. The emergency generators did not start because the auto start controls still sensed overvoltage (generators are only started on loss of voltage). Three storm pumps were needed. Because only one main switchgear was online, only one large storm pump and one small storm pump were operated. Storm Pump 3 was started remotely but Storm Pump 4 had to be started manually. The wet well level had reached approximately 75 feet when the pumps were started. Street flooding was experienced at 45 feet around the PS, hindering access.

The investigations reveal that despite storm pump availability, there were power quality issues experienced during the July 16 Rainfall Event. The teams concluded that power quality issues may have caused flooding in the PS's tributary area. The PLD and associated primary transformers have a power quality issue that affects operation. The nominal voltage is significantly higher than the 2400 volt rated equipment. High voltage can cause the main switchgear breakers to trip causing a loss of pump availability. Also, voltages varying more than 10 percent of design could cause a pump to not start. The primary transformers have taps on the primary windings that can be adjusted to increase or reduce voltage, however both transformers have their taps at the lowest voltage adjustment.

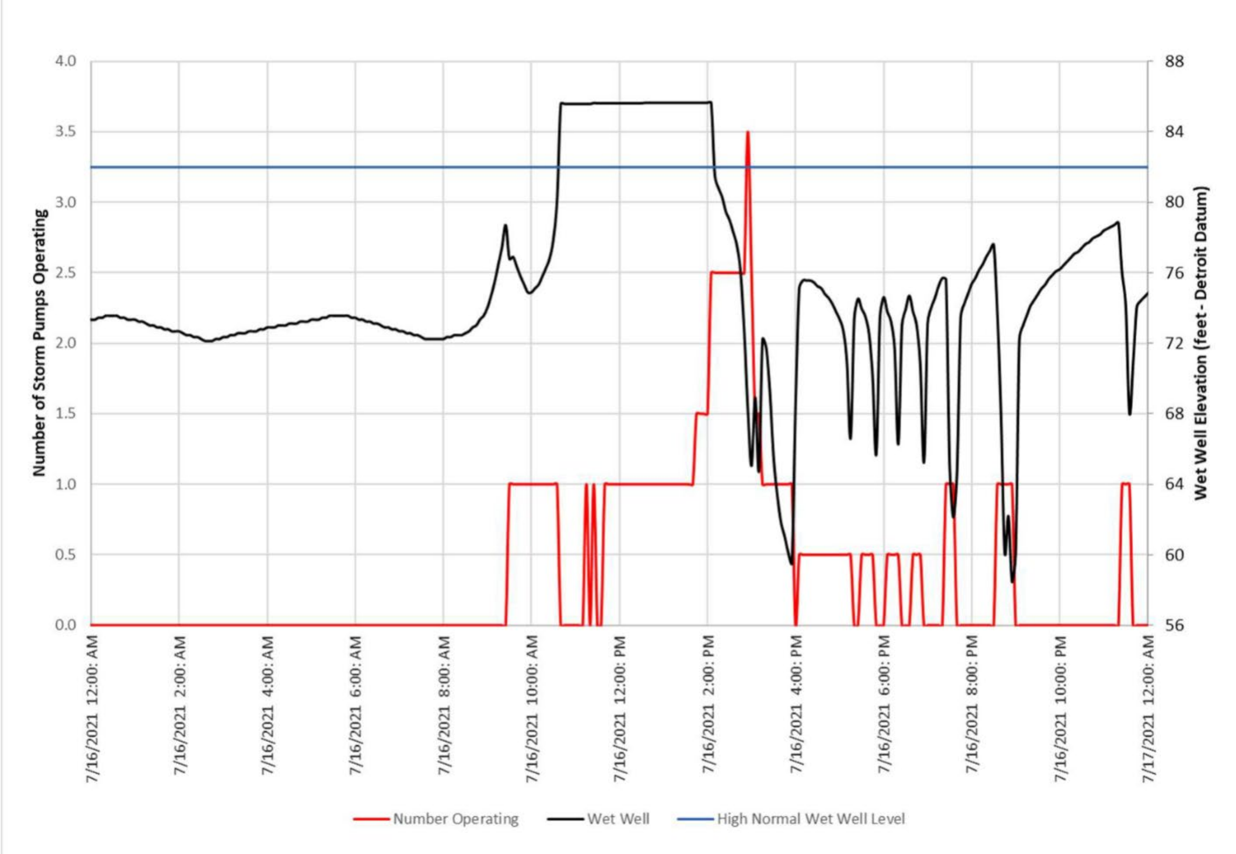


Figure 27: Storm Pump Operations at Bluehill PS during the July 16 Rainfall Event

3.3.4 Other PS

The investigations identified no significant equipment issues.

3.4 Interactions Between Systems

East Side System

A description of the East Side System and discussion of the interactions among GLWA and its customers for both storm events are provided in Section 2.5.

West Side System

A description of the West Side System is provided in Section 2.5.

Because the scope of this investigation was focused on the East Side System, the panel and teams did not perform a detailed analysis of the West Side System. GLWA reports that the internal investigation concluded that the PSs operated as intended. The following summaries are based on data and analysis included in the ASI Report (Appendix A9).

<u>July 16 Rainfall Event</u>

All customers with contract limits discharged into the GLWA system near or below their contract limit, with the exception of Allen Park, which exceeded its contract limit by approximately 2 cfs.

Inflows into the Baby Creek CSO Facility were significantly less than the maximum design. Headloss through the facility screens was within design range and Rouge River water levels were within the design range. However, upstream water levels exceeded the design level by about 1 foot, indicating that headloss in the Baby Creek Enclosure downstream was greater than expected (and similar to what was experienced during the June 25/26 Rainfall Event). A follow up investigation performed in February 2022 found no blockages in the Baby Creek Enclosure and accumulated sediment was approximately 4 percent of the total Baby Creek Enclosure storage volume. Therefore, it is concluded that the flow rate measurements on the influent conduits to the Baby Creek CSO Facility are significantly underreporting inflows.

The Hubbell-Southfield CSO Facility has a maximum operating capacity (including bypass) of 5,100 cfs; however, no estimates of inflows were provided. During this event, the Rouge River was about 3 feet below maximum design level. Within about 20 to 30 minutes of the peak rainfall, the emergency relief gates (ERGs) were being opened (at least partially). Over the next 2 hours, the ERGs were opened and closed in coordination with opening and closing the bypass relief gates (BRGs)—presumably to balance the amount of untreated water being discharged with the amount of partially treated water. Approximately 2.5 hours after peak rainfall, the ERGs remained fully open for the duration of the event. Upstream water levels at the facility remained at or below design levels throughout the event. The water level at the DT-S-3 flow sensor farther upstream in the Hubbell-Southfield box sewer reached the ground surface for approximately 20 minutes during the peak of the rainfall.

3.5 Extent of Flooding

Details regarding the extent of flooding associated with the GLWA and DWSD collection systems during the July 16 Rainfall Event is provided in this section. The analysis was performed using the same methods as those provided in Section 2.6 for the June 25/26 Rainfall Event.

Locations where citizens reported water in their basements during the July 16 Rainfall Event are shown in Figure 29 and Figure 30. The maps show the highest density of basement flooding reports were in the Cornerstone Village, East English Village, and Jefferson-Chalmers neighborhoods. No data were provided for the areas outside of the city of Detroit.

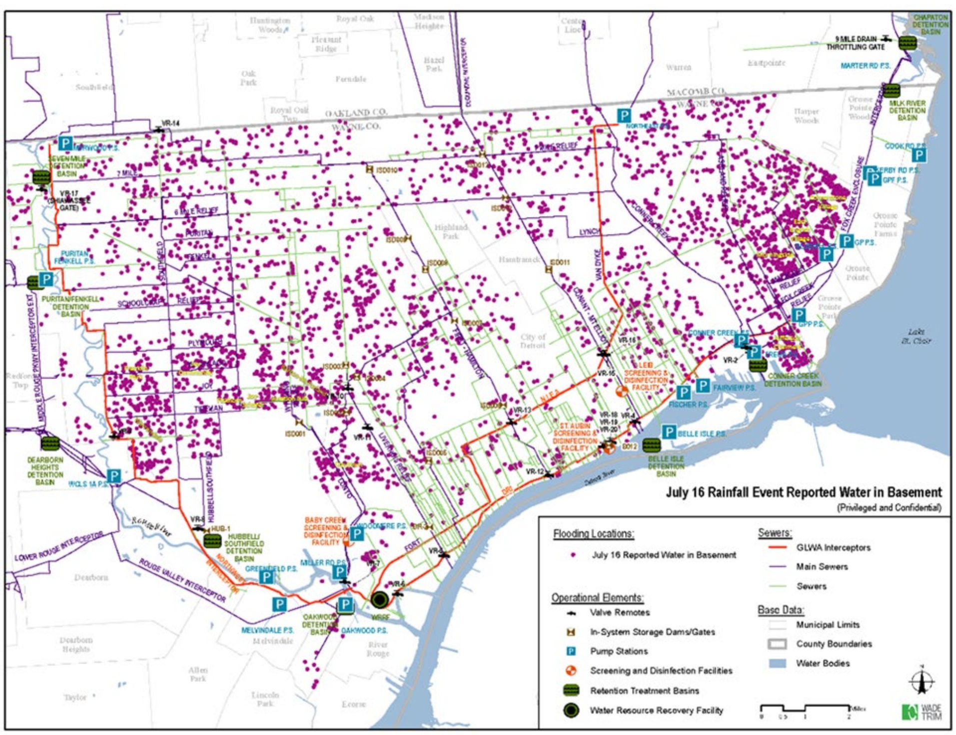


Figure 28: Reported Water in Basement in Detroit for July 16 Rainfall Event

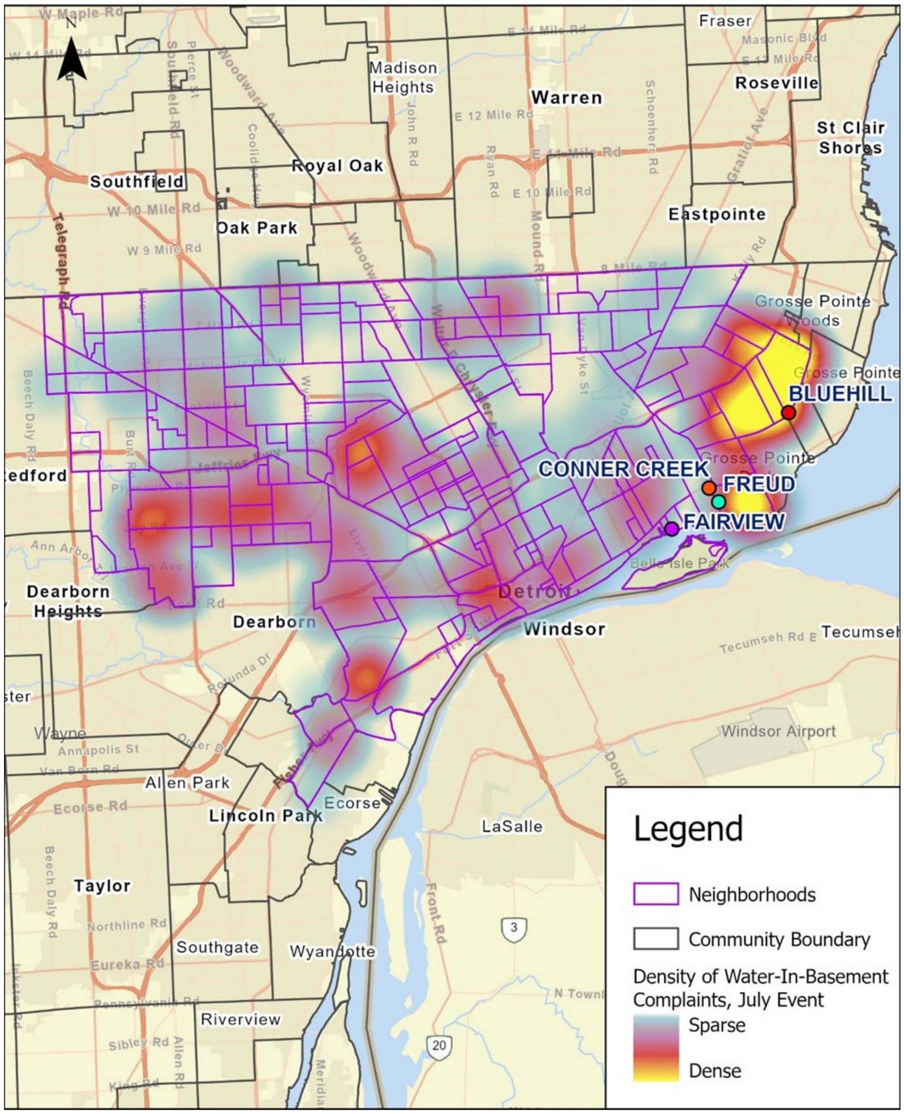


Figure 29: Heat Map of Water in Basement claims in Detroit for July 16 Rainfall Event

PCSWMM Simulation of Actual Conditions of the July 16 Rainfall Event

<u>Basement Backup Potential</u>

The validated PCSWMM model was used to estimate areas where basement backups were likely to have occurred during the July 16 Rainfall Event. These modeling results were generated using the “ACTUAL” pumping operations. Results based on the modeled “freeboard” in the sewer system are shown in Figure 31. The freeboard represents the distance between the ground surface and the maximum water level in the sewer system. The areas in red are those where the freeboard was 4 feet or less (i.e., the water surface in the sewer system reached within 4 feet of the ground surface). The orange-shaded areas indicate a freeboard between 4 and 8 feet. It is generally assumed that the potential for basement backups is highest in areas where the freeboard is less than 8 feet. The areas shaded in red and orange in Figure 30 equals 6,902 acres.

These results are based solely on the PCSWMM model. There are clearly reports of basement flooding (Figure 28) in locations where the model results show low probability of basement backups (i.e., green-shaded areas) based on a system-wide extrapolation of hydraulic grade lines. These instances of basement backups may have been caused by issues in the local sewer systems and/or individual private sewer connections.

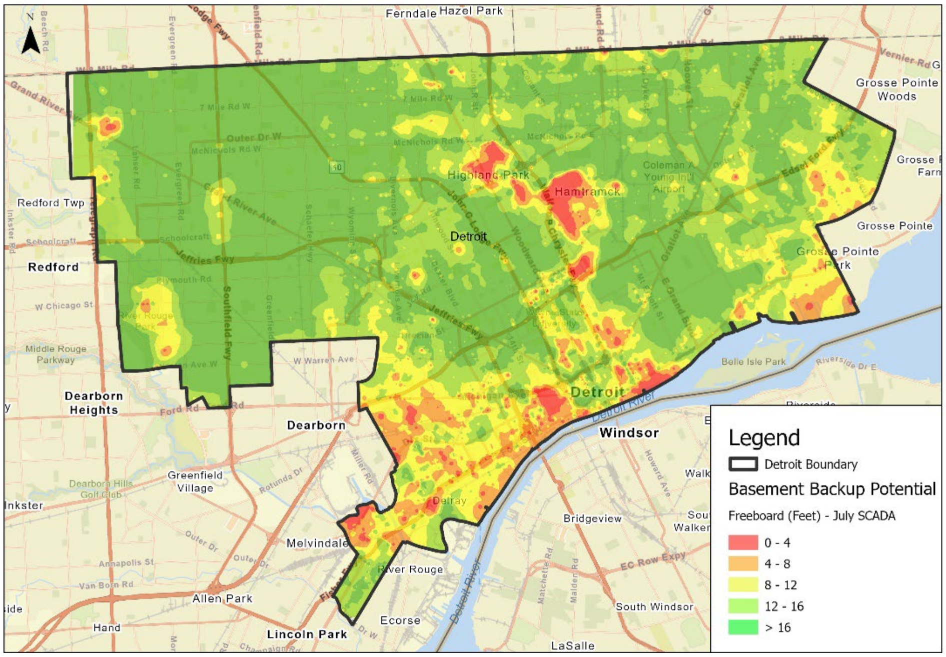


Figure 30: Predicted Risk of Water in Basement in Detroit in PCSWMM ACTUAL Scenario Simulation during the July 16 Rainfall Event (levels within 8 feet of the ground or less increase risk of basement backups)

Surface Flooding

The modeling results did not indicate any areas with significant surface flooding during the July 16 Rainfall Event (Figure 31). AECOM also reviewed over 350 basement backup complaints provided by GLWA and none of those reported significant surface (street) flooding.

As with the June 25/26 Rainfall Event, surface flooding in areas of the Grosse Pointe communities could not be simulated because those sewer systems are not included in the model.

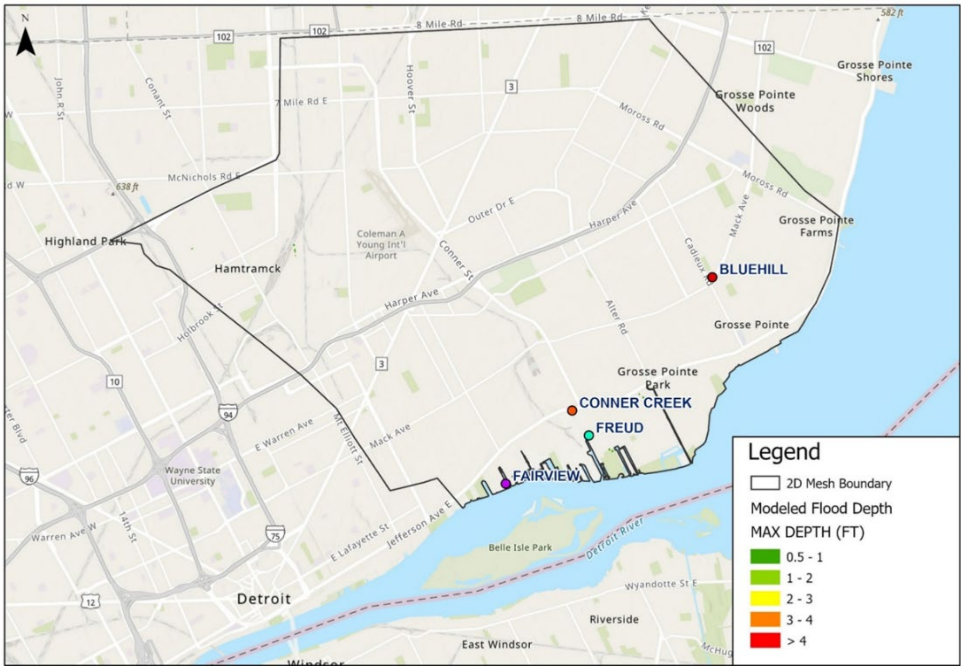


Figure 31: Predicted Surface Flooding in ACTUAL Model Simulation during the July 16 Rainfall Event

PCSWMM Simulation of Potential Conditions of July 16 Rainfall Event

A similar analysis of potential basement backups and surface flooding was performed assuming the Connors Creek, Freud, and Bluehill PS operated as intended. This scenario is referred to as the "IDEAL" scenario and uses pumping rules and operations based on the standard operating procedures identified for each PS. This scenario is representative of what might have occurred if the PS problems discussed in Section 0 had not been encountered.

Pumped Volumes and Wet Well Level Comparison: PCSWMM ACTUAL Scenario vs. PCSWMM IDEAL Scenario Results

A summary of the volumes pumped at the PSs under both the ACTUAL and IDEAL model scenarios is provided in Table 17. The Connors Creek and Freud pumping volumes are also totaled together because they are hydraulically interconnected when the Connors Creek wet well is above 68 feet elevation.

Table 17: Comparison of Pumped Volumes Had Stations Operated as Intended

	July ACTUAL Volume (MG)	July IDEAL Volume (MG)	Difference	% Change
Connors Creek PS	144	404	261	64
Freud PS	646	490	-156	-32
Total - Connors Creek PS + Freud PS	790	894	105	12
Bluehill PS	92	89	-3	-4

Notes:
MG = million gallons

The results show that GLWA could have pumped an additional 105 MG, equal to 322 acre-feet, in the July 16 Rainfall Event if the Connors Creek and Freud PS operated as intended. This is a 12 percent increase over the actual pumping volume. In the ACTUAL model, the water that was not pumped was removed from the model as either CSO or surface flooding to areas not tributary to the PS. The models do not account for water potentially removed from the conveyance system due to basement backups.

The results for the Bluehill PS show a negligible difference in pumping volumes for the IDEAL and ACTUAL scenarios. These results suggest the power quality issues that were experienced and represented in the ACTUAL scenario did not result in water being removed from system, instead the water was temporarily stored upstream of the PS within the conveyance system or as surface flooding. The effects of the power quality issues are better represented by the wet well level results presented below.

As previously noted, the models (both ACTUAL and IDEAL) do not account for water potentially removed from the conveyance system due to basement backups.

A summary of the maximum wet well levels under both the ACTUAL and IDEAL model scenarios is provided in Table 18. The results show that wet well levels at all three PSs would have been lower if the PSs had been operated as intended.

Table 18: Comparison of Wet Well Levels Had PSs Operated as Intended

	July ACTUAL	July IDEAL	Difference
	Level* (ft)	Level* (ft)	July Event
Connors Creek	85.7	73.1	12.6
Freud	85.5	70.2	15.3
Bluehill	89.9	78.1	11.8

Notes:
* Levels reported as elevations on Detroit Datum
ft = foot/feet
Wet Well Elevations (July Actual): Wet well levels in Conners Creek PS and Freud PS are simulated to be higher in the model than actually measured. The overprediction can be caused by several factors but these results do not impact conclusions presented in this report. Future model updates can investigate and address this if needed.

<u>Basement Backup Potential Comparison</u>

The areas of basement backup potential under the IDEAL pumping conditions scenario are shown in Figure 33. Visually, it is difficult to discern any significant differences compared to the ACTUAL pumping conditions scenario results shown in Figure 32. The total area where freeboard is equal to or less than 8 feet is 6,638 acres, which is approximately 260 acres less than the ACTUAL scenario.

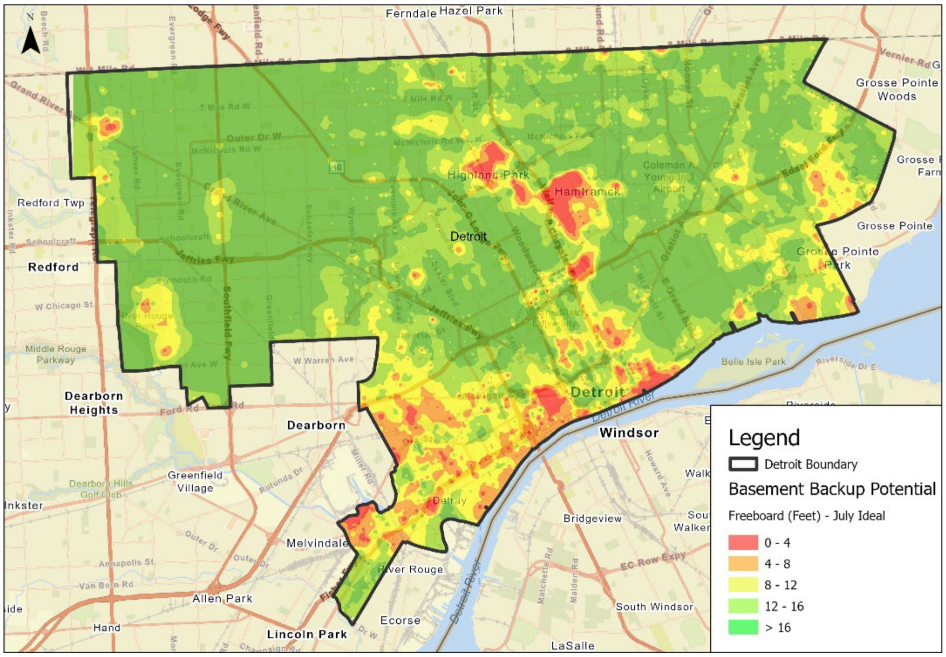


Figure 32: Predicted Risk of Water in Basement in PCSWMM IDEAL Scenario Simulation during the July 16 Rainfall Event (levels within 8 feet of the ground or less increase risk of basement backups)

Surface Flooding Comparison

No significant surface flooding was experienced during the July 16 Rainfall Event; therefore, no comparison of modeling results was performed.

3.6 Observations and Conclusions

Investigation of the July 16 Rainfall Event yielded several observations and conclusions by the Independent Panel. A summary of these observations and conclusions is provided in Table 19:

Table 19: Observations and Conclusions for July 16 Rainfall Event

Charge	Observation/Conclusion
Characterization of Rainfall Event and Extent of Flooding	• While smaller than the June 25/26 Rainfall Event, the July 16 Rainfall Event was still a large, high-intensity storm that covered much of the GLWA wastewater service area. The storm was most concentrated in the southeast portions of Dearborn, the city of Detroit, and the Grosse Pointe communities and generally intensified farther to the east. • Maximum accumulated depth of 4.7 inches over 12 hours was observed, representing a rainfall return period of 100 years to 300 years. • Areas to the north generally experienced less than 5-year rainfall, while Dearborn and the south-central part of Detroit saw rainfall in the 10 to 50 year range. Because the storm exceeded the designed capacity of the wastewater system, localized surface flooding and risk of basement backups could be expected. Areas experiencing greater than 100 year intensities would certainly incur flooding and basement backups based on local hydraulic conditions. • The City of Detroit received hundreds of water-in-basement complaints following the July 16 Rainfall Event; however, the number of complaints was far fewer than the June 25/26 Rainfall Event. Complaints in Detroit were concentrated in the east and south, including the neighborhoods of Jefferson Chalmers and Cornerstone Village.

Charge	Observation/Conclusion

Operational readiness	• Operators were deployed to the PS and CSO facilities prior to the July 16 Rainfall Event.
	• At the Freud PS, three storm pumps were not available (one with warranty issues and two with electrical issues) leaving five pumps available for service.
	• At the Connors Creek PS, all storm pump systems, except Storm Pump 1, checked out available prior to the July 16 Rainfall Event.
	• At the Bluehill PS:
	  ○ Under normal conditions, the PS is operated remotely by the operators at the SCC. Operators visit the PS to perform routine preventive maintenance duties.
	  ○ The Bluehill PS was staffed prior to the July 16 Rainfall Event.
	  ○ Based on the operator logbook, all systems appear to have been available at the time, however, Storm Pump #4 was marked for emergency use only.

System response	• At the Freud PS:
	  ○ External power quality issues were observed but did not significantly impact operations. Repairs to the main electrical feed lines to the Freud PS were completed prior to the July 16 Rainfall Event.
	  ○ Four storm pumps were operated continuously over the event and a fifth pump was started and ran for approximately 2 hours from 2 p.m. to 4 p.m.
	  ○ Wet well levels peaked slightly above the maximum normal wet well elevation, but quickly subsided and wet well levels continued to drop during the normal pump shutdown process.
	• At the Connors Creek PS:
	  ○ The investigation did not reveal any equipment issues and up to six storm pumps were operated simultaneously during the event.
	  ○ Water levels in the wet well remained well below the normal maximum wet well elevation.
	• The Bluehill PS experienced power quality issues that did not allow all available pumps to operate or delayed their operation as operators attempted to supplement with on-site generators:
	  ○ Throughout most of the July 16 Rainfall Event only one pump operated, and wet well levels surpassed the normal high water level between approximately 10:30 a.m. and 2:00 p.m. During this time, wet well levels remained above the maximum recordable level of about 86 feet.
	  ○ By 2 p.m., operators were able to first start one small pump and then an additional large pump resulting in water levels in the wet well quickly dropping within range.
	  ○ Operational issues continued, but wet well levels remained within normal limits.
	  ○ While detailed analysis and modeling of DWSD’s local collection system was beyond the scope of this investigation, it is reasonable to anticipate that surcharging of the local collection system would have occurred.
	• Modeling results did not indicate any areas in Detroit with significant surface flooding during the July 16, 2021 Rainfall Event.
	• 350 basement backup complaints provided by GLWA were reviewed and none of those reported significant surface flooding.
	• Surface flooding in Dearborn and areas of the Grosse Pointe communities could not be simulated because those sewer systems are not included in sufficient detail in the model.
	• The GLWA PC SWMM model was used to assess the risk of basement backup and over 6900 acres was estimated as having significant flood risk.
	• There are reports of basement flooding in locations in Detroit where the model results show low probability of basement backups. These instances of basement backups may have been caused by issues in the local and/or property owners sewer systems not included in the PC SWMM model.

Charge	Observation/Conclusion
System Response if Everything had worked as intended	• The intensity of the rainfall exceeded the designed capacity of the wastewater system in some areas and, in those areas, basement backups were reported. • The Connors Creek and Freud PSs operated as intended and no surface flooding was observed. Despite this, numerous basement backups were reported in the Jefferson Chalmers area, suggesting local conveyance issues/restrictions may be present. • Power quality issues at the Bluehill PS delayed the necessary starting of storm pumps, which resulted in high water levels in the PS and likely surcharge of the local upstream collection system. It is not known whether local basement flooding complaints could have been reduced if the system has operated as intended.

Notes:
CSO = Combined Sewer Overflow
DWSD = Detroit Water and Sewerage Department
GLWA = Great Lakes Water Authority
PS = Pumping Station
SCC = Systems Control Center

4. Recommendations and Funding Sources

This section includes the Independent Panel's recommendations as well as discussion on potential funding sources to support implementing those recommendations.

The recommendations are organized based on a general timeline for which they apply (i.e., short-, medium-, and long-term). Descriptions of the different categories are provided below. Recommendations provided in Section 4.4 will require coordination with GLWA and its member communities and do not have a timeframe associated with them. These recommendations should be considered and implemented as soon as feasible.

General Recommendations: The recommendations provided in these sections are intended to address overarching, programmatic concerns that arose during the Independent Panel's work.

PSs: These generally include recommendations specific to the Freud, Connors Creek, and/or Bluehill PSs operation and maintenance.

Electrical Systems: These generally include recommendations specific to the Freud, Connors Creek, and/or Bluehill PSs electrical systems.

Mechanical Systems: These generally include recommendations specific to the Freud, Connors Creek, and/or Bluehill PSs mechanical systems.

Additional Analysis/Studies: These are recommendations for additional studies that could help inform GLWA policies and decision making going forward.

A summary of the recommendations with further discussion provided in the corresponding sections is provided in Table 20. As these recommendations are reviewed and considered, the Independent Panel emphasizes that the timeframes under which each recommendation is provided is what we consider to be feasible and practicable based on our collective experience. However, addressing recommendations sooner than the identified timeframes is encouraged.

Table 20: Summary of Independent Panel Recommendations

Category (Subheading)	Summary
Short Term (approximately 12 to 18 months)	
General (4.1.1)	Take measures to reduce basement backups. Maintain a level of service of at least 14 of 16 storm pumps at Connors Creek and Freud PS and at least 3 of 4 storm pumps at Bluehill PS. Be ready for extreme storms at all times not just when predicted.
Pumping Stations (4.1.2)	Conduct tests on vacuum priming system and pump starting at Connors Creek PS to improve system reliability and to provide operator training opportunities. Develop, improve and document operational measures. Regularly use Connors Creek PS in wet weather and maintain the vacuum priming systems after a large storm events to improve system readiness and enhance operator training.
Electrical Systems (4.1.3)	Transfer power sources to DTE. Provide capability for emergency generators to be connected to any section of the switchgear to enable generators to power any group of pumps. Develop protocols to operate generators at no-load prior to expected events to enable the pumps to be quickly switched to generator power if there is an outage.
Mechanical Systems (4.1.4)	Make improvements to seal water and vacuum priming systems. Keep the Connors Creek storage gates and relief gates at the CSO Basins in good working order.
Medium Term (approximately 2 to 5 years)	

Category (Subheading)	Summary
General (4.2.1)	Define level of service objectives with respect to flooding and water quality and implications of water quality requirements. Investigate how those objectives have been achieved previously.
Pumping Stations (4.2.2)	Implement modifications to the “Freud Pump Station Improvements – DRAFT” report prepared by Arcadis/Brown and Caldwell for GLWA project number CS-120 in August 2020
Electrical Systems (4.2.3)	Provide for a policy for redundant PS power sources and perform studies to understand existing and potential power source redundancy.
Mechanical Systems (4.2.4)	Implement intake flow conditioning devices at Connors Creek PS and Freud PS wet wells based on testing and recommendations from the February 2018 Clemson Engineering Hydraulics, Inc. study. Also, replace two storm pumps with vertically suspended pumps at Connors Creek PS. Expand and improve the Connors Creek PS seal water system.
Operational Measures (4.2.5)	Operate and inspect IFC devices. Regularly clean the Connors Creek Storm wet well and IFC devices.
Additional Investigation/Studies (4.2.6)	Review existing studies with consideration of flooding and water quality objectives. Conduct additional studies to understand flooding and water quality level of service and optimize system operations using “real-time” data. Consider different operating procedures for extreme storms that maximizes conveyance but may increase CSOs.
Long Term (more than 5 years)	
General (4.3.1)	Consider implementing comprehensive policies and practices that address the frequency and extent of flood losses.
Pumping Station (4.3.2)	Make additional PS modifications at the Connors Creek PS based on performance of medium-term recommendations, including replacing the remaining six storm pumps and constructing access and screening improvements in lieu of building a new pumping station.
Regional Coordination	
General (4.4)	Foster regional coordination. Various recommendations generally intended to reduce future flood damages and requiring regional coordination to implement.

4.1 Short-Term Measures

Recommendations that should be considered and/or could be implemented in the short term (i.e., approximately 12 to 18 months) are provided in this section.

4.1.1 General Recommendations

As long-term solutions continue to be evaluated and implemented, GLWA’s highest priority should be to ensure the PSs can operate as intended. The objective should be to have as many pumps available whenever a storm is anticipated that will require the PSs to be in service. The normal standard is for no more than one pump unavailable, but the goal should be to have all pumps available for service.

In addition, the member communities should consider how they may be able to assist homeowners with short-term mitigation measures to reduce basement backups. These mitigation measures may include options such as check valves/backflow preventers, sump pumps, sewer line cleanouts, basement sealing/floodproofing, disconnecting rooftop gutters from sewer lines, yard grading, and directing rooftop drainage away from foundations. It is important to emphasize these are short-term measures and financial assistance will be required for homeowners who cannot afford these measures. Some other agencies have implemented backflow prevention subsidy programs to aid homeowners.

The recommendations detailed below are material and process improvements to the stormwater PSs. These improvements will enable the stormwater PSs to respond faster and more effectively in extreme weather events.

4.1.2 Pumping Stations

Vacuum Priming Tests

The need to vacuum prime stormwater pumps at Connors Creek PS has long been reported as a hindrance to effective stormwater pumping. Operating a vacuum priming system to raise water inside the pumps reportedly takes from 15 to 20 minutes, and in the 2016 rain events failed to prime the pumps altogether thereby preventing stormwater pumps starting at Connors Creek PS.

The Independent Panel recommends that controlled functional tests of each vacuum priming system with its respective stormwater pump be planned and conducted to validate that the priming process is effective for each set of vacuum pumps and stormwater pumps at Connors Creek PS. Results from these tests should be used to confirm system readiness, find air ingress sources in the vacuum systems, and justify proposed actions for further improving the priming process. Tests should be planned for and conducted immediately after (not prior to or during) a future storm event in which water is retained in the wet well to at least elevation 65 feet and in the discharge channel to at least elevation 82 feet (i.e., the elevation of the new discharge channel weir).

In preparation for vacuum priming system tests, the shaft seal packing in all stormwater pumps should be replaced with new packing material to minimize air leakage during the priming process. Also, provisions should be made to measure and record the vacuum pressures and water levels inside of the pump casings during and after the priming process. Test instruments such as level sensor transducers should be engineered and procured.

The vacuum priming test procedure is outlined below:

1. Set valves to isolate one vacuum pump to its assigned stormwater pump.
2. Operate the vacuum pump.
3. Measure and record vacuum pressures and water levels against real time as the priming system operates.
4. After maximum prime is achieved, shut down the vacuum pump.
5. With the system idle in a state of vacuum, measure and record vacuum pressure and water levels against time intervals.
6. Repeat the procedure for each of the eight vacuum pumps and stormwater pumps sets.

Expediting vacuum priming test results to be completed in the next 6 months—pending the ability to procure and install the necessary instrumentation—will quantify priming effectiveness of each system, identify any faults in each system, and will develop new operational measures to improve stormwater pump responses at Connors Creek PS in the short term if successful.

Pump Starting Scenario Tests

Historically and currently, GLWA operations have followed a pump starting scenario at Connors Creek PS in which stormwater pumps are started dry and then primed by the vacuum priming systems. This nonstandard starting scenario has negative consequences on pumping equipment and on pump starting cycle times.

Technical Memo 1 by Arcadis/Brown and Caldwell dated October 2017 states, “Priming from the discharge side with a rotating impeller is not ideal as it is likely causing vibration and producing a great deal of foam. This scenario impedes the priming process.” Three retired chief engineers from Worthington Pump/Ingersoll Dresser Pump recently advised that the nonstandard pump starting scenario is inconsistent with original equipment manufacturer (OEM) operating instructions that specify the stormwater pumps should be primed first and then started.

The purpose of the nonstandard pump starting scenario is unknown. One explanation offered by GLWA operations is that the motors for the stormwater pumps might not produce sufficient torque to start the pumps when primed with water. However, this hypothesis is called into question by reports from GLWA operators that during the June/July 2021 Rainfall Events, motors did successfully start pumps when fully primed by wet well levels at or above the impeller elevation.

The Independent Panel recommends that controlled functional tests to validate the standard pump starting scenario be planned and conducted. Results from pump starting scenario tests will confirm that the motors and electrical systems are capable of starting pumps with properly primed pumps. Results from these tests should quantify voltage drops during brief pump starts and confirm whether all electrical equipment and supply is acceptable. Tests should be planned for and conducted immediately after a future storm event in which water is retained in the wet well to at least elevation 65 feet and in the discharge channel to at least elevation 82 feet (i.e., the elevation of the new discharge weir).

In preparation for pump start scenario testing, the electric utility company should be engaged to plan the electrical system measurements (e.g., voltage, in-rush current) and provide test instruments (e.g., medium voltage sensors, CTs) during tests. Also, provisions with temporary instrumentation should be made to measure and record water levels in the pump casings and to measure pump shaft rotations as the motors are energized.

The pump starting scenario tests procedure is outlined below:

1. Prime an individual stormwater pump for the vacuum priming test procedure above.
2. Monitor the water level inside the stormwater pump casing.
3. When the water level in the pump casing reaches elevation 86 feet, energize the motor to start the stormwater pump.
4. If the stormwater pump fails to start and pump forward, repeat the priming process and monitor the water level inside the stormwater pump casing again.
5. When the water level in the pump casing reaches elevation 88 feet, energize the motor to start the stormwater pump.
6. Repeat steps 4 and 5 with 2-foot water level increases until the pump achieves full speed and pumps forward.
7. During the pump starts, measure and record the motor current and voltage.
8. Once full-speed operation is confirmed for 5 seconds, de-energize the motor to prevent excessive forward pumping.
9. Repeat the pump starting scenario tests for each stormwater pump and motor set.

Using the standard pump starting scenario for regular operations is expected to reduce flow surge and mechanical vibration during starting, which in turn will increase pump reliability and life cycle. Moreover, using the OEM standard starting scenario is expected to enable pre-priming of the pumps during rising wet well levels when “Pump On” levels have not yet been reached, which in turn will accelerate pump starts and create a more agile pumping system.

Expediting pump starting scenario tests in the coming months will quantify the effectiveness of each motor and electric system and will develop new operational measures to improve stormwater pump responses at Connors Creek PS in the short term if successful.

Operational Measures

Over time, operational practices for stormwater pumping at Freud and Connors Creek PS have evolved, but the Systems Operation and Maintenance Manuals have not been revised to reflect actual current practices.

The Independent Panel recommends that the Systems Operation and Maintenance Manual be revised to document current practices whether established historically or newly developed here. Updated manuals should be used to routinely train GLWA operations personnel and to conduct emergency drills at the PS.

The Independent Panel recommends the following new operational measures be developed, documented, and adopted:

1. Document the established practice of manning Connors Creek PS prior to storm events and standardize on the "Local PLC-Based Manual" operating mode.
2. Document the recently developed vacuum priming system checklist for Connors Creek PS (GLWA Contract No. PC-674).
3. Develop, document, and provide for the use of local weather forecasts to predict stormwater flow rates, wet well level rise, and pumping needs for stormwater pumps at all PSs.
4. Implement backup emergency generator recommendations in Section 4.1.3.
5. Develop, document and provide for a new process of starting vacuum systems at Connors Creek PS as soon as sufficient water elevations are achieved (i.e., elevation 65 feet in wet well and elevation 82 feet in discharge channel) to pre-prime the stormwater pumps before "Pump On" levels are realized. Incorporate recently developed vacuum system checklist into the operating manual.
6. Develop, document, and provide for a new alternating starting sequence for respective stormwater pumps at Freud and Connors Creek PSs to increase total pumping system capacity.
7. Develop, document, and provide for new ranges for "Pump On" wet well elevations at which stormwater pumps at Connors Creek PS may be started (i.e., elevation 68 feet to elevation 72 feet for Storm Water Pump No. 1) after priming to give GLWA operators flexibility to respond quickly to rapidly rising stormwater levels in the wet well.
8. Develop, document, and provide for a new process of exercising all vacuum priming systems at Connors Creek PS after a large storm event (e.g., sufficient rainfall to fill wet well and discharge channel to starting levels) to facilitate GLWA operations training.
9. Develop, document, and provide for a new process of wetting stormwater pump packing routinely at Freud and Connors Creek PSs by delivering seal water to each pump stuffing box on a weekly basis for 10 or more minutes.
10. Develop, document, and provide for a new maintenance procedure to replace shaft seal packing in all stormwater pumps at Freud and Connors Creek PSs on a regular sequenced basis every 2 years.
11. Develop, document, and provide for new log sheet formats indicating date and shift to identify storm and sanitary pump status for the shifts. The sheet should indicate times each pump is started, stopped, hours in use, identification of problems in a comment section, the operators that start, stop, and monitor the pumps while operating and any maintenance required/being performed during the shift. Operators and any team leaders working at the location during the shift should sign the log sheets.

12. Develop, document, and provide for a new process for communicating the status of critical PS equipment to senior leadership at all PSs. Communication protocol should include lists of all critical equipment and key individuals to be notified.

13. Revise the System Operation and Maintenance Manual to reflect all current/best practices and to incorporate new operational measures validated by above testing.

Expediting the above operational measures to completion in the 6 to 12 months is expected to improve storm pumping system readiness and effectiveness, which will mitigate flood risks in the short term.

4.1.3 Electrical Equipment

Electric Power Source Measures

The external power quality issues at the Freud and Bluehill PS related to electrical service being provided by PLD electrical distribution systems were areas of concern. GLWA coordinated with its energy suppliers to complete conversion of utility services from PLD to DTE in 2022. The Independent Panel recommends that an engineering study be conducted in conjunction with DTE to ensure adequate power quality at all PSs and under all operating conditions.

Any single point of failure should not prevent a PS from meeting its design stormwater flow requirements. Using the Freud PS as an example, the utility services now come from three independent 120kV feeds at the DTE Essex Station. In December 2021, the spliced feed to transformers 1 and 3 was replaced with independent feeds to these transformers. The newest feed comes from the DTE Essex Station and restores the Freud PS to 3 independent feeds. Therefore, the issue with the PLD service creating a power outage for two primary transformers because of a single utility service outage (as occurred during the June 25/26 Rainfall Event) has been rectified.

Prior to sizing transformers for full redundancy for the Bluehill PS (ability to power four pumps simultaneously), it is recommended that GLWA review hydraulic constraints at the PS. While the current O&M manual advises that hydraulic restrictions preclude four pumps from operating simultaneously, operator records indicate that four pumps have been operated on occasion. It is likely that, given their age, the pumps may operate below their original pump curves or the downstream restrictions may have been removed. As such, there may be an opportunity to operate all four pumps simultaneously. This would be in keeping with the recommended goal of having all pumps available for service.

Backup Electric Generator Measures

Emergency generators should be able to be connected to any set of switchgear to supply any group of pumps. The problem of not being able to provide power via emergency generators to any of the three primary transformer loads remains; this impacts all PSs, including Connors Creek PS. Tying the emergency generator systems into all utility services is recommended, not just one for each PS. When severe storm events (e.g., high winds, lightning, freezing rain) are anticipated, the generators should be capable of pre-starting (under no load). If utility power is lost, the generators would already be operating and can then be loaded quickly to minimize downtime of storm pumps. GLWA should also review and provide for the following recommendations related to electric generators:

Develop the capability and agreement with the electric utility company to enable backup power generators to be started and synchronized with power grid prior to severe storm events. Emergency generators should be able to be connected to all sets of switchgear, to supply any group of pumps.

When severe storm events are forecasted, generators should be brought online and idled, ready to connect to the grid if there is an outage.

Emergency generators should be exercised regularly for a sufficient duration, in coordination with the electric utility company and meet minimum exercising requirements as per the manufacturer.

Emergency generators should be periodically tested and used to supply sanitary pumps, once/quarter, in coordination with the electric utility company.

Emergency generators should be periodically tested and loaded equivalent to at least 60 percent generator capacity (with portable load bank), once per year, in coordination with the electric utility company.

Emergency generator exercising/testing schedules should comply with air quality regulations.

4.1.4 Mechanical Equipment

Seal Water System Measures

Seal water is delivered to the shaft seal packing in each of the eight stormwater pumps at the Connors Creek PS. The purpose of the seal water is to fill the gaps between the rotating shaft sleeve and the stationary packing in the stuffing box, and thereby prevent air from entering the pumps (stormwater pump sectional assembly drawing is provided in Appendix D1.1).

Delivering ample seal water to the packing is critically important during the stormwater pump starting process, because air ingress at the shaft seal compromises the vacuum priming process, which in turn significantly increases the pump starting cycle time or even prevents pump starting altogether. Seal water also lubricates the packing and shaft sleeve materials during dry running of the pumps, which is currently standard operating procedure according to the System Operation and Maintenance Manual. Lack of seal water during dry running and vacuum priming causes packing and the shaft sleeve wear, which in turn compromises the shaft sealing function and vacuum priming process further.

The source of seal water for the stormwater pumps at the Connors Creek PS is a water tank next to Unit #5 on the motor floor (photograph in Appendix D1.2). The water volume in the single tank is calculated to be approximately 250 gallons. Water in the tank is replenished by city water from the station plumbing with capacity no more than 10 gallons per minute (gpm). The water is delivered from the tank to the stuffing boxes of all eight pumps by 0.5-inch piping via gravity feed.

With as-new packing, an 11-inch diameter shaft sleeve needs approximately 6 gpm to provide proper sealing and lubrication. Therefore, in the best case, the volume of water stored in the tank is only sufficient to seal one pump for 40 minutes or two pumps for 20 minutes. Old or worn packing and shaft sleeve would require two or three times the volumetric flow rate of new packing. Because the vacuum priming process takes between 15 and 20 minutes to start pumps, the seal water system is only sized to start two stormwater pumps with new packing or one stormwater pump with worn packing with the volume of water available from the existing tank. This estimate is corroborated by GLWA operations, who reported that only two pumps can be primed and started before seal water in the tank is depleted and they must wait for the tank to refill with city water from the station plumbing before starting to prime the next set of pumps. Thus, the system delays pump starting by at least 25 minutes for each set of two pumps started in the station.

The Independent Panel recommends increasing the volume of seal water available at Connors Creek PS to improve the storm pumping system effectiveness and mitigate flood risks in the short term. For example, three additional water tanks of the same size and volume as the existing tank could be procured and installed so that seal water is available to the four sets of pumps from four corners of the PS. The new tanks should be situated next to Unit #1, Unit #4, and Unit #8 on the motor floor level of the Connors Creek PS. To minimize friction losses through the gravity feed piping, interconnecting piping should be reconstructed to deliver seal water from each tank to stuffing boxes on only two pumps closest to the tanks. Replenishing city water should be plumbed independently to each of the four seal water tanks. The design of the new tanks can be based on the existing tank to expedite engineering. Consideration should also be given to upsizing the city water supply line.

In addition, the four new seal water systems should incorporate electrical control valves to enable automation of the seal water flow function. These valves could be control automatically to lubricate the packing with seal water on daily basis (10 or more minutes) and to permit vacuum system starting only after sufficient seal water delivery to each pump stuffing box.

Increasing seal water capacity in the Connors Creek PS will enable GLWA operations to response more quickly to rapidly increasing wet well levels, which will improve the stormwater pumping system response during severe storm events. Expediting the engineering and procuring materials from local suppliers for the three new water tanks could see the new seal water systems installed in 6 months, which will mitigate flood risks in the short term.

Vacuum Priming System Measures

The vacuum priming system at Connors Creek PS includes vacuum priming pumps, vacuum isolation valves, interconnecting vacuum piping; plus, the stormwater pump suction draft tubes, casings, stuffing boxes, and discharge siphon blocks being primed. The integrity of this entire system is critical to enable GLWA operations to start stormwater pumps quickly when faced with rapidly flooding wet wells.

The new vacuum priming system was installed in approximately 2004 but had fallen into disrepair by 2016 and could not be operated during the summer 2016 rainfall events. The recent project, GLWA Contract No. PC-674 replaced vacuum priming pumps, vacuum isolation valves, and a portion of interconnecting piping at the Connors Creek PS. This project improved vacuum priming system effectiveness over the old original system, as evident by comparing the number of stormwater pumps successfully primed and started during storm events in 2021 versus 2016, when no stormwater pumps could be primed and started. However, additional short-term measures are feasible that will further increase the effectiveness of the vacuum priming system and increase the number of pumps available to pump stormwater in future events.

The design for GLWA Contract No. PC-674 interlinks all vacuum pumps with all stormwater pumps through an old piping manifold pipe running through the wet well area. This design is intended to enable GLWA operations to prime any of the eight stormwater pumps with any of the eight vacuum pumps. However, this arrangement of complete redundancy has not realized any benefit because the scope of vacuum piping and isolation valves required to integrate all vacuum priming elements into one system is too complex to operate effectively under storm conditions. Also, integration of the manifold piping hidden in the wet well to achieve complete redundancy creates increases the risk of air ingress into the vacuum system at all stormwater pumps which could potentially cause a single point of failure for the entire vacuum priming system.

Old steel piping incorporated into the new vacuum system increases the risk of air ingress. Heavy corrosion has been observed on outside surfaces of exposed sections of old vacuum piping in Connors Creek PS (photograph in Appendix D1.3). Much of this old piping cannot be inspected because it is hidden or encased in the concrete floor. Any through-wall perforations (whether in new or old pipe), leaky valve stems, or dried/worn pump packing can allow air ingress during the vacuum priming process and could potentially prevent starting stormwater pumps at Connors Creek PS.

The Independent Panel recommends that GLWA reliability/maintenance technicians be trained in use of ultrasound technologies to inspect piping, fittings, valves, and seals during exercising of the vacuum priming system to identify sources of vacuum leak and fix these prior to failure on demand.

The Independent Panel recommends eliminating the single point of failure inherent in the existing vacuum priming system at Connors Creek PS and reconfiguring this system into four separate vacuum priming systems, one for each set of two stormwater pumps. The function of the common manifold and associated valves should be eliminated by installing blind flanges on existing pipe flanges in the system.

Configuring two vacuum pumps with two stormwater pumps at Connors Creek PS will improve priming system reliability (i.e., remove single point of failure), provide sufficient redundancy, and enable GLWA operations to respond more effectively to rapidly increasing wet well levels. Expediting design and procuring materials from local suppliers to configure four separate vacuum priming systems could be completed in 6 months, which will mitigate flood risks in the short term.

4.2 Medium-Term Measures

Recommendations that should be considered and/or could be implemented in the medium-term (i.e., within approximately 2 to 5 years) are provided in this section.

4.2.1 General Recommendations

1. GLWA should evaluate and attempt to better define the prioritization in which they design and operate the collection system in the context of the conflicting objectives of reducing flooding (basement and surface) versus protecting water quality (by limiting CSO discharges). It would be beneficial to understand if more stringent water quality regulations might relate to increased flooding over the years. The Department of Environment, Great Lakes, and Energy (EGLE; with oversight from the EPA) has a mission to protect human health and the environment, yet it may not be clear to them how reducing CSO discharges can inadvertently (and more directly) impact human health by unintentionally filling basements with raw sewage. It is recommended that GLWA identify the range of objectives, responsibilities, and requirements of GLWA and EGLE. The parties will need to work together (and with other entities) in the context of existing legal and regulatory requirements to develop a shared vision on this important topic, which will have major influence on the characteristics of any long-term solutions to the regional flood problem.

2. The June/July 2021 Rainfall Events significantly exceeded the current level of service goals, and it is recommended that GLWA communicate this to the public and elected officials. However, it is equally important to understand and communicate how often the current level of service goals have been exceeded in the past, beyond the traditional ("once in 10 years" or "10% chance in any year") definition. The Independent Panel suggests an analysis of historical rainfall, flow meter, and other relevant data be performed to understand the "actual" level of service provided compared to the "expected" level of service. It is also recommended that GLWA determine if/how that has changed in recent years and to include this as well. One of the most important messages the Independent Panel can convey to the GLWA BoD is that just because the June/July 2021 Rainfall Events were far beyond the design capacity of GLWA's system, this does not mean that there is a not a serious system capacity problem that must be addressed. Far less rainfall than was experienced in June/July 2021 could still result in widespread flooding.

3. GLWA should reconsider its current use of National Oceanic and Atmospheric Administration (NOAA) Atlas 14 rainfall because the climate is changing and other research suggests the rainfall depths in NOAA Atlas 14 are biased low, in order to protect the significant infrastructure investments that GLWA will be making over the next several decades. The projects that are currently being designed for the 10-year level of service based on NOAA Atlas 14 rainfall will not meet that level of service in the future. The Independent Panel recommends that GLWA participate in ongoing studies addressing future precipitation rates or conduct their own independent study. For example, the Southeast Michigan Council of Governments recently completed an analysis[2] of potential future precipitation rates that might be useful for GLWA to consider.

4. Corresponding with the recommendation above, GLWA may want to consider how other climate change-driven factors may end up affecting the performance of its systems. Fore example, rising lake and river levels are two factors that could directly reduce CSO facility discharges.

Recommendations on additional studies and analysis to support some of the recommendations above are provided in Section 4.2.6.

[2] "Southeast Michigan Current and Future Precipitation – Climate Resiliency and Flooding Mitigation Study." Prepared for Southeast Michigan Council of Governments and Michigan Department of Transportation by Tetra Tech (June 2020).

4.2.2 Pumping Systems

A basis of design report titled “Freud Pump Station Improvements - DRAFT” is available from background documents (Appendix A5). The report was prepared by Arcadis/Brown and Caldwell for GLWA project number CS-120 in August 2020.

The CS-120 draft report includes the following major improvements for the Freud PS:

- Rehab the existing stormwater PS
- Rehab the existing stormwater pumps
- Replace the existing stormwater wet well dewatering pumps with new submersible dewatering pumps
- Add a new isolation shaft in Freud Street to provide storm well access in the existing stormwater PS
- Add a new sanitary PS within the new isolation shaft.

Separating sanitary pumping from stormwater pumping improves the effectiveness of the overall system during storm events. Isolating the storm well within Freud PS enables ongoing inspections and critical maintenance/repairs of that structure. Because of these significant benefits to the overall stormwater pumping system, the Independent Panel endorses the major improvements above with two qualifications:

1. The CS-120 draft report recommends replacing the three existing transformers with new transformers of equal power rating. The Independent Panel recommends that each transformer be uprated to power not less than seven of eight stormwater pumps at Freud PS, because redundant transformers from independent utility services improves power reliability during future storm events.
2. The CS-120 draft report recommends not to install new intake flow conditioning devices, because installing these devices raises concerns about construction complexity risk associated with their attachment to existing civil structures and flooding risk during construction. The Independent Panel recommends that intake flow conditioning devices be further developed and analyzed to address these concerns and that they be installed safely after construction of the new isolation shaft is completed.

A recent walkdown visit to the Freud PS found that some improvements documented in the CS-120 draft report are being implemented at this time (e.g., new transformers). The Independent Panel recommends that the above qualifications be adopted and the CS-120 draft report finalized in the next 3 months so that improvements to Freud PS can progress with certainty. The Independent Panel recommends that all Freud PS improvements be expedited for completion within the next 3 years.

4.2.3 Electrical Systems

Electrical Power Source Measures

The Independent Panel recommends redundant electrical power sources be established as a standard design for refitted stormwater pump operations, such as Connors Creek PS and Freud PS and any new PSs. To that end, an engineering study should be conducted with the assistance of DTE in the short term to confirm that each existing feeder line has capacity to operate the entirety of their respective PS including all stormwater pumps.

Based on positive confirmation from DTE about the feeder lines, the transformer(s) connected to each feeder line at Connors Creek PS should be sized to power the station peak demand load. There are two options to upgrading the transformers: 1) replacing existing transformers with larger transformers; or 2) adding parallel transformers on the same feeders as existing undersized transformers. However, the latter, while potentially lower investment cost, can lead to increased electrical system complexity, reliability issues, and higher operations and maintenance costs. The solution options should be studied in the context of recent transformer upgrades and overall plans for each station.

At Freud PS, the path forward to redundant power is less clear, because new transformers have already been purchased apparently based on recommendations in the CS-120 draft report. One option is to replace the three existing (albeit new) transformers with three new uprated transformers each with power ratings capable of operating seven of the eight stormwater pumps. A second, potentially less costly but more complex option is to add three new same-rated transformers on the same feeder lines as the existing transformers and double the power capacity by wiring them in parallel with the existing transformers. The Independent Panel recommends an engineering study be undertaken to assess these options for reliability and cost in the next 6 months so that the chosen design can be achieve redundant power at Freud PS can be completed in the next 2 years.

The engineering study should also consider constructing a switching station upstream of the transformers so that if one feeder goes down, DTE can switch and feed both transformers from a remaining feeder that is still in service. The switching station would be an alternative to upsizing the transformers. This concept is justified in that a feeder is more likely to fail during a rain event than a transformer.

Furthermore, the engineering study should determine whether DTE could provide the PSs electricity at the voltage level required by the pumps, such that the PSs would not need to have their own medium-to-low voltage transformers. In that case, medium-to-low voltage transformation would be done by DTE transformers within the DTE distribution network so that GLWA would not need to operate/maintain medium-to-low voltage transformers, a task much better suited to an electric utility.

Providing for redundant electrical power sources at all stormwater PSs and completing measures to implement that policy at Connors Creek PS and Freud PS within the next 3 years will improve performance of the overall stormwater system.

4.2.4 Mechanical Systems

Stormwater Wet Well Measures

In February 2018, two physical hydraulic model studies were conducted by Clemson Engineering Hydraulics, Inc. (CEH) to determine stormwater pump intake conditions from the wet well at Connors Creek PS and the wet well at Freud PS (CEH test reports are provided in Appendix A6).

For Connors Creek PS, hydraulic model tests determined that the existing stormwater wet well design is problematic to pumping storm water, because it does not deliver flow patterns to the impellers that enable pumps to perform properly under many operating conditions. For single pump operation, the wet well delivers acceptable flows to each pump alone except when Unit #3 is operated. Whenever more than one pump is operated, flow patterns at the impellers deteriorate.

Operating any of the following combinations of pumping units at Connors Creek PS cause flow patterns delivered to the pumps to be well outside of Hydraulic Institute acceptance criteria (American National Standards Institute [ANSI]/Hydraulic Institute (HI) 9.8 – 2018):

Unit #3

Units #2 and #3

Units #3 and #4

Units #2, #3, and #4

Units #1, #2, and #7

Units #1, #2, #3, #6, #7, and #8

Units #1, #2, #3, #4, #5, #6, #7, and #8

For Freud PS, hydraulic model studies determined that the existing stormwater wet well design is problematic to pumping storm water, because it does not deliver flow patterns to the impellers which enable pumps to perform properly under some operating conditions. For single pump operation, the wet well delivers acceptable flow patterns to each of pumps. Whenever more than one pump is operated, flow patterns at the impellers of one or more pumps are acceptable.

Operating any of the following combinations of pumping units at Freud PS cause flow patterns delivered to some or all the pumps to be well outside of Hydraulic Institute acceptance criteria:

Units #1, #2, and #8

Units #1, #2, #4, #6, and #8

Units #1, #2, #3, #4, #6, #7, and #8

Physical hydraulic model tests are highly accurate at predicting intake flow problems in the full-scale PSs. For Connors Creek and Freud PSs, model tests found that both stormwater pump wet wells have high turbulence levels, high and unstable pre-swirl values, and significant air entrainment occurring in the wet wells with large amounts of air ultimately entering the pumps during operations at maximum flow conditions. The Hydraulic Institute identifies that any one of these hydraulic phenomena in a wet well can adversely affect the performance of pumps. Swirl in the pump can cause a significant change in the operating conditions of the pump; in particular, pre-swirl relative to pump impeller rotation decreases the amount of water pumped by the pumps. Air ingestion can cause reductions in pump flow and fluctuations of impeller blade loads that result in noise and mechanical vibration, which over time will lead to pump damage.

Information about measured mechanical vibration for the stormwater pumps is limited. However, the CS-120 draft report identifies that high vibration amplitudes have been measured on the stormwater pumps operating at Freud PS. The Independent Panel expects that poor flow patterns in the full-size wet well, as determined by the physical hydraulic model tests are the most probable cause of high vibration amplitudes on these large and slow-speed pumps. Generally, high mechanical vibration is expected to cause shaft seal and bearings failures in the pumps.

The Independent Panel recommends that the intake flow conditioning (IFC) devices be developed to redress the problematic flow patterns and phenomena in the stormwater wet wells at Connors Creek and Freud PSs. IFC devices should be based on earlier recommendations from CEH as a starting point but should be enhanced by engineering analyses to achieve robust design and sound installations. Engineering analyses should include computational fluid dynamics modeling to study next design iterations for the devices and their placement in the wet wells. Results from computational fluid dynamics modeling including dynamic hydraulic loads on IFC elements should be used as inputs for Finite Element Analysis, which will determine resultant forces on elements of the foundation. Engineering analysis will verify mechanical designs of IFC devices, attachment bolting to the civil structure, and thereby ensure robust outcomes. After verification, new physical hydraulic model tests should be conducted to validate the final IFC device designs prior to installation in the wet wells.

Expediting development of the IFC devices for both Connors Creek and Freud PS could be completed (including tests) in the next 18 months. Procurement of IFC devices and their installation should be expedited to completion within the next 3 years. However, installation at Freud PS should only commence after the construction of the new isolation shaft at Freud Street is completed and safe access to that wet well is available.

Based on one conforming bid from Mechanical Solutions, Inc., the American Association of Cost Engineering (AACE) Class 5 budgetary costs for a project to design, procure, and install 16 IFC devices under all stormwater pumps at Connors Creek and Freud PSs should include:

- $0.5M for PS engineering and analysis (Connors Creek PS and Freud PS)
- $0.5M for IFC engineering and analysis (Connors Creek PS and Freud PS)

- $0.2M for IFC physical model tests (Connors Creek PS and Freud PS)
- $1.2M for eight IFC devices (floor cones) for Connors Creek PS
- $3.2M for eight IFC devices (floor cones and shrouds) for Freud PS
- $2.0M for PS construction including preparation of wet well and installation of eight IFC devices at Connors Creek PS
- $5.0M for PS construction including preparation of wet well and installation of eight IFC devices at Freud PS
- $3.4M for contingency/escalation
- **TOTAL: $16.0M**

Adding IFC devices to the stormwater wet wells will provide acceptable flow patterns to all stormwater pumps and thereby enable pumps to pump reliably at maximum capacity at both Connors and Freud PS. This medium-term measure will improve performance of the overall stormwater system within the next 3 years.

Vertically Suspended Stormwater Pump Retrofit Measure

A technical report titled "Vacuum Priming System Evaluation, System Analysis and Condition Survey of Sewerage Pumping Stations" is available in the background documents provided to the Independent Panel. This report is prepared by DWSD and METCO for GLWA project number CS-1499 in June 2015 (Appendix A7).

The CS-1499 report recognizes that because the existing stormwater pumps in Connors Creek PS are installed at an elevation above the water levels in the wet well, they must be primed with the vacuum priming system prior to pumping stormwater. The report reflects that this reality itself is an impediment to efficiency and reliable stormwater pumping. Three alternatives to improve the use of Connors Creek PS are evaluated and one alternate recommended.

The CS-1499 report recommends adoption of Alternate A-3, which states "Remove and replace the two existing [stormwater] pumps numbers 4 and 8 with wet pit, vertical turbine pumping units under the initial phase." The report implies that all eight stormwater volute pumps at Connors Creeks PS should be eventually retrofitted with these same vertical turbine pumping units.

In the CS-1499 report, Drawing SK-03 titled "Typical Vertical Turbine Pump Arrangement" depicts a Type VS1 vertically suspended pump (ANSI/HI ANSI/HI 14.1-14.2-Rotodynamic Pumps for Nomenclature and Definitions). Type VS1 pumps are a single casing, single or multistage design incorporating single or multiple radial vaned impellers with front and rear wear rings; each impeller has its own diffuser. Type VS1 pumps are engineered with integral suction bells for wet well installations with clear water as standard. Drawing SK-03 depicts a standard Type VS1 single-stage pump fitted into Connors Creek PS with oversized pump floor openings.

Two concerns likely influenced the apparent decision not to pursue and implement the recommendation to first retrofit two and then all eight existing stormwater pumps with standard Type VS1 pumps:

1. *Reliability*—Type VS1 pumps typically have tail bearings, open shafts and other rotating elements exposed to fluid streams being pumped. When exposed to combined sewage fluid streams, these elements collect rags which can cause Type VS1 pumps to jam and stop pumping.
2. *Ease of Construction*—Type VS1 pumps with the same capacity as the existing stormwater pumps have 120-inch diameter suction bells attached to the pump assembly. Accommodating these large suction bells for insertion through the pump floor requires demolishing and reconstructing the floor with larger diameter openings, which would be costly and risky due to the 4-foot thickness and reinforced concrete construction of the floor.

In the opinion of the Independent Panel, the recommendation to retrofit the existing stormwater volute pumps at Connors Creek PS with vertically suspended pumps has merit; eliminating the vacuum priming process is critical to enabling GLWA operations to start pumps quickly in response to rapidly rising stormwater levels in the wet well. However, the Type VS1 pump depicted in Report CS-1499 is suboptimal by design due to the above concerns.

The Independent Panel recommends that two vertically suspended pumps Type VS3 with optimized design features for stormwater pumping at Connors Creek PS be engineered, procured, and retrofitted to replace two of the existing volute pumps. This optimized vertically suspended pump design (hereafter "Type VS3i") should be engineered to:

1. Fit through the existing opens without major demolition and reconstruction of the pump floor.
2. Start pumping stormwater immediately without vacuum priming.
3. On starting, flush residual debris and fill the discharge channel under all pumps with water up to existing weir elevation at elevation 82 feet and thereby simplify and accelerate the priming process for the remaining six volute pumps.
4. Pump sewage diluted with stormwater at the same capacity as the existing volute pumps.
5. Incorporate IFC devices under all pumps to maximize stormwater pumping capacity when more the two or three pumps are operating.

The Type VS3i pumps incorporate design features to address reliability and constructability concerns with standard Type VS1 pumps:

1. Type VS3i pumps should have cantilever bowl bearings that eliminate all "tail" bearings and exposed rotating surfaces in the impeller eye area.
2. Type VS3i pumps should have "enclosing tubes" in the column pipes and use city water to flush all pump bearings.
3. Type VS3i pumps should have small outside diameters defined by only the column pipe diameter.
4. Type VS3i pumps should have adjustable curb rings into which the pump bowl assembly is inserted onto an IFC device permanently mounted on the wet well floor.

These design features enable Type VS3 pumps to be designed for large flow capacities and yet fit through floor openings with relatively small diameter. In the past, these design features have been successfully applied to large vertically suspended VS3 pumps in numerous cooling water and flood water applications (e.g., the Army Corps of Engineers [USACE]). An example of one such application in coal-fired power station is provided in Appendix D2.1.

For proof-of-concept purposes, preliminary engineering of Type VS3i pump units specifically designed to retrofit in place of existing volute pumps at Connors Creek PS is in-process: To date, a design concept sketch with dimensional requirements and constraints has been completed (Request for Quotation [RFQ] requirements and sketch are provided in Appendix D2.2 and Appendix D2.3). Preliminary specifications for pump performance and material requirements have been produced. Requests for budgetary quotations were emailed to four major pump suppliers (Xylem A-C, Flowserve, Ebara, and Indar). Three suppliers have responded with appropriate bids including pump performance curves, pump general arrangement drawings, plus cost and delivery estimates. Bids have been reviewed by members of the Independent Panel and the bids from Xylem A-C and Ebara found to conform to requirements (conforming bids from three suppliers are provided in Appendix D2.4 and Appendix D2.5). Based on the conforming bids, the AACE Class 5 budgetary costs for a project to retrofit two existing volute pumps with two new VS3i pump units at Connors Creek PS should include:

- $1.0M for engineering and design analysis
- $5.5M for two VS3i pump units including pumps, motors, soleplates, and drive shafts
- $1.0M for fabrication of discharge adapters to transition from new pump discharge to existing station piping

- $7.0M for PS construction including removal old pumps and installation of new pumps and discharge connection
- $5.0.0M for contingency/escalation
- **TOTAL: $19.5M**

Based on the conforming bids, the program schedule for a project to retrofit two existing volute pumps with two new VS3i pump units at Connors Creek PS should include:

6 months for PS engineering, final VS3i pump unit RFQs, and installation RFQs

1 month for pump supplier and contractor bids

1 month for bid clarification and evaluation

1 month for final Purchase Orders for VS3i pump units and installation contractor

20 months for manufacturing and shipment of new VS3i pump units, in parallel to removal of two existing volute pumps and installation of IFC devices during dry weather months only

6 months for unit installation and commissioning of new VS3i pump units

6 months for contingency

TOTAL: 41 months

The engineering and procurement of two Type VS3i pumps to retrofit two existing volute pumps at Connors Creek PS should commence in the next 2 months and be completed before the end of 2022. The manufacturing, installation, and commission of these new pumps should be completed before the spring of 2026, as a medium-term measure to improve stormwater pumping performance and mitigate neighborhood flooding.

4.2.5 Operational Measures

Additional Operational Measures

After the IFC devices are installed as outlined above, the Independent Panel recommends that inspections and clean-outs of the wet wells at Connors Creek PS and Freud PS be conducted regularly after each major storm event. These inspections will help qualify the condition of the wet wells generally and will quantify the amounts of debris collecting on leading edge surfaces of the IFC devices. Results of inspections should be recorded in written reports and photographs. Access to the wet wells should be reviewed and modifications made—if necessary—given the more frequent access that will be required. This measure should be developed, documented, and provided for by GLWA operations.

Inspection results and reports will provide important input in the ongoing development of long-term measures to enhance levels of stormwater pumping service.

4.2.6 Additional Investigation/Studies

Review Previous Studies

The Independent Panel recognizes that there have been multiple studies performed over the years with various scopes and objectives. It is recommended that GLWA revisit those studies to understand how the proposed solutions were evaluated for water quality, surface flooding, and/or basement backup objectives. GLWA may also consider convening a series of meetings with the senior project managers of those studies to develop a synthesized understanding on how the various studies relate to each other. Some solutions may have been proposed without full consideration of all three objectives and—to the extent that is found to be the case—we suggest those solutions be re-evaluated accordingly. These should serve as a foundation for GLWA to recognize the potential trade-offs of evaluating solutions with a single objective in mind.

Perform Additional Studies and Analysis

This section includes recommendations for additional analysis and studies that could be performed in the medium term and would be intended to identify medium-term modifications and improvements to the physical system and its operation, as well as inform GLWA on the potential implications of modifying its policies and level of service objectives.

Successful completion of these studies will require close coordination with GLWA's customers, most importantly DWSD. These studies would benefit from being performed jointly with DWSD with both organizations setting study objectives, providing funding, sharing resources, and ultimately agreeing on the study findings.

Level of Service Study

This study would provide level of service metrics for the three primary objectives of water quality, surface flooding, and basement backups.

At the most basic level, the study would provide various metrics associated with those objectives for different design storm events. Water quality metrics may include the volumes of water that are treated by the WRRF, discharged through CSO and retention treatment basin (RTB) facilities, and discharged untreated. Surface flooding could be quantified based on modeling approaches, such as the GLWA SWMM model and/or the PCSWMM 2D model as demonstrated in Section 2.6 and Section 3.5 and basement backup potential could be quantified using similar methods also demonstrated in those sections.

These metrics would then serve as a basis for comparing system modification alternatives.

Dynamic System Operations Study

The intent of this study would be to understand how operation of the system could be improved through the use of short-term forecast and real-time data. It is our understanding that current operations planning (i.e., staffing) is based on both long- and short-term weather forecasts, but that actual operations (e.g., pump cycling, gate/weir operations) are based on the actual conditions being experienced at the PSs and discharge facilities at a given time.

Dynamic system operations would involve a more flexible operating strategy based, in part, on projections of inflows that may be experienced at the various facilities over the course of a few hours. Those projections could be based on rain gages and flow sensors throughout the contribution areas and even model predictions generated in real-time. By receiving early warnings of possible issues, operators could adjust pump, gate, and weir operations to avoid or reduce those issues. It is recognized that planning is ongoing through the CSO Long Term Control Plan that GLWA is currently conducting, the results of which would be incorporated into the study recommended here.

While the intent of this study would focus on operations of the existing system, it could also provide insight into physical system modifications that may be necessary to implement the dynamic operations. For example, PSs may need to be modified to allow for pumps to start at lower wet well levels or variable-speed pumps may be needed to prevent frequent on/off pump cycling. These would be very important near-term findings that could alter how long-term solutions are evaluated.

Dynamic system operations can be very cost effective compared to traditional storage/conveyance solutions and have been successfully implemented with large, combined sewer systems throughout the world.

Stormwater/Wastewater Master Plan

GLWA should investigate interest in conducting a system-wide master plan in conjunction with its customer communities. Looking to the future, any new infrastructure should be added to the current wastewater/stormwater collection, conveyance, treatment, and discharge system in accordance with a system-wide master plan, rather than on an ad hoc basis. This master plan would differ from others by further integrating surface flooding and basement backup objectives into the analysis and hydraulic constraints in local systems. It would also begin to address the interactions between the GLWA system, its conveyance capacity, and surface flooding.

The master plan should have both near- and long-term action items. This plan needs to involve more than traditional engineering that calls for larger pipes and more pumping capacity. Instead, there should be more emphasis on capital improvements for upstream storage, surface conveyance by gravity when feasible (with less reliance on pumping), and significantly more outfall capacity. Outfall capacity should be discussed as soon as possible with local and regional permit authorities such as EPA and EGLE. Placing more reliance in the future on land use planning and zoning to reduce flood risks is also encouraged and the master plan should extend to the neighborhood (collection system) level.

4.3 Long-Term Measures

This section presents recommendations that should be considered and/or could be implemented in the long term.

4.3.1 General Recommendations

1. The Independent Panel recommends that GLWA and customer communities evaluate the feasibility of moving the regional and local collection system infrastructure to a 100-year design storm standard for the regional and community collection system for flood protection. The current collection system was designed for the 10-year return frequency, which results in widespread and relatively frequent surface flooding and basement backups.

2. Local governments should consider instituting a program for the voluntary purchase of flood-prone (repetitive loss) properties contingent upon securing adequate funding from state or federal programs. This measure has been successfully implemented in a number of large cities throughout the country. Often the purchased properties can be developed into community assets such as parks, trails, golf courses, open spaces, and green stormwater infrastructure. Federal funds can be used for such programs; however, purchased properties must previously have had flood insurance under the National Flood Insurance Program (NFIP). The Independent Panel has experience with projects where homeowners experience repetitive loss properties and can offer advice or assistance; while acknowledging the politics of suggesting to homeowners that they leave their homes are highly sensitive, even though such programs are normally voluntary and fair market value is paid.

3. A public outreach campaign on flood risk and purchasing flood insurance could be considered by the local communities. It is important for citizens to understand that most FEMA flood maps only address risks of riverine/coastal flooding and do not indicate “internal” or landlocked flooding risk. As part of this campaign, local communities may consider providing financial assistance for purchasing flood insurance. As indicated in the previous item, widespread purchase of federal flood insurance can unlock federal funding for the purchase of “repetitive loss properties.”

4. Comprehensive flooding solutions can no longer be developed using traditional engineering methods alone. Infrastructure projects are increasingly being evaluated using a “triple-bottom-line” approach that incorporates economic, social, and environmental costs and benefits. These efforts require engagement from planners, sociologists, economists, communication specialists, advocacy groups, and the public to ensure that both technical and nontechnical perspectives are considered. We encourage GLWA to consider this type of decision-making framework.

5. We encourage GLWA to reach out to leaders of other cities and organizations that have successfully implemented large-scale flood reduction projects to learn about their programs. Examples include Tulsa (Oklahoma); Harris County Flood Control District (Houston); Mile High Flood District (Denver); Washington, D.C.; St. Charles Missouri (St. Louis); New York City;

Chicago; Toronto, Canada; and others. Independent Panel members and AECOM staff have worked with many of these cities and organizations and could facilitate meetings between these leaders and GLWA BoD members. The Independent Panel acknowledges that when communities like Tulsa began to grapple with its flooding problem, the task seemed overwhelming. However, by developing and following a flood plan and proceeding gradually, tremendous progress has been made and many structures are no longer at risk of flooding.

4.3.2 Pumping Stations

The Independent Panel recommends that long-term measures be strategically outlined but developed on an ongoing basis based on new knowledge acquired from implementing the short- and medium-term measures recommended above.

For example, if the refurbishment project for Freud PS (CS-120) and the medium-term measure of retrofitting two stormwater pumps at Connors Creek PS are both successful, then the existing Connors Creek PS should be refurbished in a similar manner as a long-term measure. Furthermore, if the vacuum priming process for the remaining six volute pumps at Connors Creek PS continues to hamper stormwater pumping during severe storm events, then six new VS3i pump units like the first two retrofitted as medium-term measures should be purchased and retrofitted into the PS as long-term measures to enhance levels of stormwater pumping service. In addition, if debris accumulation in the wet wells after major storm events proves to be excessive, provisions for coarse screens at Connors Creek PS should be considered.

Good contingency planning demands that if unforeseen operational difficulties arising from the medium-term measures taken, new measures to enhance levels of service must be provided for. For example, a new pumping station or stations to replace Connors Creek PS and/or Freud PS outright might be constructed over the next 10 years.

In addition, in association with the long-term improvements improved system automation of all stormwater pump operations should be developed as a long-term measure. Such measures will reduce dependency on human operators during storm events and enhance the level of service to the community.

4.4 Approach for Continued Regional System Coordination

The Independent Panel understands that GLWA cannot address flooding issues on its own. The following recommendations will require coordination with GLWA and its member communities for successful implementation.

1. The East Side System Detroit flooding that occurred in 2021 (and previous years) is the predictable result of significant urbanization in areas upstream of what was once a low-lying marsh, with a collection system designed and constructed decades ago. This collection system was designed with gravity outfalls for higher elevation areas and pump outfalls in low lying areas. The present situation has evolved over decades in response to fragmented, “patchwork” land planning, land use, and engineering practice. Many different parties have contributed to this problem, as is the case in many American cities. It is advised that GLWA understand how the systems in these upstream areas are operated and if they contribute inequitably to downstream flooding. The solutions needed to reduce flooding should impact and benefit all contributors equitably in terms of feasibility. The 79 different local government and related entities that use the GLWA system should look forward and work together in a unified manner with common goals, policies, objectives, and design/operation criteria to mitigate the flooding problem with the over-arching goal of protecting public health, safety, and welfare. Inter-governmental communication, coordination, and sharing of financial responsibilities is essential for flooding and basement backup problems to be resolved.

2. The City of Detroit and other local governments participate in the NFIP administered by FEMA. To participate, municipalities must agree to abide by the policies and requirements of the NFIP, which are geared toward protecting properties from flooding for at least a 100-year event. GLWA

and other local governments should meet with FEMA to better understand how to move toward providing 100-year level of flood protection. Significant time and expenditures will be required to attain this level of flood protection, but in the Independent Panel's view, this is the appropriate long-term action for flood hazard mitigation. Local governments should review existing codes and ordinances pertaining to flooding (including buildings, plumbing, subdivisions, drainage criteria, and others) and evaluate if changes are necessary. The 10-year level of service metric goal should also be "benchmarked" against other large, combined sewer systems throughout the US.

3. Local governments should consider updating flood maps to represent actual flood risk throughout the service area, not just those mapped by FEMA. This is becoming more common as infrastructure designed and constructed decades ago is no longer adequate to handle more frequent and intense rainfall events and flood risk now exists where it did not previously. This is particularly relevant in the case of the GLWA service area where the collection system was designed for a 10-year event, with little consideration given to where flood waters would occur when the 10-year stormwaters are exceeded. Homeowners in these areas need to be aware of the actual risks so that they can purchase flood insurance and/or be eligible for other technical/financial assistance. For example, highly successful flood hazard reduction programs(such as Tulsa) prepared detailed inventories of properties and their history of flooding. The Independent Panel encourages local governments to do the same.

4. The need for regular, transparent public outreach and education by GLWA and the communities cannot be overstated, especially in those areas most impacted. Presentations and speakers should include outside experts/panels available to answer questions by citizens and the media.

5. Regional partners should develop a flood data collection program to complement its existing rainfall, flow, and depth data collections. This program would focus on collection of surface and basement flooding data that are generally reported by citizens with limited accuracy regarding flood depths, duration, and other factors. Data of this kind would also provide important calibration/validation points for modeling and mapping. The system of sensors currently in place within the collection system should be evaluated to determine if additional sensors are needed to support modeling and operational decision making. A high priority by regional partners is to investigate the feasibility of an early flood warning system. GLWA should coordinate with regional partners in these activities.

6. The discussion in Section 4.5 includes many conceptual ideas for financing necessary improvements to reduce flooding. For example, in early 2022, numerous federal funding sources became potentially available. In terms of wastewater and stormwater bills to customers/residents, there should be incentives for reducing imperviousness such as giving incentives for green infrastructure, disconnecting impervious areas, and other runoff-reducing measures. The near- and long-term financing methods that are ultimately used will likely be a combination of current and new methods; however, they must fundamentally be equitable and provide adequate funding to dramatically upgrade the present system.

7. The Independent Panel believes there is an opportunity for an organization to serve as the regional leader of stormwater and floodplain management in the Detroit metro area. In the Independent Panel's collective experience, the most successful flood control programs in large metro areas have a single entity in charge to develop policies, criteria, master plans, etc. that are adopted by the member governments in exchange for project implementation support (technical, financial, administrative). Given its existing regional role, GLWA should consider the role it would play in such an organization.

8. GLWA and the local governments in the service area are faced with a variety of federal, state, and local legal and regulatory requirements, some of which may need to be adjusted to expedite mitigation of flood hazards. As a more collaborative effort takes shape to plan for the future, a comprehensive summary of regulatory requirements should be prepared and examined to ensure compliance, but also not create delays in moving forth with projects that will provide flood relief.

4.5 Funding Sources

4.5.1 Framework of GLWA Revenue Sources

GLWA was formed under 1955 PA 233, as amended, MCL 124.281 et seq, and began operating on January 1, 2016. In GLWA's Articles of Incorporation—specifically, Articles 11 and 12—GLWA's revenue streams available consist of the following sources:

- Rents, fees, or other charges for use of a water supply system or sewage disposal system, including a storm water collection and treatment system, or a combination of such systems.
- Federal, state, or local government grants, loans, appropriations, payments or contributions.
- Proceeds from the sale, exchange, lease, or other disposition of property to which GLWA has title.
- Grants, loans, appropriations, payments, proceeds from repayments of loans made by GLWA, or contributions from public or private sources.
- Investment earnings on the revenues described in the bullets above.
- Borrow money and issue bonds, notes, and other evidence of indebtedness.

Statements in the executed Memorandum of Understanding leading up to the execution of the Articles of Incorporation, signed by signatories representing the City of Detroit, Wayne County, Oakland County, Macomb County, and the State of Michigan include:

- GLWA will have no taxing powers.
- Each system, as a whole, is assumed to experience revenue requirement increases of not more than 4 percent for each of the first 10 years of GLWA management.
- The State agrees to identify ways to facilitate access and eligibility for the Authority to the Clean Water State Revolving Fund and Drinking Water State Revolving Fund, grants, and other sources of State funding to mitigate the cost of improvements—particularly for areas of the greatest health and environmental need—and commits to using its best efforts to facilitate such funding for GLWA.

4.5.2 Introduction to Effective Grant Management for Resilient Infrastructure

As funding streams are renewed and new federal programs are established, GLWA will need to understand each funding sources' selection criteria, regulations, and tracking and compliance protocols. Navigating application cycles, eligibility criteria, implementation methodologies, and post-award tracking of funds will support GLWA's objectives to mitigate future flood risks.

Considering such unprecedented funding opportunities, GLWA could capture these available funds to address aging infrastructure, reduce current flood risks, expand and improve its water, wastewater, and treatment systems and achieve a more climate-resilient community.

4.5.3 The American Infrastructure Investment and Jobs Act

The American Infrastructure Investment and Jobs Act (IIJA), HR 2684, was signed into law on November 15, 2021. The IIJA was a legislative rider on the Surface Transportation Re-Authorization Act of 2021 (H.R. 3684). The act increases federal spending by $550 billion across all infrastructures including roads, transit, water, broadband, and power. The act also allocates funding to support critical safety, equity, sustainability, and resilience outcomes. Based on AECOM's research, the IIJA provides 418 funded provisions that are allocated over a 5-year period (fiscal years [FYs] 2022-2026). A high-level funding allotment analysis of the $550B is shown in Figure 34.

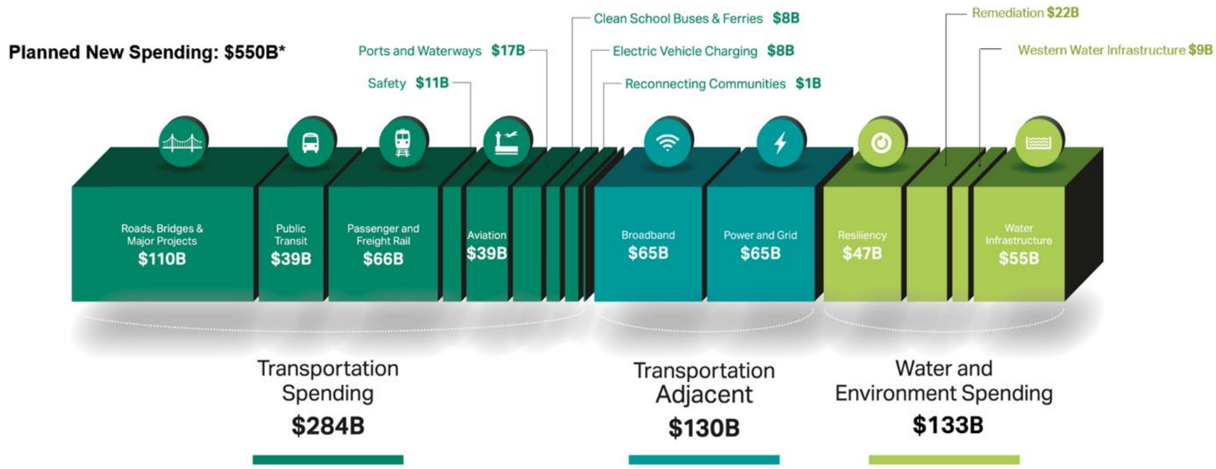


Figure 33: Infrastructure Investment and Jobs Act Breakdown

The predominate vehicles used by the IIJA for fund distribution include formula-based grants, competitive grants, programmatic grants, cooperative agreements, direct federal spending, and loans and subsidies.

This unprecedented increase in funding presents GLWA with a unique opportunity to capture funding to help implement its mitigation program. Funding provisions that correlate with the recommended actions are provided in Table 21. The funding allocations represent the total appropriation reflected in the IIJA that could be explored further by the GLWA. Note that the funding allocations in the table are evenly distributed over a 5-fiscal-year timeframe, with little exception.

Other considerations in the Infrastructure Investment Act include:

Emphasis placed on Public Private Partnerships—many types of initiatives in the act contain grantee selection that consider nonfederal contributions to a project including P3.

- Requirements for union and minority participation in funded projects.
- Encouragement for use of construction technology—over $100M for advanced digital construction management systems and related technologies.
- A focus on environmental projects—First Major Federal Investment to adapt to the impact of climate change.

Table 21: Infrastructure Investment and Jobs Act Potential Funding Opportunities

IIJA Program	Eligible Uses	Total IIJA Funding ($M)	Department	Agency	Funding Type	Project Applicability	Timeline
Clean Water SRF – Capitalization Grant	Construction of wastewater and stormwater treatment facilities and collection systems; nonpoint source pollution management; construction, repair, or replacement of decentralized wastewater treatment systems; construction of nature-based infrastructure solutions; and other uses associated with the management of wastewater and stormwater.	$11,713	EPA	Clean Water SRF	Capitalization grants and loans; 10% State match requirement; 49% of grant funding must be used by the state to provide subsidy to eligible recipients in the form of assistance agreements with a 100% forgiveness of principal or grant or combination of the two.	Flood Mitigation and Rising River Level Studies	ITA form for the CWSRF and SWQIF loan programs, Due January 31, 2022 for year 2023 consideration. The submittal deadline for final project plans in CWSRF fiscal year 2023 is June 1, 2022.
Drinking Water SRF – Capitalization Grant	Construction of expansion of drinking water treatment plants and/or distribution systems; improving drinking water treatment; fixing leaky or old pipes (water distribution); improving sources of water supply; replacing or constructing finished water storage tanks; other infrastructure projects needed to protect public health.	$11,713	EPA	Drinking Water SRF	Capitalization grants and loans; 10% State match requirement; 49% of grant funding must be used by the state to provide subsidy to eligible recipients in the form of assistance agreements with a 100% forgiveness of principal or grant or combination of the two.	Repair and expansion of undersized or damaged water treatment infrastructure.	ITA form for the DWSRF loan program, due January 31, 2022 for year 2023 consideration The submittal deadline for final project plans in DWSRF fiscal year 2023 is July 1, 2022.
Building Resilient Infrastructure and Communities (BRIC) Program	Hazard mitigation activities include: building codes, partnerships, project scoping, mitigation planning and planning-related activities, and other activities; cost-effective mitigation projects designed to increase resilience and public safety; reduce injuries and loss of life; and reduce damage and destruction to property, critical services, facilities, and infrastructure from natural hazards	$1,000	DHS	FEMA	Competitive Grants; 25% State match requirement.	Support planning, design, and implementation of community and life-line infrastructure resilience projects.	Application period for FY2021 closed on January 28, 2022. Anticipated NOFO of September 2022.

IIJA Program	Eligible Uses	Total IIJA Funding ($M)	Department	Agency	Funding Type	Project Applicability	Timeline
	and the effects of climate change; and management costs.						
STORM Act	Provide support through loans and grants to local communities facing rising water levels, coastal erosion, and flooding that have put homes and property at risk and caused millions of dollars in damage.	$500	DHS	FEMA	Competitive, Capitalization Grants; 25% State match requirement	Long-term, low-interest loans to support reduction of risk to life and property.	Assess whether all prerequisites for receiving funds have been met. Prepare request letter to FEMA administrator for funds.
Flood Mitigation Assistance	Projects that address community flood risk for the purpose of reducing NFIP flood claim payments; technical assistance to maintain a viable Flood Mitigation Assistance program; planning subapplications for the flood hazard component of state, local, territory, and tribal hazard mitigation plans and plan updates.	$3,500	DHS	FEMA	Grant; Match requirement; Focus on repetitive flood losses/claims	Funding for flood mitigation actions and assistance that reduce flood impact on structures.	Applications for FY2022 are expected to open no later than September 30, 2022
WaterSMART Grants	Water management improvements that contribute to water supply sustainability, increase drought resilience, and that have environmental benefits.	$400	DOI	Bureau of Reclamation	Competitive Grant		Estimated application opening dates in March, April, and May 2022.
Flood and Inundation Mapping and Forecasting, Water Modeling, Precipitation Frequency Studies	Coastal and inland flood and inundation mapping and forecasting next-generation water modeling activities including modernized precipitation frequency and probable maximum studies.	$492	DOC	NOAA	Various	Operational, real-time, and forecasted inland flood modeling, mapping, and alert notification functionality.	Estimated application opening date: 2 quarter 2022.
Inland Flood Risk Management Projects	Eligible federal projects to reduce the risk of damage from riverine flooding.	$1,750	DOD	USACE	Direct Federal	Construction projects that help to reduce the risk of damage from inland flooding.	Funding allocated for FY 2022; assess and advocate to USACE for project funding

IIJA Program	Eligible Uses	Total IIJA Funding ($M)	Department	Agency	Funding Type	Project Applicability	Timeline
Multi-Purpose Flood Risk Management Programs or Projects	Federal projects to reduce the risk of damage from riverine flooding.	$750	DOD	USACE	Direct Federal	Construction projects that help to reduce the risk of damage from inland flooding.	Funding allocated for FY 2022; assess and advocate to USACE for project funding.
Planning Assistance	Planning and technical assistance to states, tribes, and local communities to address water resources issues and related work.	$30	DOD	USACE	Direct Federal	Technical assistance on water related resolutions.	Funding associated for FY 2022.
Floodplain Management Services – Technical services, Planning, Guidance	Studies to determine the engineering, economic feasibility of potential solutions to water and related land resources problems as well as preconstruction engineering and design.	$45	DOD	USACE	Direct Federal	Perform economic feasibility of potential solutions and preconstruction engineering and design.	Funding allocated for FY 2022; assess and advocate to USACE for project funding.
Watershed and Flood Prevention	Flood Prevention, Watershed Protection, Public Recreation, Public Fish and Wildlife, Agricultural Water Management, Municipal and Industrial Water Supply, or Water Quality Management.	$500	DOA	NRCS	Technical and Financial Assistance	Planning, design, and construction of measures that address resource concerns in a watershed.	Estimated application opening date, first quarter 2022.
Preventing Outages and enhancing the Resilience of the Electric Grid Program	Activities that reduce the likelihood and consequence of impacts to the electric grid due extreme weather, wildfire, and natural disaster.	$2,500	DOE	Office of Electricity	Competitive Grant	Construction of extreme weather or disaster resilient electric grid.	Estimated application opening date, fourth quarter 2022.
Smart Grid Investment Matching Grant Program	Infrastructure that increases the network's operational transfer capacity and anticipates and mitigate impacts of extreme weather events or natural disasters on grid resilience.	$3,000	DOE	Office of Electricity	Competitive Grant	More resilient power supply.	Estimated application opening date, fourth quarter 2022.

Notes:
CWSRF = Clean Water State Revolving Fund

BRIC = Building Resilient Infrastructure and Communities
DHS = Department of Homeland Security
DOA = Department of Agriculture
DOC = Department of Commerce
DOD = Department of Defense
DOE = Department of Energy
DOI = Department of the Interior
DWSRF = Drinking Water State Revolving Fund
EPA = Environmental Protection Agency
FEMA = Federal Emergency Management Agency
FY = Fiscal Year
IIJA = Infrastructure Investment and Jobs Act
ITA = Intent-to-Apply
NFIP = National Flood Insurance Program
NOAA = National Oceanic and Atmospheric Administration
NOFO = Notice of Funding Opportunity
NRCS = Natural Resource Conservation Service
SRF = State Revolving Fund
USACE = US Army Corps of Engineers

4.5.4 State Revolving Funds

The State of Michigan—through EGLE and Michigan Finance Authority—manages and oversees both the Clean Water State Revolving Fund (CWSRF) and the Drinking Water State Revolving Fund (DWSRF).

Leveraging the 2021 federal CWSRF capitalization grant of $68.2M, $13.7M in state match funds, and proceeds from previously financed CWSRF projects, Michigan's FY 2022 CWSRF fundable range was $800.0M. EGLE received 53 eligible projects totaling $601.2M, leaving an unobligated balance of approximately $198.8M.

Leveraging 2020 grants, state match and proceeds from previously financed DWSRF projects, the DWSRF fundable range amount was $275M. EGLE received a total of 16 eligible projects that were issued loans totaling $190.7M. Seven communities issued loans declined or postponed loan closings in FY 2021.

Since FY 2016, GLWA has leveraged these SRFs seven times. As the IIJA infuses additional funding for both SRFs with greater principal forgiveness opportunities, GLWA should consider this funding source to implement the recommended infrastructure items.

4.5.5 Water Infrastructure Finance and Innovation Act

The Water Resources Reform and Development Act of 2014 (Public Law 113-121) authorized the establishment of the Water Infrastructure Finance and Innovation Act (WIFIA) pilot program to accelerate investment in water infrastructure. WIFIA is a federal credit program administered by the EPA for eligible water and wastewater infrastructure projects.

WIFIA is available for federal, state, local, tribal government entities; partnerships and joint ventures; corporations and trusts; and CWSRF programs. The WIFIA program can support development and implementation activities for CWSRF. It should be noted that projects for flood damage reduction; hurricane and storm damage reduction are also eligible for assistance if the secretary determines it is technically sound, economically justified, and environmentally acceptable.

Important features of the WIFIA program include:

- $20M minimum project size for large communities
- $5M minimum project size for small communities (population of 25,000 or less).
- Maximum of 49 percent funding of total project cost by WIFIA
- Maximum of 80 percent total, combined federal assistance for an eligible project's cost
- Maximum of 35 years maturity date from project completion
- Maximum of 5 years deferred payment after project completion
- Interest rate equal to or greater than the US Treasury rate at project completion
- Projects must be creditworthy and have a dedicated source of revenue
- Project compliance with National Environmental Protection Act, Davis-Bacon, American Iron and Steel, and all other federal cross-cutting provisions

To date, one WIFIA Letter of Interest has been submitted and closed. The Downriver Utility Wastewater Authority was credited $17.9M on February 3, 2021 for biosolids dryer facility and other critical projects.

Since its inception, the WIFIA program has continued to be modified through legislation. Most recently, the America's Water Infrastructure Act of 2018 established a new loan program, State Water Infrastructure Finance Innovation Act (SWIFIA). The SWIFIA program is exclusively for state infrastructure financing authority borrowers, commonly known as State Revolving Fund (SRF) programs. Whereas WIFIA is managed by EPA, SWIFIA is received and managed by SRF programs. SWIFIA loans are eligible to

SRFs for projects that are deemed ready to proceed (no later than 24 months after the Letter of Interest deadline). To date, five states have submitted for state finance authorities WIFIA loans totaling $1.28B.

Congress has continued to appropriate funding for the WIFIA program; FY 2017, $30M; FY 2018, $63M; FY 2018, $68M; FY 2020, $60M; FY 2021, $59.5M. Most recently, section 50215 of the IIJA reauthorizes WIFIA appropriations for subsidy costs at $50M annually for FY 2022 through FY 2026.

For FY 2021, EPA made available $5.5B through the WIFIA program, with another $1B in funding for the SWIFIA program.

4.5.6 American Rescue Plan Act

The State and Local Fiscal Recovery Fund, a component of the American Rescue Plan Act, provides $350B to state, local, and tribal governments to aid in the financial impacts from responding to and recovering from the pandemic. In May 2021, the US Department of Treasury published an Interim Final Rule that defined eligible uses of these dollars by governments in addition to providing fiscal recovery. On April 1, 2022, the department published a Final Rule that broadened the permissible uses of the funds to include making necessary investments to water and sewer infrastructure.

Eligible projects under the CWSRF include—but are not limited to—the following:

- Construction of publicly owned treatment works
- Projects pursuant to implementation of a nonpoint source pollution management program established under the Clean Water Act (CWA)
- Decentralized wastewater treatment systems that treat municipal wastewater or domestic sewage
- Management and treatment of stormwater or subsurface drainage water
- Water conservation, efficiency, or reuse measures
- Development and implementation of a conservation and management plan under the CWA
- Watershed projects meeting the criteria set forth in the CWA
- Energy consumption reduction for publicly owned treatment works
- Reuse or recycling of wastewater, stormwater, or subsurface drainage water
- Security of publicly owned treatment works

Eligible projects under the DWSRF include—but are not limited to—the following:

- Facilities to improve drinking water quality
- Transmission and distribution, including improvements of water pressure or prevention of contamination in infrastructure and lead service line replacements
- New sources to replace contaminated drinking water or increase drought resilience, including aquifer storage and recovery system for water storage
- Green infrastructure, including green roofs, rainwater harvesting collection, and permeable pavement
- Storage of drinking water, such as to prevent contaminants or equalize water demands
- Purchase of water systems and interconnection of systems
- New community water systems

Note, the full list of eligible uses for both EPA Drinking Water and Clean Water State Revolving Fund is available at: https://www.epa.gov. The City of Detroit received $86.7 million as part of the American Rescue Plan Act in March 2021. The City Council approved a spending plan that funded 15 initiative categories. GLWA should explore with the City whether these funds could be used for this project.

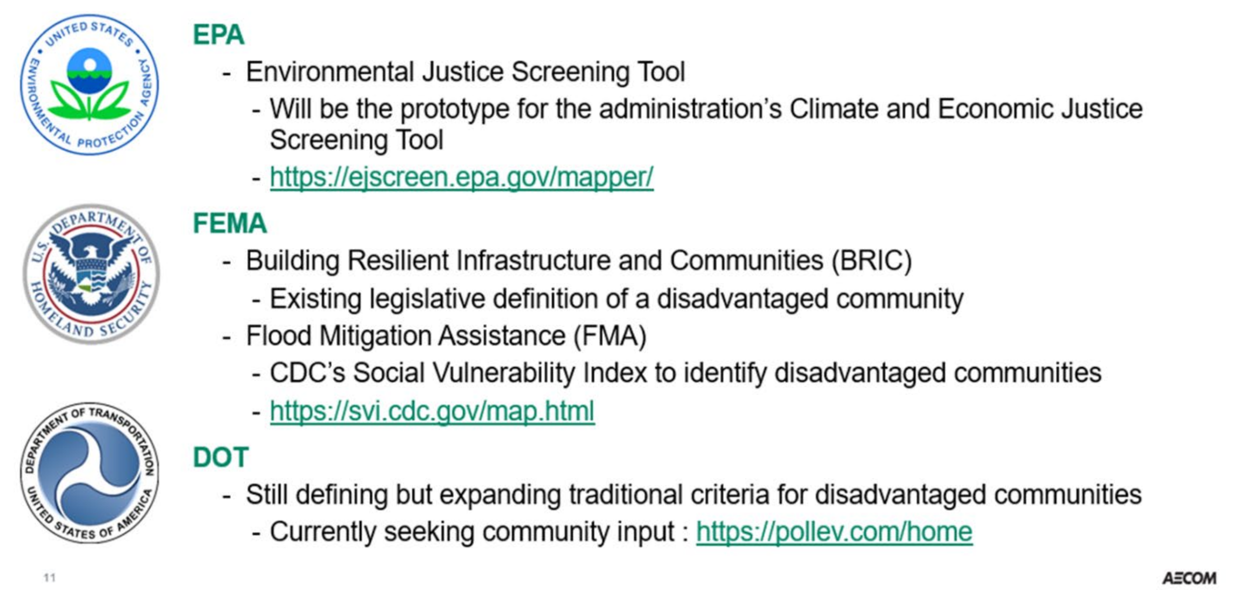
4.5.7 Justice40 Initiative

On his first day in office, President Biden signed Executive Order 13985 on Advancing Racial Justice and Support for Underserved Communities Through the Federal Government (January 20, 2021). The Justice40 Initiative was established to ensure that federal agencies work with states and local communities to deliver at least 40 percent of the overall benefits from federal investments in climate and clean energy to disadvantaged communities. This whole-of-government effort will fundamentally change how federal grants will be submitted, awarded and implemented by awardees, such as GLWA. Each of the managing agencies for IIJA, WIFIA, SRF, and American Rescue Plan Act will be using metric indicators and tools to review and award funding.

An initial pilot of 21 programs across nine federal agencies has begun to determine how climate-focused programs can support disadvantaged communities. These pilots will help serve to develop best practices and metrics for program success.

Identification of how three agencies are using available tools to define disadvantaged communities as it relates to their focus and programs is provided in Table 22.

Table 22: Available Tools to Define Disadvantaged Communities



It is important to note that the way an underserved or disadvantaged community is defined is still in development. For example, depending on the agency and the type of infrastructure used, the methodology for determining a "disadvantaged" community may be different. The EPA has constructed a prototype Environmental Justice Screening Tool (https://ejscreen.epa.gov/mapper/) to help determine disadvantaged communities. The tool calculates overall scoring based on a suite of both demographic and environmental indicators. These draft indicators are provided in Table 21.

Table 23: Draft Indicators in the EPA Environmental Justice Screening Tool

Demographic Indicators	Environmental Indicators
Income Less than 2x Federal Poverty Level	Lifetime Cancer Risk from Inhalation of Airborne Toxins
Non-White	Respiratory Hazard Index
Less than High School Education	Diesel Particulate Levels
English Language Ability	Particulate Matter Levels
Below the Age of 5	Ozone Concentration
Above the Age of 64	Traffic Proximity and Average
Demographic Index = Average % Income + % Non- White	% Housing Units Built <1960
	Proximity to Potential Chemical Accident Site
	Proximity to Hazardous Waste Facility
	Proximity to Superfund Site
	Proximity to Toxic Wastewater Discharge Site

FEMA currently is using the Centers for Disease Control and Prevention's Social Vulnerability Index to identify disadvantaged communities (https://svi.cdc.gov/map.html). The Centers for Disease Control and Prevention's vulnerability scoring for the city of Detroit and surrounding area is shown in Figure 35.

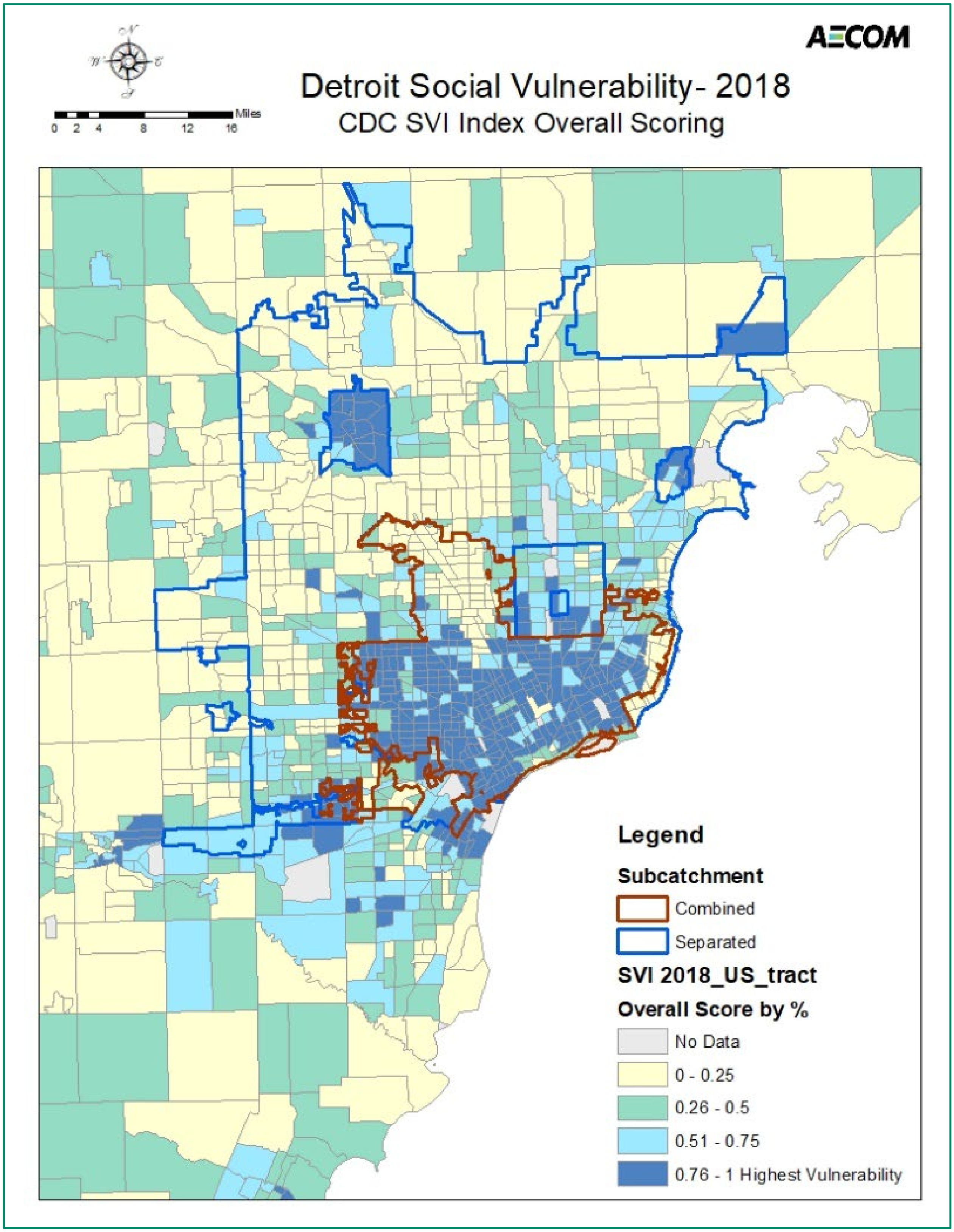


Figure 34: Vulnerability Scoring for Detroit and Surrounding Areas

4.5.8 Strategic Use

To ensure the timely implementation of actions recommended through this report, effective capture and use of all funding sources will be necessary. In working toward this goal, GLWA should:

- Establish a Linear Implementation Plan prioritizing and scheduling all capital improvements and facility upgrades mentioned in the report.
- Match specific infrastructure capital improvement needs with specific federal funding opportunities.
- Construct a Justice40 Implementation Plan that leverages demographic, environmental, and infrastructure improvements. This plan should be shared and used during the development of all grant applications.
- Conduct a Funding Gap Analysis to determine the nonfederal funding that must be generated through state and or local funding vehicles.

APPENDIX A – BACKGROUND MATERIAL

A1 – Investigation: Board and Staff Interviews

Interviews with GLWA BoD members and selected staff were conducted by Attorney Jeffrey Collins, Principal Investigator Glen Daigger, and AECOM Team Manager Devan Thomas. The interviews informed the assessment as documented in this report. The interviews are listed in alphabetical order by first name in Table 23.

Table 24: Staff Interviews Conducted By Investigative Team

Name	Organization	Role	Interview Date
Anthony Troy	GLWA Staff	Team Leader – Systems Control	13 September 2021
Antony Smith	GLWA Staff	Team Leader	28 October 2021
Beverly Walker-Griffea	GLWA Board	State of Michigan Representative	20 August 2021
Bill Wolfson	GLWA Staff	Chief Administrator and Compliance Officer	2 September 2021
Biren Saparia	GLWA Staff	Manager – Systems Control	1 October 2021
Brian Baker	GLWA Board	Macomb County Representative	19 August 2021
Cheryl Porter	GLWA Staff	Chief Operating Officer – Water and Field Services	2 September 2021
Clarence White	GLWA Staff	Team Leader	28 October 2021
Davin Fox	GLWA Staff	Operator	9 September 2021
Freman Hendrix	GLWA Board	Board Secretary, City of Detroit Representative	25 August 2021
Gary Brown	GLWA Board	City of Detroit Representative	27 August 2021
Jaye Quadrozzi	GLWA Board	Oakland County Representative	23 August 2021
John Zech	GLWA Board	Board Chair, Wayne County Representative	18 August 2021
Katherine Miracle	GLWA Staff	Operator	9 September 2021
Keith Duncan	GLWA Staff	Water Systems Technician	13 September 2021
Nathan Ward	GLWA Staff	Electrician	13 September 2021
Navid Mehram	GLWA Staff	Chief Operating Officer – Wastewater Operating Services	31 August 2021
Sue McCormick	Formerly GLWA Staff	Former Chief Executive Officer	30 September 2021
Suzanne Coffey	GLWA Staff	Interim Chief Executive Officer	3 September 2021
Todd King	GLWA Staff	Director – Field Services	20 September 2021

A2 – 2016 Rainfall Events: Outcomes and Status of Remedial Measures

There have been several heavy storm events in recent years that have resulted in flooding due to failures at the Connors Creek and Freud PSs and Connors Creek CSO basin, including events on August 11, 2014; July 8, 2016; and August 16, 2016. Flooding during these events resulted from several factors.

The Connors Creek CSO Basin was designed with a launder weir with downstream effluent launder gates "ELGs) that can convey about 4,100 cfs. The design capacity of the CSO basin is close to 14,000 cfs. The CSO basin also has emergency relief gates (ERGs) that are submerged by the river on the downstream end wall of the CSO basin and are operated when inflows to the basin exceed the storage and treatment capacity. For the 2014 and 2016 storms, the ELGs and ERGs were operated only locally and not through the SCADA system from the control room at the CSO or the SCC. In addition, the ERGs had been chained and padlocked prior to the July 8, 2016 event, to prevent inadvertent opening of the gates when the CSO basin was empty. Opening the gates required operators to physically unlock the gate actuators. Also, the influent screen gates (ISGs) were initially closed for the July 8, 2016 storm and were not operable remotely through the SCADA system. After the July 8, 2016 event, they are kept open during wet weather events.

During the event in August 2014, all the storm pumps at the Connors Creek PS were inoperable because the vacuum priming system had fallen into disrepair and was not functioning.

Flooding during the event in July 8, 2016 event resulted from a similar issue (nonoperable vacuum priming system), compounded by the fact that operations personnel were not stationed at the Connor Creek CSO facility prior to the rain event to operate the Connor Storage Gates, ELGs, and ERGs. With the ERGs closed, the CSO Basin and Connors Creek Enclosure surcharged and flooded to grade. This localized street flooding prevented operations staff from reaching the CSO Basin in a timely manner.

For the August 2016 storm, the chains and padlocks had been removed from the ERGs, and staff were stationed at the CSO to properly open the gates. However, the Connors Creek storm pumps remained inoperable due to the vacuum priming issue.

Studies were commissioned after these events to determine causes of failures and provide recommendations to reduce the potential for future flooding. Studies reviewed for this assessment included:

METCO (June 2015), *Vacuum Priming System Evaluation, System Analysis and Condition Survey of Sewerage PS,* report prepared for DWSD.

This report was commissioned after the storm event on August 11, 2014. The objectives of this report were to:

- Enhance operational reliability of the Connors Creek PS
- Develop and Operational Strategy to optimize use of the Connors Creek CSO basin and associated CSO control facilities
- Determine the optimum hydraulic pumping capacity at Freud, Connors Creek, and Fairview PS
- Conduct a condition assessment and identified required repair/upgrades to major equipment at Connors Creek and Freud PS

GLWA (21 November 2016), *Detroit East Side Flooding Event Analysis – July 8 and August 16, 2016.*

This report was commissioned by GLWA after the storm events of July 8, 2016 and August 16, 2016. The objectives of this report were to provide an understanding of the circumstances around the storm events that led to flooding, including:

- Prediction/advance warning of the heavy rain events

- The intensity of the rainfall events
- The local and regional sewer systems to convey the rainfall
- The characteristics of the areas and sewers where flooding occurred
- The operator’s responses to the events

OHM Advisors (January 17, 2017), *DWSD Basement Backup Evaluation Following the July 8, 2016 and August 16, 2016 Rain Events and Related Flooding,* report prepared for Detroit Water and Sewerage Department.

This report was independently commissioned by DWSD after the storm events of July 8, 2016 and August 16, 2016 to identify the causes of flooding and develop alternatives to better protect the area. The report does not provide specific recommendations, but does summarize measures that were currently in progress to reduce flooding potential, and outlines additional improvements that could be considered, including:

- Base-level improvements to existing system
- Enhancements to the conveyance system
- Peak flow reduction measures
- Damage reduction measures

A summary of the recommendations from the various reports and the status of implementation of the recommendations are provided in Table 24.

Table 25: Summary of Recommendations from Prior Studies

Report [1]	Rec. No.[2]	Recommendation	Area of Focus [3]			Completed		Comments
			Oper.	Phys.	O&M	Yes	No	
METCO	CN-01	Remove two (or four) existing centrifugal storm pumps and replace with vertically suspended wet-pit turbine pumps		X			X	Would eliminate need for priming system for first-used pumps at Connors Creek PS enabling those pumps to start without having to wait for discharge level to reach required height for vacuum priming system.
METCO	CN-02	Maintain existing siphon block in discharge piping	X			X		Would continue to provide function of check valve to control backflow from discharge channel.
METCO	CN-03	Detailed internal inspection of existing storm pumps			X		X	Unable to determine based on visual inspection during AECOM site visit (2021).
METCO	CN-04	Convert existing electric motors to brushless type		X			X	Existing motors beyond range of general life period.
METCO	CN-05	Install machine safety guards for storm pumps			X		X	Rotating shafts are exposed at intermediate floor levels, creating a safety hazard.
METCO	CN-06	Replace the two existing primary transformers and associated controls		X			X	Existing transformers beyond range of general life period.
METCO	CN-07	Upgrade existing lighting system			X		X	Lighting did not meet IES standards at time of METCO inspection (2014). Lighting appeared adequate during AECOM site visit (2021).
METCO	CN-08	Replace existing boilers, condensate pumps, associated piping and valves			X		X	Only one of two boilers operational; corrosion present on remaining boiler. No indication work was done.
METCO	CN-09	Replace existing heaters and ventilation fans			X		X	Current equipment was in poor condition. No indication work was done.
METCO	CN-10	Resurface existing driveway			X		X	Cracks noted in existing driveway. Does not appear to have been addressed, based on Google Earth imagery from 2015 to 2021.
METCO	CN-11	Repair/seal cracks between storm and sanitary pump buildings			X		X	Unclear if/when this was done based on visual inspection during AECOM site visit (2021).
METCO	CN-12	Replace roof on storm pump building			X	X		Shingles missing at several places; appears to have been fixed, based on Google Earth imagery from 2016 versus. 2017.

Report [1]	Rec. No.[2]	Recommendation	Area of Focus [3]			Completed		Comments
			Oper.	Phys.	O&M	Yes	No	
METCO	CN-13	Allow level in Connors Creek Discharge Channel to reach elevation 95 ft before starting Connors Creek PS storm pumps	X				X	METCO rationale: By allowing the level in the discharge channel to rise, the siphon blocks at Connors Creek PS will be submerged enough to allow vacuum priming system to prime storm pumps effectively. Current SOP indicates discharge channel level should be at minimum of 83.0 ft prior to starting storm pumps.
METCO	CN-14	Revise Connors Creek storm PS peak design flow to 2,000 cfs	X				X	METCO recommended installed capacity of 2,500 cfs (5 pumps @ 500 cfs each), for N+1 firm capacity of 2,000 cfs.
METCO	CN-15	Raise weir in Connors Creek Discharge channel from elevation 80.5 ft to 84.5 ft		X		X		A new, higher weir was installed in the Connors Creek discharge channel.
METCO	FR-01	Modify existing storm pumps with new mechanical seals and self-lubricated bearings			X		X	METCO found existing seals/bearings difficult for maintenance staff to access; recommendation would provide increased safety for personnel.
METCO	FR-02	Evaluate suction hydraulics and relocate two sanitary pumps to intermediate bearing floor level			X		X	METCO found access to existing pumps limited, making routine maintenance difficult.
METCO	FR-03	Install stop logs at inlet to wet well for isolation purposes			X		X	Addition of stop logs would allow inspection/cleaning of wet well.
METCO	FR-04	Modify existing triple-barrel discharge channel to eliminate pumping restrictions and increase transport capacity		X			X	METCO's analysis indicated existing conduit capacity limited due to shallow construction. Would allow more storm pumps to be run at Freud PS and help relieve sewers upstream of Freud PS and reduce HGL.
METCO	FR-05	Replace the three existing primary transformers and associated controls		X			X	Existing transformers beyond range of general life period.
METCO	FR-06	Upgrade existing lighting system			X	X		Lighting did not meet IES standards at time of METCO inspection (2014). Lighting appeared adequate during AECOM site visit (2021).
METCO	FR-07	Replace existing boilers, condensate pumps, associated piping and valves			X		X	Only one of two boilers operational; corrosion present on remaining boiler. No indication work was done.
METCO	FR-08	Replace existing heaters and ventilation fans			X		X	Current equipment was in poor condition. No indication work was done.

Report [1]	Rec. No.[2]	Recommendation	Area of Focus [3]			Completed		Comments
			Oper.	Phys.	O&M	Yes	No	
METCO	FR-09	Resurface existing driveway			X	X		Cracks noted in existing driveway. Appears to have been addressed, based on Google Earth imagery from 2015 to 2017.
METCO	FR-10	Modify existing stairs to comply with ADA			X		X	Not evaluated during site visit (2021).
METCO	FR-11	No change in pump operations	X			X		Per METCO, start/stop levels in storm wet well appear adequate.
METCO	FR-12	Revise Freud storm PS peak design flow to 2,200 cfs	X				X	METCO recommended installed capacity of 2,700 cfs (6 pumps at 450 cfs each), for N+1 firm capacity of 2,250 cfs.
METCO	FV-01	Keep Fairview PS running at dry weather levels during wet weather events	X			X		At the time of the 2014 events, the Fairview PS was generally shut off during peak wet weather conditions to provide additional capacity in the downstream DRI. METCO recommended allowing Fairview PS to maintain operation at dry weather flowrates to provide some relief to the upstream DRI and allow stormwater stored in the CSO basin / Connor Sewer to be effectively dewatered as quick as possible. Subsequent to this recommendation, MDEQ stated in a letter (August 16, 2016) that Fairview PS should continue to operate during wet weather events. Currently, this recommendation is implemented until the DRI is flowing eight-tenths full, when pumping is reduced to allow other flow inputs into the DRI.
METCO	CCE-01	Close Forebay regulator gates when DRI level reaches 0.8D	X			X		This is the current operating protocol of the VR-2 regulator gates.
METCO	CCE-02	Open Forebay in-system storage gates when water level in Forebay reaches elevation 95 ft, or when Forebay regulator gates close	X				X	The Connor Storage Gates are opened when either the upstream or downstream wastewater level reaches approximate elevation of 90 feet per the current operating protocol.
METCO	CSO-01	Lower CSO Basin effluent launder weir from elevation 98 ft to elev. 96 ft		X			X	Recommendation based on METCO analysis of river elevations; this would lower the HGL in the CCE and allow more flow out of the CSO basin. Adverse impacts would be expected for the high river levels that have been experienced recently.

Report [1]	Rec. No.[2]	Recommendation	Area of Focus [3]			Completed		Comments
			Oper.	Phys.	O&M	Yes	No	
								This would require extensive evaluation of the proposed operating protocol, expected performance, adverse impacts, and costs.
METCO	CSO-02	Open CSO Basin Emergency Relief Sluice Gates (ERGs) when basin level reaches elev. 96.5 ft (instead of elev. 98.5 ft)	X				X	In conjunction with Recommendation # CSO-01, this operational change would result in gates opening when basin water level is only 0.5 ft above effluent launder weirs. More captured sewage solids would be discharged to the Detroit River. This would require extensive evaluation of the proposed operating protocol, expected performance, adverse impacts, and costs.
GLWA	CSO-03	Revise staffing schedule at CSO basin to have personnel on-site 24/7	X			X		Implemented after event of July 8, 2016 and before event of 16 August 16, 2016
GLWA	CN-16	Station staff at Connors Creek PS prior to rain events	X			X		Implemented after event of July 8, 2016 and before event of 16 August 16, 2016
GLWA	FR-13	Station staff at Freud PS prior to rain events	X			X		Implemented after event of July 8, 2016 and before event of 16 August 16, 2016
GLWA	CSO-04	Revise CSO basin launder gate opening settings to be kept in open position through summer and fall storm season to improve early flow-through characteristics	X			X		Implemented after event of July 8, 2016 and before event of 16 August 16, 2016. Subsequent to the 2016 events, the launder gates were retrofitted to be remotely operated from both the Connors Creek CSO Basin and the SCC. These improvements eliminated the need to maintain the launder gates in an open position.
GLWA	CSO-05	Revise CSO influent gate settings to be normally open at all times to prevent delays in opening during events	X			X		Implemented after event of July 8, 2016 and before event of August 16, 2016. Current operational protocol is to leave influent gates open at all times.
GLWA	CSO-06	Revise CSO emergency relief gate operations so that one gate per CSO bay (4 gates out of total of 16) are unlocked and can be opened locally without a key to provide more rapid response when opening	X			X		Implemented after event of July 8, 2016 and before event of August 16, 2016. Currently, GLWA maintains all emergency relief gates in an unchained and unlocked condition. Subsequent to the 2016 events, the emergency gates were

Report [1]	Rec. No.[2]	Recommendation	Area of Focus [3]			Completed		Comments
			Oper.	Phys.	O&M	Yes	No	
								retrofitted to be remotely operated from both the Connors Creek CSO Basin and the SCC.
GLWA	FV-02	Revise operational procedure to continue pumping operations during storms	X			X		Implemented after event of August 16,2016 (same as METCO Rec. No. FV-01). This recommendation is implemented until the DRI is flowing 8/10th full, when pumping is scaled back.
GLWA	FR-14	Repair two out-of-service storm pumps at Freud PS	X			X		Implemented after event of July 8, 2016 and before event of August 16, 2016.
GLWA	GEN-01	Inspect interceptor sewers and major trunk sewers for obstructions, structural defects, and sediment accumulation	X			X		Currently being done under Capital Project programs CIP 222002, CIP 260204 (among others)
GLWA	CN-17	Evaluate and recommend modifications to vacuum priming system to improve reliability & operability of storm pumps	X	X		X		Implemented after event of 8 July 8, 2016 and before event of August 16, 2016. Changes implemented included construction of new weir in Connors Creek PS discharge channel; reestablished a 7-foot conduit connecting the Connor Sewer to the Connors Creek PS discharge channel upstream of the weir and automated the 7-foot sluice gate for local and remote operation by the SCC. These changes allow water to partially fill the siphon block, so that the vacuum priming system can function.
GLWA	CN-18	Permanent modifications to vacuum priming system to improve reliable operability		X		X		Longer-term modifications are being addressed through current capital project, CIP# 232002.
GLWA	GEN-02	Additional system analysis including updating/refining models to evaluate short-term and long-term system relief options.	X			X		CDM Smith and ASI updated the PCSWMM computer model under the WWMP and developed and evaluated sewer separation projects. ASI prepared a further update for this study (2021). It is unlikely that the model is used to determine operational response/readiness in advance of specific storms. Should be revisited in Phase 2 specifically for desired levels of service.
GLWA	CSO-07	Repair/replace instrumentation and controls to allow remote operation of influent basin gates,		X		X		Connors Creek CSO basin gates can now be remotely operated through the SCADA system.

Report [1]	Rec. No.[2]	Recommendation	Area of Focus [3] Oper.	Phys.	O&M	Completed Yes	No	Comments
		launder gates and emergency relief gates from SCC.						
GLWA	CSO-08	Add separate UPS to instrumentation / controls system to provide operability in case of power failure at CSO facility		X		X		An uninterruptible power supply has been installed.
GLWA	GEN-03	Install additional monitoring equipment to system including additional level sensors and flowmeters		X		X	X	Flowmeters have been installed in the Connors Creek Enclosure upstream of the Connors Creek CSO basin. Flowmeters were installed on the influent conduits of the Freud PS. Additional locations (if needed) can be determined in Phase 2 based on desired levels of service.
GLWA	CN-19	Modify weir in Connors Creek PS discharge channel to provide sufficient depth of water to enable vacuum priming system to operate		X		X		(Same as METCO Rec. No. CN-15) A new, higher weir was installed in the Connors Creek discharge channel.
GLWA	FCR-01	Investigate option of throttling the regulator gates at the Fox Creek Regulator to limit flow into East Jefferson Relief Sewer and relieve downstream system	X				X	Staff interviews suggest this is a known issue, but unclear whether this is a routine/documented operational response. Suzanne Coffey recommended Todd King inspect Fox Creek Enclosure. This measure would require extensive development and evaluation of concepts, expected performance, adverse impacts, and costs.
GLWA	CN-20	Evaluate overall Connors Creek Storm PS (e.g., pumps, vacuum priming system, transformers) for rehabilitation or replacement	X			X		Current capital project, in design phase. Start of construction is anticipated to be in 2023.
GLWA	FR-15	Evaluate overall Freud Storm PS (e.g., pumps, vacuum priming system, transformers) for rehabilitation or replacement	X			X		Current capital project, in design phase. Start of construction is anticipated to be in 2022.
GLWA	GEN-04	Evaluate feasibility of restoring emergency overflow capabilities at Connors Creek and Freud Storm PSs and Connor Creek Enclosure	X				X	The historic overflows from the original Connors Creek and Freud PS and Connors Creek Enclosure were eliminated when the CSO Basin was constructed. This could provide system relief during emergency conditions. The historic overflows no longer exist and would require extensive construction.

Report [1]	Rec. No.[2]	Recommendation	Area of Focus [3]			Completed		Comments
			Oper.	Phys.	O&M	Yes	No	
								This measure is being reviewed as part of the design process for the new Connors Creek PS and improvements to the Freud PS.
OHM	GEN-05	Install additional flowmeters / level sensors with alarms farther upstream in sewer system to provide operators greater time to react to higher flows		X			X	General suggestion/presentation of concept, no specific location recommended. Locations can be determined in Phase 2 based on desired levels of service.
OHM	GEN-06	Update and calibrate existing sewer system computer model	X			X		CDM Smith and ASI updated the PCSWMM computer model under the WWMP and developed and evaluated sewer separation projects. ASI prepared a further update for this study (2021). It is unlikely that the model is used to determine operational response/readiness in advance of specific storms. Should be revisited in Phase 2 specifically for desired levels of service.
OHM	CCE-03	Modify one barrel of Connors Creek Enclosure to convey only stormwater (not combined sewage), and route that flow directly to river (i.e., partial sewer separation)	X	X			X	General suggestion/presentation of concept, not specific recommendation. This measure would require extensive development and evaluation of concepts, expected performance, adverse impacts, and costs.
OHM	GEN-07	Increased use of stormwater BMPs in upstream portions of sewershed (e.g., detention in ponds, temporary detention or on roadways, use of flow restrictors upstream) to reduce peak flows in downstream part of system.	X	X		X		General suggestion/presentation of concept, not specific recommendation. Implementation of Green Stormwater Infrastructure has occurred and is continuing to be implemented in Detroit as a result of new ordinances and DWSD drainage charges.
OHM	GEN-08	Use of dynamic controls to restrict /hold back flow from some areas for short periods of time	X	X			X	General suggestion/presentation of concept, not specific recommendation This measure would require extensive development and evaluation of concepts, expected performance, adverse impacts, and costs.
OHM	GEN-09	Install damage reduction measures (e.g., anti-backwater valves) on residential sanitary connections to prevent basement flooding in individual buildings		X			X	To be determined in Phase 2 with consultation with member communities.

Report [1]	Rec. No.[2]	Recommendation	Area of Focus [3]			Completed		Comments
			Oper.	Phys.	O&M	Yes	No	
OHM	GEN-10	Create targeted emergency text alert system (similar to police alerts) to directly notify residents/business owners of potential for sewer backup conditions and to take precautionary measures.	X	X			X	To be determined in Phase 2 with consultation with member communities.

Notes:
ADA = Americans with Disabilities Act
AECOM = AECOM Technical Services, Inc.
ASI = Applied Science, Inc.
cfs = cubic feet per second
CIP = Classification of Instructional Program
CSO = combined sewer overflow
DRI = Detroit River Interceptor
DWSD = Detroit Water and Sewerage Department
ft = foot/feet
HGL = Hydraulic Grade Line
IES = Illuminating Engineering Society
MDEQ = Michigan Department of Environmental Quality (
PS = Pumping Station
SCADA = SCADA = supervisory control and data acquisition
SOP = Standard Operating Procedure
SCC = Systems Control Center
UPS = uninterruptable power supply
[1]Refers to primary report author noted above
[2]Recommendation numbers added here for convenience, with following codes to denote specific facilities:
BH = Bluehill PS
CCE = Connors Creek Enclosure (sewer)
CN = Connors Creek Storm PS
CSO = Connors Creek CSO Basin
FR = Freud Storm Pump Station
FV = Fairview Pump Station
GEN = General system[3]Type of recommendations:
Oper. = operational change to enhance capabilities / response during storm events
Phys. = physical change / modification to provide modified or new functionality during storm events
O&M = operations and maintenance; routine asset management activities, some of which would improve working conditions / response capabilities for operations staff during storm events

A3 – Regional Wastewater Conveyance System

A3.1 – Regional System Overview

The GLWA provides wastewater collection and treatment services to 79 communities in southeast Michigan. The GLWA service area covers communities in Wayne, Oakland, and Macomb counties as shown in Figure 35.

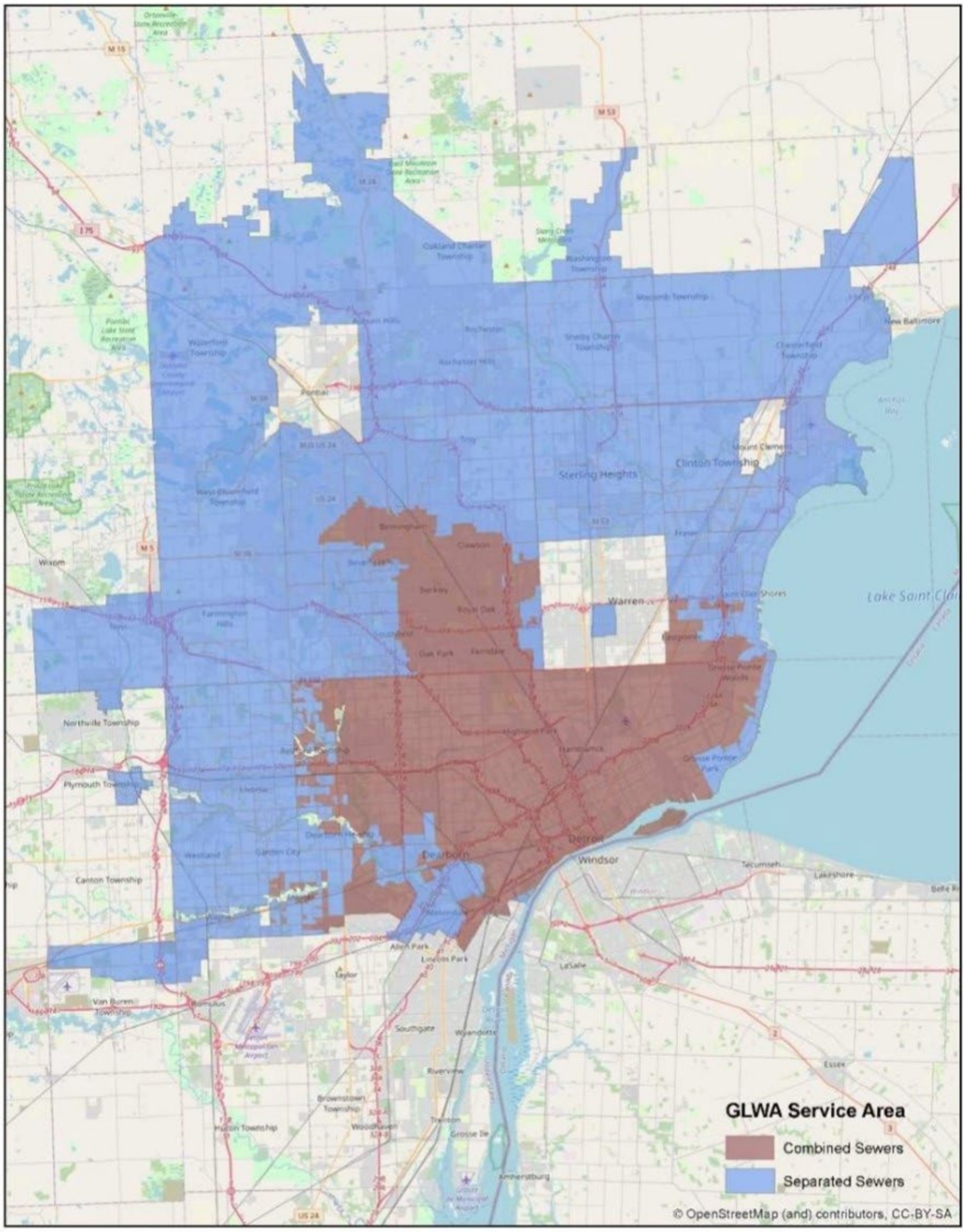


Figure 35: GLWA Wastewater Service Area

The city of Detroit is served by combined sewers, as are the communities of Hamtramck and Highland Park. Most of the Southeast Oakland Sanitary District (currently known as the GWK Drain Drainage District) is served by combined sewers. Also, parts of the Evergreen-Farmington Sanitary District, Dearborn, Grosse Pointe, Grosse Pointe Farms, the Rouge Valley Sewage Disposal System, and

SEMSD are served by combined sewers as shown. There are uncontrolled CSO outfalls in Detroit, Dearborn, Dearborn Heights, Inkster, and Redford in the GLWA service area.

Details of the wastewater conveyance systems for these communities are described below.

A3.2 – Local Wastewater Conveyance Systems

City of Detroit (DWSD)

All discharges from DWSD to the East Side System are from combined sewers with no regulated inflows or alternate discharge points. Most of the DWSD discharges are conveyed directly to the Connors Creek and Freud PS through various DWSD and GLWA-operated relief sewers and interceptors. Areas near and within the Fox Creek District discharge to the Bluehill PS via the Rivard/Marseilles Sewer. The Rivard/Marseilles Sewer is the large intercepting sewer tributary to the Bluehill PS. There are several "arms" that branch off the main interceptor. Most notably the Mack Avenue Arm, the Linville Arm, Harper Avenue Arm, and Outer Drive Arm. DWSD is the only tributary system to the Bluehill PS during wet weather.

City of Grosse Pointe Park

The City of Grosse Pointe Park has a separate storm sewer system and only sends sanitary flows to the GLWA system. The sanitary flows are pumped directly into the DRI to the Fairview PS. The city has a contract limit with GLWA to limit discharges to the DRI to 84 cfs.

City of Grosse Pointe

The City of Grosse Pointe has an "inland" combined sewer district with the remaining portions of the city having separate sewer systems. Combined sewer and sanitary sewer flows are pumped into the Wayne County Fox Creek Enclosure, which in turn drains to the Connors Creek and Freud PS. The city has a contract limit with GLWA to limit discharges to the Wayne County Fox Creek Enclosure to 192 cfs and does not have any existing combined sewer storage or outfall facilities.

City of Grosse Pointe Farms

The City of Grosse Pointe Farms also has an "inland" combined sewer district with the remaining portions of the city having separate sewer systems. Combined sewer and sanitary sewer flows are pumped into the Wayne County Fox Creek Enclosure, which in turn drains to the Connors Creek and Freud PS. The City has a contract limit with GLWA to limit discharges to the Wayne County Fox Creek Enclosure to 554 cfs and does not have any existing combined sewer storage or outfall facilities.

City of Grosse Pointe Shores

The City of Grosse Pointe Shores has a separate storm sewer system and only sends sanitary flows to the SEMSD system. The sanitary flows are pumped into the Grosse Pointe Interceptor which is upstream of the Fox Creek Enclosure, Connors Creek and Freud PS. The City does not have a contract limit with GLWA.

Milk River Intercounty Drain Drainage District

The MRIDDD includes the cities of Grosse Pointe Woods and Harper Woods, both of which have combined sewers. The MRIDDD pumps combined sewer flows into the Grosse Pointe Interceptor which is upstream of the Fox Creek Enclosure, Connors Creek, and Freud PS. The MRIDDD has a contract limit with SEMSD to limit discharges to the Grosse Pointe Interceptor to 22 cfs. MRIDDD also has a RTB that can discharge to Lake St. Clair via the Milk River. MRIDDD sewers and facilities are operated by SEMSD.

The City of Grosse Pointe Woods has installed catch basin inlet restrictors to limit the amount of storm flow that enters the combined sewer system. The restrictors work well to flood the streets, for short durations, during high intensity storms to reduce the amount of basement backups.

Southeast Macomb Sanitary District

SEMSD includes the cities of St. Clair Shores, Eastpointe, and Roseville and are served by both sanitary and combined sewers. SEMSD also acquired the assets of the Wayne County Northeast Sewage Disposal System and MRIDDD and Grosse Pointe Shores are customers of SEMSD. SEMSD pumps flow into the Grosse Pointe Interceptor which is upstream of the Wayne County Fox Creek Enclosure, and the GLWA Connors Creek and Freud PS. SEMSD has a contract limit with GLWA to limit discharges to the Fox Creek Enclosure to 127 cfs. The Macomb County Public Works Office operates, on behalf of SEMSD, two CSO facilities (Martin and Chapaton) that can discharge to Lake St. Clair.

Issues with the conveyance system can manifest themselves in several ways; however, two are described below:

Street Flooding

Street flooding may be caused by inadequate inlet capacity of the local storm system; the capacity of the local storm pipes; or the capacity of downstream trunk sewers or facilities necessary to convey the storm flow from the tributary area.

During high intensity rainfall, street flooding has reportedly been the result of insufficient inlet capacity at the catch basins. Catch basins that are blocked with debris or intentionally limiting the inflow can result in street flooding when the rainfall intensity surpasses the catch basin capacity. Street flooding can also occur when there is a bottleneck downstream, and the upstream flow exceeds the sewer capacity. In this case, flow may exit the sewer from the maintenance holes along the sewer line. When street flooding occurs due to bottlenecks in the trunk sewer, basement flooding may also occur if the trunk sewer backs up into hydraulically connected sanitary laterals.

Basement Backups

Basement backups occur for a range of reasons including: blockages, collapses, and overloading of house leads, sanitary laterals, and downstream combined sewers; and/or backwater from downstream PS/CSO outfalls. In Detroit and the older suburban areas with homes predominately built prior to about 1970, the downspouts and footing drains were connected to the sanitary/combined sewer system that existed at the time. State law now requires the disconnection of downspouts in combined systems.

Many local collection systems consist of sanitary laterals that discharge flow behind residences and discharge flow to a combined system at the street. In these systems, basement backups can occur when the combined system becomes surcharged either locally or due to a downstream constraint. The water can enter the basement through floor drains, sinks, or toilets that are not protected by a check valve (backflow prevention valve). If the sanitary system is completely separated, basement backups can also occur during wet weather when significant infiltration or storm inflow from either an illicit or accidental tie-in is present, but these are generally considered to be less frequent and more easily managed.

A3.2.1 – East Side Conveyance Details

A detailed schematic of the east side Detroit facilities is shown in Figure 36. The east side PSs include the Connors Creek, Freud, Bluehill, and Fairview PSs. The service areas include the SEMSD, the east side of Detroit, Grosse Pointe Park, Grosse Pointe City, and Grosse Pointe Farms. The East Jefferson District of Detroit includes the Jefferson-Chalmers neighborhood. The Fox Creek District of Detroit includes the Cornerstone neighborhood that is tributary to the Bluehill PS.

[redacted]

Figure 36: East Side Conveyance System Schematic

During dry weather, the DRI conveys wastewater flows from the East Side to the Fairview PS. The Fairview PS lifts the wastewater and discharges into the downstream DRI which flows by gravity to the raw wastewater pumps at the GLWA WRRF. The DRI receives flows from the Connors Creek PS, the Connors Creek Enclosure, the Alter sewer and the Grosse Pointe Park PS.

The Connors Creek PS receives flows from the East Jefferson Relief sewer that runs in Jefferson Avenue to the east and west of the Connors Creek PS. The East Jefferson Relief sewer is larger and deeper than the DRI and receives flows from the following:

- The Fox Creek Enclosure
- The Ashland sewer
- The sanitary pumps at the Freud PS through the Tennessee sewer
- The dewatering pumps at the Connors Creek CSO Basin through the Lycaste sewer
- The Fox Creek Relief sewer
- Other DWSD trunk sewers in the East Side

The Bluehill PS discharges into the Cadieux sewer that flows into the Fox Creek Relief sewer. The Freud PS receives a very small dry weather flow rate from the Ashland Relief and Fox Creek Relief sewers. The Fox Creek Enclosure receives flows from three PSs: the Kerby Road PS operated by SEMSD; the Grosse Pointe Farms PS at Kerby Road; and the Grosse Pointe PS at Neff Road.

During wet weather, the storm pumps at the Connors Creek and Freud PSs operate and discharge wet weather flow rates into the Connor Creek CSO Basin and the Connors Creek Enclosure. Also, the storm pumps operate at the Bluehill PS and discharge into the Mack Avenue Relief sewer and the Cadieux/Fox Creek Relief sewers. These wet weather flow rates run toward the Connors Creek PS, but may overflow a weir and through portholes along the East Jefferson Relief sewer and flow toward the Freud PS. Therefore, the Connors Creek and Freud PSs wet wells are hydraulically connected and in-common when the wet well levels exceed elevation 68 feet.

The Connors Creek CSO Basin has about 28 MG of storage volume and there is significant in-system storage in the Connors Creek Enclosure and in the large combined sewers tributary to the Connors Creek and Freud PS. After wet weather recedes, the stored wastewater is dewatered through the DRI, the Connors Creek PS, and the Fairview PS.

The pumping rates are reduced, sometimes to zero, at the Fairview PS when the downstream DRI level at Meters DT-S-8 and DT-S-12 exceeds about the eight-tenths point. This is part of the Interim Wet Weather Operating Plan and is done to allow the downstream trunk sewers to use the DRI capacity and minimize untreated CSO. When this occurs, the sanitary pumps at the Connors Creek, Freud, and Bluehill PSs also are turned off.

Wastewater is discharged through the Connors Creek CSO Basin for larger wet weather events after the CSO Basin and in-system storage is full. The discharges occur to the Connors Creek canal and onto the Detroit River. The Connors Creek CSO Retention Basin has a 3,788-foot weir with a crest level of 98 feet and a capacity of about 4,100 cfs. There are effluent launder gates (ELGs) that are opened to activate the weir and allow overflow. For discharge flow rates greater than 4,100 cfs, emergency relief gates (ERGs) are opened that allow higher flow rates with a maximum wastewater level of about 99 feet in the CSO Basin. When this occurs, the settled solids in the CSO Basin are discharged and only screening, skimming and disinfection of the effluent is provided. There are 16 ERGs that each are 9-foot high by 12-foot wide sluice gates. The peak design flow rate of the CSO Basin is about 13,963 cfs.

The Fox Creek Enclosure and the Ashland sewer combine just upstream of the Fox Creek regulator chamber near Ashland Street and Jefferson Avenue. There are three regulator openings with normally fully open sluice gates that can restrict the flow rates from the regulator chamber into the East Jefferson Relief sewer. The flow rates into the East Jefferson Relief sewer also may be limited by high wastewater levels in the East Jefferson Relief sewer caused by high wet well levels at the Connors Creek and

Freud PSs. Reverse flow from the East Jefferson Relief sewer into the regulator chamber also is possible if the wastewater levels are excessively high in the East Jefferson Relief sewer. There is a gravity outfall to the Fox Creek canal at the Fox Creek regulator chamber with backwater gates. The canal runs for over 6,900 feet to the Detroit River near Windmill Pointe. Flow from the Fox Creek regulator chamber can occur through the backwater gates if the wastewater level in the regulator chamber exceeds that of the water in the canal. If reverse flow occurs from the East Jefferson Relief sewer to the Fox Creek regulator chamber due to high Connors Creek and Freud PS wet well levels, street flooding in low-lying areas of Detroit and Grosse Pointe Park from overflowing manholes can occur.

In Grosse Pointe Woods (a combined sewer area that is part of the Milk River Intercounty Drain Drainage District), restrictive catch basin inlets are being used to limit peak flow rates in the combined sewer system and raise the level of service. Few water in basement reports occurred for Grosse Pointe Woods during the June 25/26 Rainfall Event. This solution will not protect against all flooding as this area did experience extensive street flooding and there were a few cases of basement flooding due to catch basin clogging resulting in property flooding. However, during extreme storm events provides protection against basement backups.

Other communities could implement restrictive inlets to reduce the peak flow. If the City of Detroit implemented inlet flow restrictions, many considerations must be weighed. First, the cost of implementing this type of flow restriction would require additional capital and maintenance costs. The city would need to replace a large number of inlets and clean them regularly. This would require additional employees to maintain these structures. In addition, making use of the streets to store wet weather flows might substantially reduce basement flooding but could also increase the number of flooded cars and damage.

A3.3 – Pumping Stations

A3.3.1 – Connors Creek PS (GLWA)

The Connors Creek PS receives combined sewage from the East Jefferson Relief Sewer. Dry weather flow is pumped via four sanitary pumps to the DRI Wet weather flow is pumped via eight storm pumps to the Connors Creek CSO Control Facility. The stormwater PS was constructed in 1929; the sanitary PS was added in around 1960.

The storm pumps (numbered 1 to 8) are vertically mounted bottom-suction centrifugal solids handling pumps, driven by constant speed synchronous electric motors. Each storm pump is rated by the manufacturer at 500 cfs but it is estimated that they operate at about 80 percent of their rated capacity. The centerline of the pumps (elevation 87.6 feet) is generally above the water level in the storm wet well. Starting the pumps requires opening the 7-foot sluice gate to flood the discharge syphon blocks and then priming from vacuum priming systems.

There are eight vacuum priming pumps; each was originally married to a single stormwater pump at the time of original pump installation. In 2004, a newer, more complex vacuum priming system was installed in that interconnected the vacuum priming systems of the storm pumps and allow for flexibility of priming more than one stormwater pump for each vacuum priming system. However, after the 2016 storm, the vacuum priming systems were set by valving to be dedicated to a single storm pump to alleviate operational complexity. Operators generally match one vacuum priming pump to one stormwater pump.

The stormwater pumps provide lift to syphon and the discharged stormwater then flows by gravity to the Connors Creek CSO control facility. The stormwater pumps are rarely operated and generally have low run times (the last impeller rehabilitation was in 1987). Based upon operator interviews, storm pumps 3, 5, and 8 are most frequently used due to being easier to prime and initiate operation.

The sanitary pumps (numbered 9 to 12) are also vertically mounted bottom-suction centrifugal solids handling pumps, driven by electric motors, with capacities ranging from approximately 40 to 110 cfs each. The sanitary pumps have flooded suction inlets that do not require vacuum priming.

Electrical power at the Connors Creek PS is provided via two separate DTE 24kV trunk line utility services to provide a level of utility redundancy, as shown schematically in Figure 37. The two DTE services power two primary transformers; each transformer is sized to power four of the eight storm pumps. Therefore, the capacity of the primary transformers prevents full redundancy to power all storm pumps from a single transformer. The two services allow the station to operate at half capacity if one transformer is down (and the emergency generators are not running or are not connected to the downed service).

Four emergency generators are connected to one utility service. The generators are not configured to power both primary transformers; only transformer 2. The emergency generators start automatically during a utility power outage to transformer 2 and are sized to power a maximum of two storm pumps. Therefore, if power is lost to transformer 1, the generators will not automatically start and cannot power additional pumps over the capacity of the transformer 2, even if the generators are started manually because they do not have synchronizing equipment to allow both generators and utility to power bus no. 2.

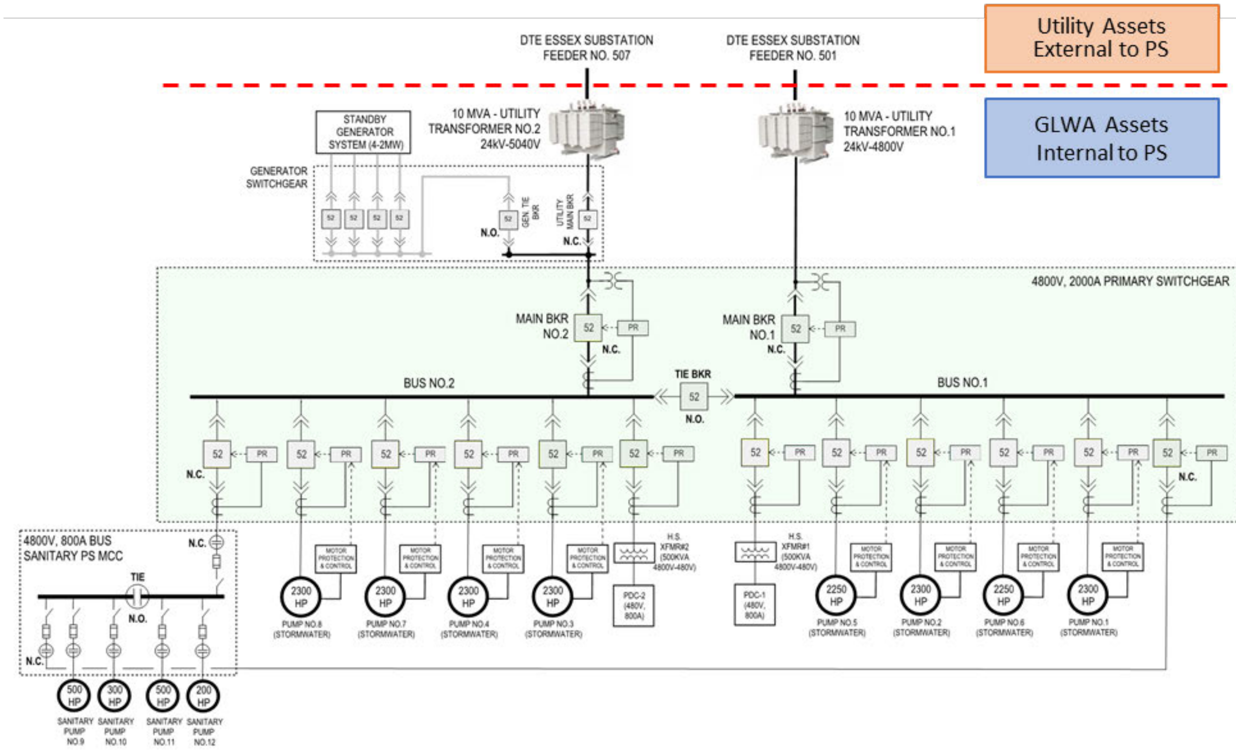


Figure 37: Connors Creek PS Electrical Single Line Diagram

The operational readiness of the stormwater pumps with different scenarios of transformer/utility and generator system availability is shown in Figure 38.

Scenarios No.	Description	Transformer No.1	Transformer No.2	Generator System	Maximum Storm Pumps That Can Be Operated
1	Two transformers are powered ON (Generator not Needed)	✓	✓	Not Needed	All Pumps
2	Only transformer 1 is powered ON (Generator Offline)	✓	✗	✗	4
3	Only transformer 1 is powered ON (Generator Online)	✓	✗	✓	6
4	Only transformer 2 is powered ON	✗	✓	N/A	4
5	Two transformers are powered OFF (Generator Online)	✗	✗	✓	2

Notes:
1. *Each transformer is sized at 10 MVA.*
2. *Generator system consists of four 2 MW units.*
3. *Each single transformer can only run a maximum of four storm pumps.*
4. *The generator system configured and connected to only backup the loss of transformer 2.*
5. *The generator system can only run a maximum of two storm pumps.*

Legend: ✓ *Powered ON* ✗ *Powered OFF*

Figure 38: Connors Creek PS Electrical Power Failure / Operational Scenarios

Under normal conditions the station is operated remotely by the operators at the SCC. During storms that are forecasted to have at least 1.5 inches of rain over a 24-hour period, GLWA operators are scheduled to be on site and local manual operation is performed.

A3.3.2 – Freud PS (GLWA)

The Freud PS receives combined sewage from the Ashland and Fox Creek relief sewers. Dry weather flow is pumped via two sanitary pumps to the East Jefferson Relief Sewer and then delivered to the Connors Creek PS. Wet weather flow is pumped via eight storm pumps to the Connors Creek CSO Control Facility. The Freud PS also receives overflow from the East Jefferson Relief Sewer when the Connors Creek PS wet well is above about elevation 68 feet. As such, Connors Creek and Freud PSs wet wells are hydraulically connected when the wet wells are higher than about elevation 68 feet.

The Freud PS was constructed in the 1950s to work together with the Connors Creek PS and supply additional wet weather pumping capacity. The storm pumps are vertically mounted bottom-suction centrifugal solids handling pumps, driven by constant speed synchronous electric motors. Each storm pump can deliver approximately 450 cfs.

At the time of the June/July 2021 Rainfall Events, electrical power at the Freud PS was provided via two separate 24kV PLD utility services to provide a level of utility redundancy, shown schematically in Figure 39. The station has three GLWA primary transformers, each sized to power three of the eight storm pumps. Therefore, the capacity of the primary transformers prevents full redundancy to power all storm pumps. Primary transformers 1 and 3 are powered from one PLD service and primary transformer 2 is powered from the other PLD service. Because two transformers are connected to a single service (as further discussed below) a single service outage can bring down two-thirds of the PS's transformers.

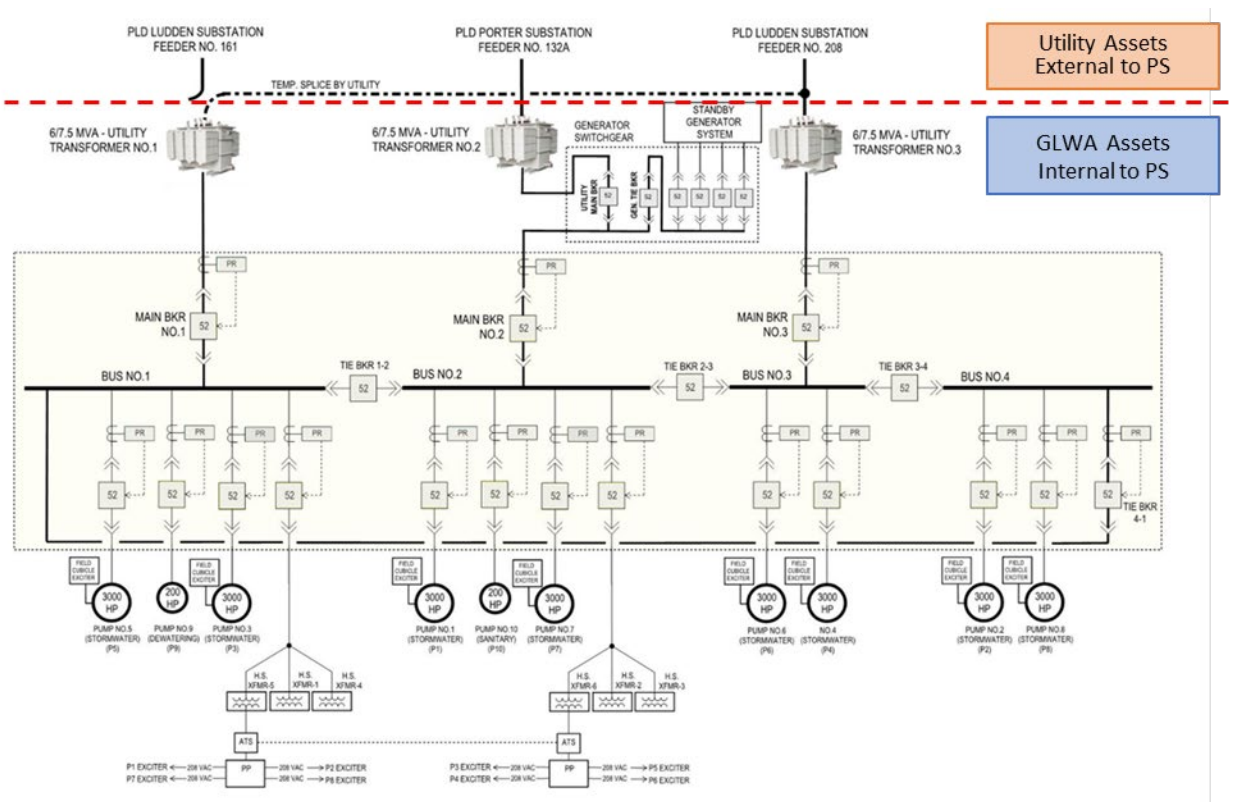


Figure 39: Freud PS Electrical Single Line Diagram

Four emergency generators are connected to PLD utility service #2, which is the service feeding primary transformer 2. The generators are not configured to power primary transformers 1 and 3. The emergency generators start automatically during a power outage of PLD service #2 or its associated primary transformer.

The operational readiness of the Freud PS stormwater pumps with different scenarios of utility/transformer and generator system availability is shown in Figure 41.

Scenarios No.	Scenarios Description	Transformer No.1	Transformer No.2	Transformer No.3	Generator System	Maximum Storm Pumps That Can Be Operated
1	Three transformers are powered ON (Generator not Needed)	✓	✓	✓	Not Needed	7
2	Only transformers 1 & 2 are powered ON	✓	✓	✗	N/A	6
3	Only transformers 2 & 3 are powered ON	✗	✓	✓	N/A	6
4	Only transformers 1 & 3 are powered ON (Generator Offline)	✓	✗	✓	✗	6
5	Only transformers 1 & 3 are powered ON (Generator Online)	✓	✗	✓	✓	7
6	Only transformer 1 is powered ON (Generator Offline)	✓	✗	✗	✗	3
7	Only transformer 1 is powered ON (Generator Online)	✓	✗	✗	✓	5
8	Only transformer 2 is powered ON (Generator Not Applicable)	✗	✓	✗	N/A	3
9	Only transformer 3 is powered ON (Generator Offline)	✗	✗	✓	✗	3
10	Only transformer 3 is powered ON (Generator Online)	✗	✗	✓	✓	5
11	Three transformers are powered OFF (Generator Online)	✗	✗	✗	✓	2

Notes:
1. *Each transformer is sized at 6 MVA (air-cooled mode) /7.5 MVA (fan-cooled mode).*
2. *Generator system consists of four 2281 kW units.*
3. *Each single transformer can only run a maximum of three storm pumps (with the transformer running in the fan cooled mode).*
4. *The generator system configured and connected to only backup the loss of transformer 2.*
5. *The generator system can only run a maximum of two storm pumps.*

Legend: ✓ *Powered ON* ✗ *Powered OFF*

Figure 40: Freud PS Electrical Power Failure / Operating Scenarios

Historically, the PLD and associated primary transformers also have a power quality issue that affects operational readiness. As shown in Figure 41, the voltage drop when one pump is operational is about 7 percent and 11 percent when two pumps are operational on the same transformer. The voltage drop with three pumps operating from one transformer will be even higher. To prevent motors from faulting on low voltage during starting, the transformer tap settings are set to about 4600 volts, well above the 4160-volt nominal rating. The 4670 volts (12 percent above the nominal 4160 volts) on two of the transformers (Figure 7) when no storm pumps are operational is well above the +/-10 percent expected from the utility. Any higher voltage will cause the switchgear breakers to trip. Even with the high voltage prior to pump starting, a third pump powered from a transformer may trip on low voltage and may not be available.

Construction was completed for the transfer of utility services from PLD to DTE in 2022. The DTE services are from three separate DTE transformers that are powered from three independent 120kV feeds in the DTE Essex Substation. Therefore, the issue with the present PLD service creating a power outage for two primary transformers as a result of a single utility service outage (as occurred during the June 25/26 Rainfall Event) has been rectified. However, the issue of not being able to provide power via emergency generators to any of the three primary transformer loads remains.

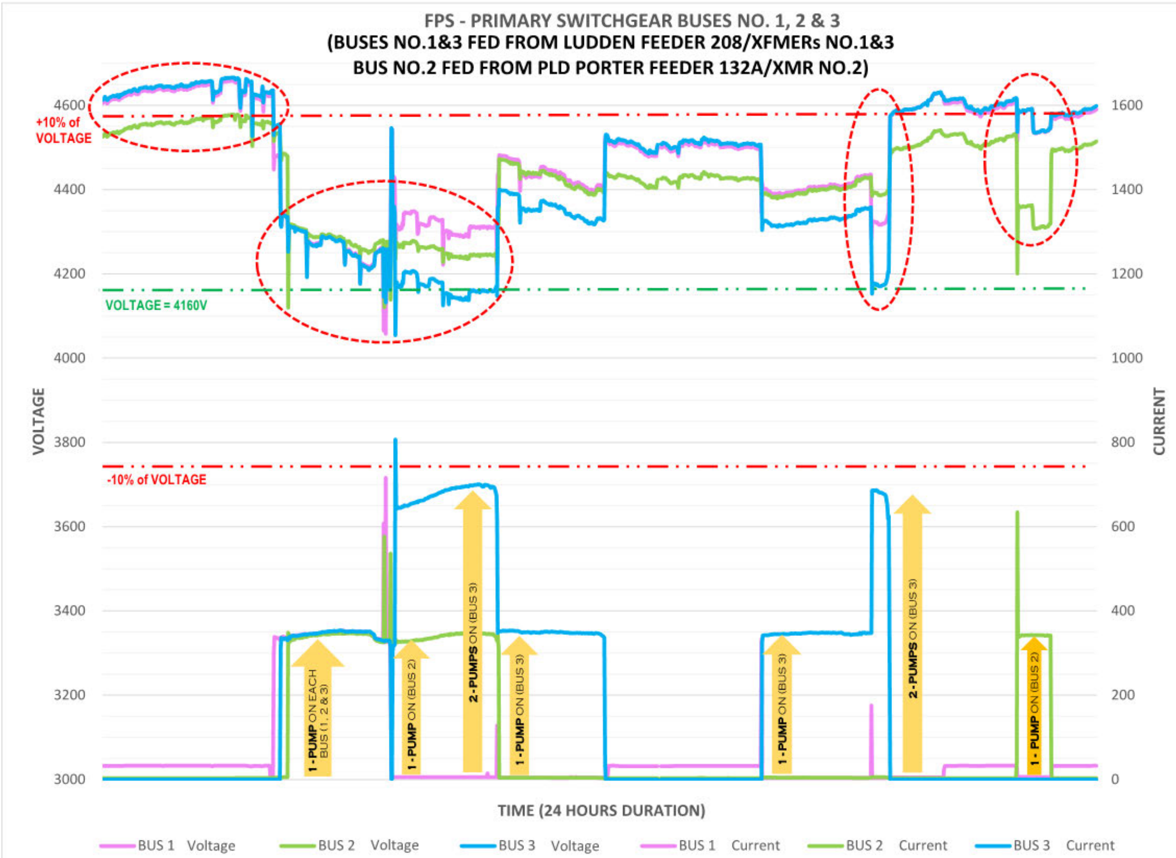


Figure 41: Freud Power Quality Issues – Primary Switchgear Buses Voltage and Current

Like the Connors Creek PS, under normal conditions the Freud PS is operated remotely by the operators at the SCC. During storms that are forecasted to have at least 1.5 inches of rain over a 24-hour period, the operators are scheduled to be on site and local manual operation is performed.

A3.3.3 – Blue Hill PS (DWSD)

The Bluehill PS is a local system PS, but it is operated and maintained by GLWA. The Bluehill PS receives combined sewage from the Rivard/Marseilles sewer. Dry weather flow is pumped via two sanitary pumps to the Cadieux Sewer, then delivered to the Fox Creek Relief sewer, and finally to the East Jefferson relief sewer and Connors Creek PS. Wet weather flow is pumped via four storm pumps to the Fox Creek Relief and Mack Avenue relief sewers.

Under normal conditions, the PS is operated remotely by the operators at the SCC. Operators visit the PS to perform routine preventive maintenance duties. During storm events, staff operators are dispatched if the automated systems indicate a fault at the PS.

The storm pumps are vertically mounted bottom-suction centrifugal solids handling pumps. Three of the pumps are driven by constant speed synchronous motors with a rated capacity of 387 cfs; one is a variable speed pump with a maximum rated capacity of 177 cfs. According to the current O&M manual, hydraulic restrictions downstream of the PS limit operation to only three of four pumps. However, operating records indicate that four pumps have been operated simultaneously on occasion. A detailed hydraulic assessment of the Bluehill PS could verify downstream restrictions and potentially identify ways to enable all pumps to operate.

Electrical power at the Bluehill PS is provided via two separate 24kV utility services from PLD's distribution system to provide a level of utility redundancy. The PS has two primary transformers, each sized to power any three of the four storm pumps. Therefore, the primary transformers do not provide for full redundancy of each primary. One of the power sources is backed up by three 1,825 kW emergency generators (Figure 42). There are no provisions to connect the emergency generators to back up utility service 2.

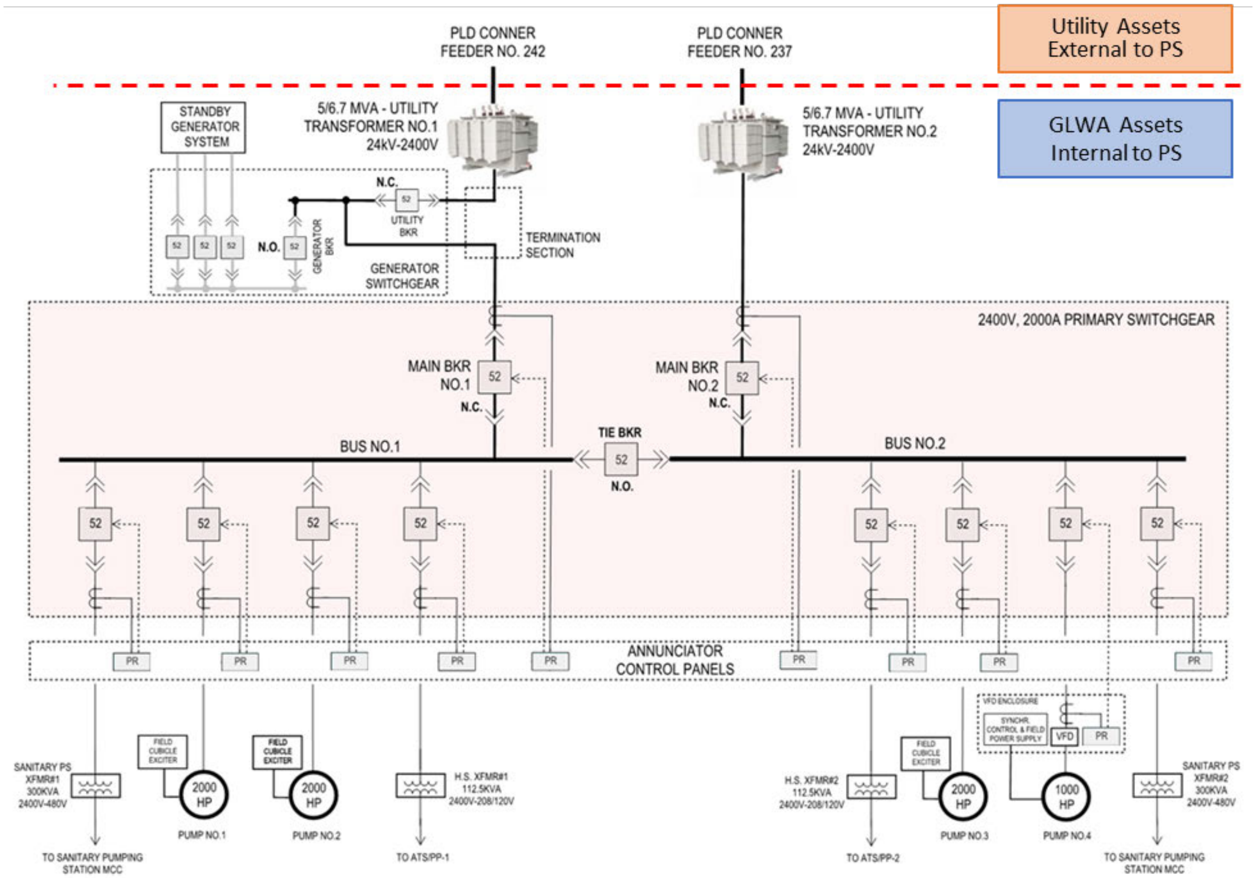


Figure 42: Bluehill PS Electrical Single Line Diagram

The operational readiness of the stormwater pumps with different scenarios of utility/transformer and generator system availability is shown in Figure 43.

Scenarios No.	Description	Transformer No.1	Transformer No.2	Generator System	Maximum Storm Pumps That Can Be Operated
1	Two transformers are powered ON (Generator not Needed)	✓	✓	Not Needed	All pumps
2	Only transformer 1 is powered ON	✓	✗	N/A	3
3	Only transformer 2 is powered ON (Generator Offline)	✗	✓	✗	3
4	Only transformer 2 is powered ON (Generator Online)	✗	✓	✓	All pumps
5	Two transformers are powered OFF (Generator Online)	✗	✗	✓	2

Notes:
1. *Each transformer is sized at 5 MVA (air-cooled mode) /6.7 MVA (fan-cooled mode).*
2. *Generator system consists of three 2281 kW units.*
3. *Each single transformer can only run a maximum of three storm pumps.*
4. *The generator system configured and connected to only backup the loss of transformer 1.*
5. *The generator system can only run a maximum of two storm pumps.*
6. *O&M manual advises that hydraulic restrictions limit maximum storm pumps that can be operated to 3, but this investigation did not confirm these restrictions.*

Legend: ✓ *Powered ON* ✗ *Powered OFF*

Figure 43: Bluehill PS Electrical Power Failure / Operating Scenarios

The PLD and associated primary transformers also have a power quality issue that affects operational readiness. As shown in Figure 44, the voltage with no pumps operating varies from 2500 volts to 2600 volts for one 24-hour period, which is significantly higher than the 2400 volt rated equipment. High voltage will cause the main switchgear breakers to trip causing a loss of pump capacity. Voltages varying more than 10 percent of design would cause a pump not to start. One of the power sources is backed up by three 1,825 kW emergency generators as occurred during the July 16, 2021 incident that tripped the main breaker #2 on high voltage. The primary transformers have taps on the primary windings that can be adjusted to increase or reduce voltage; however both, transformers have their taps at the lowest voltage adjustment.

Construction was completed for the transfer of utility services from PLD to DTE in 2022. The DTE services are from two separate busses from two separate DTE transformers that are powered from two independent 120kV feeds in the DTE Mack Substation. The two existing primary transformers were also replaced in 2022 with new 5MVA transformers by DTE. This should resolve the issue with the high voltage in the existing system.

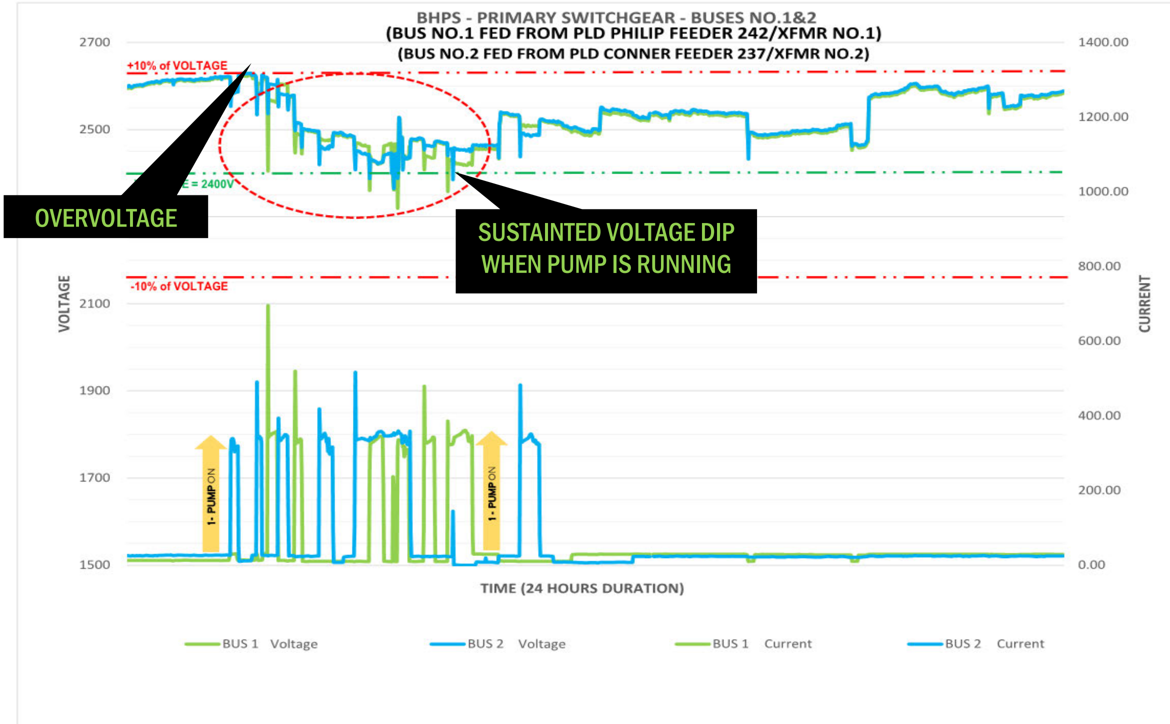


Figure 44: Bluehill PS Power Quality Issues – Primary Switchgear Buses Voltage and Current

A3.3.4 – Fairview and Other PS

During dry weather, the DRI conveys wastewater flows from the East Side System to the Fairview PS. The Fairview PS lifts the wastewater and discharges into the downstream DRI, which flows by gravity to the raw wastewater pumps at the WRRF.

During the June/July 2021 Rainfall Events, temporary bypass PS existed on the site. The temporary station conveyed wastewater from the upstream DRI to the downstream DRI with up to seven vertical turbine pumps.

The DRI receives flows from the Connors Creek PS, the Connors Creek Enclosure, the Alter sewer, and the Grosse Pointe Park PS.

A3.4 – CSO Facilities

In the city of Detroit, there are nine CSO control facilities that are operated by GLWA. Six of these are RTBs and include Seven Mile, Puritan-Fenkell, Hubbell-Southfield, Oakwood, Belle Isle, and Connors Creek RTBs. There are also three screening/disinfection facilities (SDFs) (Baby Creek, Lieb, and St. Aubin) that provide CSO control.

There are three RTBs for CSO control in the Evergreen-Farmington Sanitary District, four in the Rouge Valley Sewage Disposal System, one in the GWK Drain Drainage District, and three in the SEMSD system.

Untreated CSO outfalls exist in Detroit, Dearborn, Redford, Dearborn Heights, and Inkster.

A4 – System Operations and Staffing

A4.1 – Weekly Red Tag Reports

GLWA Stations - Equipment Out-of-Service (Red Tag/Yellow Tag) Report - Systems Control Center- Updated: July 13, 2021

Water Booster Stations

% of all Booster Pumps OOS= **8.33%** — O.O.S.: 9 — Total Pumps: 108

Station	Pump 1	Pump 2	Pump 3	Pump 4	Pump 5	Pump 6	Pump 7	Pump 8	Pump 9	Pump 10	Pump 11	Pump 12	Pump 13	Pump 14	Notes	O.O.S.	Total Pumps
Adams	A L1	A L2	A L 3	A L 4	A R 1	A R 2									R2: Runs with valve >30%	0	6
Eastside (Canyon)	A R 1	A R 2	A R 3													0	3
Electric	A L1	A L2	A R 3	A R 4												0	4
Ford	A L1	A L 2	A L 3	A L 4	A L 5	A R 6	A R 7	R R 8	A R 9	A R 10					R8: Controls transformer	1	10
Franklin	A L1	A L2	A L 3	A L 4	A R 1	A R 2										0	6
Haggerty	A L1	A L2	A L 3	A R 1	A R 2											0	5
Imlay	A R 1	A R 2	R LR 3	A LR 4	R LR 5	A LR 6	A LR 7	A LR 8							LR3: Chiller problems; LR5: Soft starter	2	8
Joy Road	A L1	A L2	A L 3	A R 1	A R 2	R R 3									R3: Pump bearing	1	6
Michigan	A L1	A L2	A L 3	A R 4	A R 5											0	5
Newburgh	A L1	A L2	A L 3	A L 4	A L 5											0	5
North Service Ctr		A L2	R L 3	A L 4	R L 5	A L 6	A L 7	A L 8	A L 9	R L 10	A R 1	A R 2	A R 3	A R 4	NSC- L3: Pump replacement; L5: Thrust bearing; L10: Complete rotating assembly removal	3	13
Northwest	R 1	R 2	A R 3	A R 4	R5										R1,R2,R5: Pump decommissioned	0	2
Orion	A L1	A L2	A L 3	A L 4												0	5
Rochester	A L1	A L2	A L 3	A L 4	A L 5											0	5
Schoolcraft	A L1	A L2	A R 1	A R 2												0	4
West Chicago	A L1	A L2	A L 3	R4	R5	R6									R4,R5,R6 : Pump decommissioned	0	3
West Service Ctr	A L1	R L2	R L 3	A L 4	A L 5	A L 6	A R 1	A R 2	A R 3	A R 4					L2: Relay replacement; L3: Linkage problem	2	10
Wick	A L1	A L2	A R 1	A R 2	A R 3											0	5
Ypsilanti	A L1	A L2	A L 3													0	3

Sewage Pumping Stations

% of all Sewage Pumps OOS= **18.33%** — O.O.S.: 11 — Total Pumps: 60

Station	Pump 1	Pump 2	Pump 3	Pump 4	Pump 5	Pump 6	Pump 7	Pump 8	Pump 9	Pump 10	Pump 11	Pump 12	Notes	O.O.S.	Total Pumps
Belle Isle	A SN 1	A SN 2	A ST 1	A ST 2	A ST 3									0	5
Bluehill	A ST 1	A ST 2	A ST 3	A ST 4	A SN 5	A SN 6							ST4: Emergency use only	0	6
Conners Creek	R ST 1	A ST 2	A ST 3	A ST 4	A ST 5	A ST 6	A ST 7	A ST 8	A SN 9	R SN 10	A SN 11	A SN 12	ST1: Amperage problem; SN10: Packing; SN11: Local only; SN12: Emergency use only	2	12
Fairview	R SN 1	R SN 2	R SN 3	R SN 4									SN1,SN2,SN3,SN4: CIP work	4	4
Fischer	A SN 1	A SN 2												0	2
Freud	R ST 1	A ST 2	A ST 3	A ST 4	R ST 5	A ST 6	A ST 7	A ST 8	A SN 9	A SN 10			ST1: Warranty issue; ST5: PLD Power Outage	2	10
Northeast	R SN 1	A SN 2			A SN 5	A SN 6							SN1: Pump replacement	1	4
Oakwood	A SN 1	A SN 2	A SN 3	A SN 4	A ST 1	A ST 2	A ST 3	A ST 4	R ST 5	A ST 6	A ST 7	A ST 8	ST5: Pump being pulled for inspection	1	12
Woodmere	A ST 1	A ST 2	A ST 3		A SN 5	R SN 6							SN6: Broken U-joint on shaft	1	5

Legend:
- **R** RED-Tagged Pump for Maintenance
- **A** Pump is AVAILABLE
- LINE or SANITARY Pump
- RESERVOIR or STORM Pump
- COMBINATION L/R Pump
- In Service (green)
- Out of Service (red)
- Decommissioned (white)

GLWA Stations - Equipment Out-of-Service (Red Tag/Yellow Tag) Report - Systems Control Center- Updated: June 22, 2021

Water Booster Stations

% of all Booster Pumps OOS= 6.48%

Station	Pump 1	Pump 2	Pump 3	Pump 4	Pump 5	Pump 6	Pump 7	Pump 8	Pump 9	Pump 10	Pump 11	Pump 12	Pump 13	Pump 14	Notes	O.O.S.	Total Pumps
																7	108
Adams	A L1	A L2	A L 3	A L 4	A R 1	A R 2									R2: Runs with valve >30%	0	6
Eastside (Canyon)	A R 1	A R 2	A R 3													0	3
Electric	A L1	A L2	A R 3	A R 4												0	4
Ford	A L1	A L 2	A L 3	R L 4	A L 5	A R 6	A R 7	R R 8	A R 9	A R 10					L4: Gland seal water line; R8: Controls transformer	2	10
Franklin	A L1	A L2	A L 3	A L 4	A R 1	A R 2										0	6
Haggerty	A L1	A L2	A L 3	A R 1	A R 2											0	5
Imlay	A R 1	A R 2	A LR 3	A LR 4	R LR 5	A LR 6	A LR 7	A LR 8							LR5: Soft starter	1	8
Joy Road	A L1	A L2	A L 3	A R 1	A R 2	R R 3									R3: Pump bearing	1	6
Michigan	A L1	A L2	A L 3	A R 4	A R 5											0	5
Newburgh	A L1	A L2	A L 3	A L 4	A L 5											0	5
North Service Ctr	[hatched]	A L2	R L 3	A L 4	R L 5	R L 6	A L 7	A L 8	A L 9	A L 10	A R 1	A R 2	A R 3	A R 4	NSC- L3: Pump replacement; L5: Thrust bearing; L6: D/V issues	3	13
Northwest	R 1	R 2	A R 3	A R 4	R5										R1,R2,R5: Pump decommissioned	0	2
Orion	A L1	A L2	A L 3	A L 4												0	5
Rochester	A L1	A L2	A L 3	A L 4	A L 5											0	5
Schoolcraft	A L1	A L2	A R 1	A R 2												0	4
West Chicago	A L1	A L2	A L 3	R4	R5	R6									R4,R5,R6 : Pump decommissioned	0	3
West Service Ctr	A L1	A L2	A L 3	A L 4	A L 5	A L 6	A R 1	A R 2	A R 3	A R 4						0	10
Wick	A L1	A L2	A R 1	A R 2	A R 3											0	5
Ypsilanti	A L1	A L2	A L 3													0	3

Sewage Pumping Stations

% of all Sewage Pumps OOS= 16.67%

Station	Pump 1	Pump 2	Pump 3	Pump 4	Pump 5	Pump 6	Pump 7	Pump 8	Pump 9	Pump 10	Pump 11	Pump 12	Notes	O.O.S.	Total Pumps
														10	60
Belle Isle	A SN 1	A SN 2	A ST 1	A ST 2	A ST 3									0	5
Bluehill	A ST 1	A ST 2	A ST 3	A ST 4	A SN 5	A SN 6							ST4: Emergency use only	0	6
Conners Creek	A ST 1	A ST 2	A ST 3	R ST 4	R ST 5	A ST 6	A ST 7	A ST 8	A SN 9	R SN 10	A SN 11	A SN 12	ST4&5: Protection relays; SN10: Packing gland; SN11: Local only; SN12: Emergency use only	3	12
Fairview	R SN 1	R SN 2	R SN 3	R SN 4									SN1,SN2,SN3,SN4: CIP work	4	4
Fischer	A SN 1	A SN 2												0	2
Freud	R ST 1	A ST 2	A ST 3	A ST 4	A ST 5	A ST 6	A ST 7	A ST 8	A SN 9	A SN 10			ST1: Warranty issue (motor protection)	1	10
Northeast	R SN 1	A SN 2	[hatched]	[hatched]	A SN 5	A SN 6							SN1: Pump replacement	1	4
Oakwood	A SN 1	A SN 2	A SN 3	A SN 4	A ST 1	A ST 2	A ST 3	A ST 4	R ST 5	A ST 6	A ST 7	A ST 8	ST5: Pump being pulled for inspection	1	12
Woodmere	A ST 1	A ST 2	A ST 3	[hatched]	A SN 5	A SN 6								0	5

Legend:
- **R** RED-Tagged Pump for Maintenance
- **A** Pump is AVAILABLE
- LINE or SANITARY Pump
- RESERVOIR or STORM Pump
- COMBINATION L/R Pump
- In Service
- Out of Service
- Decommissioned

A4.2 – Rainfall Event Timeline Tables for Storm Pump Operations

Due to discrepancies in the interviews and logbooks, some events may have been estimated by personnel dealing with emergencies. In addition, pump run status recordings appear to be displayed in 5-minute intervals.

The findings of this investigation from noon on June 25, 2021 to noon on June 26, 2021 at Blue Hill, Connors Creek, and Freud PSs are provided in Table 25, Table 26, and Table 27, respectively.

Table 26: Bluehill PS Activity during the June 25/26 Rainfall Event

Date	Time	Event	Comments
June 25	12:00	SANITARY PUMP 5 ON	1 sanitary pump on
	14:15	SANITARY PUMP 5 OFF STORM PUMP 2 ON	1 storm pump on
	17:45	STORM PUMP 2 OFF	
	18:55	SANITARY PUMP 6 ON	1 sanitary pump on
	19:35	STORM PUMP 2 ON	1 storm pump on and 1 sanitary pump on
	20:05	STORM PUMP 2 OFF	1 sanitary pump on
	22:00	SANITARY PUMP 5 ON	2 sanitary pumps on
	22:40	SANITARY PUMP 5 OFF STORM PUMP 2 ON	1 storm pump on and 1 sanitary pump on
	23:50	STORM PUMP 1 ON	2 storm pumps on and 1 sanitary pump on
June 26	2:00	SANITARY PUMP 5 ON	2 storm pumps on and 2 sanitary pumps on
	6:05	SANITARY PUMP 5 OFF STORM PUMP 3 ON	3 storm pumps on and 1 sanitary pump on
	6:25	STORM PUMP 1 OFF	2 storm pumps on and 1 sanitary pump on
	6:30	STORM PUMP 2 OFF	1 storm pump on and 1 sanitary pump on
	6:40	STORM PUMP 3 OFF	1 sanitary pump on
	6:55	SANITARY PUMP 5 ON	2 sanitary pumps on
	7:40	SANITARY PUMP 5 OFF STORM PUMP 1 ON	1 storm pump on and 1 sanitary pump on
	8:35	STORM PUMP 1 OFF	1 sanitary pump on
	10:10	STORM PUMP 2 ON	1 storm pump on and 1 sanitary pump on
	11:55	STORM PUMP 2 OFF	1 sanitary pump on

Table 27: Connors Creek PS Activity during the June 25/26 Rainfall Event

Date	Time	Event	Comments
June 25	12:00	SANITARY PUMP 10 ON SANITARY PUMP 12 ON	2 sanitary pumps on
	13:30		Team Leader Katherine Miracle and staff tested Vacuum Priming System in preparation for storm; system checked ok
	13:55	SANITARY PUMP 10 OFF SANITARY PUMP 12 OFF	
	19:48		Electrician Nathan Ward arrived at Connors Creek
	21:36		Electrician Nathan Ward dispatched to Freud
	23:40	STORM PUMP 3 ON	1 storm pump on
	23:45	STORM PUMP 2 ON	2 storm pumps on
June 26	0:45	STORM PUMP 7 & 8 ON	4 storm pumps on, ST 8 kicks off for one 10-min interval (5:15-5:25)
	0:55	STORM PUMP 6 ON	5 storm pumps on
	1:18		Electrician Nathan Ward returned to Connors Creek to trouble shoot power issue – maintenance had to cut locks for entrance
	1:45		Power to pumps was not interrupted. Leak from vacuum priming line sprayed onto MCC adjacent to Storm Pump 2. The MCC breaker opened resulting in the vacuum priming system and environmental systems being temporarily out of service. Once the issue was identified, the electrician attended to the issue and then closed the breaker to bring back power to the vacuum priming system and environmental systems.
	6:10	STORM PUMP 8 OFF	4 storm pumps on
	7:00	STORM PUMP 7 OFF	3 storm pumps on
	7:25	STORM PUMP 2 OFF	2 storm pumps on
	8:20	STORM PUMP 6 OFF	1 storm pump on
	9:05	STORM PUMP 3 OFF	

Notes:
MCC = motor control center

Table 28: Freud PS Activity during the June 25/26 Rainfall Event

Date	Time	Event	Comments
June 25	13:05	SANITARY PUMP 10 ON	1 sanitary pump on
	13:35	SANITARY PUMP 10 OFF	
	15:55	STORM PUMP 3 ON	1 storm pump on
	16:15	STORM PUMP 3 OFF	
	16:30	STORM PUMP 7 ON	1 storm pump on
	17:10	STORM PUMP 3 ON	2 storm pumps on
	17:15	STORM PUMP 7 & 3 OFF	
	17:35	STORM PUMP 7 ON	1 storm pump on
	17:40	STORM PUMP 3 ON	2 storm pumps on
	19:00	STORM PUMP 7 & 3 OFF	
	20:25	STORM PUMP 3 ON	1 storm pump on, STORM PUMP 3 kicks off for two 5 min intervals at (21:10 and 21:25)
	20:30	STORM PUMP 7 ON	2 storm pumps on
	21:15	STORM PUMP 8 ON/OFF	3 storm pumps on for 5 min
	21:36		Electrician Nathan Ward dispatched to Freud PS to troubleshoot power issues and assist with starting pumps.
	21:50		Initiated attempts to get third pump started. Starting a third pump tripped out the 2 running pumps. After several attempts, got 3 pumps operating. No GLWA power issues. Only had one utility service.
June 26	1:25	STORM PUMP 6 ON	3 storm pumps on. At 0:40 to 1:00 max level in storm pump wet well =100.23 ft-DD
	4:54		Stormwater levels started coming down
	13:10	ALL STORM PUMPS OFF	

Notes:
DD = Detroit Datum

The SCADA system recorded pump operation on July 16, 2021 at Blue Hill, Connors Creek, and Freud PSs is provided in Table 28, Table 29, and Table 30, respectively.

Table 29: Bluehill PS Activity during the July 16 Rainfall Event

Date	Time	Event	Comments
July 16	0:00		No pumps on
	0:25	SANITARY PUMP 6 ON	1 sanitary pump on
	2:30	SANITARY PUMP 6 OFF	
	5:40	SANITARY PUMP 6 ON	1 sanitary pump on
	7:40	SANITARY PUMP 6 OFF	
	8:55	SANITARY PUMP 6 ON	1 sanitary pump on
	9:10	SANITARY PUMP 5 ON	2 sanitary pumps on
	9:30	STORM PUMP 3 ON	2 sanitary pumps on and 1 storm pump on
	9:55	SANITARY PUMP 5 OFF	1 sanitary pump on and 1 storm pump on
	10:35	STORM PUMP 3 OFF	1 sanitary pump on
	10:40	SANITARY PUMP 6 OFF	
	11:15	STORM PUMP 1 and SANITARY PUMP 6 ON	1 sanitary pump on and 1 storm pump on
	11:25	STORM PUMP 1 and SANITARY PUMP 6 OFF	
	11:40	STORM PUMP 3 ON and OFF	
	11:45	STORM PUMP 1 ON	1 storm pump on
	12:10	SANITARY PUMPS 5 and 6 ON	2 sanitary pumps on and 1 storm pump on
	13:45	STORM PUMP 4 ON	2 sanitary pumps on and 2 storm pumps on
	14:05	STORM PUMP 3 ON	2 sanitary pumps on and 3 storm pumps on
	14:20	SANITARY PUMPS 5 and 6 OFF	3 storm pumps on
	14:55	STORM PUMP 1 OFF and STORM PUMP 2 ON	3 storm pumps on
	15:05	STORM PUMP 2 OFF	2 storm pumps on
	15:10	STORM PUMP 4 OFF	1 storm pump on
	15:55	STORM PUMP 3 OFF	
	16:05	STORM PUMP 4 ON and SANITARY PUMP 5 ON	1 sanitary pump on and 1 storm pump on
	17:05	SANITARY PUMP 5 OFF	1 storm pump on
	17:05	STORM PUMP 4 OFF	
	17:30	STORM PUMP 4 ON	1 storm pump on
	17:50	STORM PUMP 4 OFF	
	18:00	SANITARY PUMP 6 ON	1 sanitary pump on
	18:05	STORM PUMP 4 ON	1 sanitary pump on and 1 storm pump on

Date	Time	Event	Comments
	18:20	STORM PUMP 4 OFF and SANITARY PUMP 6 OFF	
	18:30	SANITARY PUMP 6 ON	1 sanitary pump on
	18:40	STORM PUMP 4 ON	1 sanitary pump on and 1 storm pump on
	18:50	STORM PUMP 4 OFF and SANITARY PUMP 6 OFF	
	19:05	SANITARY PUMP 6 ON	1 sanitary pump on
	19:15	SANITARY PUMP 6 OFF	
	19:25	STORM PUMP 1 ON	1 storm pump on
	19:40	STORM PUMP 1 OFF	
	20:35	STORM PUMP 2 ON	1 storm pump on
	21:00	STORM PUMP 2 OFF	
	21:20	SANITARY PUMP 6 ON	1 sanitary pump on
	21:30	SANITARY PUMP 5 ON	2 sanitary pumps on
	22:20	STORM PUMP 2 ON and SANITARY PUMP 5 OFF	1 sanitary pump on and 1 storm pump on
	22:40	STORM PUMP 2 OFF	1 sanitary pump on

Table 30: Connors Creek PS Activity during the July 16 Rainfall Event (15-minute data)

Date	Time	Event	Comments
July 16	0:00	SANITARY PUMP 11 & 12 ON	2 sanitary pumps on
	7:15	SANITARY PUMP 11 & 12 OFF	
	8:15	SANITARY PUMP 12 ON	1 sanitary pump on
	8:45	SANITARY PUMP 10 ON	2 sanitary pumps on
	9:00	SANITARY PUMP 9 ON	3 sanitary pumps on
	9:15	SANITARY PUMP 11 ON	4 sanitary pumps on
	10:15	SANITARY PUMP 11 & 12 OFF STORM PUMPS 7 & 3 ON	2 sanitary pumps on and 2 storm pumps on
	10:30	SANITARY PUMP 10 OFF STORM PUMP 7 OFF STORM PUMP 5 ON	1 sanitary pump on and 2 storm pumps on
	10:45	SANITARY PUMP 9 OFF STORM PUMPS 2, 4, & 8 ON	5 storm pumps on
	11:00	STORM PUMP 5 OFF STORM PUMP 6 ON	5 storm pumps on
	11:30	STORM PUMP 7 ON	6 storm pumps on
	11:45	STORM PUMPS 4, 6, & 7 OFF	3 storm pumps on
	12:30	STORM PUMP 2 OFF	2 storm pumps on
	13:45	STORM PUMPS 2 & 5 ON	4 storm pumps on
	14:00	STORM PUMP 5 OFF	3 storm pumps on
	14:15	STORM PUMP 2 OFF	2 storm pumps on
	14:45	STORM PUMP 8 OFF	1 storm pump on
	15:00	STORM PUMP 3 OFF	
	19:00	SANITARY PUMP 12 ON	1 sanitary pump on
	19:48		Electrician arrived at Connors Creek
	20:45	SANITARY PUMP 12 OFF SANITARY PUMP 11 ON	1 sanitary pump on
	22:30	SANITARY PUMP 11 OFF SANITARY PUMP 9 ON	1 sanitary pump on

Table 31: Freud PS Activity during the July 16 Rainfall Event

Date	Time	Event	Comments
July 16	0:00	SANITARY PUMP 9 ON	1 sanitary pump on
	0:15	SANITARY PUMP 9 OFF SANITARY PUMP 10 ON	1 sanitary pump on
	1:20	SANITARY PUMP 10 OFF	
	8:25	SANITARY PUMP 10 ON	1 sanitary pump on
	8:50	SANITARY PUMP 10 OFF	
	9:10	SANITARY PUMP 10 ON	1 sanitary pump on
	9:20	SANITARY PUMP 9 ON	2 sanitary pumps on
	10:00	SANITARY PUMP 9 OFF SANITARY PUMP 10 ON STORM PUMP 6 ON	1 storm pump on
	10:05	STORM PUMP 7 ON	2 storm pumps on
	10:10	STORM PUMP 3 ON	3 storm pumps on
	10:20	STORM PUMP 4 ON	4 storm pumps on
	11:15	STORM PUMP 7 OFF STORM PUMP 2 ON	4 storm pumps on
	11:30	STORM PUMP 7 ON	5 storm pumps on
	11:35	STORM PUMP 2 & 7 OFF	3 storm pumps on
	11:45	STORM PUMP 2 ON	4 storm pumps on
	13:50	STORM PUMP 7 ON	5 storm pumps on
	15:40	STORM PUMP 6 OFF	4 storm pumps on
	16:50	STORM PUMP 3 OFF	3 storm pumps on
	19:15	STORM PUMP 2 OFF	2 storm pumps on
	21:50	STORM PUMP 7 OFF	1 storm pump on

A4.3 – Freud and Connors Creek PS Staffing Information During the June 25/26 Rainfall Event

The following tables were developed using the PS logbooks, interview statements, and PS time event sheets (Table 31, Table 32, Table 33). Staff roles were identified from an organization chart supplied by GLWA and interviews. Personnel not listed on the organization chart and roles not known by GLWA Team Leader Anthony Troy are listed as contractors as assumed by Mr. Troy.

Table 32: Freud PS Staffing Entering June 25 7:49 a.m. Through Staff Entering 1:33 p.m. June 26

Date	Staff Name	Staff Role	Arrival Time	Departure Time	Key Activities
25-Jun	Ronnie Duke	Contractor*	7:49 a.m.	Unknown	None identified
25-Jun	Justin Peel	Contractor*	8:10 a.m.	12:23 p.m.	None identified
25-Jun	John Boyd	Contractor*	8:23 a.m.	Unknown	None identified
25-Jun	JaJuan Moore/Joshua Beverly	Mechanical Technicians	~8:20 a.m.	~11:40 a.m.	Identified Storm Pumps 1,2,4,5 and 8 o/s
25-Jun	Satwinder Singh	Electrician	8:41 a.m.	2:43 p.m.	None identified
25-Jun	Paul Shannon	Systems Technician, Operations	8:47 a.m.	8:54 a.m.	None identified
25-Jun	Kenneth Volkman	Contractor*	9:59 a.m.	10:49 a.m.	None identified
25-Jun	Lamar Grant	Contractor*	10:02 a.m.	2:34 p.m.	None identified
25-Jun	Rufus Jackson Jr.	Contractor*	10:35 a.m.	11:03 a.m.	None identified
25-Jun	Anthony Carey	Contractor*	11:06 a.m.	11:57 a.m.	None identified
25-Jun	Darvin Fox	Systems Technician, Operations	12:33 p.m.	1:59 p.m.	Operations support
25-Jun	Lawrence Goddard	Electrician	1:29 p.m.	7:49 p.m.	Reported Problem with Storm Pump 5 exciter
25-Jun	Leroy Mathis	Contractor*	2:26 p.m.	Unknown	None identified
25-Jun	Charles McDonald	Contractor*	4:05 p.m.	6:52 p.m.	None identified
25-Jun	James McDaniel	Contractor*	4:10 p.m.	Unknown	None identified
25-Jun	Calvin Davis	Instrumentation Technician	Unknown	6:43 p.m.	None identified
25-Jun	Darvin Fox	System Technician Operations	6:15 p.m.	8:24 p.m.	
25-Jun	Katherine Miracle	Team Leader, Mechanical	7:00-7:30 p.m. (statement)	After walkthrough	Walkthrough prior to storm
25-Jun	Jamal Hamilton	Contractor*	8:39 p.m.	10:14 a.m. (6/26)	None identified
25-Jun	Tod Fuchs	Contractor*	9:24 p.m.	Unknown	None identified
25-Jun	Nathan Ward	Electrician	9:43 p.m.	1:19 a.m. (6/26)	Dispatched to start third pump -

Date	Staff Name	Staff Role	Arrival Time	Departure Time	Key Activities
					able to start the pump at 1:25 a.m.
25-Jun	Mark Jones	Instrumentation Technician	Unknown	1:21 p.m. (6/26)	None identified
25-Jun	Darvin Fox	Systems Technician, Operations	10:02 p.m.	9:59 a.m. (6/26)	Could only run 2 storm pumps due to 1 of 3 transformers available.
26-Jun	Todd King	Director, Field Services	8:13 a.m.	8:17 a.m.	Checked in at Freud and Connors Creek PS
26-Jun	Adam Kudla	Systems Technician, Operations	9:11 a.m.	11:12 a.m.	None identified
26-Jun	James Chiodini	Contractor Electrician	9:20 a.m.	1:48 p.m.	None identified
26-Jun	Toney Saxton	Instrumentation Technician	9:23 a.m.	11:08 a.m.	None identified
26-Jun	Reginald Hodo	Contractor*	10:02 a.m.	Unknown	None identified
26-Jun	Clarence White Sr.	Team Leader Electrical	11:23 a.m.	12:03 p.m.	None identified
26-Jun	Keith Snowden	Systems Technician, Operations	1:33 p.m.	3:52 p.m.	Stopped Storm Pumps 3, 6, and 7 at 2 p.m.

Notes:
*Personnel were not identified on the GLWA Organization Chart; Anthony Troy, Team Leader, Operations speculated that the personnel were contractors

Table 33: Connors Creek PS Staff Entering Starting 7:20 a.m. June 25 Through Staff Entering 12:00 p.m. June 26

Date	Staff Name	Staff Role	Arrival Time	Departure Time	Key Activities
25-Jun	Sherman West	Instrumentation Technician	7:20 a.m.	11:44 a.m. (estimated)	Checked instrumentation
25-Jun	Gari Levy	Instrumentation Technician	7:26 a.m.	11:44 a.m.	Checked instrumentation
25-Jun	Thomas Chicon	Instrumentation Technician	9:05 a.m.		Checked instrumentation
25-Jun	Michael Grimes	Instrumentation Technician	9:13 a.m.	11:22 a.m.	Checked instrumentation
25-Jun	Anthony Carey	Contractor*	10:20 a.m.	11:55 a.m.	None identified
25-Jun	Aaron Parrot	Instrumentation Technician	11:08 a.m.	11:26 a.m.	None identified
25-Jun	Katherine Miracle	Team Leader, Mechanical	11:17 a.m.	6:40 p.m.	Checked out vacuum priming system and equipment prior to storm event with team; identified all Storm Pumps except Number 5 are available for service
25-Jun	Joshua Beverley	Mechanical Technician	11:58 a.m.	6:40 (estimated)	Checked out vacuum priming system and equipment prior to storm event
25-Jun	Raymond Battle	Mechanical Technician	12:18 p.m.	6:44 p.m.	Checked out vacuum priming system and equipment prior to storm event
25-Jun	JuJuan Moore	Mechanical Technician	12:25 p.m.	3:33 p.m.	Checked out vacuum priming system and equipment prior to storm event
25-Jun	Ronnie Duke	Contractor*	11:30 (estimated)	Unknown	None identified
25-Jun	Dustin Peel	Contractor*	11:30 (estimated)	2:47 p.m.	None identified
25-Jun	Darvin Fox	Systems Technician, Operations	1:42 p.m.	1:53 p.m.	None identified
25-Jun	Joshua Beverley	Systems Technician Operations	3:00 p.m.	7:00 a.m. 6/26	Assisted storm pump #5 start at 12 midnight
25-Jun	Lawrence Goddard	Electrician	4:34 p.m.	5:24 p.m.	Reset Storm Pumps 3 and 7

Date	Staff Name	Staff Role	Arrival Time	Departure Time	Key Activities
25-Jun	Skitch Rowe	Instrument Technician	7:09 p.m.		None identified
25-Jun	Lorrance Lewis	Team Lead Mechanical	7:22:00 p.m.	10:03 a.m. (6/26)	Monitored levels; assisted with vacuum priming system restart and starting storm pumps
25-Jun	Naythan Ward	Electrician	7:46 p.m.	9:40 p.m.	Dispatched to Freud at 9:36 p.m.
25-Jun	Bilal Bell-Mahammad	Instrumentation Technician	7:48 p.m.	12:13 a.m. (6/26)	None identified
25-Jun	Mark Jones	Instrumentation Technician	7:50 p.m. (estimated)	10:50 p.m.	None identified
25-Jun	Wanda Brown	Team Leader Basin Operations	9:33 p.m.	9:42 p.m.	Checked Gates
26-Jun	Keith Duncan	Systems Technician, Operations	12:10 a.m.	11:25 a.m.	None identified
26-Jun	Lavaughnda Flowers	Team Leader Instrumentation	12:22 a.m.	1:43 a.m.	None identified
26-Jun	Naythan Ward	Electrician	1: 26 a.m.	8:38	Identified MCC issue; Assisted starting Storm Pumps at 2 a.m.
26-Jun	Mark Jones	Instrumentation Technician	1:51 a.m.	7:46 a.m.	None identified
26-Jun	Thomas Hall	Team Leader Instrumentation	4:29 a.m.	9:51 a.m.	None identified
26-Jun	Marcus Jackson	Mechanical Technician	6:48 a.m.	Unknown	None identified
26-Jun	Katherine Miracle	Team Leader, Mechanical	7:25 a.m.	11:08 a.m.	Turned off Storm Pumps 4 and 5, one a t a time; wet well levels were down
26-Jun	James Chiodini	Electrician	7:29 a.m.	8:14 a.m.	Relieved Naythan Ward as per Naythan Ward's interview
26-Jun	Anthony Carey	Contractor*	7:40 a.m.	Unknown	None identified
26-Jun	Toney Saxton	Instrumentation Technician	7:49 a.m.	8:10 a.m.	None identified
26-Jun	Todd King	Director, Field Services	~8:00 a.m.	8:11 a.m.	Checked in with Tom Hall
26-Jun	Keith Greene	Contractor*	8:00 a.m.	9:06 a.m.	None identified

Date	Staff Name	Staff Role	Arrival Time	Departure Time	Key Activities
26-Jun	Keith Carfagno	Contractor*	10:33 a.m.	11:20 a.m.	None identified
26-Jun	Kenneth Volkman	Contractor*	10:51 a.m.	11:01 a.m.	None identified
26-Jun	James Chiodini	Contractor Electrician	11:12 a.m.	1:34 a.m.	None identified
26-Jun	Kenneth Volkman	Contractor*	11:17 a.m.	1:21 p.m.	None identified
26-Jun	Keith Carfagno	Contractor*	11:56 a.m.	1:32 p.m.	None identified
26-Jun	Katherine Miracle	Team Leader, Mechanical	12:00 p.m.	6:26 p.m.	None identified

Notes:
MCC = motor control center
*Personnel were not identified on the GLWA Organization Chart; Anthony Troy, Team Leader, Operations speculated that the personnel were contractors

Table 34: Bluehill PS Staffing Entering June 25 12:30 a.m. Through Staff Entering 1:33 p.m. June 26

Date	Staff Name	Staff Role	Arrival Time	Departure Time	Key Activities
25-Jun	Marcus Jackson	Mechanical Technician	12:32 a.m.	12:40 p.m.	None identified
25-Jun	Keith Duncan	Systems Technician, Operations	1:08 p.m.	1:09 p.m.	None identified
25-Jun	Marcus Jackson	Mechanical Technician	2:06 p.m.	2:09 p.m.	None identified
25-Jun	Ian Sizemore	Mechanical Technician	2:39 p.m.	2:43 p.m.	None identified
25-Jun	Darvin Fox	Systems Technician, Operations	8:40 p.m.	9:45 p.m.	None identified
25-Jun	Keith Duncan	Systems Technician, Operations	11:24 p.m.	11:56 p.m.	None identified
26-Jun	Adam Kudla	Systems Technician, Operations	2:41 a.m.	7:47 a.m.	None identified
26-Jun	Lawrence Goddard	Electrician	6:14 a.m.	Unknown	Reset Storm Pump 3
26-Jun	Toney Saxton	Instrumentation Technician	7:34 a.m.	Unknown	None identified
26-Jun	Gari Levy	Instrumentation Technician	8:11 a.m.	8:42 a.m.	None identified
26-Jun	Sherman West	Instrumentation Technician	8:14 a.m.	Unknown	None identified
26-Jun	James Chiodini	Contractor Electrician	8:26 a.m.	9:04 a.m.	None identified
26-Jun	Toney Saxton	Instrumentation Technician	8:54 a.m.	Unknown	None identified
26-Jun	Keith Carfagno	Contractor*	10:14 a.m.	Unknown	None identified
26-Jun	Darvin Fox	Systems Technician, Operations	10:29 a.m.	2:29 p.m.	None identified
26-Jun	Keith Duncan	Systems Technician, Operations	11:52 a.m.	6:26 p.m.	None identified

Notes:
*Personnel were not identified on the GLWA Organization Chart; Anthony Troy, Team Leader, Operations speculated that the personnel were contractors

The general response times for GLWA Key Personnel during the June 25/26 storm event are provided in Figure 46.

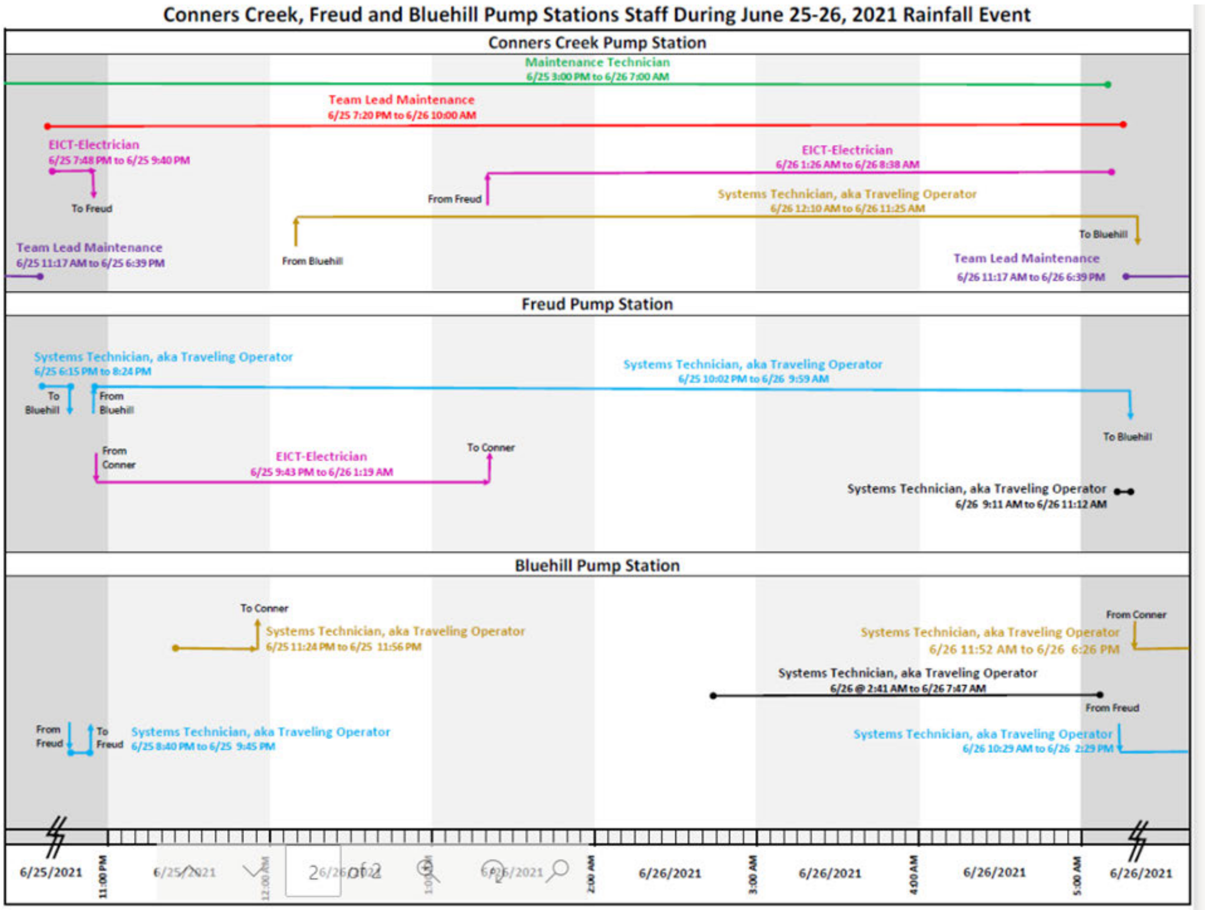


Figure 45: Staff Attendance and Movement During June 25/26 Rainfall Event

A5 – Freud and Connor Creek PS Improvements: Concept Alternatives Evaluation

Great Lakes Water Authority

FREUD AND CONNER CREEK PUMP STATION IMPROVEMENTS

Concept Alternatives Evaluation

November 2017

FREUD AND CONNER CREEK PUMP STATION IMPROVEMENTS

Concept Alternatives Evaluation

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Technical Memorandum

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Prepared for: Great Lakes Water Authority

Project Title: Freud and Conner Creek Pump Station Improvements

Project No.: CS-120

Technical Memorandum No. 2

Subject: Freud and Conner Creek Pump Station Improvements - Concept Alternatives Evaluation

Date: November 22, 2017

To: Ms. Mini Panicker, PE

From: Mr. Jeff Swartz, PE

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List of Abbreviations

AACE	Advancement of Cost Engineering International
AOR	allowable operating range
BEP	best efficiency point
BTU	British Thermal Unit
CC	Conner Creek
CCF	Hundred Cubic Feet
CFD	computational fluid dynamics
CSO	Combined Sewer Overflow
CMU	concrete masonry unit
DIP	Ductile Iron Pipe
DRI	Detroit River Interceptor
DWSD	Detroit Water and Sewerage Department
EL	Elevation – City of Detroit Datum
ft	feet
GLWA	Great Lakes Water Authority
HI	Hydraulic Institute
HTHV	High Temperature Heating and Ventilation
HVAC	Heating, Ventilation, and Cooling
HVAC	Heating, Ventilating, and Air Conditioning
IES	Illuminating Engineering Society
in	inches
kWh	Kilowatt-hour
MBTU	One Million British Thermal Unit
MDEQ	Michigan Department of Environmental Quality
mgd	million gallons per day
NPSHr	Net Positive Suction Head Required
O&M	Operation and Maintenance
POR	preferred operating range
PS	pump station
R&R	Replacement and Repair
RS	Raw Sewage
TM	Technical Memorandum
WTP	water treatment plant
WRRF	water resource recovery facility

Section 1: Introduction

1.1 Purpose

This Technical Memorandum 2 - Concept Alternatives Evaluation (TM2) is part of the CS-120 Freud and Conner Creek Pump Station Improvements Project. The purpose of this technical memorandum is to provide the following:

- Establish the new functional requirements for both the Freud and Conner Creek Pump Stations,
- Describe and compare the Freud and Conner Creek Pump Station improvement alternatives, and
- Provide recommendations for the improvements.

Many of the improvements described in the memorandum are derived from the findings of the Condition Assessment submitted to GLWA on October 13, 2017. Refer to the Condition Assessment Report for the basis of these recommended improvements.

A key component of this TM2 is to step back and analyze the entire system to answer questions regarding system operation and capacity. This evaluation, in addition to the condition assessment report, provides a road map of the improvements necessary at the Freud and Conner Creek Pump Stations to make them reliable, functional, and sustainable into the future, as well as safely maintaining operations during construction activities.

1.2 Pump Station History

The Freud and Conner Creek pumping systems are key components in relaying wastewater and storm water generated in the eastern portion of Detroit to the Fairview Sewage Pump Station, and ultimately, to the Detroit Water Resource Recovery Facility (WRRF). The operation of these facilities is critical to prevent flooding of stakeholders' premises, but they also protect the water quality in the Detroit River and ultimately the drinking water supply for Detroit. The conveyance system is very complex involving at least eight interceptors/sewers, multiple regulating structures, three large pump stations, and a CSO treatment system. The conveyance system has grown and been modified numerous times over the past 100-years with the last major improvement being the construction of the Conner Creek CSO Basin and Treatment Facility which was placed into operation in 2005.

In the past, many improvements made to the conveyance system were reactive improvements to address immediate issues. While these reactive improvements endeavored to review the operation of the entire system, in some instances, the immediate problem was corrected, but generated other issues with the overall operation of the conveyance system. The completion of the Conner Creek CSO Basin is an example of this effect. By all accounts, the vacuum priming system on the Conner storm water pumps worked effectively prior to the CSO basin being placed into operation. The impact of the CSO basin on the operation of the Conner storm water pumps was identified as a potential problem due to the Conner outfall being drained as a result of operation of the CSO facility. The solution was the construction of a low head dam in the Conner outfall to capture and retain a sufficient quantity of water to seal the Conner storm water pump's discharge siphon. This solution did not solve the primary concern (priming of the Conner storm water pumps) and caused a secondary issue with solids settling out upstream of the dam.

The Freud Pump Station (FPS) was constructed in the mid-1950s primarily to handle the overflows from the Conner Creek Pump Station (CCPS). When the capacity of the CCPS is exceeded, the East Jefferson Relief Sewer overflows to the Fox Creek and Ashland Relief Sewers. The original concept was for the FPS and the Fox Creek and Ashland Relief Sewers to store approximately 20 million gallons for return to the CCPS through the East Jefferson Relief sewer when the CCPS could handle the flow. The operation concept of Freud was changed when the Conner Creek CSO Facility was placed into operation. The change was made so that the Freud storm water pumps would fill up the Conner outfall, thereby facilitating the priming of the Conner storm water pumps.

The Conner Creek Pump Station was originally constructed in the late-1920s to handle the flows from the East and West Jefferson Relief Sewers. The CCPS consists of two distinct components, the sanitary pump station and the storm water pump station, along with the ancillary support appurtenances (emergency generators, switch house and backwater gates). Sanitary and low storm water flows are pumped by the sanitary pump station into the Detroit River Interceptor. The Sanitary Pump Station was constructed in the 1950s.

1.3 Current Conditions

A summary of the findings for the existing conditions at each station is included in the tables below for both the Freud Pump Station and Conner Creek Pump Station.

Table 1-1. Freud Pump Station - Summary of Existing Conditions Major Findings

<u>Operations and Hydraulics Assessment</u>
• Insufficient Sanitary Pump Capacity
• Sanitary Pumps operating beyond acceptable range
• Undesirable Sanitary Pump Operating Conditions
• Unacceptable Pump Suction Intake Conditions
• Installation not compliant with HI Standards
	<u>Process-Mechanical Assessment</u>
	• Inability to Isolate Wet Well for Storm and Sanitary Pumps
	• Excessive wear on Sanitary Pumps
	  o Spare pumps are stored at the Pump station for replacements.
	  o Each pump has a dedicated range and no installed redundancy is provided

<u>Electrical Assessment</u> • Aging Outdoor Service Transformers • Aging Motors • Poor Interior Lighting • Aging 125vdc Power Distribution System • Aging Back-Up Power System • Obsolete motor field cubicles	<u>Instrumentation Assessment</u> • Heavily Retrofitted Mimic/Control Panel • Aging Ovation PLC System
<u>Architectural and Structural Assessment</u> • Aging membrane roof, exterior doors, and windows • Brick tuckpointing and small brick patch repairs • Deteriorating tile flooring surface on top floor and exterior concrete stairs • Insufficient access stairs to loading dock/PS • Deteriorated exterior concrete flume and loading dock top slabs and slab edges, steel building column base at loading dock • Deficient concrete pump bases • Corroded interior and exterior gratings and platform and stair leading to lowest sump level • Corroded window and door lintels • Deteriorated concrete wall surfaces of lowest sump level	<u>HVAC and Plumbing Assessment</u> • All major HVAC equipment - end of useful service life • All major plumbing fixtures and equipment - end of useful service life
<u>Civil Assessment</u> • Poor Site Vehicle Access for large vehicles.	

<table>
<tr><th colspan="2">Table 1-2. Conner Creek Pump Station - Summary of Existing Conditions Major Findings</th></tr>
<tr><td><u>Operations and Hydraulics Assessment</u>
Insufficient Sanitary Pump Capacity
Standby capacity not provided for current flow
Poor suction hydraulics cause pump wear
Vacuum priming systems for Storm Pumps is complex and unreliable
Operators must be on site to operate vacuum priming system and start pumps
Installation not compliant with HI Standards</td><td><u>Process-Mechanical Assessment</u>
Inability to isolate Wet Well for Storm Pumps
Desire to eliminate the Vacuum Priming System
Pump replacement will be required using a different pump style
Pump Station and piping modifications will be required</td></tr>
<tr><td><u>Electrical Assessment</u>
Aging Outdoor Service Transformers
Aging Motors
Poor Interior Lighting
Aging Back-Up Power System</td><td><u>Instrumentation Assessment</u>
Aging Ovation PLC System</td></tr>
<tr><td><u>Architectural and Structural Assessment</u>
Aging membrane roof (Sanitary and Switchgear Buildings)
Aging gutters, exterior doors, and windows
Brick tuckpointing and small brick patch repairs
Deteriorated exterior concrete surge tank top slab
Corroded interior and exterior gratings
Corroded window and door lintels
Corroded steel crane runway beam of Storm PS
Corroded upper steel platform members of Backwater Gate Structure</td><td><u>HVAC and Plumbing Assessment</u>
Need for replacement of all major HVAC equipment
Need for replacement of all major plumbing fixtures and equipment</td></tr>
<tr><td><u>Civil Assessment</u>
Poor Site Vehicle Access outside gate and lack of parking for vehicles</td><td></td></tr>
</table>

Section 2: Pump Facility Functional Requirements

Clearly defining the desired functional requirements for the improved facilities is critical to successful improvement of the pump stations. The functional requirements describe the required operational capabilities and the maintainability expectations. The functional requirements were developed based on review of current operating procedures, analysis of historic operations, and GLWA staff input for future operations and maintenance requirements. It should be noted that many of the requirements listed below are directly related to elements outlined in *Recommended Standards for Wastewater Facilities (2014 edition)*.

2.1 Freud Pump Station

2.1.1 Operational Requirements

The recommended operational functional requirements are as follows:

Proposed Firm Capacity – Provide 30 mgd firm Sanitary pumping capacity at a low wet well level (Elevation [EL.] 25-ft) with any pumping unit out of service. Provide 2,030 mgd firm Storm pumping capacity with any pumping unit out of service.

Wet Well Range – Provide firm capacity throughout the existing operating wet well range of EL. 25-ft to EL. 65-ft for the Sanitary Pumps, and EL. 45-ft to EL. 75-ft for the Storm Pumps, which provides some overlap between the Sanitary and Storm Pumps.

Pump Performance – Provide pumps that operate within their Preferred Operating Range (POR) throughout this normal range and within their Allowable Operating Range (AOR) for infrequent wet weather events.

Suction Intake Conditions – Meet Hydraulic Institute (HI) recommendations for suction intake conditions for normal operating conditions. Physical modelling is being completed by Clemson Engineering Hydraulics to evaluate the conditions for the existing wet wells, both for the Storm Pumps and the Sanitary Pumps to determine modifications that are beneficial to the pump suction conditions, specifically for the Sanitary Pumps.

Power Supply Redundancy – Provide a redundant power supply to support the pumping capacity.

2.1.2 Maintenance Requirements

The recommended maintenance functional requirements are as follows:

Isolation of Individual Sanitary Pump Units – Provide the ability to reliably and safely isolate or remove the individual pumping units for maintenance without impacting the performance of the other pumping units. The existing station layout provides isolation for the Sanitary Pumps, but not for the Storm Pumps.

Isolation of Wet Wells – Provide the ability to reliably and safely isolate the Pump Station wet well to allow maintenance. This is a criterion of GLWA, as there is currently no means to prevent flow from entering the station from the two 16-ft diameter sewers. In addition, the Sanitary Wet Well is contained within the Storm Wet Well, and there is no means to separate the two wet wells.

Equipment Removal Safety – Provide provisions to enhance removal of pumps, motors, and other major mechanical or electrical equipment. Individual pump and motor removal shall not interfere with continued operation of remaining pumps.

2.2 Conner Creek Pump Station

2.2.1 Operational Requirements

The recommended operational functional requirements are as follows:

Proposed Firm Capacity – Provide 184 mgd firm Sanitary pumping capacity (increased from existing) at a low wet well level (Elevation [EL.] 62-ft) with any pumping unit out of service. Provide 2,226 mgd firm Storm pumping capacity with any pumping unit out of service.

Wet Well Range – Provide firm capacity throughout the existing operating wet well range of EL. 59-ft to EL. 65-ft. for the Sanitary Pumps, and EL. 65-ft to EL. 79-ft for the Storm Pumps.

Pump Performance – Provide pumps that operate within their Preferred Operating Range (POR) throughout this normal range and within their Allowable Operating Range (AOR) for infrequent wet weather events.

Suction Intake Conditions – Meet Hydraulic Institute (HI) recommendations for suction intake conditions for normal operating conditions. Physical modelling is being completed by Clemson Engineering Hydraulics to evaluate the conditions for the existing wet wells, both for the Storm Pumps and the Sanitary Pumps to determine modifications that are beneficial to the pump suction conditions, specifically for the Sanitary Pumps.

Power Supply Redundancy – Provide a redundant power supply to support the firm pumping capacity.

Start-up Reliability / Ease-of-Operation – Provide pumping systems that can be reliably operated in remote-manual or remote-automatic mode. Pumping systems start-up shall not be reliant on vacuum priming systems.

2.2.2 Maintenance Requirements

The recommended maintenance functional requirements are as follows:

Isolation of Individual Sanitary Pump Units – Provide the ability to reliably and safely isolate or remove the individual pumping units for maintenance without impacting the performance of the other pumping units. The existing station layout provides isolation for the Sanitary Pumps, but not for the Storm Pumps.

Isolation of Wet Wells – Provide the ability to reliably and safely isolate the Pump Station wet wells to allow maintenance. This is a criterion of GLWA, as there is currently no means to prevent flow from entering the Storm Wet Well from the two 14-ft diameter sewers. The Sanitary Wet Well currently can be isolated.

Equipment Removal Safety – Provide provisions to facilitate removal of pumps, motors, and other major mechanical or electrical equipment. Individual pump and motor removal shall not interfere with continued operation of remaining pumps.

Section 3: Pumping Improvement Concept Alternatives Analysis

This section provides a description, analysis, and comparison of alternatives.

3.1 Alternatives Analysis Methodology

3.1.1 Methodology Overview

The Arcadis Team used a step-wise approach to developing and analyzing pumping concept alternatives for improvements to the Freud and Conner Creek Pump Stations. This approach was as follows:

- PS concept feasibility screening,
- Pump-type screening evaluation, and
- Alternatives development and comparison.

Alternatives development and comparison focused on achieving the functional requirements outlined above in Section 2.

3.1.2 Pump Station Concept Feasibility Screening

Numerous pump station concept alternatives were developed in the feasibility screening phase. Three alternatives were selected for further consideration; however, other concepts were developed and vetted. Some of the alternatives not selected for further consideration (screened-out) included:

Table 3-2. Pump Station Concept Feasibility Screening	
Possible Feature	Cons/ Fatal Flaw
Conner PS Storm Pumps • Different style of priming system	• Still presents a priming system that may be complex and/or difficult to maintain
Conner PS Storm Wet Well • Modify existing wet well to be deeper and more functional	• To maintain PS during construction would require essentially a new Conner Storm Station for “temporary” bypass

3.1.3 Pump-Type Screening Evaluation

Based on knowledge of industry best practices and experience with other wastewater pump station design projects, the Project Team performed a screening evaluation of candidate pumping equipment types for use in the Freud and Conner Creek PS improvements. Table 3-1 below summarizes the screening evaluation conclusions. In brief, three pump-types were selected for further consideration: dry-pit vertical centrifugal, submersible non-clog centrifugal, and vertical axial flow column pumps.

Table 3-1. Pump-Type Screening Evaluation

Pumping Equipment Alternative		Advantages	Disadvantages	Comments/Conclusions
Dry-Pit Vertical Centrifugal Pump		• Easy access to motors and pumps for in-situ maintenance. • Robust construction well suited for solids handling. • Wide selection of products and performance curves.	• Requires deep dry-well adjacent to wet well. • Most complex facility; requires egress, HVAC, lighting, and equipment handling provisions.	• Good fit for rehabilitation of existing PS. • Selected for alternatives feasibility screening.
Submersible Non-Clog Centrifugal Pump		• No motor noise due to submergence. • Robust construction well suited for solids handling. • No external flushing water or oil/grease lube systems. • Very simple facility. • Wet-pit or dry-pit installation possible.	• Largest commercially available unit is approximately 40 mgd. • Numerous units needed for larger capacity PSs. • Wet-pit installation not readily accessible for inspection. May require maintenance at certified service centers.	• Wet-pit installation for new wet well would limit impact to residential neighborhood. • Selected for alternatives feasibility screening.
Vertical Axial Flow Column Pump		• Simple facility. Does not require dry-pit. • Does not require submersible motor. Easy access to motor. • Lower equipment cost.	• More prone to clogging. • Not well suited for solids handling (e.g. raw sewage). Common for storm water. • Requires above-ground building for motors. • Narrow POR, sensitive to intake conditions.	• Some potential, however, inferior to Non-Clog Solids Handling Vertical Column pumps. • Selected for alternatives feasibility screening.
Non-Clog Solids Handling Vertical Column Pump		• Robust construction purpose-built for wastewater solids-handling applications. • Simple facility. Does not require dry-pit. • Does not require submersible motor. Easy access to motor. • Capable of handling large solids. • Broad POR, excellent for variable speed operation.	• Access to pump bowl requires handling of motor and pump column. • Higher equipment cost. • Requires above-ground building for motors. • Large suction bell may not fit into existing wet well.	• Will not fit in existing Conner PS. • *Not selected for alternatives feasibility screening.*
Submersible Axial Flow Pump		• No motor noise due to submergence. • No external flushing water or oil/grease lube systems. • Very simple and secure facility.	• Not typically used for raw wastewater. Common for screened storm water. • Not readily accessible for inspection. • May require maintenance at certified service centers. • Narrow POR, sensitive to intake conditions.	• *Not selected for alternatives feasibility screening.*
Screw Pump		• Limited wet well size. • Can handle high solids loading.	• Very large concrete structure required. • Very high capital cost. • High potential for odors. • Large screw units are difficult to handle. • Most suitable for very low TDH applications.	• *Not selected for alternatives feasibility screening.*

3.2 Concept Alternatives Overview

Three conceptual categories were selected for further consideration. A brief description of each alternative is as follows:

- Alternative 1 – Minimum Improvements for Freud PS and Conner Creek PS.
  - Freud PS - This alternative includes the replacement of the two existing Sanitary Pumps with two submersible non-clog centrifugal pumps (30 mgd each) in the existing configuration to better cover the pumping range required. The pump station also requires isolation of the wet well which will be accomplished by constructing new junction shafts with stop gates on each of the 16-ft diameter sewers at the site along Freud Avenue.
  - Conner Creek PS - This alternative includes the addition of two new submersible Sanitary Pumps (40 mgd each) located in a new wet well on the site with connections to the existing Sanitary PS and 14-ft diameter sewers, as well as force mains to the existing Sanitary Discharge Box and the Storm Water Discharge structure (two layout options in figures). The pump station also requires isolation of the wet well which will be accomplished by constructing new junction shafts with stop gates on each of the 14-ft diameter sewers at the site. Elimination of the vacuum priming systems requires that the Storm Pumps be replaced with eight vertical column pumps installed through the existing openings in the pump room floor.
- Alternative 2 – Intermediate Improvements for Freud PS and New Conner Creek PS.
  - Freud PS - This alternative includes modification of the existing Sanitary Pumps to replace them with two Dewatering Pumps (30 mgd each) in the existing configuration. The pump station also requires isolation of the wet well which will be accomplished by constructing new junction shafts with stop gates on each of the 16-ft diameter sewers at the site along Freud Avenue. A new Sanitary Pump Station will be constructed on the north side of the site to house two new submersible non-clog Sanitary Pumps (30 mgd each). This will include 48-in diameter sewers from the Junction Shafts to the station, and two 36-in diameter force mains to the existing Discharge Chamber.
  - Conner Creek PS - This alternative includes construction of a new Conner Creek PS adjacent to the existing Conner Creek Pump Station, potentially to the west on a currently vacant parcel. The new station will include new stations for both Storm Pumps and Sanitary Pumps, with a divided wet well for the Storm pumps to allow half of the pumps to be isolated for maintenance. The Sanitary Pumps will be six new submersible non-clog pumps (40 mgd each) installed in a trench style wet well. The Storm Pumps will be twelve new vertical-column axial-flow pumps (200 mgd each, six in each wet well).
- Alternative 3 – New Combined Pump Station.
  - Freud PS & Conner PS - This alternative includes the construction of an entirely new PS adjacent to the existing Conner Creek Pump Station, potentially to the west on a currently vacant parcel. This will have a combined capacity to handle influent and effluent flows associated with both existing stations and deep enough to accept gravity flow from the existing Freud Pump Station by means of a new connecting tunnel. The concept for the new PS will include ten Storm Pumps and six Sanitary Pumps, as well as divided wet wells for both the sanitary and storm pumps to allow half of each group of pumps to be isolated for maintenance. This alternative effectively replaces the two existing stations with one new station.

3.3 Construction Cost Estimate Methodology

3.3.1 Class of Estimate

According to the Association for the Advancement of Cost Engineering International (AACE) criteria:

- A Class 5 estimate is defined as a Concept Screening Estimate.
  - Typically, project definition is from 0 to 2 percent complete.
  - Expected accuracy from -50 to +100 percent.
- A Class 4 estimate is defined as a Study or Feasibility Estimate.
  - Typically, project definition is from 1 to 15 percent complete.
  - Expected accuracy from -20 to +30 percent.

The alternatives presented in this report are still very conceptual in nature, but have been preliminarily evaluated for feasibility. Therefore, the estimates prepared for Alternatives 1, 2, and 3 are considered to be somewhere between a Class 4 and a Class 5 estimate. So, a range of uncertainty of -30 to +50 percent was applied to capital cost estimates for Alternatives 1, 2, and 3.

3.3.2 Cost Basis

The estimate was prepared using quantity take-offs, vendor quotes, and equipment pricing and construction costs from recent projects. Labor and Material construction cost data from RS Means was applied to the conceptual quantities available.

Alternatives 2 and 3 will likely require land acquisition, which introduces additional project complexity related to capital cost and construction schedule. Due to the uncertainty of associated costs, the Opinion of Probable Cost tables presented at the end of each alternative does not include dollars for land acquisition.

3.3.3 Estimate Markups

Contractor and other estimate markups are based on the following conventionally accepted values. The markups included for this evaluation are presented in Table 3-3.

Table 3-3. Estimate Markups

Item	Rate
Overhead and Profit	15%
Contractor General Conditions	12%
Contractor Startup, Training, O&M	
Building Risk, Liability, Auto Insurance	
Bonds and Insurance	
Escalation (3% per year – 3 years)	9%
Estimator’s Contingency	-30 to +50%

3.4 Alternative 1: Minimum Improvements of Existing Pump Stations

3.4.1 Description – Alternative 1

The major construction elements of Alternative 1 are presented in the bulleted list below.

- Freud Pump Station Improvements
    - Civil-Site
        - New Junction Shaft for Stop Gate – Ashland Relief Sewer
        - New Junction Shaft for Stop Gate – Fox Creek Relief Sewer
        - Provide access drives for new Junction Shafts and modify fencing.
    - Process-Mechanical
        - Replace existing Sanitary Pumps (2 pumps, 30 mgd each) and piping
        - Rehabilitate existing storm pumps (8 pumps total)
    - HVAC/Plumbing
        - Replace second steam boiler
        - Replace condensate return system
        - Replace steam unit heaters
        - Replace exhaust and supply fans serving motor room and pump shaft
        - Replace electric water heater
    - Architectural
        - Exterior brick tuckpointing and small brick repair patches for the Main Building and site retaining wall
        - Replace upper and lower membrane roofs of Main Building
        - Replace tile on top floor surface (both inside and outside of building) with more durable top slab surface that can withstand material handling and maintenance operations
        - Repair exterior concrete stairs near the west exterior top slab
        - Provide handrail along the edges of all exterior concrete slabs; use removable handrail along the east exterior loading dock slab edge
        - Provide new permanent stair access for entry to Pump Station on east exterior loading dock
        - Replace existing personnel elevator
    - Structural
        - Repair structural steel column base at loading dock
        - Provide safety cage on ladder from lower to upper roof
        - Prepare and repaint exterior structural steel lintels
        - Inspect and service overhead bridge crane
        - Repair and rebuild crane runway beam stops and repair glazed CMU block wall
        - Install pull points for material handling operations from loading dock
        - Demo and repair portions of defective concrete top slabs on north and east exterior top slabs
        - Replace existing corroding and warping grating on all exterior top slabs (north, south, east and west)

        - Demo existing steel edge angle edge of east exterior loading dock and repair exterior concrete slab edges (on top of masonry walls below) on all exterior top slabs (north, south, east and west)
        - Injection grout concrete cracks in substructure walls
        - Demo and replace damaged concrete storm pump bases and anchor bolts
        - Replace grating above and prepare and repaint structural steel framing supporting grating over lowest sump level
        - Prepare and repaint structural steel walkway members, floor plates and stair treads leading down to lowest sump level. Replace all handrail and its connections to walls and walkway members.
        - Concrete surface repairs and injection grout of walls throughout the perimeter of the lowest sump level.
        - New concrete pad with containment curb for new transformers
    - Electrical
        - Replace Outdoor Service Transformers (3 transformers, 6/7.5 MVA each)
        - Replace motor field cubicles (8 total)
        - Replace indoor switchgear dc power distribution system
        - Replace and supplement lighting to meet IES recommended illumination levels.
    - I&C
        - Retrofit aging Ovation panel
        - Retrofit heavily reworked control/mimic panel
- Conner Creek Pump Station Improvements
    - Civil-Site
        - New Junction Shaft for Stop Gate – West Jefferson Interceptor
        - New Junction Shaft for Stop Gate – East Jefferson Interceptor
        - Modify drives to access Junction Shafts and modify site fencing
        - Add ne access drive to Pump Station and improve parking lot capacity
    - Process-Mechanical
        - Rehabilitation Sanitary Pumps (4 existing pumps)
        - Construct new Sanitary wet well and install two supplemental Sanitary Pumps (2 pumps, 40 mgd each) and piping
        - Replace Storm Pumps with new vertical column pumps (8 pumps, 317 mgd each)
    - HVAC/Plumbing
        - Conner Creek Storm Water Pump Station
            - Replace second steam boiler
            - Replace condensate return system
            - Install new outside air and supply ductwork to make-up air handling unit located in the Boiler Room
            - Replace the three exhaust fans located in the upper portion of the Strom Water Pump Station upper cupola
        - Conner Creek Sanitary Pump Station
            - Replace corroded exhaust ductwork

        - Replace condensate return system
        - Replace exhaust and supply fans
        - Replace electric water heater
    - Conner Creek Primary Switchgear Building
        - Replace one of the electric unit heaters located in the Electrical Room
        - Replace electric radiant baseboard heater located in the Basement
        - Replace rooftop mounted natural gas fired make-up air handling unit
        - Replace electric water heater
    - Conner Creek New Sanitary Pump Station
        - All new HVAC systems and controls
        - All new plumbing systems
- Architectural
    - General
        - Exterior brick tuckpointing and cast stone joint repairs on Storm and Sanitary Pump Stations and Switchgear Building
    - Storm Water Pump Station
        - New gutters and downspouts
        - New roof on low roof over connection of Sanitary and Storm Pump Station
    - Sanitary Pump Station
        - Ladder from upper roof to low roof over
        - Replace existing personnel elevator
    - Switchgear Building
        - New membrane roofing
    - Misc. Site Structures
        - Provide stair for access to the top of the surge tank

- Structural
    - Storm Pump Station
        - Prepare and repaint structural steel runway beams for bridge crane (also verify adequate capacity for replacement pump weights)
        - Inspect and service overhead bridge crane (also verify adequate capacity for replacement pumps)
        - New grating platform, on top of Storm Pumps, to access storm pump shafts
        - New access hatch doors on exterior concrete patio slab and caulk exterior concrete patio slab cracks
        - Repair/patch floor openings when vacuum priming systems are removed.
        - Demo old concrete bases and pour new concrete pump bases for new Storm pumps
    - Sanitary Pump Station
        - Inspect and service overhead bridge crane
        - Provide new grating on 3rd floor (1st floor up from basement – top of steel beam EL 68.00 from record drawings) where framing exists but no grating currently exists
        - Injection grout concrete cracks in substructure walls
    - Misc. Site Structures
        - New concrete pad with containment curb for new transformers

        - Caulk existing joints and cracks in generator containment slab and fix grading to remedy portions of slab being undermined
        - Demo and repair portions of defective concrete top slab on surge tank and replace existing corroding and warping access hatches and floor plates
        - Prepare and repaint structural steel upper platform framing beams at Back-water Gate Structure

- Electrical
    - Replace Outdoor Service Transformers (2 transformers, 10 MVA each)
    - Replace and supplement lighting to meet IES recommended illumination levels.
- I&C
    - Retrofit aging Ovation panel

Figure 3-1 shows the proposed layout for Alternative 1 at the Freud Pump Station.

Figure 3-2 illustrates the proposed site improvements at Conner Creek Pump Station Alternative 1A.

Figure 3-3 illustrates the proposed site improvements at Conner Creek Pump Station Alternative 1B.

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F				DESIGNED BY: X
E				DRAWN BY: X
D				CHECKED BY: X
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SEAL / STAMP

FACILITY: FREUD PUMP STATION

PROJECT TITLE: ALTERNATIVE 1

DRAWING TITLE: BASE FREUD LOW FLOW PUMPING STATION OVERALL SITE PLAN

FIRM NAME: ARCADIS Brown AND Caldwell

GLWA Great Lakes Water Authority

MDEQ PERMIT No.

GLWA CONTRACT No.

GLWA CIP No.

SECTION MAP | TOWN | RANGE | SECTION | Q | QQ

DRAWING No. FIG. 3–1

Figure 3-1. Alternative 1 - Freud Pump Station

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F					DESIGNED BY: X	SEAL / STAMP	FACILITY: CONNER CREEK PUMP STATION
E					DRAWN BY: X		PROJECT TITLE: ALTERNATE 1A
D					CHECKED BY: X		DRAWING TITLE: CONNER CREEK SANITARY PUMP STATION OVERALL SITE PLAN
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	DESCRIPTIONS / REVISIONS	CHK'D	APPR	DATE			

FIRM NAME: ARCADIS Brown and Caldwell

GLWA Great Lakes Water Authority

MDEQ PERMIT No.

GLWA CONTRACT No.

GLWA CIP No.

SECTION MAP | TOWN | RANGE | SECTION | Q | QQ

DRAWING No. FIG. 3-2

Figure 3-2. Alternative 1A - Conner Creek Pump Station

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CHECKED BY: X
APPROVED BY: X

PROJECT TITLE: CONNER CREEK PUMP STATION
ALTERNATE 1B

DRAWING TITLE: CONNER CREEK SANITARY PUMP STATION
OVERALL SITE PLAN

ARCADIS Brown and Caldwell

GLWA Great Lakes Water Authority

SECTION MAP | TOWN | RANGE | SECTION | Q | QQ

GLWA CONTRACT No.
GLWA CIP No.
DRAWING No. FIG. 3–3

Figure 3-3. Alternative 1B - Conner Creek Pump Station

3.4.2 Analysis – Alternative 1

3.4.2.1 Discussion – Alternative 1

The main objective for Alternative 1 at both the Freud Station and the Conner Creek Station is to provide isolation for the wet wells and to firm up the Sanitary pumping capacity. In addition, the Conner Creek Station has the criteria to eliminate the vacuum priming systems, which requires that the Storm Pumps be replaced.

The Freud Station improvements include Junction Shafts for isolation of the wet well and replacement of the Sanitary Pumps to better suit the operating range and increase reliability.

The Conner Creek Station improvements include Junction Shafts for isolation of the Storm wet well and adding Sanitary Pump capacity with two additional pumps in a new wet well.

A disadvantage of this alternative is the risk and cost associated with maintaining pumping capacity during construction. It is anticipated that it is impractical to provide the full Storm Pump capacity with bypass pumping during construction due to the magnitude of the flows and poor access to install a temporary pumping system. Therefore, the proposed construction sequence below is based on upgrades to the Sanitary Pumps and diverting low flows to the Sanitary Pumps to allow work to be completed for the Junction Shafts at both stations and the Storm Pumps at Conner Creek. This will require an intermittent work schedule to complete the Junction Shafts and Stop Gates, as these will be in a "flow through" area when the Storm Pumps need to be operational.

Additionally, although maintainability of the Storm Pumps will be improved compared to the existing conditions, the existing wet well configuration would continue to provide no wet well redundancy. Wet well redundancy is a recommended industry best practice (*Recommended Standards for Wastewater Facilities*; 2014). Additionally, even with described improvements to the stations, these facilities are beyond their useful life and will likely require replacement within 40 years.

3.4.2.2 Constructability – Alternative 1

Freud Pump Station - Constructability challenges for this alternative include: maintaining pumping capacity during construction (need for bypass pumping), likelihood of unforeseen conditions, and providing adequate contractor laydown area. Bypass pumping will be required for Alternative 1, or some approach to allow construction in phases during dry periods to reduce the necessary bypass pumping capacity.

The likely sequence of construction for Alternative 1 is as follows:

1. Modify/replace the existing Dewatering Pumps to achieve the desired operating range,
2. Install the two new Junction Shafts to the extent possible without opening the 16-ft diameter sewers,
3. Cut out the sewers within the Junction Shafts to expose the flow,
4. Initiate temporary pumping for dry weather flow from the Junction Shafts to the Discharge Chamber,
5. Complete work in the Junction Shafts to install the stop gates and access for handling the gates,
6. Remove the temporary pumping.

Alternative 1 will present a challenging schedule, as all work is to be completed during low flow periods to allow the 16-ft sewers to remain open for high flow. This allows the Storm Pumps to remain on line and reduces the risk associated with bypass pumping for the full storm flow capacity. This limits work periods to dry weather when flows remain low and a weir in the Junction Shafts will provide a dry working area, although the bypass pumps would need to be secured or removed during high flow periods. Ongoing work in the Junction Shafts would require them to be cleaned as work started/stopped to continue construction until the stop gates and guides are completed.

Alternative 1 is anticipated to be contained on the existing Freud Station site, but will require the use of portions of the right-of-way for Freud Avenue and Tennessee Avenue during construction. The actual location of the existing 16-ft diameter sewers must be determined during design.

Conner Creek Pump Station - Constructability challenges for alternatives 1A and 1B include: maintaining pumping capacity during construction (need for bypass pumping), site constraints with existing infrastructure, likelihood of unforeseen conditions, and providing adequate contractor laydown area. Bypass pumping will be required for Alternatives 1A and 1B, or some approach to allow construction in phases during dry periods to reduce the necessary bypass pumping capacity.

The likely sequence of construction for Alternative 1A and 1B is as follows:

1. Modify/replace the existing Sanitary Pumps to achieve the desired operating range,
2. Install the two new Junction Shafts to the extent possible without opening the 14-ft diameter sewers, including stubs out for connections to the new Sanitary Station,
3. Install the new Sanitary Station, sewers, pumps, and discharge piping,
4. Put the new Sanitary Station into service to handle low flows in conjunction with the existing Sanitary Pumps,
5. Cut out the sewers within the Junction Shafts to expose the flow, and divert low flows to the existing and new Sanitary Stations,
6. Complete work in the Junction Shafts to install the stop gates and access for handling the gates,
7. Remove the diversion weirs to the Sanitary Stations.
8. During low flow periods, install Stop Gates and replace Storm Pumps individually to maintain station capacity. Coordination will be required to block floor openings any time a pump is removed to allow the Storm Pumps to be used during high flow periods.

Alternatives 1A and 1B will present a challenging schedule, as all work is to be completed during low flow periods to allow the 14-ft sewers to remain open for high flow. This allows the Storm Pumps to remain on line and reduces the risk associated with bypass pumping for the full storm flow capacity. This limits work periods to dry weather when flows remain low and a weir in the Junction Shafts will provide a dry working area. Ongoing work in the Junction Shafts would require them to be cleaned as work is started/stopped to continue construction until the stop gates and guides are completed.

Alternatives 1A and 1B will be contained on the existing Conner Creek Station site. The actual location of the existing sewers must be determined during design.

3.4.2.3 Construction Cost Estimate – Alternative 1

The opinion of probable construction cost is presented Table 3-4. Note that these costs include all estimate markups detailed above. The probable construction cost is bracketed with a lower and upper range also defined above.

Table 3-4. Opinion of Probable Construction Cost – Alternative 1

Estimate	Lower Range (-30%)	Probable Cost	Upper Range (+50%)
Probable Construction Cost	$41,700,000	$59,600,000	$89,400,000

- Alternative 1A and Alternative 1B are estimated to be approximately the same cost.

3.5 Alternative 2: Significant Improvements of Freud PS and New Conner Creek PS

3.5.1 Description – Alternative 2

The major construction elements of Alternative 2 are presented in the bulleted list below.

- Freud Pump Station Improvements
    - Civil-Site
        - New Junction Shaft for Stop Gate – Ashland Relief Sewer
        - New Junction Shaft for Stop Gate – Fox Creek Relief Sewer
        - Provide access drives for new Junction Shafts and modify fencing.
        - New Sanitary PS, connecting sewers and force mains
    - Process-Mechanical
        - Replace existing Dewatering Pumps (2 pumps, 30 mgd each) and piping
        - Rehabilitate existing storm pumps (8 pumps total)
        - New Sanitary Pumps (2 pumps, 30 mgd each)
    - HVAC/Plumbing
        - Replace all HVAC systems and controls
        - Replace all plumbing fixtures, equipment, and piping
    - Architectural
        - All the items listed in Alternative 1 and the following:
        - Exterior brick cleaning of Main Building and site retaining wall
        - Provide new stair to south exterior concrete slab.
        - Provide new platform or means of accessing west exterior concrete slab
    - Structural
        - All the items listed in Alternative 1 and the following:
        - Prepare and repaint portions of structural steel roof trusses and roof purlins that have experienced slight corrosion from past roof leaks
        - Prepare and repaint structural steel runway beams for bridge crane
        - Replace damaged grating pieces in 2nd and 3rd floors
        - Prepare and repaint portions of structural steel grating support beams on 2nd floor and 3rd floor
        - Install means of drainage along strip of soil between concrete slab and perimeter wall at northwest side of pad
    - Electrical
        - Replace Outdoor Service Transformers (3 transformers, 6/7.5 MVA each)
        - Replace standby generator units and medium voltage switchgear associated with generator system (2035 project)
        - Replace motor field cubicles (8 total)
        - Replace indoor switchgear dc power distribution system
        - Replace and supplement lighting to meet IES recommended illumination levels

    - I&C
        - Retrofit aging Ovation panel
        - Retrofit heavily reworked control/mimic panel
- Conner Creek Pump Station Improvements
    - Civil-Site
        - New Storm Pump Station with divided wet well and isolation stop gates
        - New Sanitary Pump Station with isolation gate
        - Provide access drives and fencing to access new facilities
        - Decommission and isolate portion of existing CC PS to be taken out of service
    - Process-Mechanical
        - Install connector pipe to existing 14-ft diameter sewers
        - Install new Junction Shaft to connect sewers to Storm and Sanitary wet wells
        - Install new Storm Pumps (12 pumps, 205 mgd each)
        - Install new Sanitary Pumps (6 pumps, 40 mgd each)
    - HVAC/Plumbing
        - All new HVAC systems and controls
        - All new plumbing systems
    - Architectural
        - No improvements to the Storm Pump Station
        - No improvements to the Sanitary Pump Station
        - Switchgear Building and Misc. Site Structures – All the items listed in Alternative 1 and the following:
            - Exterior brick cleaning of Switchgear Building
    - Structural
        - No improvements to the Storm Pump Station
        - No improvements to the Sanitary Pump Station
        - Switchgear Building and Misc. Site Structures – All the items listed in Alternative 1
    - Electrical
        - New medium voltage electrical distribution system, including service transformers, medium voltage transformers, and motor starters
        - New standby generator system, including medium voltage switchgear
        - New low voltage (600VAC and below) power distribution system
        - Indoor and outdoor lighting to meet IES recommended illumination levels
    - I&C
        - New SCADA system
        - New field instrumentation

Figure 3-4 illustrates the proposed site improvements for Alternative 2 at the Freud Pump Station.

Figure 3-5 illustrates the proposed new Conner Creek Pump Station Alternative 2.

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DRAWN BY: X
CHECKED BY: X
APPROVED BY: X

FREUD PUMP STATION
PROJECT TITLE: ALTERNATIVE 2
DRAWING TITLE: FREUD LOW FLOW PUMPING STATION OVERALL SITE PLAN

ARCADIS Brown AND Caldwell

GLWA Great Lakes Water Authority

SECTION MAP | TOWN | RANGE | SECTION | Q | QQ

GLWA CONTRACT No.
GLWA CIP No.
DRAWING No. FIG. 3-4

Figure 3-4. Alternative 2 - Freud Pump Station

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DESIGNED BY: X
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CHECKED BY: X
APPROVED BY: X

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FACILITY: CONNER CREEK PUMP STATION
PROJECT TITLE: ALTERNATE 2
DRAWING TITLE: CONNER CREEK PUMP STATION OVERALL SITE PLAN

FIRM NAME: ARCADIS Brown AND Caldwell

GLWA Great Lakes Water Authority

MDEQ PERMIT No.
GLWA CONTRACT No.
GLWA CIP No.
SECTION MAP | TOWN | RANGE | SECTION | Q | QQ
DRAWING No. FIG. 3–5

A B C D E F G H

Figure 3-5. Alternative 2 - Conner Creek Pump Station

3.5.2 Analysis – Alternative 2

3.5.2.1 Discussion – Alternative 2

The major differences between Alternative 2 and Alternative 1 are described as follows:

The Freud Station improvements are similar to Alternative 1, but adds a new Sanitary Station on the site to provide dedicated Sanitary Pumps in a new wet well that can be isolated for maintenance. This will allow the existing Dewatering Pumps to be dedicated for that purpose and sized for the required operating range.

The Conner Station improvements are more extensive as this is a replacement station with an increased Sanitary Pump capacity, and the same Storm Pump capacity which utilizes a deeper wet well to provide the proper submergence for new vertical mixed-flow pumps. This alternative requires the acquisition of new property near the Conner Creek Station. As result, there is some risk related to availability of a site and potential for delay related to property acquisition.

Similar to Alternative 1, the major benefits of this alternative are those associated with meeting functional requirements as described above. These include isolation of the wet wells, with a divided wet well at the new Conner Station, and isolation for the existing Freud Station, although it will still not have a divided wet well for redundancy (best practice).

Alternative 2 eliminates the risk related to maintaining pumping capacity during construction and electrical switchover by providing a full new permanent pumping facility prior to switchover from the existing Conner Creek Station. Property acquisition is required for the new PS site, laydown area and discharge conduits, tentatively to the west of the existing Conner Creek Station. As a result, there is some risk related to availability of a site and potential for delay related to property acquisition.

3.5.2.2 Constructability – Alternative 2

Freud Pump Station - Constructability challenges for this alternative are similar to Alternative 1, but with the addition of the new low flow Sanitary Pump Station. These include: maintaining pumping capacity during construction (need for bypass pumping), adding electrical gear for the new pumps, likelihood of unforeseen conditions, and providing adequate contractor laydown area. Limited bypass pumping can be provided by the new Sanitary Pumps for Alternative 2, to allow construction in phases during dry periods to reduce the necessary bypass pumping capacity.

The likely sequence of construction for Alternative 2 is as follows:

1. Replace the existing Dewatering Pumps to achieve the desired operating range,
2. Install the two new Junction Shafts to the extent possible without opening the 16-ft diameter sewers, including stubs out for connections to the new Sanitary Station,
3. Install the new Sanitary Station, sewers, pumps, and discharge piping,
4. Put the new Sanitary Station into service to handle low flows,
5. Cut out the sewers within the Junction Shafts to expose the flow, and divert low flows to the new Sanitary Station,
6. Complete work in the Junction Shafts to install the stop gates and access for handling the gates,
7. Remove the diversion weirs to the Sanitary Station.
8. Rehabilitate the Storm Pumps.

Alternative 2 will present a challenging schedule, as all work is to be completed during low flow periods to allow the 16-ft sewers to remain open for high flow. This allows the Storm Pumps to remain on line and reduces the risk associated with bypass pumping for the full storm flow capacity. This limits work periods to dry weather when flows remain low and a weir in the Junction Shafts will provide a dry working area. Ongoing work in the Junction Shafts would require them to be cleaned as work is started/stopped to continue construction until the stop gates and guides are completed.

Alternative 2 is expected to be contained on the existing Freud Station site, but will require the use of portions of the right-of-way for Freud Avenue and Tennessee Avenue during construction. The actual location of the existing sewers must be determined during design.

Conner Creek Pump Station - Constructability challenges for this alternative are different, as this is a new station to replace the existing Conner Creek Station. These include: acquiring adjacent property for the new station, adding electrical gear for the new pumps, likelihood of unforeseen conditions, and providing adequate contractor laydown area. Bypass pumping is not necessary as flow can be diverted from the existing station to the new station after it is on-line.

The likely sequence of construction for Alternative 2 is as follows:

1. Construct the new Conner Creek Station (shown on the parcel to the west of the existing station) with sewers and force mains to the existing discharge conduits,
2. Concurrently, construct a new Junction Shaft to connect the existing station, the new Sanitary Station, and the new Storm Station. Complete this structure without cutting through the wall into the existing station,
3. Cut out the wall to the existing station in the Junction Shaft to send flow to the new Conner Creek Station,
4. Install the Connector Pipe through the wet well of the existing station during low flow. Sanitary flow can be routed through the existing Sanitary Station during this period.
5. Decommission all of the existing Sanitary and Storm pumps and remove them from the stations.

Alternative 2 will constructed on a schedule that will be independent of current operations for the most part. Portions of the work will need to be completed during low flow periods to make connections to the new station and allow the 14-ft sewers to remain open for high flow. This allows high flows to be conveyed to the new station and reduces the risk associated with bypass pumping for the full storm flow capacity. This limits work periods to dry weather when flows remain low and are handled by the Sanitary Pumps. Ongoing work for the Connector Pipe in the existing station would require cleaning as work is started/stopped to continue construction until the stop gates and guides are completed.

Alternative 2 could be constructed on the adjacent parcel to the west of the existing Conner Creek Station. The actual location of the existing sewers must be determined during design.

3.5.2.3 Construction Cost Estimate – Alternative 2

The opinion of probable construction cost is presented Table 3-5. Note that these costs include all estimate markups detailed above. The probable construction cost is bracketed with a lower and upper range also defined above.

Table 3-5. Opinion of Probable Construction Cost – Alternative 2

Estimate	Lower Range (-30%)	Probable Cost	Upper Range (+50%)
Probable Construction Cost	$93,800,000	$134,100,000	$201,100,000

- Probable cost does not include land acquisition.

3.6 Alternative 3: New Combined Pump Station

3.6.1 Description – Alternative 3

The major construction elements of Alternative 3 are presented in the bulleted list below.

- New site location (tentatively west of existing CC PS)
- New wet well structures, two for storm pumps and two for sanitary pumps
- Connector from the existing CC PS to new Combined PS
- New 24-ft diameter connector sewer from Freud PS to new Combined PS
- New Storm Pumps (10 pumps, 475 mgd each)
- New Sanitary Pumps (6 pumps, 45 mgd each)
- Sluice gates and stop gates to isolate wet wells
- Civil work for drives, parking, fencing, and grading
- HVAC/Plumbing for pumping, operating, electrical, and office areas
- Architectural for new superstructure building
- Structural for new station and superstructure, equipment handling, and stairs
- Electrical for power, lighting, controls, and standby power
- I&C for monitoring and control of pumping and building systems

Figure 3-6, Figure 3-7, and Figure 3-8 provide an overview of the new combined pump station concept. It should be noted that is one of a few possible new pump station concepts.

[redacted]

F				
E				
D				
C				
B				
A				
	DESCRIPTIONS / REVISIONS	CHK'D	APPR	DATE

DESIGNED BY: X
DRAWN BY: X
CHECKED BY: X
APPROVED BY: X

SEAL / STAMP

FACILITY
PROJECT TITLE
CONNER CREEK AND FREUD PUMP STATIONS ALTERNATE 3

DRAWING TITLE
OVERALL SITE MAP

FIRM NAME
ARCADIS Brown and Caldwell

GLWA Great Lakes Water Authority

GLWA CONTRACT No.
GLWA CIP No.
SECTION MAP | TOWN | RANGE | SECTION | Q | QQ
DRAWING No.
FIG. 3–6

Figure 3-6. Alternative 3 – Combined Pump Station Site Plan

[redacted]

F				DESIGNED BY:
E				X
D				DRAWN BY: X
C				CHECKED BY: X
B				
A				APPROVED BY:
	DESCRIPTIONS / REVISIONS	CHK'D	APPR	DATE X

SEAL/STAMP

NEW COMBINED PUMP STATION

PROJECT TITLE

DRAWING TITLE

CONCEPTUAL PLAN

ARCADIS Brown AND Caldwell

GLWA Great Lakes Water Authority

SECTION MAP | TOWN | RANGE | SECTION | Q | QQ

GLWA CONTRACT No.

GLWA CIP No.

DRAWING No.

FIG. 3–7

Figure 3-7. Alternative 3 – Combined Pump Station Pump Layout Plan

[redacted]

F				DESIGNED BY: X
E				DRAWN BY: X
D				CHECKED BY: X
C				APPROVED BY: X
B				
A				
	DESCRIPTIONS / REVISIONS	CHK'D	APPR	DATE

SEAL / STAMP

FACILITY: NEW COMBINED PUMP STATION

PROJECT TITLE

DRAWING TITLE: CONCEPTUAL SECTION

FIRM NAME: ARCADIS Brown AND Caldwell

GLWA Great Lakes Water Authority

SECTION MAP | TOWN | RANGE | SECTION | Q | QQ

GLWA CONTRACT No.

GLWA CIP No.

DRAWING No. FIG. 3–8

Figure 3-8. Alternative 3 – Combined Pump Station Section

3.6.2 Analysis – Alternative 3

3.6.2.1 Discussion – Alternative 3

The concept of constructing a new combined pump station to replace both Freud and Conner Creek was requested by GLWA for inclusion as an alternative due to limitations and present age of both the existing stations. The tentative location for a new station is on a vacant parcel immediately adjacent and west of the existing Conner Creek Station. Key issues include:

- The proposed location for a combined station is based on space availability adjacent to the existing Conner Creek Station, and the fact that the Freud Station is essentially "landlocked". This brings up the issue of conveying flow from both stations to one site and then discharging it to the Conner Creek CSO facility. This requires flow to be conveyed from the two existing 16-ft diameter sewers at the Freud Station through a new 24-ft diameter tunnel to the new station, and providing discharge channels to convey flow to the CSO facility. The existing discharge from the Conner Creek Station will carry half of the flow and a second parallel conduit will need to be constructed and connect south of Freud Avenue.
- Significant capital investment in 60 to 90+ year old structures is not common in the water/wastewater industry primarily due to a desire to manage risk. DWSD has benefited over the years from the robust construction techniques of the early-to-mid 1900's. Unfortunately, these old facilities also limit GLWA from fully realizing the operations and maintenance efficiencies of modern design practices. In short, a new pump station would position GLWA for continued operations for the next 50 to 100 years, whereas modifying the existing Freud and Conner Creek Pump Stations will result in a functioning facility in the near term but will continue to tie GLWA to the capital replacement cycle of old facilities (e.g. routine major re-investment).

3.6.2.2 Constructability – Alternative 3

Constructability challenges for all three alternatives include: maintaining pumping capacity during construction, ease of electrical switchover, likelihood of unforeseen conditions, and providing adequate contractor laydown area.

The likely sequence of construction for Alternative 3 is as follows:

1. Construct and equip new pump station (complete),
2. Construct new Junction Shaft to consolidate influent flow,
3. Construct new tunnel to convey flow from the Freud PS to the new Combined Station,
4. Construct new discharge channels from the new station to the CSO facility,
5. Perform influent/effluent tie-ins,
6. Begin operation of new PS

Alternative 3 involves deep excavation, tunneling, and tie-ins to existing facilities. Alternative 3 eliminates the risk related to maintaining pumping capacity during construction and electrical switchover by providing a full new permanent pumping facilities prior switchover from the existing Freud and Conner Creek Stations. Property acquisition is required for the new PS site, tunnel path and discharge conduits. Figure 3-6 shows new PS to the west of the existing Conner Creek Station. As result, there is some risk related to availability of a site and potential for delay related to property acquisition.

3.6.2.3 Construction Cost Estimate – Alternative 3

The opinion of probable construction cost is presented Table 3-6. Note that these costs include all estimate markups detailed above. The probable construction cost is bracketed with a lower and upper range also defined above.

Table 3-6. Opinion of Probable Construction Cost – Alternative 3

Estimate	Lower Range (-30%)	Probable Cost	Upper Range (+50%)
Probable Construction Cost	**$181,700,000**	**$259,600,000**	**$389,400,000**

- Probable cost does not include land acquisition.

Section 4: Discussion and Recommendations

The major construction elements, advantages, disadvantages, and capital cost for the alternatives are summarized in Table 4-1.

Table 4-1. Pump Station Alternatives Summary

Alternative 1 Minimum Improvements for Freud PS and Conner Creek PS	Alternative 2 Intermediate Improvements for Freud PS and New Conner Creek PS	Alternative 3 New Combined Pump Station
Major Construction Elements		
• Rehabilitation of Storm Pumps at Freud PS • New Dewatering Pumps (2 x 30 mgd) at Freud PS • New Storm Water Pumps (8 x 317 mgd) at Conner PS • Rehabilitation of existing Sanitary Pumps at Conner PS • New additional Sanitary Pumps (2 x 40 mgd) at Conner PS • Significant temporary bypass pumping • Significant constructability challenges to maintain PS operation during construction • New wet well isolation at both PS • Eliminate vacuum priming system at Conner PS	• Property acquisition (adjacent property) • Rehabilitation of Freud PS • New Sanitary Pump Station at Freud PS • New Sanitary (6 x 40 mgd) and Storm (12 x 200 mgd) PS at Conner with 2 wet wells • New wet well isolation at both PS • New connection piping at both PS	• Significant property acquisition • All new 4 bgd PS, 2 wet wells • 6 x 45 mgd Sanitary Pumps • 10 x 475 mgd Storm Pumps • New tunnel connection to influent sewers at existing Freud PS • New discharge channel (parallel existing discharge channel) to existing CSO • New wet well and junction chambers • Abandonment of Freud PS and Conner PS
Advantages		
• Lowest capital (initial) cost • Meets most functional requirements • Construction activities contained within existing property, plus right-of-way	• Meets all functional requirements • Improves operational reliability with new Sanitary Pump Station at Freud PS • Two wet wells at Conner PS increase redundancy, reliability, and maintainability • Eliminate expensive routine maintenance and O&M costs at 90+ year old Conner PS • Reduced bypass pumping / risk • Can take advantage of modern pumping equipment and PS design concepts at Conner PS	• Lowest long-term O&M • Can take full advantage of modern pumping equipment and PS design concepts • Most energy efficient option (pumping and facility) • Reduced temporary bypass pumping / lowest risk • Longest useful life for overall facility
Disadvantages		
• Risks/Limitations/Costs of existing Conner PS superstructure still exist • Least favorable match to functional needs	• Substantial Capital cost	• Highest Capital cost • Risk of tunneling construction near residential area
Cost		
• Capital Cost: $59.6M	• Capital Cost: $134.1M	• Capital Cost: $259.6M

A qualitative comparison of the alternatives related to their ability to meet the functional performance requirements described in Section 2 is presented as Table 4-2.

Table 4-2. Functional Requirements Qualitative Comparison

	Alt 1 – Minimum Improvements for Freud PS and Conner Creek PS	Alt 2 – Intermediate Improvements at Freud PS and New Conner Creek PS	Alt 3 – New Combined Pump Station
Operational Requirements (Freud PS / Conner PS)			
Firm Capacity	Good / Good	Good / Best	Best / Best
Wet Well Range	Good / Limited	Good/ Best	Best / Best
Pump Performance	Good / Good	Better	Best / Best
Suction Intake Conditions	Good / Limited	Good/ Best	Best / Best
Power Supply Redundancy	Good / Good	Good / Good	Good / Good
Maintenance Requirements (Freud PS / Conner PS)			
Pump Isolation	Limited	Better	Best
Wet Well Isolation	Good	Better	Best
Equipment Removal Safety	Limited	Better	Best

The Arcadis Team's recommended ranking of the three alternatives is presented here:

1) Alternative #2 – New Freud Sanitary PS and new Conner Creek PS – This alternative receives the highest ranking, as it satisfies most of the operational and maintenance requirements. Although this alternative is still tied to the aging Freud Pump Station, the Storm Pump configuration is acceptable and the addition of a new Sanitary Pump Station allows for improved isolation and maintenance. The new Conner Creek Pump Station achieves all of the requirements for divided (redundant) wet wells, improved pump isolation, and wet wells that are in compliance with HI Standards for proper pump suction hydraulics.

2) Alternative #3 - New Combined Pump Station – This alternative receives the second highest ranking because it does satisfy all of the operational and maintenance requirements, but at a significantly higher cost. Also, property acquisition, construction of the connecting tunnel between the pump stations, and the final construction is likely to take a significant amount of time to complete.

3) Alternative #1 – Rehabilitation of Existing PS Configuration – This alternative receives the lowest ranking due to the limited long-term benefits that it provides. While the primary objectives are met by providing isolation of the storm wet wells at both stations and elimination of the vacuum priming system at Conner Creek, there are other issues that remain. The Freud Pump Station still has the sanitary wet well within the storm wet well and this cannot be separately isolated. While the Conner Creek Storm Pumps can be replaced with vertical column pumps, these likely will not have sufficient submergence to meet the required Net Positive Suction Head (NPSHr), due to the existing configuration of the station and the limited depth available in the wet well. We believe that the NPSH requirements can be achieved at high wet well levels, but not for lower operating levels in the normal pumping range.

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A6 – Physical Model Tests Performed for Connors Creek and Freud PS

CLEMSON ENGINEERING HYDRAULICS

CONNER STORMWATER PUMP INTAKE STRUCTURE PHYSICAL HYDRAULIC MODEL STUDY

Final Report

Conducted For

Arcadis

CEH Report No. 703-18

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CONNER STORMWATER PUMP INTAKE TRUCTURE PHYSICAL HYDRAULIC MODEL STUDY

Final Report

Conducted For

Arcadis

CEH Report No. 703-18

February, 2018

Prepared by:

Matthew Havice, P.E.
Project Engineer

Approved by:

David E. Werth. Ph.D., P.E.
Principal Engineer

EXECUTIVE SUMMARY

A physical model of the Conner Creek storm water pump intake was conducted. A 1:14.0 scale physical model was constructed, and tests were conducted to determine the nature and severity of any adverse hydraulic conditions that may affect pump performance.

Initial testing showed that overall conditions in the wet-well were dependent on the number of pumps in operation with conditions deteriorating as more pumps come online. Single pump operation resulted in in relatively calm conditions in and around the pumps and conditions were extremely turbulent and unstable with all pumps operating. In general, the overall turbulence resulted in some air entrainment as flow entered the wet-well. Given the relatively small wet-well footprint and the close proximity of the pumps to the influent pipes, this resulted in consistent air entrainment in the pumps at the maximum station flows. Less air entrainment was observed at lower flows.

Strong floor vortices were observed under all pumps. No other submerged vortex activity was observed. Intermittent surface vortex activity was observed when only a single pump was operating. With more than one pump in operation surface vortex activity was typically flushed out due to the overall circulation and instability. Pre-swirl values were unstable, and varied dependent on which pumps were operating. For some tests, overall values were very high and well outside of criteria. Velocity and turbulence levels were generally in criteria, but again, depending on which pumps were in service, the turbulence levels did increase. The long suction tubes helped to condition the flow by providing time for the flow to stabilize prior to reaching the pump location. However, vortices and swirl clearly reached the pump impeller location and air entrainment was observed entering the pumps.

Floor cones incorporating eight (8) vanes were installed under Pumps 1-4. Testing showed these were very effective at eliminating floor vortex activity. Model observations showed that the circulation around the pump suctions pulled air into the pump suctions. The floor cones minimized this circulation which significantly reduced the amount of air bubbles entrained and concentrated in the flow around the pumps and therefore reduced the amount entering the pumps. Model observations showed a significant reduction in air entering the pumps with the cones versus those without the cones. It is noted that with the modifications installed, overall conditions remained turbulent and unstable around the pumps but the cones improved flow as it entered the suction tubes. With the cones installed pre-swirl; as well as velocity and turbulence variations were within HI criteria but some air entrainment is still possible.

It is recommended that a floor cone be installed under each pump. The recommended modifications can be seen on Figures 5-1 and 5-2.

1.0 INTRODUCTION

1.1 Background

Clemson Engineering Hydraulics, Inc. (CEH) conducted a physical hydraulic model study of the Conner Creek storm water pump intake structure for Arcadis. The Conner Creek storm water pump station consists of eight (8) pumps, each rated at 500 cfs for a firm station capacity of 3,500 cfs. The pumps are located in two rows of four (4) within a rectangular wet well which is fed from one end by two large 14-ft diameter influent shafts. The existing pumps are bottom suction pumps which withdraw flow vertically from the wet well from a draft tube with an 11'-8" inlet flare. No remedial or anti-vortex devices are present.

The model was used to evaluate the hydraulic conditions within the intake and to determine any adverse hydraulic phenomena that may exist within the intake. In addition, the model was used to develop recommended modifications to remediate any adverse hydraulic phenomena, which could impact pump performance.

1.2 Objective

The objectives of this model study were as follows:

- Evaluate the performance of the intake structure to determine if any potential problems may exist with the approach flow hydraulics that may adversely impact the performance of the pumps.

- If necessary, develop modifications to the design or implement corrective measures that would mitigate or eliminate problems associated with the adverse approach flow.

- Test and document the approach flow conditions in the sump with the final recommended modifications in place.

1.3 Sump Hydraulics & Pump Problems

The pump manufacturer typically develops pump curves at the manufacturing facility. The head-flow curves, efficiencies, net positive suction head, and power requirements are usually determined by conducting a pump test with the actual prototype pump or a geometrically similar model. This pump test is conducted in a controlled environment with uniform approach flow to the pumps. Therefore, to ensure that the pump will perform as tested at the manufacturing facility; the prototype field installation must also have similarly uniform approach flow conditions.

Failure to provide uniform approach flow hydraulics can result in pump performance that differs significantly from that predicted from the performance curves. The pump may not operate at its best efficiency point, flow or head may be less than expected, power requirements may vary, and if the approach flow conditions vary enough, significant damage could occur to the pump itself.

Pump sumps are often designed to adhere to the 2012 Hydraulic Institute Standards (HI 2012). A consortium of pump manufactures, engineers, and end users developed these standards. Failure to adhere to these standards can lead to a number of problems including air entrainment, vortex activity, skewed velocity distributions and turbulence at the pump impeller. Research has shown that these conditions can lead to fluctuating loading on pump impellers, vibration, cavitation, and decreased flow and efficiency (Sweeney and Rockwell 1982).

Following the HI standards helps to minimize adverse approach flow conditions within the pump sump. However, the standards were developed for pumps with individual capacities of 40,000 gallons per minute (gpm) or less, and overall station capacities of less than 100,000 gpm. When dealing with systems that exceed these capacities, it is necessary to utilize physical and numerical modeling techniques to investigate the hydraulic conditions within the sump.

Physical models are used to evaluate the level of temporal velocity fluctuations, or turbulence, within the pump bell. Changes in pressure are directly related to changes in velocity. Therefore, velocity fluctuations, whether temporal, or as a result of skewed approach flow, can cause pressure fluctuations on the pump impeller. These pressure fluctuations translate into a loading imbalance on the pump shaft, possibly causing vibration or pre-mature bearing wear.

Physical models are also used to evaluate the uniformity of the flow within the pump bell. Should more flow be traveling down one side of a pump bay than the other, such as that which occurs when there is flow separation at the bay entrance, the velocity may be higher on one side of the impeller or the other. This may cause pre-swirl of the flow entering the pump. Depending on the direction of the pre-swirl relative to the pump rotation, this may cause the pump to consume more or less power than anticipated, resulting in the pump operating at a point other than its best efficiency. The pre-swirl may also result in the flow hitting the impeller blade at an angle of attack other than what it was designed for. This can result in localized flow separation on the impeller. These separation zones can cause low-pressure regions, which result in localized areas of cavitation.

Vortices are another hydraulic phenomenon with which physical models are used to identify and eradicate. Vortices are localized regions of high velocity swirling flow. The velocity at the core of a vortex can be high enough that the pressure falls below the vapor pressure of the fluid. If the vortex forms below the surface, it is called a submerged vortex, and can result in vapor being pulled out of suspension. If it forms as a surface vortex, it can pull a vapor core into the pump. Either of these vortices can result in air entrainment or cavitation within the pump. Depending on the system, this entrained air may be able to accumulate within the downstream piping network, possibly causing damage to other system components. The low-pressure core of a vortex can also lead to localized cavitation, noise, decreased pump capacity, and vibration.

Numerical modeling of pump sumps is a relatively new approach to investigating wet well hydraulics. The ability of numerical models to predict the general flow patterns within the sump is constantly improving. However, numerically modeling highly mobile surface vortices presents a challenge. Research is constantly being conducted to improve the ability to numerically predict mobile vortex activity. However, at the present, physical models remain the only method available to reliably simulate mobile prototype vortex activity.

2.0 MODEL SCALING AND ACCEPTANCE CRITERIA

2.1 Model Scaling

To obtain accurate results from a physical model study, there must be dynamic similitude between the model and the prototype. To satisfy this requirement, there must be exact geometric similitude. In addition, the ratio of the dynamic pressures must also be maintained. Strictly satisfying dynamic similitude requires a 1:1 scale model. This is usually not feasible, so some compromise is made. To accomplish this, geometric similarity is maintained and the dominant forces associated with the prototype are determined and maintained between the model and prototype.

The primary forces that affect fluid flow are viscosity, surface tension, velocity (inertial), pressure, gravity and elastic forces. In structures with a free surface, such as a pump intake, gravitational and inertial forces are far greater than the viscous and turbulent shear forces. Therefore, when modeling free surface structures, geometric similarity and the ratio of inertial to gravitational forces, or the Froude number, is maintained between the model and prototype.

Simply holding the Froude number constant violates the strict definition of dynamic similitude. However, if the model is operated within a high enough range of Reynolds numbers, viscous and surface tension scale effects may be minimized. The 2012 Hydraulic Institute Standards (HI 1998) recommends that the minimum Reynolds number at the bell be greater than 6 x 10^4. Therefore, when choosing the model scale, it is necessary to ensure that the scaled flow rate will result in a high enough Reynolds number to minimize scale effects. It is common to be conservative and select a scale that results in a Reynolds number greater than 1 x 10^5.

Upon selecting an appropriate model or length scale, it is possible to determine relationships such as velocity, flow, and pressure between the model and prototype. This is accomplished by setting the model and prototype governing equations equal to one another. As mentioned above, the governing equation is determined by evaluating the dominating forces. These equations are typically dimensionless numbers such as the Froude, Reynolds, Weber, Euler, or Mach numbers. These common modeling relationships are shown below:

$$\text{Froude Number} \quad F = \frac{U}{\sqrt{gL}} = \frac{\text{Inertial Force}}{\text{Gravity Force}} \qquad (2\text{-}1)$$

$$\text{Reynolds Number} \quad Re = \frac{UL}{\nu} = \frac{\text{Inertial Force}}{\text{Viscous Force}} \qquad (2\text{-}2)$$

$$\text{Euler Number} \quad E = \frac{\rho U^2}{\Delta P} = \frac{\text{Inertial Force}}{\text{Pressure Force}} \qquad (2\text{-}3)$$

$$\textit{Weber Number} \qquad W = \frac{U}{\sqrt{\sigma/\rho L}} = \frac{\textit{Inertial Force}}{\textit{Surface Tension Force}} \qquad (2\text{-}4)$$

$$\textit{Mach Number} \qquad M = \frac{U}{\sqrt{K/\rho}} = \frac{\textit{Inertial Force}}{\textit{Compressive Force}} \qquad (2\text{-}5)$$

Where:

U = characteristic velocity
g = gravitational constant
L = characteristic length
ρ = fluid density
ΔP = pressure difference
ν = kinematic viscosity of the fluid
σ = surface tension of the fluid
K = bulk modulus of elasticity of the fluid

If the governing equation is held constant between the model and prototype, the corresponding model flow rate, velocity, pressure, etc., can be solved directly. For example, setting the Froude number of the model equal to the prototype yields the following relationships, where the subscripts *p* & *m* denote prototype & model, respectively:

$$F_P = F_m \qquad (2\text{-}6)$$

$$\frac{U_p}{\sqrt{gL_p}} = \frac{U_m}{\sqrt{gL_m}} \qquad (2\text{-}7)$$

Using equation 2-7, the model velocity, and therefore, the flow rate Q can be solved for if the prototype velocity and length ratio is known. Typically, the model parameters are solved for based on the prototype to model length ratio, L_P/L_M, or L_R. Doing so yields the following equations for Q & U:

$$\frac{Q_p}{Q_m} = L_R^{5/2} \qquad (2\text{-}8)$$

$$\frac{U_P}{U_M} = \sqrt{L_R} \qquad (2\text{-}9)$$

Using these equations, it is possible to determine the flow rates at which the model should be operated. The Conner storm water model was constructed at a 1:14.0 scale. The resulting pump bell Reynolds number was approximately 1.0×10^5 and the resulting Weber number was in excess of 500.

2.2 Acceptance Criteria

In addition to choosing an appropriate scale with which to construct the model, it is important to evaluate the performance of the model against a set of pre-determined acceptance criteria. The criteria used for this model study closely follow those suggested in the 2012 Hydraulic Institute Standards and are as follows:

1. No organized free surface or submerged vortices greater than a Type 1 (general rotation) should be permitted at Froude scaled flow rates

2. Pre-swirl should be less than 5-degrees at the pump impeller location (ideally less than 2.5-degrees per best practice)

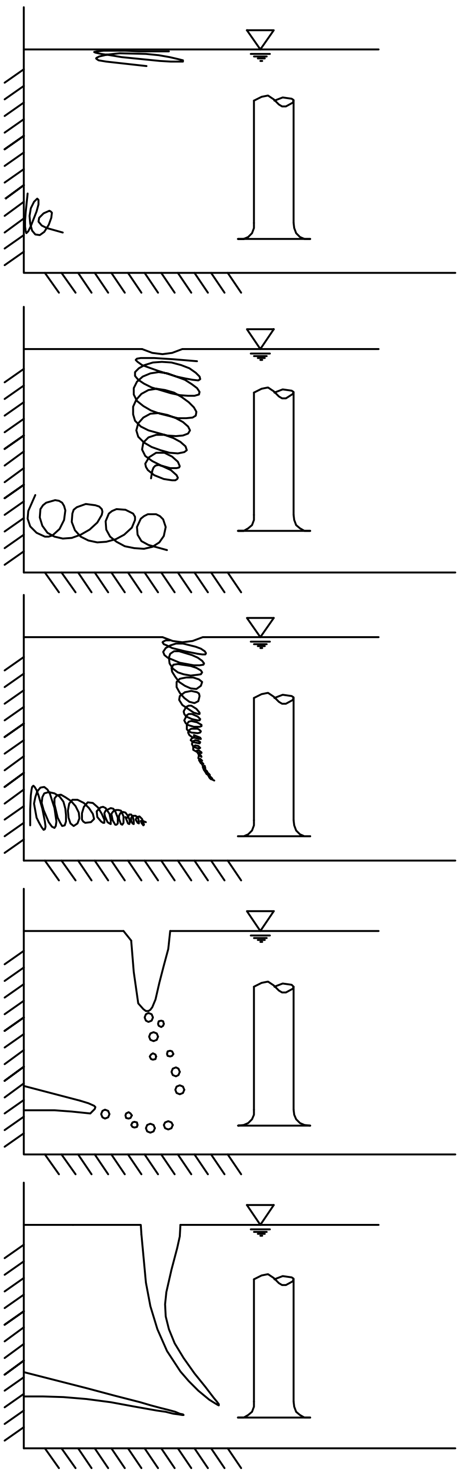
3. Time averaged velocities within the pump throat should deviate less than 10 percent of the cross-sectional area average velocity

4. Time-varying velocity fluctuations (turbulence) at a point within the pump throat should be less than 10 percent

5. These criteria will meet 2012 Hydraulic Institute test specifications.

Vortex activity is evaluated qualitatively. The Hydraulic Institute Standards suggest using a scale of 1 to 6 to rank the severity of a vortex. A scale of 1 to 5 was utilized for this study, with a Type 1 being the least severe and a Type 5 being the most severe, pulling air and trash into the intake. HI varies slightly by ranking a vortex that pulls trash into the intake as a Type 5 and one that pulls air as a Type 6. However, since the acceptance criteria do not permit vortices greater than a Type 1, this variation of the HI scale does not have any effect on the outcome of the model study. Figure 2-1 presents a graphical representation of the vortex ranking used in this study.

FIGURE 2-1
SURFACE & SUB-SURFACE VORTEX CLASSIFICATION



TYPE 1
SURFACE OR SUBSURFACE SWIRL

TYPE 2
SURFACE OR SUBSURFACE DIMPLE
COHERENT SWIRL

TYPE 3
ORGANIZED DYE CORE TO THE INTAKE
COHERENT SWIRL THROUGHOUT WATER
COLUMN

TYPE 4
COHERENT SWIRL AND ORGANIZED DYE CORE
PULLING BUBBLES AND SOME AIR INTO THE INTAKE

TYPE 5
COHERENT SWIRL AND SOLID AIR/VAPOR CORE PULLING DEBRIS
AND AIR INTO THE INTAKE

3.0 THE MODEL

3.1 Model Boundaries

When evaluating the portions of the pump station that are to be included in the model, it is necessary to include any components that could affect the approach flow to the pumps. This is first determined by evaluating the upstream and downstream controls. In this application, an upstream hydraulic control is a structure or component that controls the downstream flow. This may be a change in grade that results in critical flow, a sluice gate or opening that directs the flow, or simply a long stretch that results in uniform flow conditions. The Conner storm water intake structure is fed via two 14-ft diameter influent lines. A portion of both of these were included in the model and serve as the upstream model boundaries. The existing pumps are bottom suction pumps which withdraw flow vertically from the wet well from a draft (suction) tube with an 11'-8" inlet flare. No remedial or anti-vortex devices were present. The internal geometry of the wet-well was included in the model. In addition, all eight (8) pumps were included and simulated in detail.

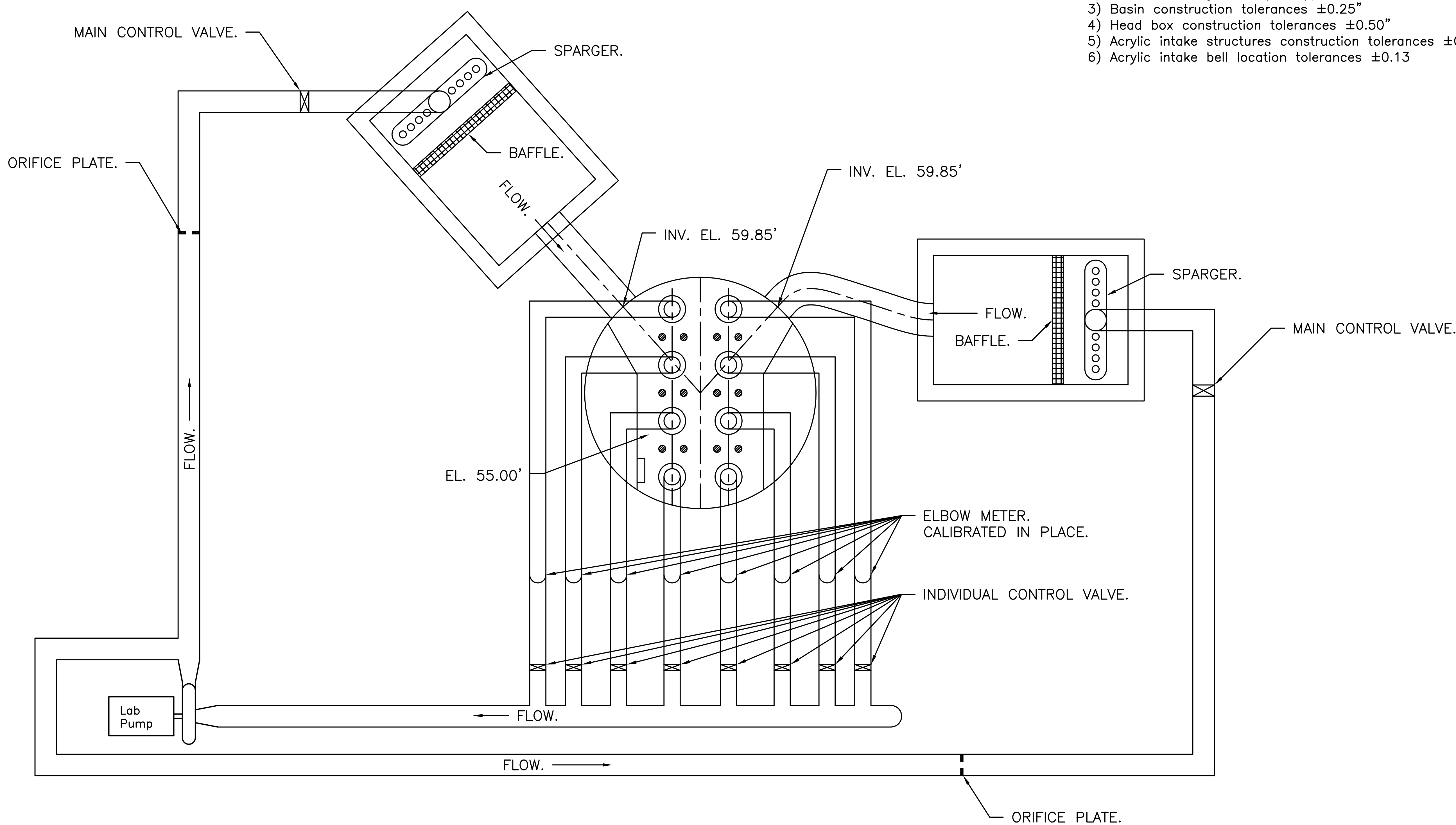
Physical model studies are used to evaluate the approach flow and ensure that the flow is uniform up to the pump impeller. Therefore, the downstream model boundary was chosen as the entrance to the pump impeller. It is not necessary to include a model pump impeller because the pump performance is tested at the manufacturer's facility. The manufacturers test was conducted with uniform approach flow conditions. Therefore, with other design consideration being equal, if those conditions can be duplicated in the prototype structure, the performance of the pump in the field should match that determined by the manufacturer.

3.2 Model Construction

The model was constructed on a raised deck to facilitate viewing and data collection. The model head box, floor, and sidewalls were constructed with waterproof wood. The model pumps, intake piping and pump bells were fabricated out of clear acrylic up to the impeller location. The additional piping was fabricated out of PVC pipe. Friction losses within the model limits are negligible when compared to form or boundary losses. Therefore, it is assumed that materials mentioned above were appropriate for model construction.

The overall model basin was constructed with a tolerance of +/- 0.25 model inches. The model pump throats were constructed to within +/- 0.06 model inches. Valves were used to control the individual pump flows as well as the total model flow. A pump was installed downstream of the model pumps to re-circulate flow back to the model head box. Flow straightening devices were installed in the model head-box to ensure that flow entering the head box was uniform. Figures 3-1 through 3-4 and Photos 3-1 through 3-3 show the model.

Note: 1) All dimensions given in model inches
2) All elevations given in prototype feet
3) Basin construction tolerances ±0.25"
4) Head box construction tolerances ±0.50"
5) Acrylic intake structures construction tolerances ±0.06
6) Acrylic intake bell location tolerances ±0.13



Model Scale: 1 model inch =14 prototype inches (1:14)

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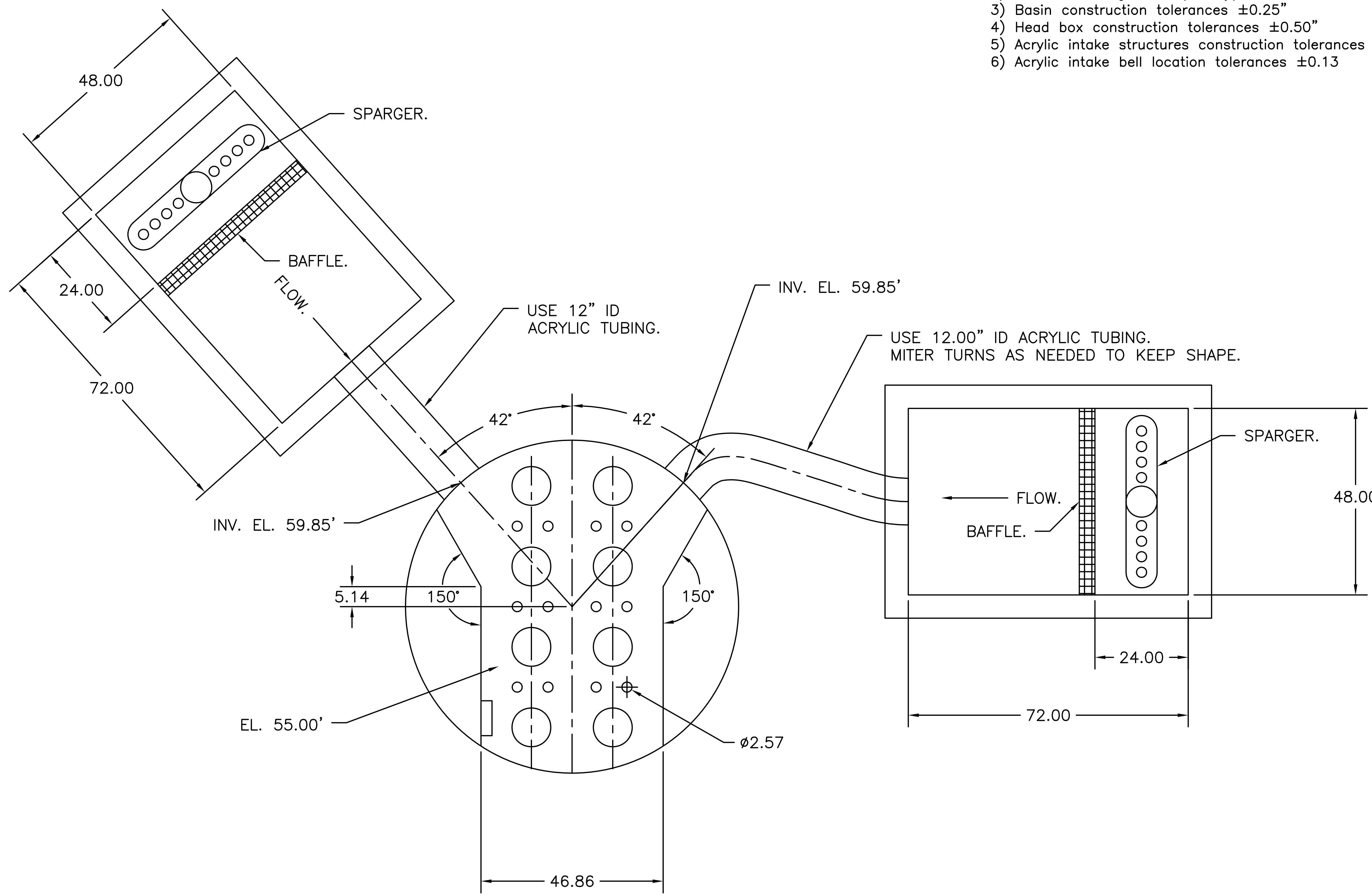
FIGURE 3–1
MODEL OVERVIEW
CONNER STORM
ARCADIS

Note: 1) All dimensions given in model inches
2) All elevations given in prototype feet
3) Basin construction tolerances ±0.25"
4) Head box construction tolerances ±0.50"
5) Acrylic intake structures construction tolerances ±0.06
6) Acrylic intake bell location tolerances ±0.13



Model Scale: 1 model inch =14 prototype inches (1:14)

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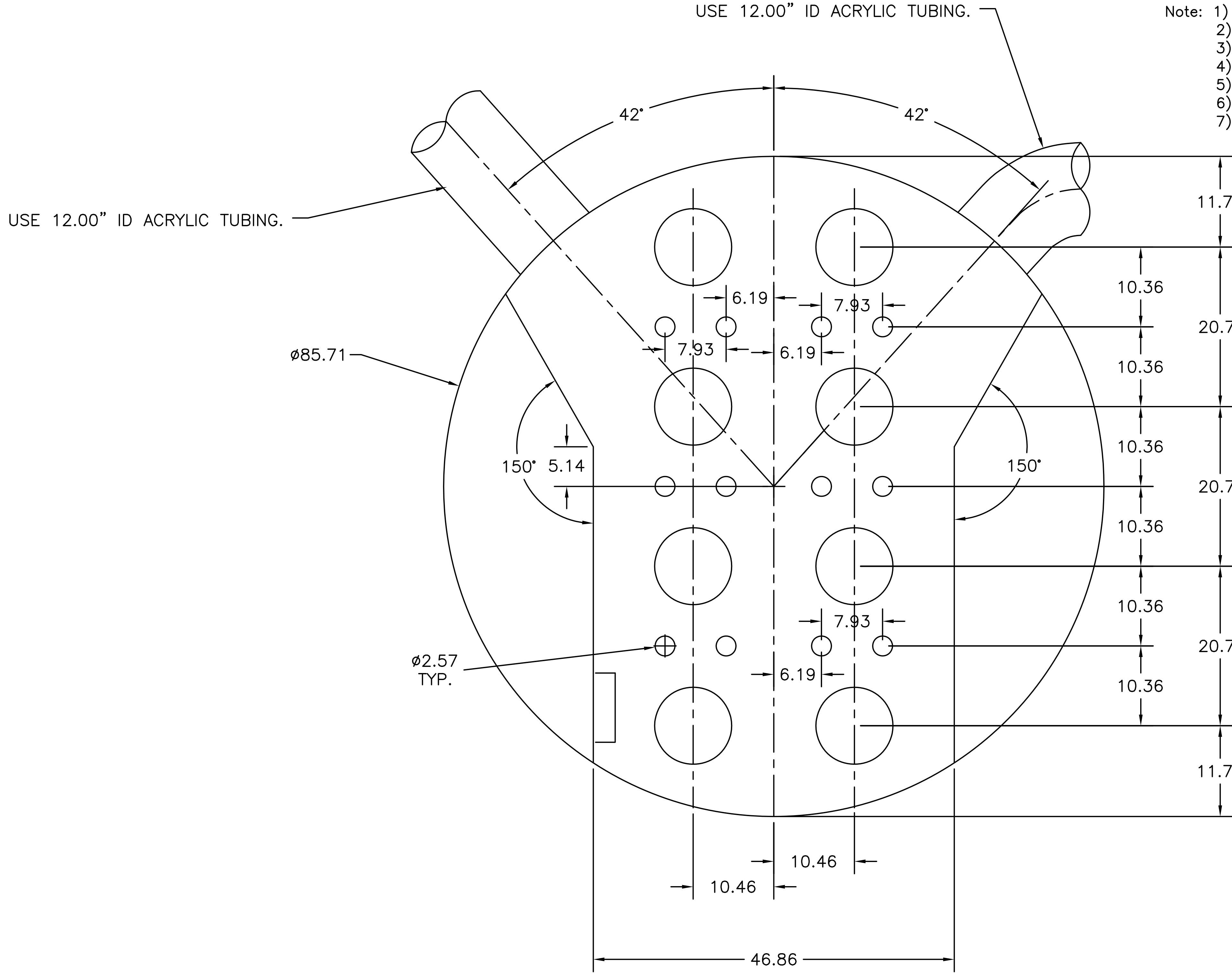
FIGURE 3-2
MODEL LAYOUT DETAILS
CONNER STORM
ARCADIS



Note: 1) All dimensions given in model inches
2) All elevations given in prototype feet
3) Basin construction tolerances ±0.25"
4) Head box construction tolerances ±0.50"
5) Acrylic intake structures construction tolerances ±0.06
6) Acrylic intake bell location tolerances ±0.13
7) Many dimensions were scaled

Model Scale: 1 model inch =14 prototype inches (1:14)

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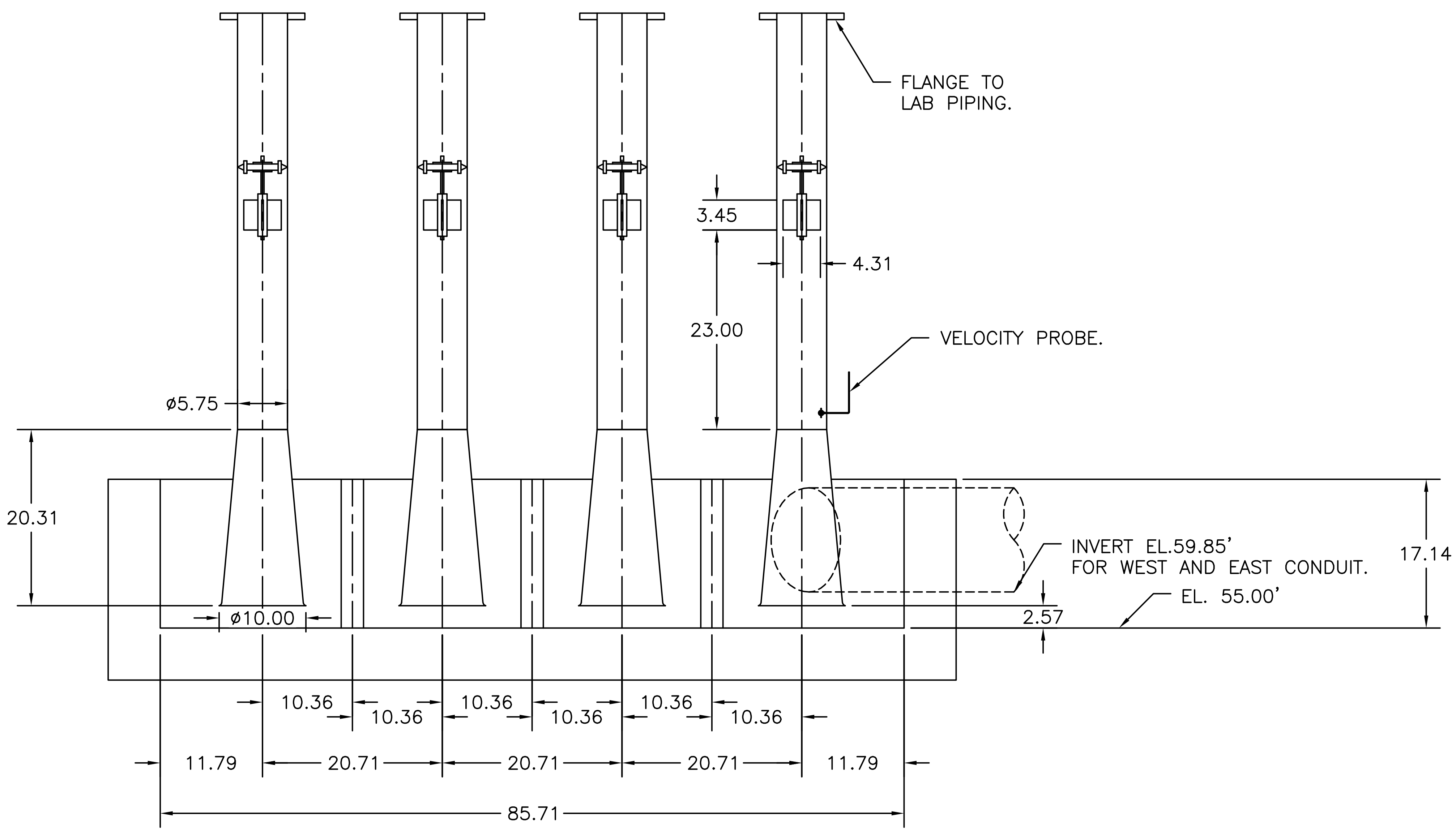
FIGURE 3–3
MODEL SUMP LAYOUT DETAILS
CONNER STORM
ARCADIS

Note: 1) All dimensions given in model inches
2) All elevations given in prototype feet
3) Basin construction tolerances ±0.25"
4) Head box construction tolerances ±0.50"
5) Acrylic intake structures construction tolerances ±0.06
6) Acrylic intake bell location tolerances ±0.13
7) Many dimensions were scaled



Model Scale: 1 model inch =14 prototype inches (1:14)

NO.	DATE:	REVISION	DRAWN:	CHK. BY:

DRAWING SCALE:	DRAWN: K. Davy	DATE: 8/7/2017	PROJECT NO:
1:30	FILE NO: Plan	CHECKED:	

FIGURE 3-4
MODEL ELEVATION DETAILS
CONNER STORM
ARCADIS

Photo 3-1 Model Overview

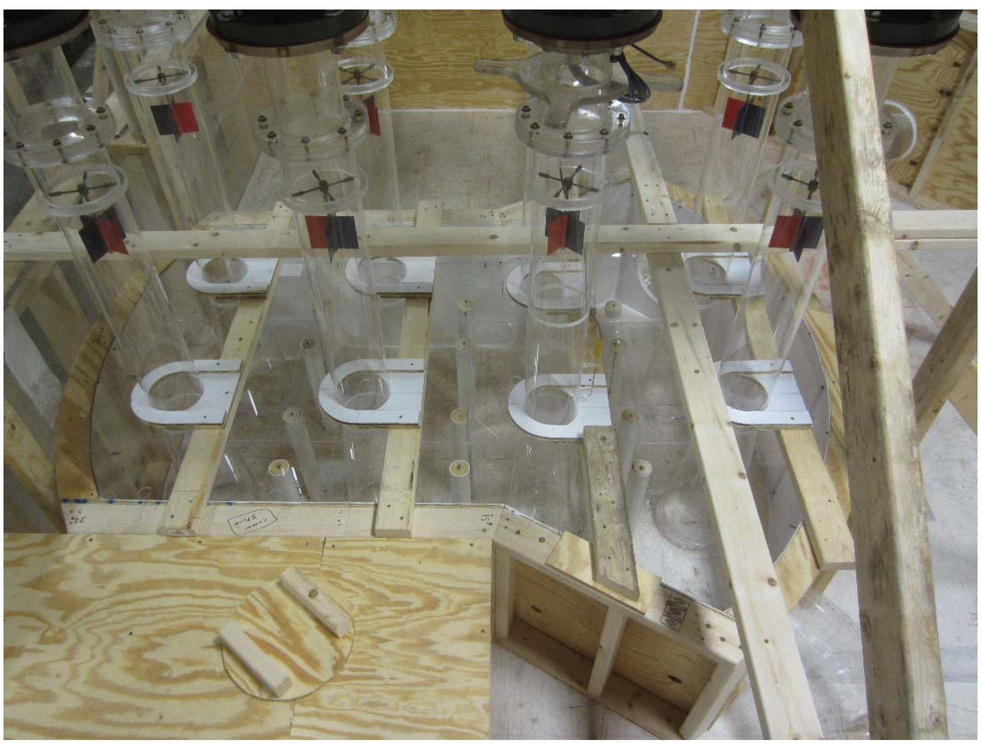


Photo 3-2 Alternate Overview

Photo 3-3 Model Pumps – Suction Tube

4.0 INSTRUMENTATION AND TESTING PROCEDURES

4.1 Instrumentation and Data Collection

The individual model pump flow rates, as well as the total model flow rate were determined with an ASME standard orifice meter with an accuracy of +/- 2 percent or better. Mercury U-tube manometers as well as a Dwyer Series 475 differential manometer were used to measure the manometer deflection. The Dwyer manometer was calibrated prior to the model study. Valves were adjusted in the model piping until the manometer deflections indicated that the proper flow rates were set.

The water levels in the pump sump were recorded with a staff gauge referenced to the sump floor with an accuracy of 3-mm (0.01-ft) or better). Vortex formation was visually observed. Dye was used to aid in the visualization of vortex formation. Vortex strength was rated according to the scale presented in Figure 2-1. Digital photographs and video footage were also used to document vortex formation.

Velocity fluctuations and turbulence levels were measured just upstream of the pump bell. A free spinning miniature propeller Model 412 Nixon Streamflow probe was used to measure the velocities. A data acquisition board was connected to the Nixon probe and recorded approximately 9000 samples over a 30-second period. The software program HPVEE was used to record this data and determine the mean and standard deviation of the velocity data. The pump bell was attached to a turn-column, which allowed the velocity probe to be rotated 360 degrees. Velocities were collected at 8 points around the pump bell, at a fixed radius, in 45-degree increments.

A swirl meter was installed in each detailed pump to measure the level of pre-swirl of flow entering the pump. Each swirl meter consists of 4 straight vanes mounted on a shaft. The swirl angle can be calculated with the following equation:

$$\theta = \tan^{-1}\left(\frac{\pi dn}{u}\right)$$

Where: u = average axial velocity
d = diameter of the pipe in which the swirl meter is installed
n = revolutions per second of the swirl meter

4.2 Test Program

Testing is conducted in three phases, baseline, modification, and final documentation testing. Each of these phases is described below:

- Baseline Testing: Tests were conducted with the intake structure as designed. These tests were conducted to evaluate the approach flow conditions, and to determine if any adverse hydraulic phenomena were present. In general, vortex activity, pre-swirl, velocity distribution, turbulence levels, and overall approach flow conditions were evaluated.

- Modification Testing: Tests were conducted to develop modifications that would alleviate or minimize any potentially damaging hydraulic conditions within the sump. These tests were conducted systematically to minimize design changes while still meeting the pre-determined acceptance criteria.

- Final Documentation Testing: Following the witness test, documentation testing is conducted to verify that the recommended modifications are effective for a range of expected operating conditions.

5.0 TEST RESULTS

5.1 Baseline Testing

Baseline tests were conducted for the station with several possible operating conditions. These tests were conducted at low and high water levels. In general, the following observations were made:

1. Initial testing showed that overall conditions in the wet-well were dependent on the number of pumps in operation with conditions deteriorating as more pumps come online. Single pump operation resulted in in relatively calm conditions in and around the pumps and conditions were extremely turbulent and unstable with all pumps operating.
2. In general, the overall turbulence resulted in some air entrainment as flow entered the wet-well. Given the relatively small wet-well footprint and the close proximity of the pumps to the influent pipes, this resulted in consistent air entrainment in the pumps at the maximum station flows. Less air entrainment was observed at lower flows.
3. Strong floor vortices were observed under all pumps. No other submerged vortex activity was observed. Intermittent surface vortex activity was observed when only a single pump was operating. With more than one pump in operation surface vortex activity was typically flushed out due to the overall circulation and instability.
4. Pre-swirl values were unstable, and varied dependent on which pumps were operating. For some tests, overall values were very high and well outside of criteria.
5. Velocity and turbulence levels were generally in criteria, but again, depending on which pumps were in service, the turbulence levels did increase. The long suction tubes helped to condition the flow by providing time for the flow to stabilize prior to reaching the pump location. However, vortices and swirl clearly reached the pump impeller location and air entrainment was observed entering the pumps.

A summary of the baseline testing is shown in Table 5-1.

Table 5-1 Baseline Data Summary

Note: Pumps 1-4 are on the upstream right; Pump 5-8 are on the upstream left side. Pump 2 was instrumented with a velocity probe. All pumps were instrumented with rotometers. Velocity fluctuations should be less than 10%, pre-swirl should be less than 5.0-degrees (ideally less than 2.5), and no vortices greater than type 1 or weak type 2 should enter the pump.

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 1	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	I 3	none	none	C 2-3	none	No probe installed			1.1
Pump 2	0									
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									

Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Overall conditions are relatively stable
Flow around the wet-well approaches the pump – intermittent stalling and drifting observed
Flow enter the suction tube uniformly around the circumference
Floor vortex is consistent bit does not fully organize
Surface vortex is stable and well developed

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 2	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	500	I 4-5	none	none	C 2-3	none	-6.0	7.1	9.5	2.7
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									

Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Overall conditions are relatively stable
Flow around the wet-well approaches the pump – intermittent stalling and drifting observed
Flow enter the suction tube uniformly around the circumference
Floor vortex is consistent bit does not fully organize
Surface vortex remains stable but is stronger – intermittent air entrainment observed

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 3	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	500	I 4-5	none	none	C 3	none	No probe installed			19.7
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									

Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Overall conditions are relatively stable
Flow around the wet-well approaches the pump – intermittent stalling and drifting observed
Flow enter the suction tube uniformly around the circumference
Floor vortex is stable and well developed
Surface vortex remains stable and well developed – intermittent air entrainment observed

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 4	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	0									
Pump 4	500	I 3	none	none	C 3	none	No probe installed			5.3
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8										

Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Overall conditions are relatively stable
Flow around the wet-well approaches the pump – intermittent stalling and drifting observed
Flow enter the suction tube uniformly around the circumference
Floor vortex is stable and well developed
Surface vortex remains stable and well developed – no air entrainment observed

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 5	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	500	I 1-2	none	none	C 3	none	-5.7	6.1	10.6	7.2
Pump 3	500	I 4-5	none	none	C 3	none	No probe installed			34.8
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8										

Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Overall conditions are still relatively stable
Intermittent stalling and drifting observed in the wet-well
Floor vortex is stable and well developed
Surface around Pump 2 is too turbulent for surface vortex formation – Type 4-5 enters Pump 3
Pre-swirl values are much higher and less stable

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 6	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	500	I 1-2	none	none	C 3	none	No probe installed			11.2
Pump 4	500	I 4-5	none	none	C 3	none	No probe installed			16.6
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8										

Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Overall conditions are still relatively stable
Intermittent stalling and drifting observed in the wet-well
Floor vortex is stable and well developed
Surface around Pump 3 is too turbulent for surface vortex formation – Type 4-5 enters Pump 4
Pre-swirl values are high and unstable – frequent burst swirl observed

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 7	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	500	I 1-2	none	none	C 3	none	-10.8	10.6	18.0	21.0
Pump 3	500	I 1-2	none	none	C 3	none	No probe installed			5.7
Pump 4	500	I 4-5	none	none	C 3	none	No probe installed			3.8
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8										

Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Overall conditions are turbulent and unstable – frequent lifting off the floor and directional changes
Air entrainment observed as flow enters the wet-well
Floor vortex is unstable – mobile due to overall instability
Surface around Pumps 2 and 3 is too turbulent for surface vortex formation – Type 4-5 enters Pump 4
Pre-swirl values are high and unstable – frequent burst swirl observed

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 8	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	I 1-2	none	none	C 3	none	No probe installed			41.8
Pump 2	500	I 1-2	none	none	C 3	none	-12.5	10.4	27.6	3.0
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	500	I 1-2	none	none	C 3	none	No probe installed			3.4
Pump 8	0									

Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Overall conditions are turbulent and unstable – frequent lifting off the floor and directional changes
Air entrainment observed as flow enters the wet-well
Floor vortex is unstable – mobile due to overall instability
Surface around pumps is too turbulent for stable surface vortex formation
Pre-swirl values are high and unstable – frequent burst swirl observed

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 9	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	C 3	none	No probe installed			28.2
Pump 2	500	none	none	none	C 3	none	-7.5	9.0	16.6	22.7
Pump 3	500	none	none	none	C 3	none	No probe installed			27.9
Pump 4	0									
Pump 5	0									
Pump 6	500	none	none	none	C 3	none	No probe installed			12.0
Pump 7	500	none	none	none	C 3	none	No probe installed			9.0
Pump 8	500	none	none	none	C 3	none	No probe installed			24.9

Comment: Water Level El. 73.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Overall conditions are turbulent and unstable – frequent lifting off the floor and directional changes
Air entrainment observed as flow enters the wet-well
Vortex activity is unchanged
Pre-swirl values are high and unstable – frequent burst swirl observed
Air entrainment observed in the upstream pumps

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 10	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	C 3	none	No probe installed			31.1
Pump 2	500	none	none	none	C 3	none	-8.5	8.7	15.9	19.0
Pump 3	500	none	none	none	C 3	none	No probe installed			39.4
Pump 4	500	none	none	none	C 3	none	No probe installed			15.6
Pump 5	500	none	none	none	C 3	none	No probe installed			10.5
Pump 6	500	none	none	none	C 3	none	No probe installed			5.3
Pump 7	500	none	none	none	C 3	none	No probe installed			7.9
Pump 8	500	none	none	none	C 3	none	No probe installed			40.1
Comment: Water Level El. 75.0-ft (Sump Invert El. 55.0-ft.) Influent Flow Split: 50/50 Overall conditions are turbulent and unstable – frequent lifting off the floor and directional changes Air entrainment observed as flow enters the wet-well Vortex activity is unchanged Pre-swirl values are high and unstable – frequent burst swirl observed Air entrainment observed in all pumps										

The following pictures show some of the conditions observed in the wet well. Photography is difficult with this wet well configuration due to the pump geometry and curvature of the back-wall but video is being provided which will allow easier observation of conditions. Video footage of the testing will show conditions more clearly.

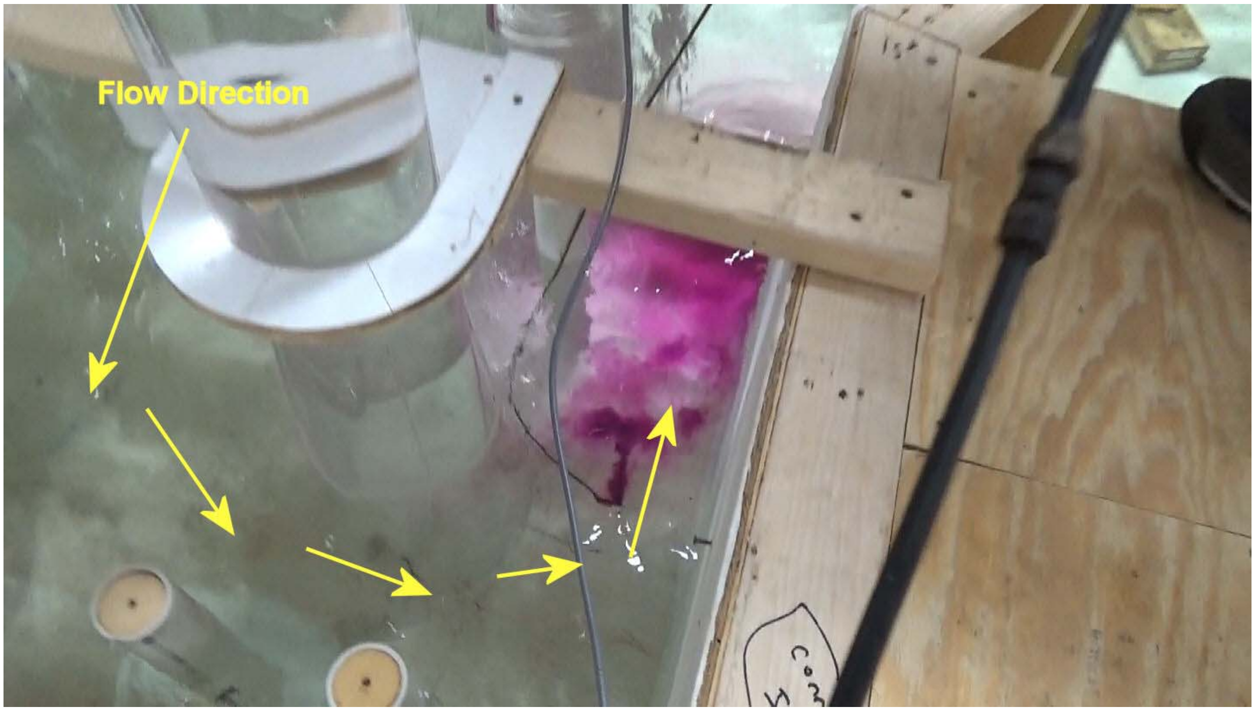


Photo 5-1 Flow Circulating Around Pump

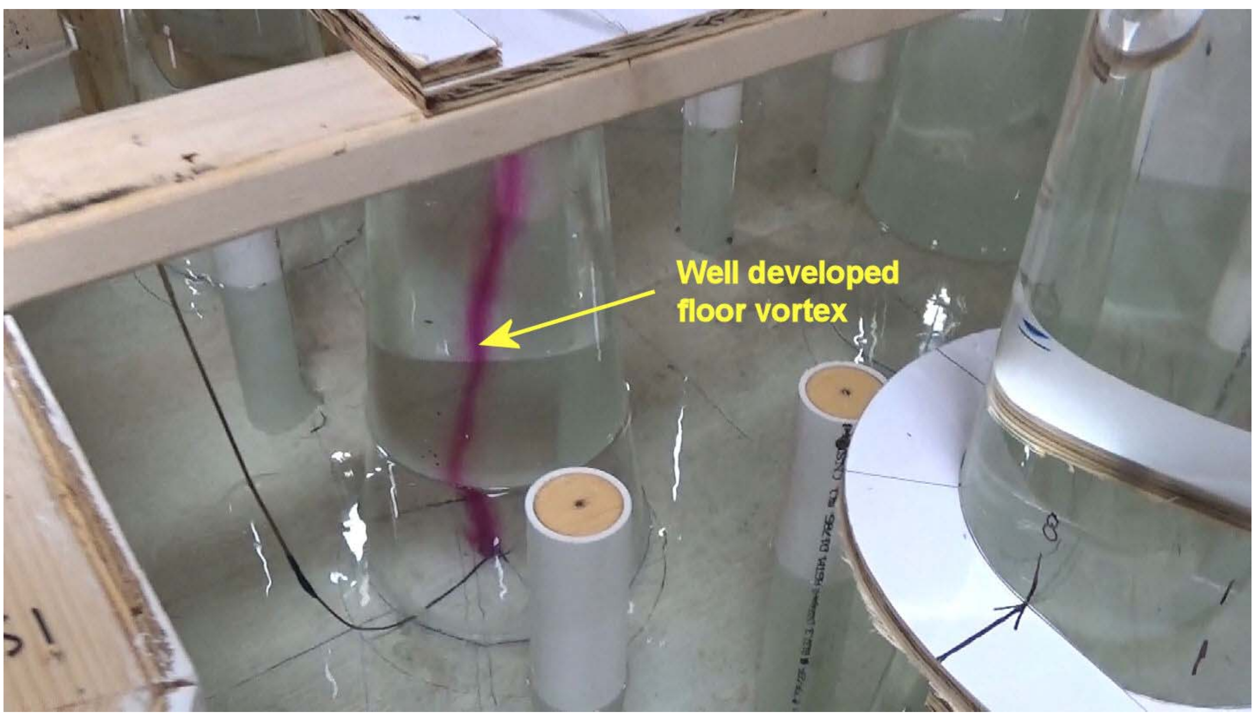


Photo 5-2 Floor Vortex

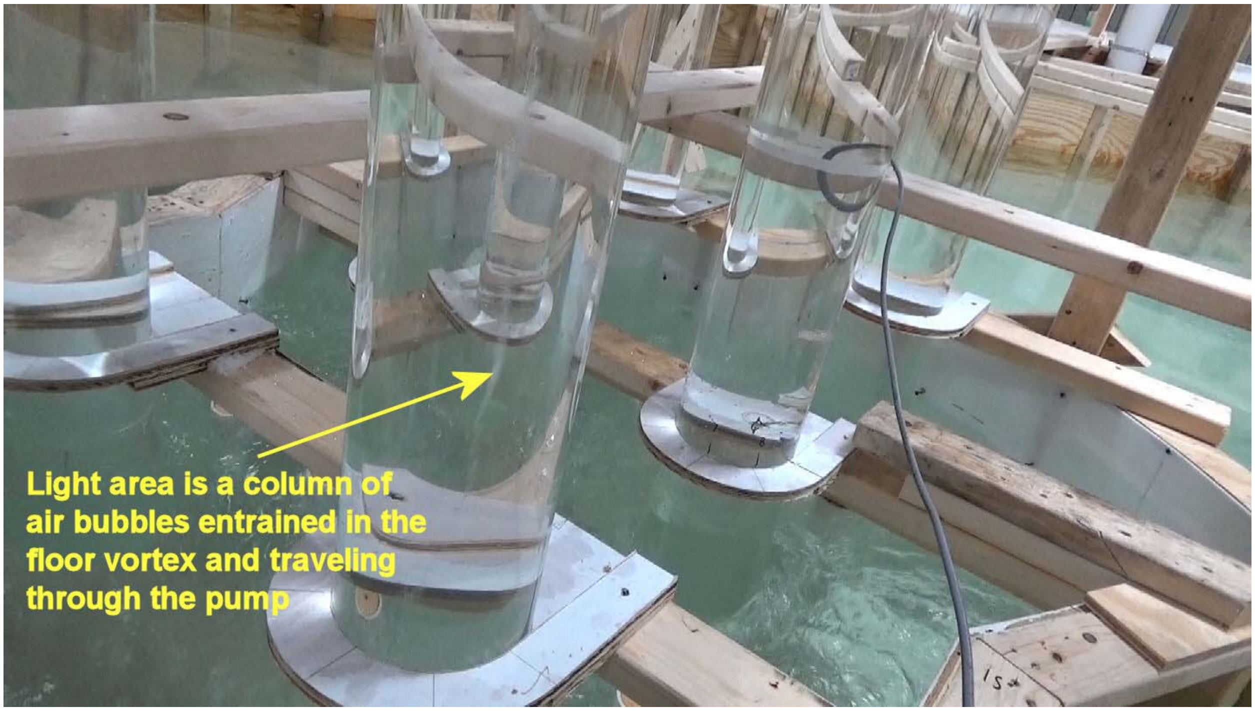


Photo 5-3 Air Entrained in Floor Vortex

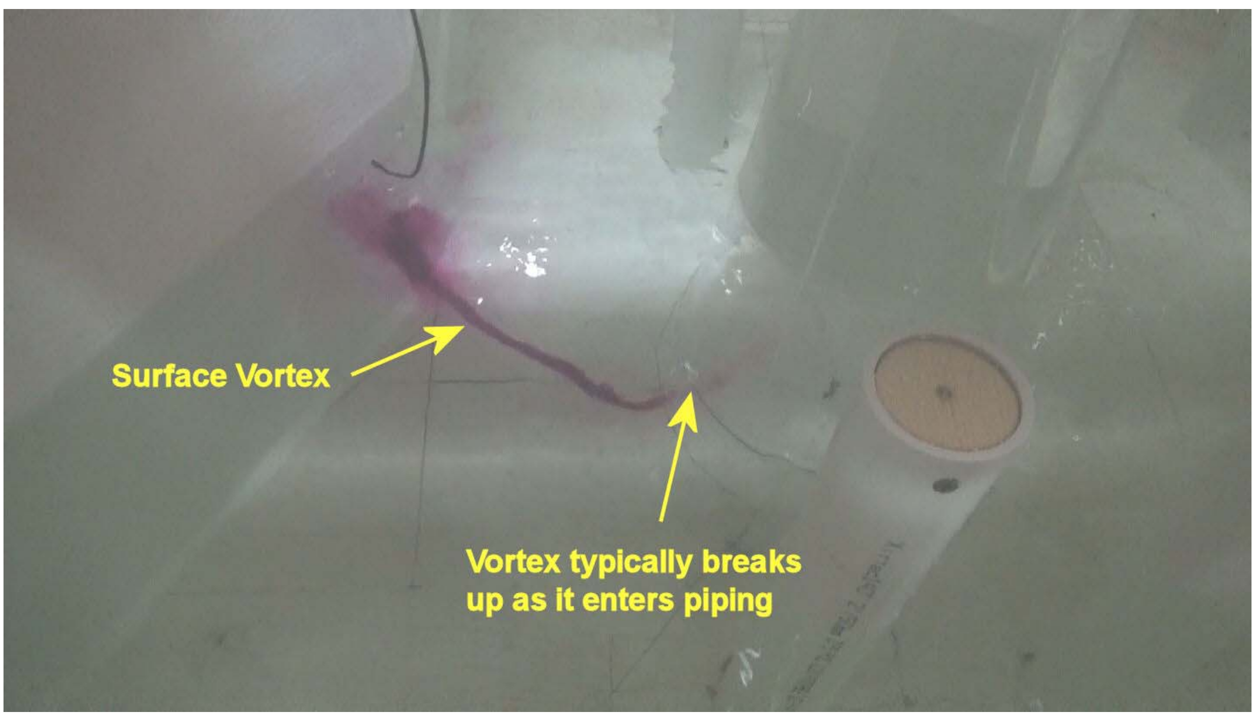


Photo 5-4 Surface Vortex Breaks Up Entering Pump

5.2 Modification Testing

Modification tests were conducted to improve the approach flow conditions within the pump sump. Complete data sets may not be taken during each test and all conditions are not investigated during this phase of testing. In general:

1. Floor cones incorporating eight (8) vanes were installed under Pumps 1-4. Testing showed these were very effective at eliminating floor vortex activity.
2. Model observations showed that the circulation around the pump suctions pulled air into the pump suctions. The floor cones minimized this circulation which significantly reduced the amount of air bubbles entrained and concentrated in the flow around the pumps and therefore reduced the amount entering the pumps.
3. Model observations showed a significant reduction in air entering the pumps with the cones versus those without the cones.
4. It is noted that with the modifications installed, overall conditions remained turbulent and unstable around the pumps but the cones improved flow as it entered the suction tubes. With the cones installed pre-swirl; as well as velocity and turbulence variations were within HI criteria but some air entrainment is still possible.

Table 5-2 summarizes the modification testing. Figures 5-1 and 5-2 show the recommended modification details and Photos 5-5 and 5-6 show the modifications in place.

Table 5-2 Summary of Modification Tests

Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 1	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	none	none	No probe installed			0.8
Pump 2	500	none	none	none	none	none	-1.4	1.7	9.5	1.5
Pump 3	500	none	none	none	none	none	No probe installed			1.1
Pump 4	500	none	none	none	none	none	No probe installed			1.1
Pump 5	500	Flow withdrawn – no modifications installed								
Pump 6	500	Flow withdrawn – no modifications installed								
Pump 7	500	Flow withdrawn – no modifications installed								
Pump 8	500	Flow withdrawn – no modifications installed								
Comment: Water Level El. 75.0-ft (Sump Invert El. 55.0-ft.) Influent Flow Split: 50/50 Mods: Floor cones installed under Pumps 1-4 Floor vortex / circulation under pumps eliminated Air entrainment is significantly reduced Cones stabilize flow as it enters the pumps – pre-swirl is low and stable										

Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 2	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	none	none	No probe installed			1.5
Pump 2	500	none	none	none	none	none	-2.4	3.2	8.5	1.9
Pump 3	500	none	none	none	none	none	No probe installed			1.1
Pump 4	0									
Pump 5	0									
Pump 6	500	Flow withdrawn – no modifications installed								
Pump 7	500	Flow withdrawn – no modifications installed								
Pump 8	500	Flow withdrawn – no modifications installed								
Comment: Water Level El. 73.0-ft (Sump Invert El. 55.0-ft.) Influent Flow Split: 50/50 Mods: Floor cones installed under Pumps 1-4 Floor vortex / circulation under pumps eliminated Air entrainment is significantly reduced Cones stabilize flow as it enters the pumps – pre-swirl is low and stable										

Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 3	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	none	none	No probe installed			2.3
Pump 2	500	none	none	none	none	none	-5.6	5.9	6.3	1.5
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	500	Flow withdrawn – no modifications installed								
Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.) Influent Flow Split: 50/50 Mods: Floor cones installed under Pumps 1-4 Floor vortex / circulation under pumps eliminated Air entrainment is significantly reduced Cones stabilize flow as it enters the pumps – pre-swirl is low and stable										

Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 4	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	500	none	none	none	none	none	-4.8	7.6	9.3	1.1
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									
Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.) Influent Flow Split: 50/50 Mods: Floor cones installed under Pumps 1-4 Floor vortex / circulation under pumps eliminated Air entrainment is significantly reduced Cones stabilize flow as it enters the pumps – pre-swirl is low and stable										

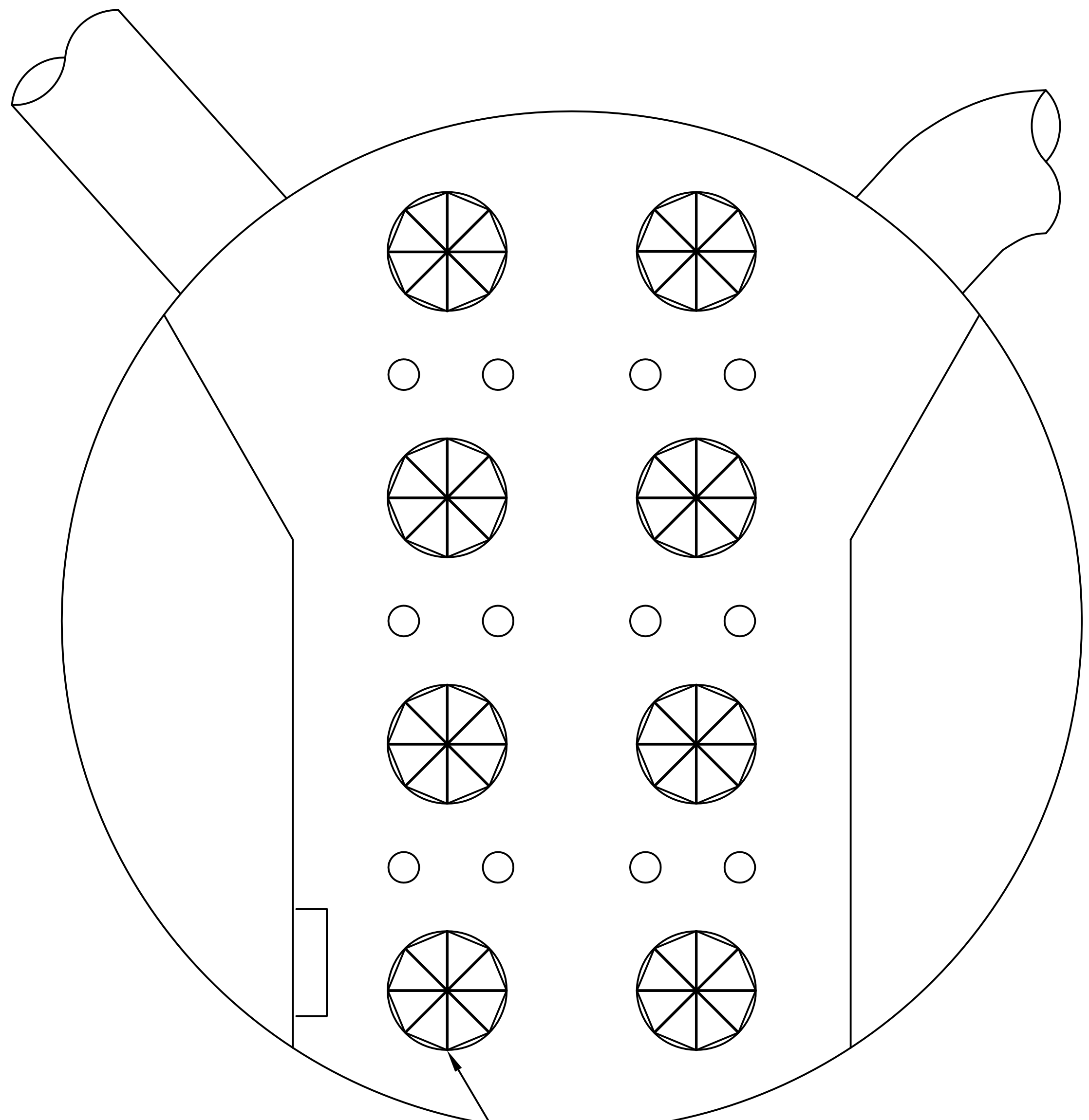
Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 5	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	none	none	No probe installed			0.8
Pump 2	0									
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									
Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.) Influent Flow Split: 50/50 Mods: Floor cones installed under Pumps 1-4 Floor vortex / circulation under pumps eliminated Air entrainment is significantly reduced Cones stabilize flow as it enters the pumps – pre-swirl is low and stable										

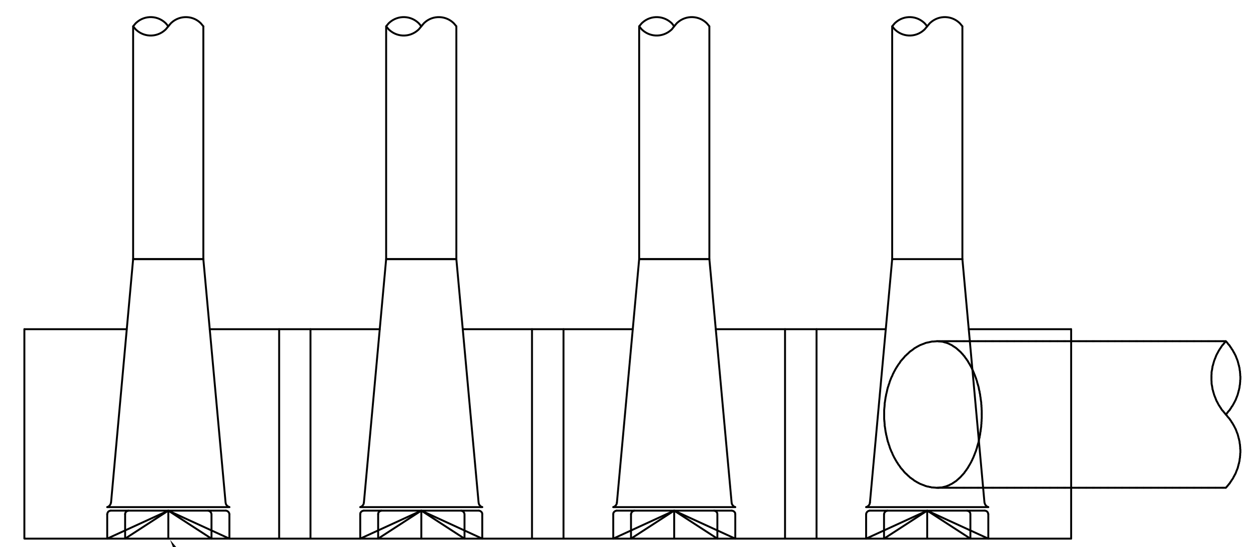
Photo 5-5 Floor Cones

Photo 5-6 Floor Cone (Alternate View)

The following modifications are recommended for the lift pumps:

1. Floor cones should be installed under each of the pumps.





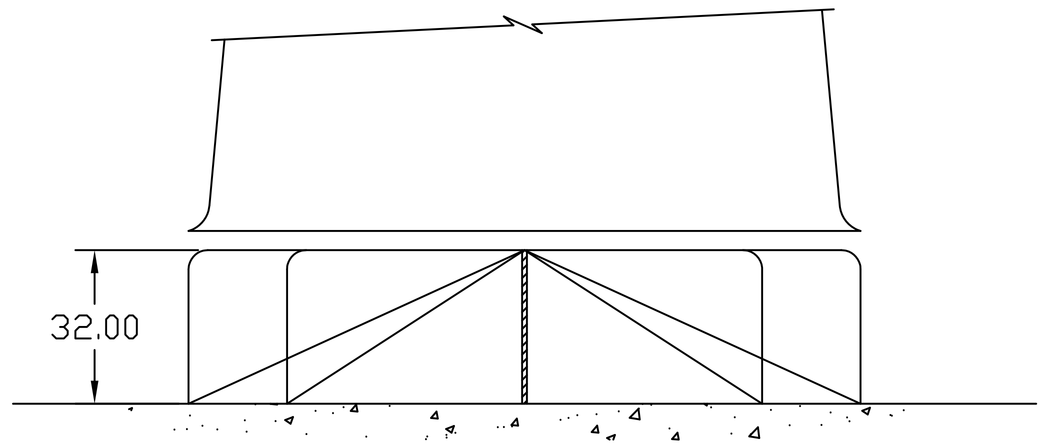
Note: Drawing intended for reference only. Not to be used as a construction drawing.

Note: 1. All dimensions given in prototype inches.
2. All elevations given in prototype feet.

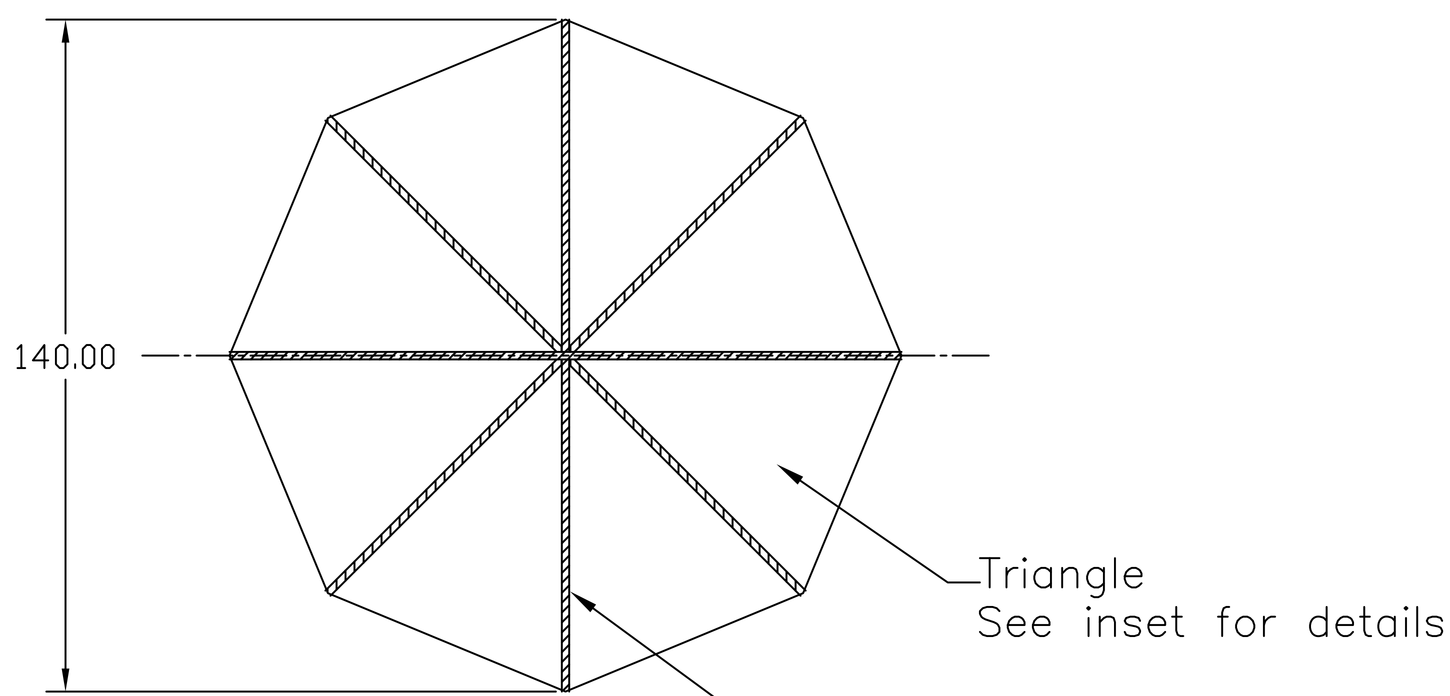
NO.	DATE:	REVISION	DRAWN:	CHK. BY:

DRAWING SCALE:	DRAWN: M. Havice	DATE: 2/9/2018	PROJECT NO:
1:220	FILE NO: Plan	CHECKED:	

FIGURE 5–1
MODIFICATION DETAILS – OVERVIEW
CONNER STORM
ARCADIS

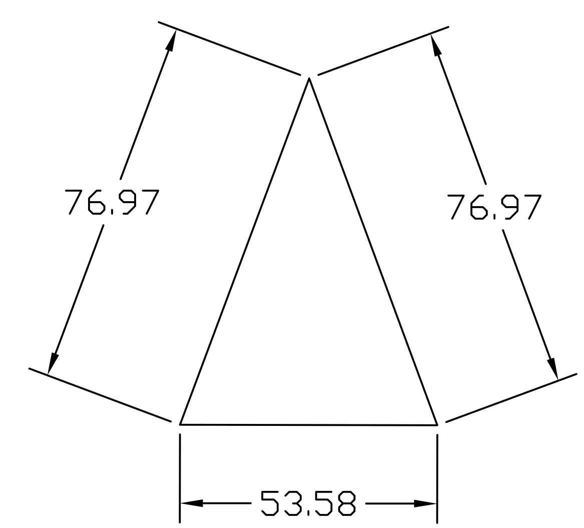


Notes:
1. All dimensions given in prototype inches
2. Cone Specifications:
   Fabricated out of 8 triangle pieces (see detail)
   Total Height = 32.0 in.
   Base Diameter = 140.0 in.
3. Structural analysis required for fabrication and attachment design

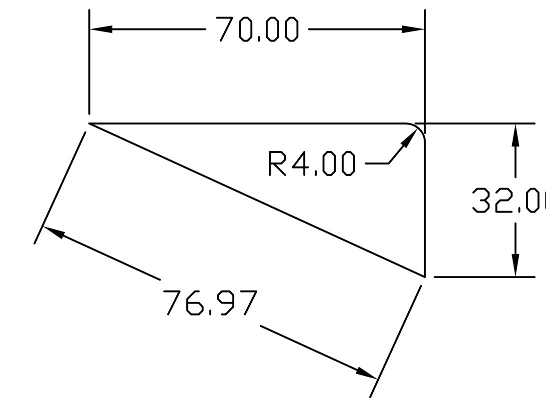


Top View

Triangle Details



Vane Details



Drawing to be used for reference only.
Not to be used as a construction drawing.

Note: Elevations given in prototype feet.
Dimensions given in prototype inches.

REVISION	DRAWN:	CHK. BY:	SCALE:	DRAWN: M. Havice	DATE: 2/9/2018	PROJECT NO:
			1:40	FILE NO:	CHECKED: D. Werth	

FIGURE 5-2
FLOOR CONE DETAILS
CONNER STORMWATER
ARCADIS

5.3 Witness Testing

A formal witness test was held on Monday, February 19th with representatives from Arcadis as well as an owner's representative in attendance. During the witness test the model was demonstrated with and without modifications in place. Final documentation testing was conducted after approval of this draft report. Video of baseline and final documentation testing will be included with the final report.

5.4 Final Documentation Testing

After approval of the draft report, final documentation tests were conducted for various operating conditions. The following modifications were installed:

- Floor cones were installed under each pump.

Table 5-3 shows the final documentation test data.

Table 5-3 Summary Final Documentation Testing

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 1	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	none	none	No probe installed			1.1
Pump 2	500	none	none	none	none	none	-3.4	2.7	9.8	1.1
Pump 3	500	none	none	none	none	none	No probe installed			1.9
Pump 4	500	none	none	none	none	none	No probe installed			0.4
Pump 5	500	none	none	none	none	none	No probe installed			1.5
Pump 6	500	none	none	none	none	none	No probe installed			1.1
Pump 7	500	none	none	none	none	none	No probe installed			2.3
Pump 8	500	none	none	none	none	none	No probe installed			1.5

Comment: Water Level El. 75.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Mods: Floor cones installed under all pumps
Floor vortex / circulation under pumps eliminated
Air entrainment is significantly reduced
Cones stabilize flow as it enters the pumps – pre-swirl is low and stable

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 2	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	none	none	No probe installed			0.4
Pump 2	500	none	none	none	none	none	-5.7	7.1	8.9	1.1
Pump 3	500	none	none	none	none	none	No probe installed			2.7
Pump 4	0									
Pump 5	500	none	none	none	none	none	No probe installed			2.7
Pump 6	500	none	none	none	none	none	No probe installed			1.5
Pump 7	500	none	none	none	none	none	No probe installed			1.5
Pump 8	0									
Comment: Water Level El. 73.0-ft (Sump Invert El. 55.0-ft.) Influent Flow Split: 50/50 Mods: Floor cones installed under all pumps Floor vortex / circulation under pumps eliminated Air entrainment is significantly reduced Cones stabilize flow as it enters the pumps – pre-swirl is low and stable										

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 3	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	none	none	No probe installed			0.8
Pump 2	500	none	none	none	none	none	-5.9	9.1	8.7	1.1
Pump 3	500	none	none	none	none	none	No probe installed			1.1
Pump 4	500	none	none	none	none	none	No probe installed			0.4
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									
Comment: Water Level El. 71.0-ft (Sump Invert El. 55.0-ft.) Influent Flow Split: 50/50 Mods: Floor cones installed under all pumps Floor vortex / circulation under pumps eliminated Air entrainment is significantly reduced Cones stabilize flow as it enters the pumps – pre-swirl is low and stable										

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 4	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	500	none	none	none	none	none	No probe installed			1.9
Pump 4	500	none	none	none	none	none	No probe installed			1.5
Pump 5	0									
Pump 6	0									
Pump 7	500	none	none	none	none	none	No probe installed			2.3
Pump 8	500	none	none	none	none	none	No probe installed			1.5

Comment: Water Level El. 71.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Mods: Floor cones installed under all pumps
Floor vortex / circulation under pumps eliminated
Air entrainment is significantly reduced
Cones stabilize flow as it enters the pumps – pre-swirl is low and stable

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 5	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	none	none	No probe installed			1.9
Pump 2	500	none	none	none	none	none	-4.4	6.9	6.9	1.9
Pump 3	0									
Pump 4	0									
Pump 5	500	none	none	none	none	none	No probe installed			1.5
Pump 6	500	none	none	none	none	none	No probe installed			2.3
Pump 7	0									
Pump 8	0									

Comment: Water Level El. 71.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Mods: Floor cones installed under all pumps
Floor vortex / circulation under pumps eliminated
Air entrainment is significantly reduced
Cones stabilize flow as it enters the pumps – pre-swirl is low and stable

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 6	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	none	none	No probe installed			1.5
Pump 2	500	none	none	none	none	none	-3.7	3.4	6.5	1.5
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									

Comment: Water Level El. 69.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Mods: Floor cones installed under all pumps
Floor vortex / circulation under pumps eliminated
Air entrainment is significantly reduced
Cones stabilize flow as it enters the pumps – pre-swirl is low and stable

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 7	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	500	none	none	none	none	none	-5.0	3.4	6.4	1.5
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	500	none	none	none	none	none	No probe installed			2.7
Pump 7	0									
Pump 8	0									

Comment: Water Level El. 69.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Mods: Floor cones installed under all pumps
Floor vortex / circulation under pumps eliminated
Air entrainment is significantly reduced
Cones stabilize flow as it enters the pumps – pre-swirl is low and stable

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 8	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	0									
Pump 4	500	none	none	none	none	none	No probe installed			2.3
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	500	none	none	none	none	none	No probe installed			2.3

Comment: Water Level El. 69.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Mods: Floor cones installed under all pumps
Floor vortex / circulation under pumps eliminated
Air entrainment is significantly reduced
Cones stabilize flow as it enters the pumps – pre-swirl is low and stable

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 9	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	500	none	none	none	none	none	No probe installed			1.1
Pump 2	0									
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									

Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Mods: Floor cones installed under all pumps
Floor vortex / circulation under pumps eliminated
Air entrainment is significantly reduced
Cones stabilize flow as it enters the pumps – pre-swirl is low and stable

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 10	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	500	none	none	none	none	none	-4.8	5.7	5.4	1.5
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									
Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.) Influent Flow Split: 50/50 Mods: Floor cones installed under all pumps Floor vortex / circulation under pumps eliminated Air entrainment is significantly reduced Cones stabilize flow as it enters the pumps – pre-swirl is low and stable										

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 11	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	500	none	none	none	none	none	No probe installed			1.5
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									
Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.) Influent Flow Split: 50/50 Mods: Floor cones installed under all pumps Floor vortex / circulation under pumps eliminated Air entrainment is significantly reduced Cones stabilize flow as it enters the pumps – pre-swirl is low and stable										

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 12	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	0									
Pump 4	500	none	none	none	none	none	No probe installed			1.5
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									

Comment: Water Level El. 68.0-ft (Sump Invert El. 55.0-ft.)
Influent Flow Split: 50/50
Mods: Floor cones installed under all pumps
Floor vortex / circulation under pumps eliminated
Air entrainment is significantly reduced
Cones stabilize flow as it enters the pumps – pre-swirl is low and stable

6.0 CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

Initial testing showed that overall conditions in the wet-well were dependent on the number of pumps in operation with conditions deteriorating as more pumps come online. Single pump operation resulted in in relatively calm conditions in and around the pumps and conditions were extremely turbulent and unstable with all pumps operating. In general, the overall turbulence resulted in some air entrainment as flow entered the wet-well. Given the relatively small wet-well footprint and the close proximity of the pumps to the influent pipes, this resulted in consistent air entrainment in the pumps at the maximum station flows. Less air entrainment was observed at lower flows.

Strong floor vortices were observed under all pumps. No other submerged vortex activity was observed. Intermittent surface vortex activity was observed when only a single pump was operating. With more than one pump in operation surface vortex activity was typically flushed out due to the overall circulation and instability. Pre-swirl values were unstable, and varied dependent on which pumps were operating. For some tests, overall values were very high and well outside of criteria. Velocity and turbulence levels were generally in criteria, but again, depending on which pumps were in service, the turbulence levels did increase. The long suction tubes helped to condition the flow by providing time for the flow to stabilize prior to reaching the pump location. However, vortices and swirl clearly reached the pump impeller location and air entrainment was observed entering the pumps.

Floor cones incorporating eight (8) vanes were installed under Pumps 1-4. Testing showed these were very effective at eliminating floor vortex activity. Model observations showed that the circulation around the pump suctions pulled air into the pump suctions. The floor cones minimized this circulation which significantly reduced the amount of air bubbles entrained and concentrated in the flow around the pumps and therefore reduced the amount entering the pumps. Model observations showed a significant reduction in air entering the pumps with the cones versus those without the cones. It is noted that with the modifications installed, overall conditions remained turbulent and unstable around the pumps but the cones improved flow as it entered the suction tubes. With the cones installed pre-swirl; as well as velocity and turbulence variations were within HI criteria but some air entrainment is still possible.

6.2 Recommendations

It is recommended that a floor cone be installed under each pump. The recommended modifications can be seen on Figures 5-1 and 5-2.

7.0 REFERENCES

Hydraulic Institute Standards, 2012. American National Standard for Pump Intake Design. Hydraulic Institute, Parsippany, New Jersey, 07054-3802

Sweeney, C.E. and G.E. Rockwell, 1982. Pump Sump Design Acceptance through Hydraulic Model Testing. Proc. of the International Association for Hydraulic Research: Symposium on Operating Problems of Pump Stations and Power Plants. Amsterdam, the Netherlands, pp. 13-17, September 1982.

FREUD STORMWATER PUMP INTAKE STRUCTURE PHYSICAL HYDRAULIC MODEL STUDY

Final Report

Conducted For

Arcadis

CEH Report No. 706-18

CEH
CLEMSON ENGINEERING HYDRAULICS, INC.
1203 River Heights Circle • Anderson, SC 29621
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FREUD STORMWATER PUMP INTAKE STRUCTURE PHYSICAL HYDRAULIC MODEL STUDY

Final Report

Conducted For

Arcadis

CEH Report No. 703-18

February, 2018

Prepared by:

Matthew Havice, P.E.
Project Engineer

Approved by:

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EXECUTIVE SUMMARY

A physical model of the Great Lake Water Authority's Freud storm water pump intake was conducted. A 1:13.0 scale physical model was constructed, and tests were conducted to determine the nature and severity of any adverse hydraulic conditions that may affect pump performance. Initial testing was conducted with 1-7 pumps is operation. Significant air entrainment occurred at the desired "pump off" levels with large amounts of air entering the wet well and ultimately the pumps. The amount of air observed with three of more pumps operating was significant and excessive. Vortex activity was generally minimal because the general turbulence within the wet well washed out vortices before they could become fully developed. Some highly mobile floor and occasional "mid-flow" vortices were observed forming off the floor and mid-flow near the suction bells but these were not well developed and dissipated quickly. Pre-swirl values were unstable, and very dependent of pump combinations. For some tests, overall values were well outside of criteria. Velocity and turbulence levels were generally in criteria, but again, depending on which pumps were in service, the turbulence levels did increase. The long suction tubes helped to condition the flow by providing time for the flow to stabilize prior to reaching the pump location. However, vortices and swirl clearly reached the pump impeller location.

Water levels were revised to minimize air entrainment and suction tubes / suction shrouds (similar to those on the Conner storm water pumps), were installed on the ceiling under each of the pumps. These forced the pumps to receive water from lower in the water column as opposed to along the wet-well ceiling which minimized the amount of air entering the pumps. Four vanes were installed in each of the suction tubes to reduce pre-swirl and rotation. With the modifications installed and the increased water levels in the drop shafts significantly less air entrainment was observed and conditions within the pumps were improved. Pre-swirl, velocity/turbulence and vortex activity was within HI criteria. It was noted that increased air entrainment was observed at El. 45-ft. Operating a pump located further from the vertical shafts would minimize air entrainment at this minimum level.

It is recommended that a floor cone be installed under each pump. In addition, suction tubes / shrouds should be installed on the ceiling under each of the pumps. Four vanes should also be installed in the suction tubes / shrouds. The "pump off" elevations should be revised as follows:

Pump 7 Off – El. 61.0-ft
Pump 6 Off – El. 59.0-ft
Pump 5 Off – El. 57.0-ft
Pump 4 Off – El. 55.0-ft
Pump 3 Off – El. 51.0-ft
Pump 2 Off – El. 49.0 ft
Pump 1 Off – El. 45.0 ft

The recommended modifications can be seen on Figures 5-1 and 5-2.

1.0 INTRODUCTION

1.1 Background

Clemson Engineering Hydraulics, Inc. (CEH) conducted a physical hydraulic model study of the Great Lakes Water Authority's Freud storm water pump intake structure for Arcadis. The Freud storm water pump station consists of eight (8) pumps, each rated at 450 cfs for a firm station capacity of 3,150 cfs. The pumps are located around the circumference of a circular wet well which is fed from around the perimeter from six (6) influent lines which take-off from two large 16-ft cylinders. The existing pumps are bottom suction pumps which withdraw flow vertically from the wet well from a draft tube with a 12-ft diameter inlet flare.

The model was used to evaluate the hydraulic conditions within the intake and to determine any adverse hydraulic phenomena that may exist within the intake. In addition, the model was used to develop recommended modifications to remediate any adverse hydraulic phenomena, which could impact pump performance.

1.2 Objective

The objectives of this model study were as follows:

- Evaluate the performance of the intake structure to determine if any potential problems may exist with the approach flow hydraulics that may adversely impact the performance of the pumps.

- If necessary, develop modifications to the design or implement corrective measures that would mitigate or eliminate problems associated with the adverse approach flow.

- Test and document the approach flow conditions in the sump with the final recommended modifications in place.

1.3 Sump Hydraulics & Pump Problems

The pump manufacturer typically develops pump curves at the manufacturing facility. The head-flow curves, efficiencies, net positive suction head, and power requirements are usually determined by conducting a pump test with the actual prototype pump or a geometrically similar model. This pump test is conducted in a controlled environment with uniform approach flow to the pumps. Therefore, to ensure that the pump will perform as tested at the manufacturing facility, the prototype field installation must also have similarly uniform approach flow conditions.

Failure to provide uniform approach flow hydraulics can result in pump performance that differs significantly from that predicted on the performance curves. The pump may not operate at its best efficiency point, flow or head may be less than expected, power requirements may vary, and if the approach flow conditions vary enough, significant damage could occur to the pump itself.

Pump sumps are often designed to adhere to the 2012 Hydraulic Institute Standards (HI 2012). A consortium of pump manufactures, engineers, and end users developed these standards. Failure to adhere to these standards can lead to a number of problems including air entrainment, vortex activity, skewed velocity distributions and turbulence at the pump impeller. Research has shown that these conditions can lead to fluctuating loading on pump impellers, vibration, cavitation, and decreased flow and efficiency (Sweeney and Rockwell 1982).

Following the HI standards helps to minimize adverse approach flow conditions within the pump sump. However, the standards were developed for pumps with individual capacities of 40,000 gallons per minute (gpm) or less, and overall station capacities of less than 100,000 gpm. When dealing with systems that exceed these capacities, it is necessary to utilize physical and numerical modeling techniques to investigate the hydraulic conditions within the sump.

Physical models are used to evaluate the level of temporal velocity fluctuations, or turbulence, within the pump suction. Changes in pressure are directly related to changes in velocity. Therefore, velocity fluctuations, whether temporal, or as a result of skewed approach flow, can cause pressure fluctuations on the pump impeller. These pressure fluctuations translate into a loading imbalance on the pump shaft, possibly causing vibration or pre-mature bearing wear.

Physical models are also used to evaluate the uniformity of the flow within the pump suction. Should more flow be traveling down one side of a pump bay than the other, such as that which occurs when there is flow separation at the bay entrance, the velocity may be higher on one side of the impeller or the other. This may cause pre-swirl of the flow entering the pump. Depending on the direction of the pre-swirl relative to the pump rotation, this may cause the pump to consume more or less power than anticipated, resulting in the pump operating at a point other than its best efficiency. The pre-swirl may also result in the flow hitting the impeller blade at an angle of attack other than what it was designed for. This can result in localized flow separation on the impeller. These separation zones can cause low-pressure regions, which result in localized areas of cavitation.

Vortices are another hydraulic phenomenon with which physical models are used to identify and eradicate. Vortices are localized regions of high velocity swirling flow. The velocity at the core of a vortex can be high enough that the pressure falls below the vapor pressure of the fluid. If the vortex forms below the surface, it is called a submerged vortex, and can result in vapor being pulled out of suspension. If it forms as a surface vortex, it can pull a vapor core into the pump. Either of these vortices can result in air entrainment or cavitation within the pump. Depending on the system, this entrained air may be able to accumulate within the downstream piping network, possibly causing damage to other system components. The low-pressure core of a vortex can also lead to localized cavitation, noise, decreased pump capacity, and vibration.

Numerical modeling of pump sumps is a relatively new approach to investigating wet well hydraulics. The ability of numerical models to predict the general flow patterns within the sump is constantly improving. However, numerically modeling highly mobile surface vortices presents a challenge. Research is constantly being conducted to improve the ability to numerically predict mobile vortex activity. However, at the present, physical models remain the only method available to reliably simulate mobile prototype vortex activity.

2.0 MODEL SCALING AND ACCEPTANCE CRITERIA

2.1 Model Scaling

To obtain accurate results from a physical model study, there must be dynamic similitude between the model and the prototype. To satisfy this requirement, there must be exact geometric similitude. In addition, the ratio of the dynamic pressures must also be maintained. Strictly satisfying dynamic similitude requires a 1:1 scale model. This is usually not feasible, so some compromise is made. To accomplish this, geometric similarity is maintained and the dominant forces associated with the prototype are determined and maintained between the model and prototype.

The primary forces that affect fluid flow are viscosity, surface tension, velocity (inertial), pressure, gravity and elastic forces. In structures with a free surface, such as a pump intake, gravitational and inertial forces are far greater than the viscous and turbulent shear forces. Therefore, when modeling free surface structures, geometric similarity and the ratio of inertial to gravitational forces, or the Froude number, is maintained between the model and prototype.

Simply holding the Froude number constant violates the strict definition of dynamic similitude. However, if the model is operated within a high enough range of Reynolds numbers, viscous and surface tension scale effects may be minimized. The 2012 Hydraulic Institute Standards (HI 1998) recommends that the minimum Reynolds number at the pump suction be greater than 6×10^4. Therefore, when choosing the model scale, it is necessary to ensure that the scaled flow rate will result in a high enough Reynolds number to minimize scale effects. It is common to be conservative and select a scale that results in a Reynolds number greater than 1×10^5.

Upon selecting an appropriate model or length scale, it is possible to determine relationships such as velocity, flow, and pressure between the model and prototype. This is accomplished by setting the model and prototype governing equations equal to one another. As mentioned above, the governing equation is determined by evaluating the dominating forces. These equations are typically dimensionless numbers such as the Froude, Reynolds, Weber, Euler, or Mach numbers. These common modeling relationships are shown below:

$$\text{Froude Number} \qquad F = \frac{U}{\sqrt{gL}} = \frac{\text{Inertial Force}}{\text{Gravity Force}} \tag{2-1}$$

$$\text{Reynolds Number} \qquad Re = \frac{UL}{\nu} = \frac{\text{Inertial Force}}{\text{Viscous Force}} \tag{2-2}$$

$$\text{Euler Number} \qquad E = \frac{\rho U^2}{\Delta P} = \frac{\text{Inertial Force}}{\text{Pressure Force}} \tag{2-3}$$

$$\text{Weber Number} \qquad W = \frac{U}{\sqrt{\sigma / \rho L}} = \frac{\text{Inertial Force}}{\text{Surface Tension Force}} \qquad (2\text{-}4)$$

$$\text{Mach Number} \qquad M = \frac{U}{\sqrt{K / \rho}} = \frac{\text{Inertial Force}}{\text{Compressive Force}} \qquad (2\text{-}5)$$

Where:

U = characteristic velocity
g = gravitational constant
L = characteristic length
ρ = fluid density
ΔP = pressure difference
ν = kinematic viscosity of the fluid
σ = surface tension of the fluid
K = bulk modulus of elasticity of the fluid

If the governing equation is held constant between the model and prototype, the corresponding model flow rate, velocity, pressure, etc., can be solved directly. For example, setting the Froude number of the model equal to the prototype yields the following relationships, where the subscripts *p* & *m* denote prototype & model, respectively:

$$F_P = F_m \qquad (2\text{-}6)$$

$$\frac{U_p}{\sqrt{gL_p}} = \frac{U_m}{\sqrt{gL_m}} \qquad (2\text{-}7)$$

Using equation 2-7, the model velocity, and therefore, the flow rate Q can be solved for if the prototype velocity and length ratio is known. Typically, the model parameters are solved for based on the prototype to model length ratio, L_P/L_M, or L_R. Doing so yields the following equations for Q & U:

$$\frac{Q_p}{Q_m} = \mathrm{L}_{\mathrm{R}}^{5/2} \qquad (2\text{-}8)$$

$$\frac{U_P}{U_M} = \sqrt{\mathrm{L}_{\mathrm{R}}} \qquad (2\text{-}9)$$

Using these equations, it is possible to determine the flow rates at which the model should be operated. The Freud storm water model was constructed at a 1:13.0 scale. The resulting pump inlet

Reynolds number was approximately 1.0 x 10^5 and the resulting Weber number was in excess of 400. This provides significant margin if a pump with a larger inlet is chosen.

2.2 Acceptance Criteria

In addition to choosing an appropriate scale with which to construct the model, it is important to evaluate the performance of the model against a set of pre-determined acceptance criteria. The criteria used for this model study closely follow those suggested in the 2012 Hydraulic Institute Standards and are as follows:

1. No organized free surface or submerged vortices greater than a Type 1 (general rotation) should be permitted at Froude scaled flow rates

2. Pre-swirl should be less than 5-degrees at the pump impeller location (ideally less than 2.5-degrees per best practice)

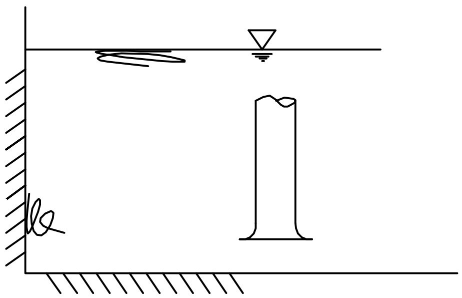
3. Time averaged velocities within the pump throat should deviate less than 10 percent of the cross-sectional area average velocity

4. Time-varying velocity fluctuations (turbulence) at a point within the pump throat should be less than 10 percent

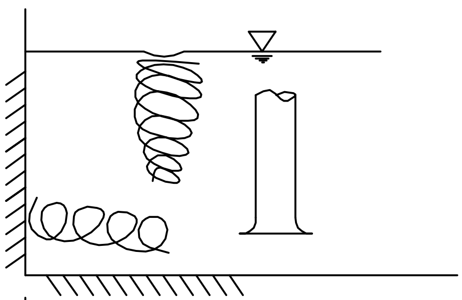
5. These criteria will meet 2012 Hydraulic Institute test specifications.

Vortex activity is evaluated qualitatively. The Hydraulic Institute Standards suggest using a scale of 1 to 6 to rank the severity of a vortex. A scale of 1 to 5 was utilized for this study, with a Type 1 being the least severe and a Type 5 being the most severe, pulling air and trash into the intake. HI varies slightly by ranking a vortex that pulls trash into the intake as a Type 5 and one that pulls air as a Type 6. However, since the acceptance criteria do not permit vortices greater than a Type 1, this variation of the HI scale does not have any effect on the outcome of the model study. Figure 2-1 presents a graphical representation of the vortex ranking used in this study.

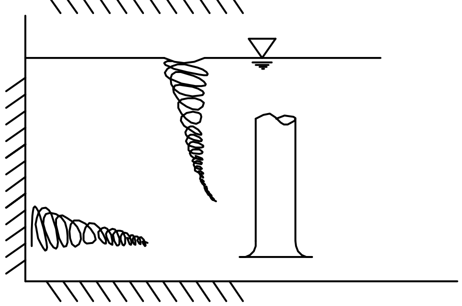
FIGURE 2-1
SURFACE & SUB-SURFACE VORTEX CLASSIFICATION



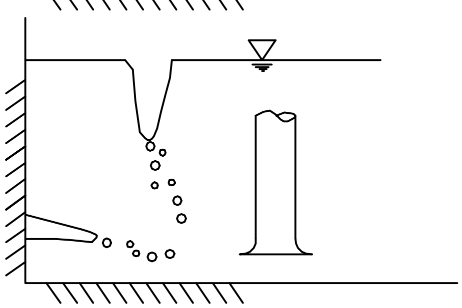
TYPE 1
SURFACE OR SUBSURFACE SWIRL



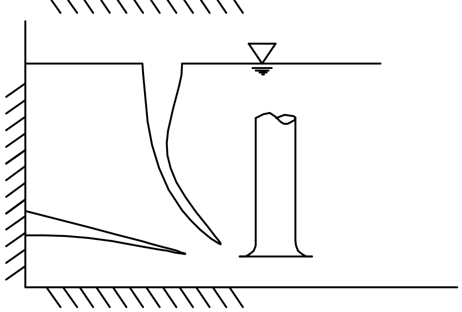
TYPE 2
SURFACE OR SUBSURFACE DIMPLE
COHERENT SWIRL



TYPE 3
ORGANIZED DYE CORE TO THE INTAKE
COHERENT SWIRL THROUGHOUT WATER COLUMN



TYPE 4
COHERENT SWIRL AND ORGANIZED DYE CORE
PULLING BUBBLES AND SOME AIR INTO THE INTAKE



TYPE 5
COHERENT SWIRL AND SOLID AIR/VAPOR CORE PULLING DEBRIS AND AIR INTO THE INTAKE

3.0 THE MODEL

3.1 Model Boundaries

When evaluating the portions of the pump station that are to be included in the model, it is necessary to include any components that could affect the approach flow to the pumps. This is first determined by evaluating the upstream and downstream controls. In this application, an upstream hydraulic control is a structure or component that controls the downstream flow. This may be a change in grade that results in critical flow, a sluice gate or opening that directs the flow, or simply a long stretch that results in uniform flow conditions. The Freud storm water intake structure is fed from around the perimeter from six (6) influent lines which take-off from two large 16-ft cylinders. A portion of the 16-ft cylinders, including all six influent lines were included in the model and serve as the upstream model boundary. The internal geometry of the wet-well was included in the model. In addition, all eight pumps were simulated in detail. The existing pumps are bottom suction pumps which withdraw flow vertically from the wet well from a draft tube with a 12-ft diameter inlet flare.

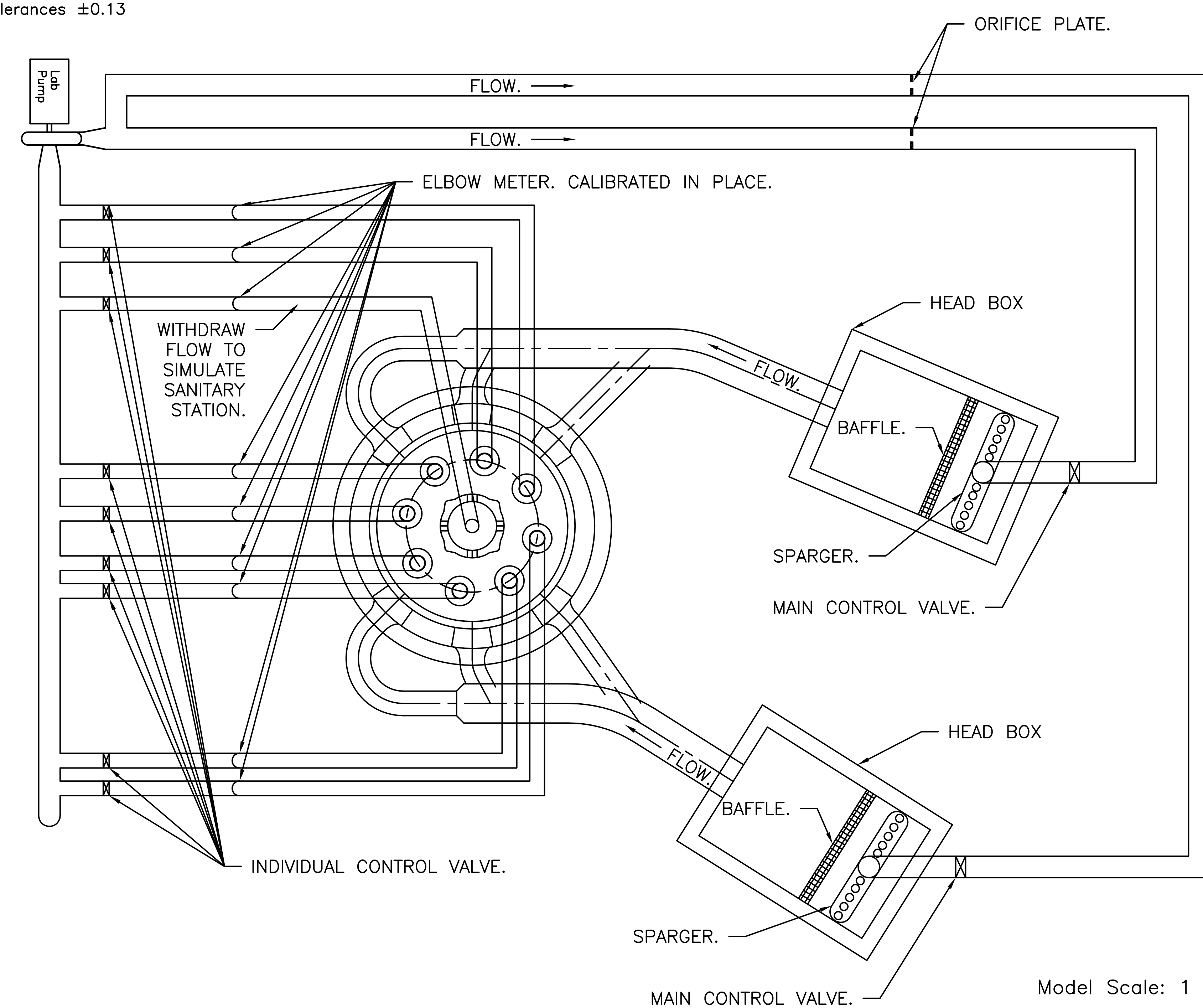
Physical model studies are used to evaluate the approach flow and ensure that the flow is uniform up to the pump impeller. Therefore, the downstream model boundary was chosen as the entrance to the pump impeller. It is not necessary to include a model pump impeller because the pump performance is tested at the manufacturer's facility. The manufacturers test was conducted with uniform approach flow conditions. Therefore, with other design consideration being equal, if those conditions can be duplicated in the prototype structure, the performance of the pump in the field should match that determined by the manufacturer.

3.2 Model Construction

The model was constructed on a raised deck to facilitate viewing and data collection. The model head box, floor, and sidewalls were constructed with waterproof wood. The model pumps, intake piping and pump bells were fabricated out of clear acrylic up to the impeller location. The additional piping was fabricated out of PVC pipe. Friction losses within the model limits are negligible when compared to form or boundary losses. Therefore, it is assumed that materials mentioned above were appropriate for model construction.

The overall model basin was constructed with a tolerance of +/- 0.25 model inches. The model pump throats were constructed to within +/- 0.06 model inches. Valves were used to control the individual pump flows as well as the total model flow. A pump was installed downstream of the model pumps to re-circulate flow back to the model head box. Flow straightening devices were installed in the model head-box to ensure that flow entering the head box was uniform. Figures 3-1 through 3-4 and Photos 3-1 through 3-4 show the model.

Note: 1) All dimensions given in model inches
2) All elevations given in prototype feet
3) Basin construction tolerances ±0.25"
4) Head box construction tolerances ±0.50"
5) Acrylic intake structures construction tolerances ±0.06
6) Acrylic intake bell location tolerances ±0.13



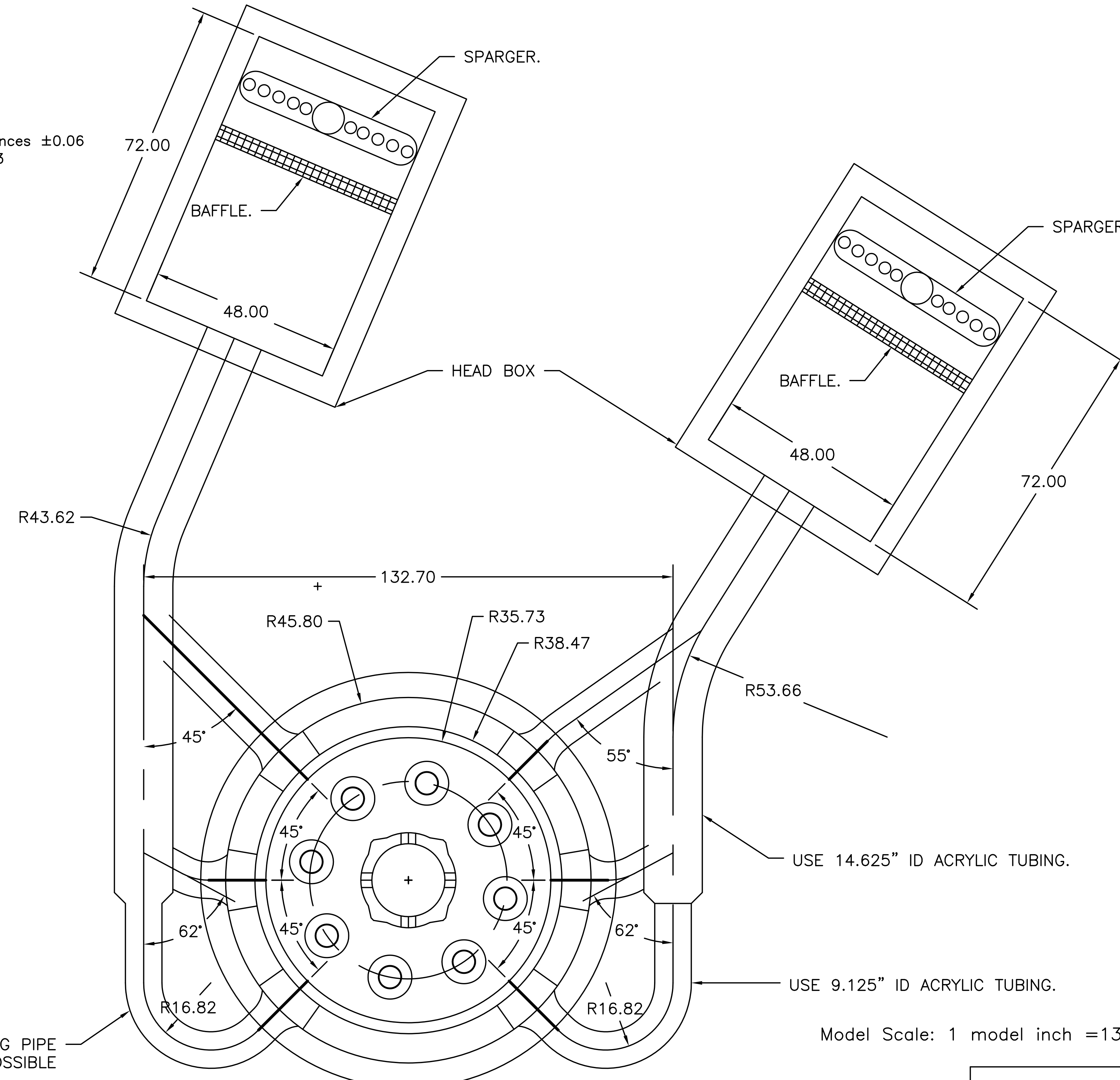
Model Scale: 1 model inch =13.1 prototype inches (1:13.1)

NO.	DATE:	REVISION	DRAWN:	CHK. BY:

DRAWING SCALE:	DRAWN: K. Davy	DATE: 8/7/2017	PROJECT NO:
1:50	FILE NO: OVERVIEW	CHECKED:	

FIGURE 3-1
MODEL OVERVIEW
FREUD STORM
ARCADIS

Note: 1) All dimensions given in model inches
2) All elevations given in prototype feet
3) Basin construction tolerances ±0.25"
4) Head box construction tolerances ±0.50"
5) Acrylic intake structures construction tolerances ±0.06
6) Acrylic intake bell location tolerances ±0.13



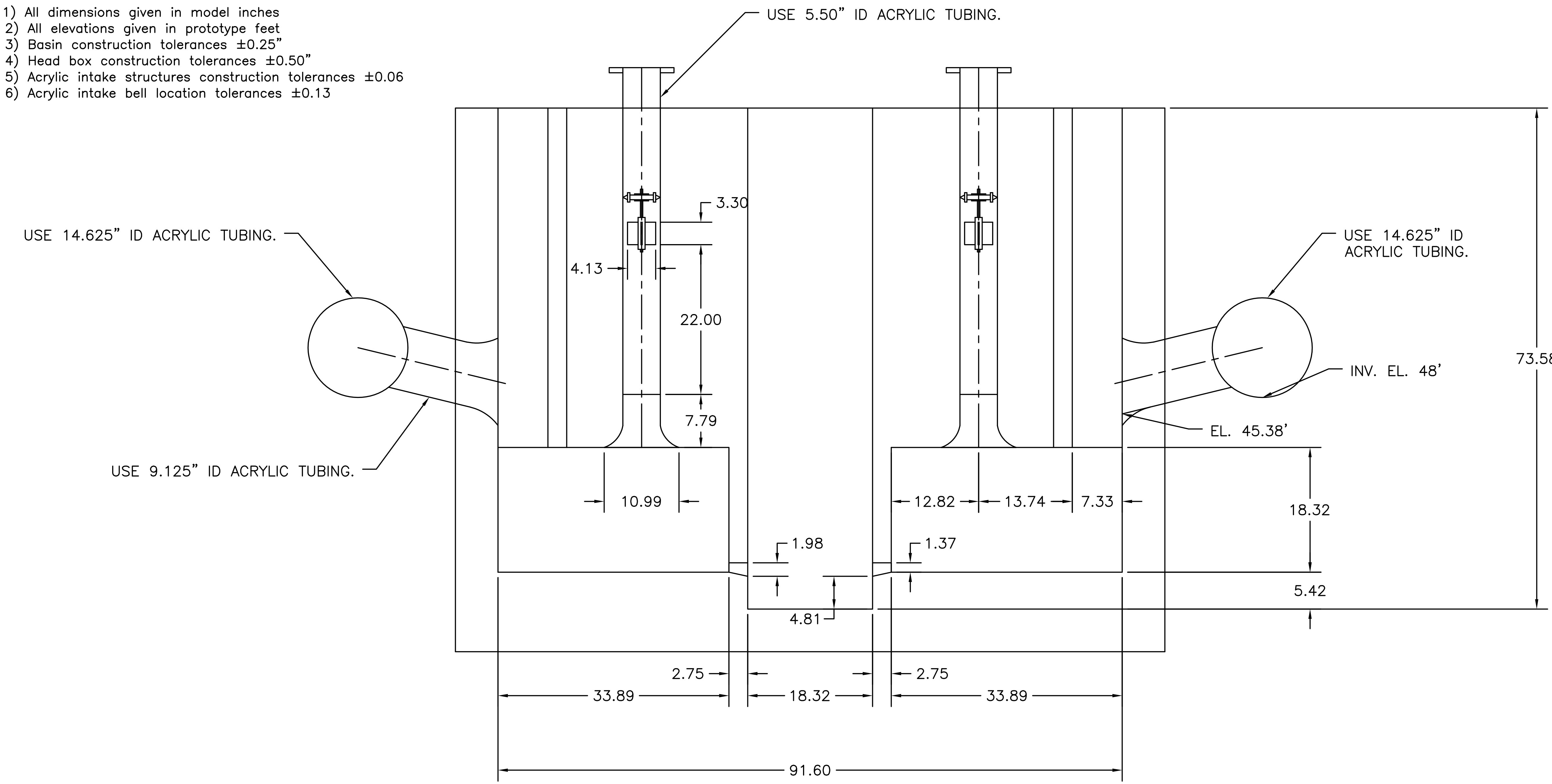
Model Scale: 1 model inch =13.1 prototype inches (1:13.1)

NO.	DATE:	REVISION	DRAWN:	CHK. BY:

DRAWING SCALE:	DRAWN: K. Davy	DATE: 8/7/2017	PROJECT NO:
1:30	FILE NO: PLAN	CHECKED:	

FIGURE 3-2
MODEL LAYOUT DETAILS
FREUD STORM
ARCADIS

Note: 1) All dimensions given in model inches
2) All elevations given in prototype feet
3) Basin construction tolerances ±0.25"
4) Head box construction tolerances ±0.50"
5) Acrylic intake structures construction tolerances ±0.06
6) Acrylic intake bell location tolerances ±0.13



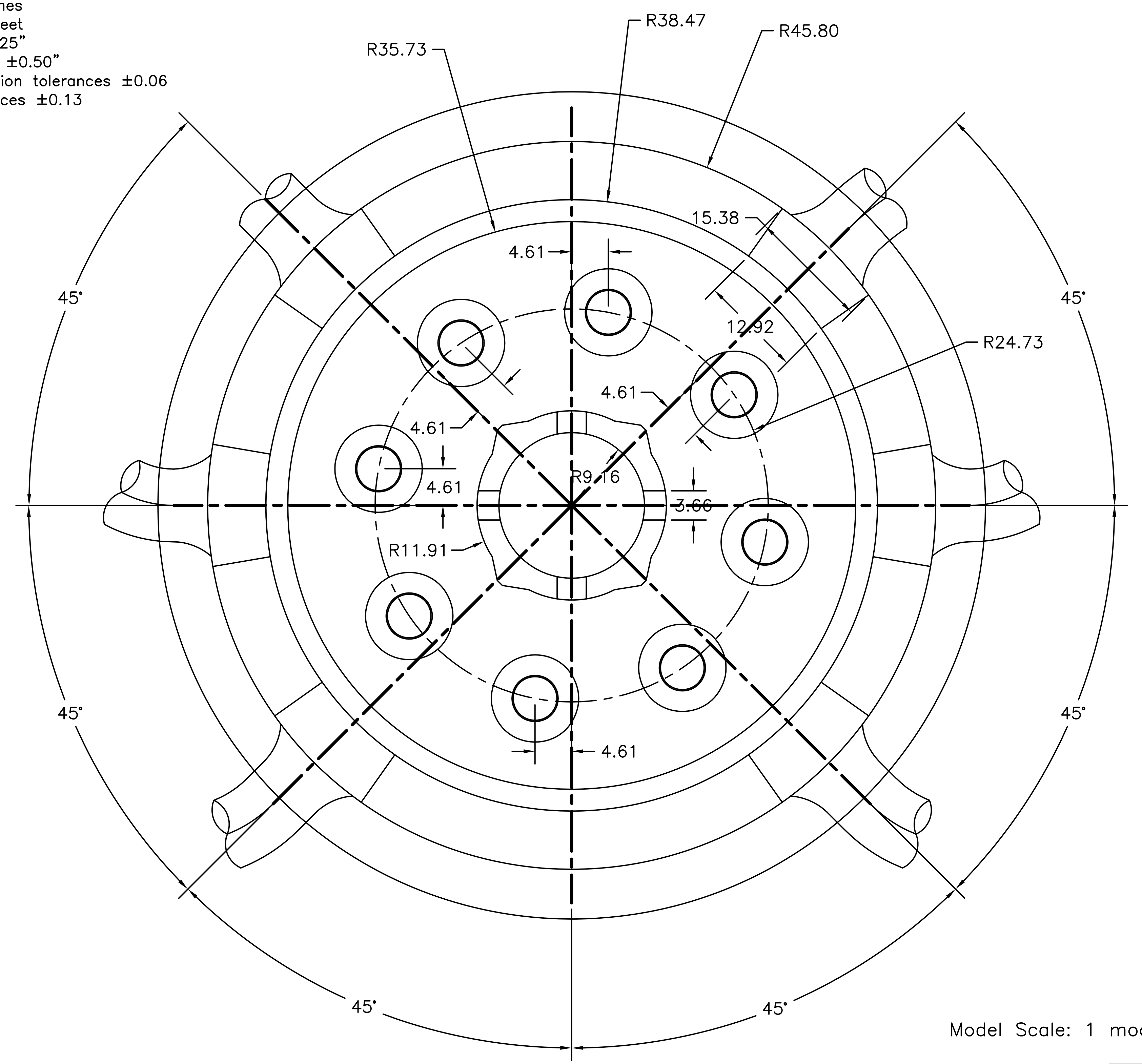
Model Scale: 1 model inch =13.1 prototype inches (1:13.1)

NO.	DATE:	REVISION	DRAWN:	CHK. BY:

DRAWING SCALE:	DRAWN: K. Davy	DATE: 8/4/2017	PROJECT NO:
1:16	FILE NO: SECTION	CHECKED:	

FIGURE 3-2
MODEL LAYOUT DETAILS
FREUD STORM
ARCADIS

Note: 1) All dimensions given in model inches
2) All elevations given in prototype feet
3) Basin construction tolerances ±0.25"
4) Head box construction tolerances ±0.50"
5) Acrylic intake structures construction tolerances ±0.06
6) Acrylic intake bell location tolerances ±0.13



Model Scale: 1 model inch =13.1 prototype inches (1:13.1)

NO.	DATE:	REVISION	DRAWN:	CHK. BY:

DRAWING SCALE:	DRAWN: K. Davy	DATE: 8/7/2017	PROJECT NO:
1:16	FILE NO: PLAN	CHECKED:	

FIGURE 3-4
MODEL SUMP DETAILS
FREUD STORM
ARCADIS

Photo 3-1 Model Overview

Photo 3-2 Supply Lines

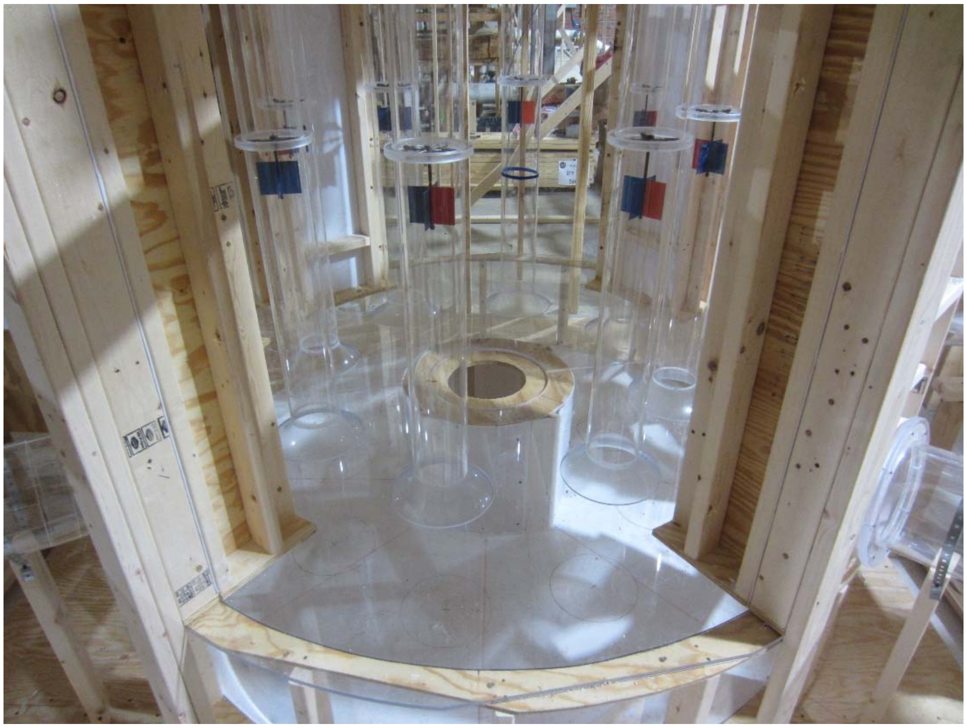


Photo 3-3 Model Pumps

Photo 3-4 Model Pumps

4.0 INSTRUMENTATION AND TESTING PROCEDURES

4.1 Instrumentation and Data Collection

The individual model pump flow rates, as well as the total model flow rate were determined with an ASME standard orifice meter with an accuracy of +/- 2 percent or better. Mercury U-tube manometers as well as a Dwyer Series 475 differential manometer were used to measure the manometer deflection. The Dwyer manometer was calibrated prior to the model study. Valves were adjusted in the model piping until the manometer deflections indicated that the proper flow rates were set.

The water levels in the pump sump were recorded with a staff gauge referenced to the sump floor with an accuracy of 3-mm (0.01-ft) or better). Vortex formation was visually observed. Dye was used to aid in the visualization of vortex formation. Vortex strength was rated according to the scale presented in Figure 2-1. Digital photographs and video footage were also used to document vortex formation.

Velocity fluctuations and turbulence levels were measured at the pump impeller location. A free spinning miniature propeller Model 412 Nixon Streamflow probe was used to measure the velocities. A data acquisition board was connected to the Nixon probe and recorded approximately 9000 samples over a 30-second period. The software program HPVEE was used to record this data and determine the mean and standard deviation of the velocity data. The velocity probe was attached to a turn-column, which allowed the probe to be rotated 360 degrees. Velocities were collected at 8 points around the pump bell, at a fixed radius, in 45-degree increments.

A swirl meter was installed in each detailed pump to measure the level of pre-swirl of flow entering the pump. Each swirl meter consists of 4 straight vanes mounted on a shaft. The swirl angle can be calculated with the following equation:

$$\theta = \tan^{-1}\left(\frac{\pi d n}{u}\right)$$

Where: u = average axial velocity
d = diameter of the pipe in which the swirl meter is installed
n = revolutions per second of the swirl meter

4.2 Test Program

Testing is conducted in three phases, baseline, modification, and final documentation testing. Each of these phases is described below:

- Baseline Testing: Tests were conducted with the intake structure as designed. These tests were conducted to evaluate the approach flow conditions, and to determine if any adverse hydraulic phenomena were present. In general, vortex activity, pre-swirl, velocity distribution, turbulence levels, and overall approach flow conditions were evaluated.

- Modification Testing: Tests were conducted to develop modifications that would alleviate or minimize any potentially damaging hydraulic conditions within the sump. These tests were conducted systematically to minimize design changes while still meeting the pre-determined acceptance criteria.

- Final Documentation Testing: Following the witness test, documentation testing is conducted to verify that the recommended modifications are effective for a range of expected operating conditions.

5.0 TEST RESULTS

5.1 Baseline Testing

Baseline tests were conducted for the station with several possible operating conditions. These tests were conducted at low and high water levels. In general, the following observations were made:

1. Initial testing was conducted with 1-7 pumps is operation. These tests were conducted at the water level initially set at the pump off levels for the number of pumps operating during that test.
2. Significant air entrainment occurred at these levels with large amounts of air entering the wet well and ultimately the pumps. The air entrainment occurred within the vertical shafts that transitioned flow from the influent pipes to the wet well. The amount of air observed with three of more pumps operating was significant and excessive.
3. Vortex activity was generally minimal because the general turbulence within the wet well washed out vortices before they could become fully developed. Some highly mobile floor and occasional “mid-flow” vortices were observed forming off the floor and mid-flow near the suction bells but these were not well developed and dissipated quickly.
4. Pre-swirl values were unstable, and very dependent of pump combinations. For some tests, overall values were well outside of criteria.
5. Velocity and turbulence levels were generally in criteria, but again, depending on which pumps were in service, the turbulence levels did increase. The long suction tubes helped to condition the flow by providing time for the flow to stabilize prior to reaching the pump impeller location. However, vortices and swirl clearly reached the pump impeller location.

A summary of the baseline testing is shown in Table 5-1.

Table 5-1 Baseline Data Summary

Note: Pump 1 was instrumented with a velocity probe. All pumps were instrumented with rotometers. Velocity fluctuations should be less than 10%, pre-swirl should be less than 5.0-degrees (ideally less than 2.5), and no vortices greater than type 1 or weak type 2 should enter the pump.

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 1	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	I 2-3	I 2-3	-9.1	6.3	9.0	1.6
Pump 2	0									
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									

Comment: Water Level El. 45.0-ft – 1 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Overall conditions are relatively stable
Flow enters the pump uniformly around the pump bell
Weak floor and mid-flow vortex activity observed – typically flushed out before full organization
Pre-swirl is stable

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 2	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	none	none				5.6
Pump 2	450	none	none	none	none	none	No probe installed			5.9
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	450	none	none	none	none	none	No probe installed			8.7
Comment: Water Level El. 48.0-ft – 3 pump off (Sump Invert El. 20.0-ft.) Influent Flow Split: 50/50 Overall conditions are extremely turbulent and unstable Significant air entrainment observed in the wet-well and in the pumps Pre-swirl is high and unstable – frequent stalling and burst swirl observed Vortex activity gets flushed out No velocity data collected – too much air										

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 3	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	I 2-3	I 2-3	-4.2	7.6	8.4	6.8
Pump 2	450	none	none	none	I 2-3	I 2-3	No probe installed			0.6
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	450	none	none	none	I 2-3	I 2-3	No probe installed			2.5
Comment: Water Level El. 51.0-ft – Revised 3 pump off (Sump Invert El. 20.0-ft.) Influent Flow Split: 50/50 Water level increased to minimize air entrainment Overall conditions remain turbulent and unstable Increasing water level minimizes air entrainment Pre-swirl is high and unstable – frequent stalling and burst swirl observed Floor and mid-flow vortices observed – very mobile and intermittent										

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 4	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	I 2-3	I 2-3	-6.0	6.4	9.9	3.7
Pump 2	450	none	none	none	I 2-3	I 2-3	No probe installed			5.9
Pump 3	0									
Pump 4	450	none	none	none	I 2-3	I 2-3	No probe installed			9.9
Pump 5	0									
Pump 6	450	none	none	none	I 2-3	I 2-3	No probe installed			0.6
Pump 7	0									
Pump 8	450	none	none	none	I 2-3	I 2-3	No probe installed			1.6

Comment: Water Level El. 57.0-ft – Revised 4 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Water level increased to minimize air entrainment
Overall conditions remain turbulent and unstable
Increasing water level minimizes air entrainment
Pre-swirl is high and unstable – frequent stalling and burst swirl observed
Floor and mid-flow vortices observed – very mobile and intermittent

Base Line	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 5	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	I 2-3	I 2-3	-5.9	3.2	9.3	8.7
Pump 2	450	none	none	none	I 2-3	I 2-3	No probe installed			1.9
Pump 3	450	none	none	none	I 2-3	I 2-3	No probe installed			0.3
Pump 4	450	none	none	none	I 2-3	I 2-3	No probe installed			7.4
Pump 5	0									
Pump 6	450	none	none	none	I 2-3	I 2-3	No probe installed			1.2
Pump 7	450	none	none	none	I 2-3	I 2-3	No probe installed			1.9
Pump 8	450	none	none	none	I 2-3	I 2-3	No probe installed			2.5

Comment: Water Level El. 61.0-ft – Revised 7 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Water level increased to minimize air entrainment
Overall conditions remain turbulent and unstable
Increasing water level minimizes air entrainment
Pre-swirl is high and unstable – frequent stalling and burst swirl observed
Floor and mid-flow vortices observed – very mobile and intermittent

The following pictures show some of the conditions observed in the wet well. Photography is difficult with this wet well configuration but video is being provided which will allow easier observation of conditions. Video footage of the testing will show conditions more clearly.

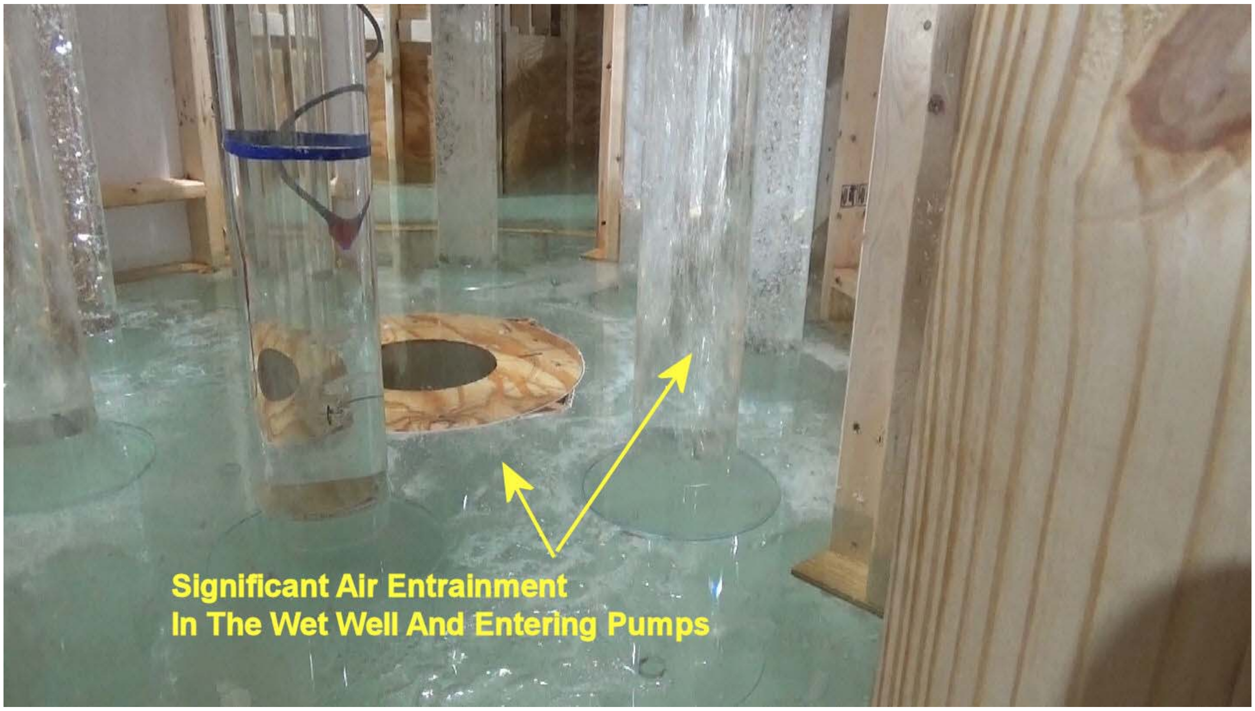


Photo 5-1 Air Entrainment

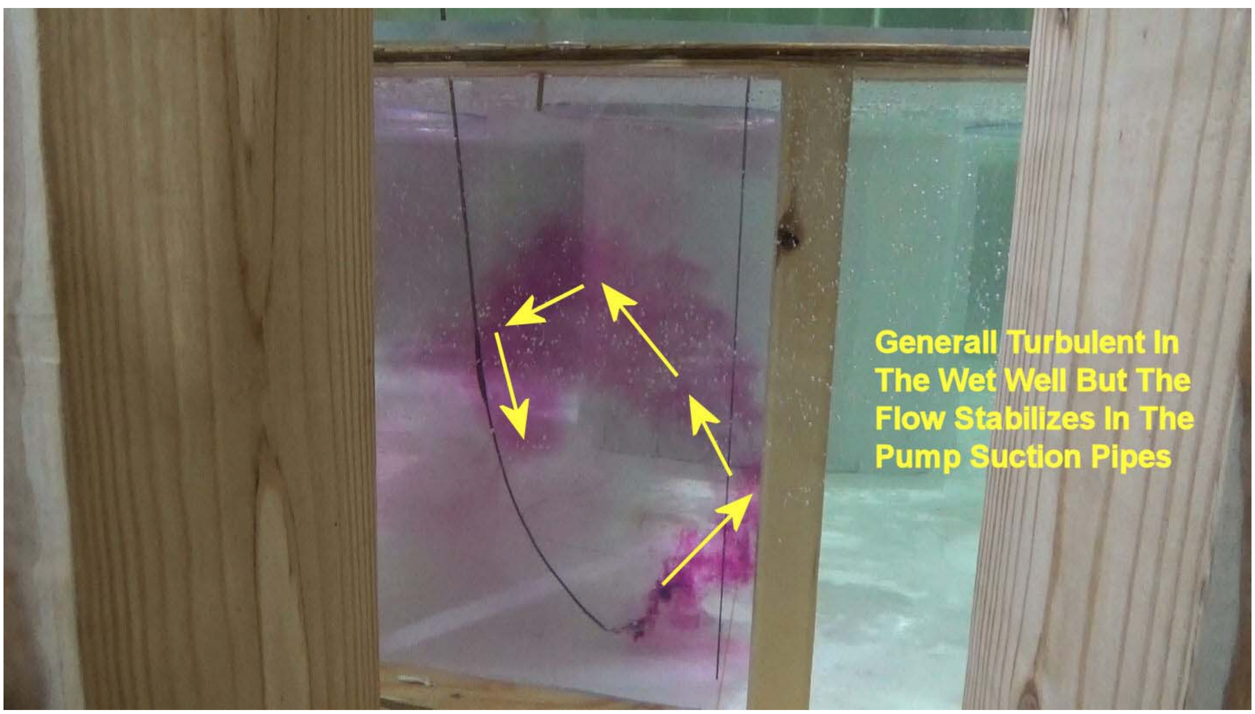


Photo 5-2 Overall Instability

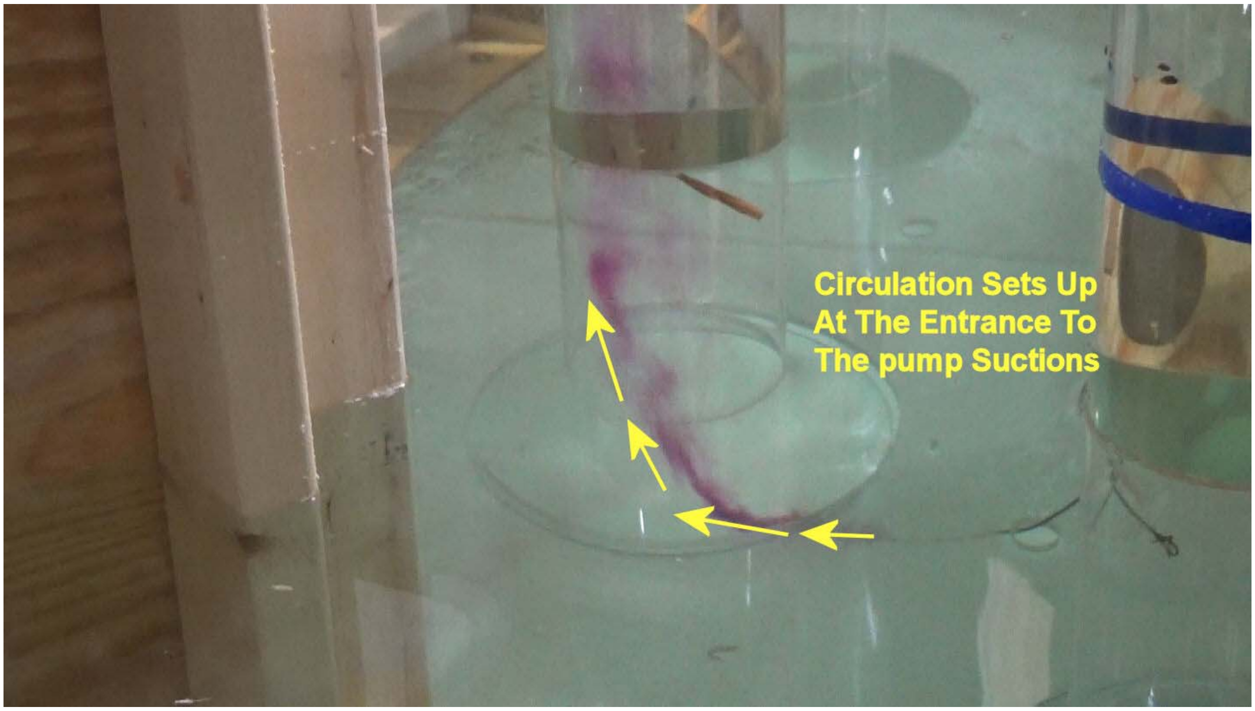


Photo 5-3 Circulation Observed Within the Pumps

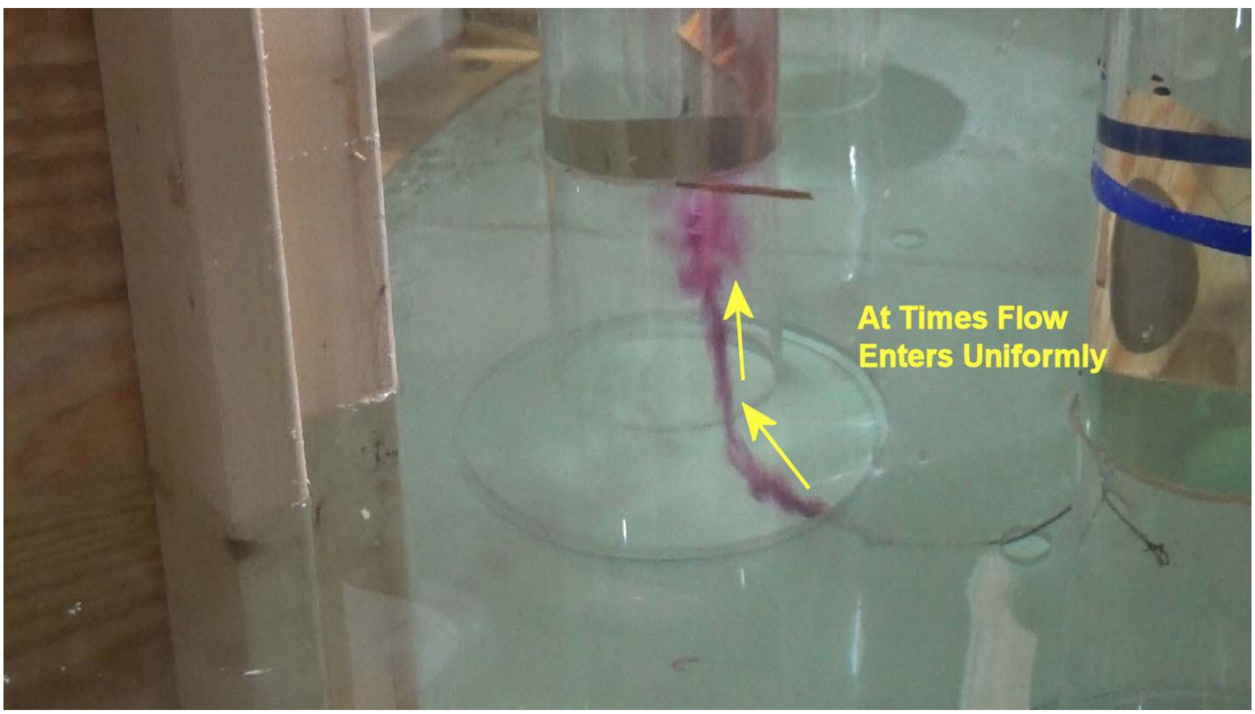


Photo 5-4 Intermittent Stability Within Pump

Photo 5-5 Revised Water Levels Minimize Air Entrainment

5.2 Modification Testing

Modification tests were conducted to improve the approach flow conditions within the pump sump. Complete data sets may not be taken during each test and all conditions are not investigated during this phase of testing. In general:

1. Initial modifications were evaluated during baseline testing. Water levels were revised to minimize air entrainment.
2. Similar to the Conner Creek storm water and sanitary sewer intakes, suction tubes / suction shrouds were installed on the ceiling under each of the pumps. These forced the pumps to receive water flow lower in the water column as opposed to along the wet-well ceiling. Testing with the suction tubes / shrouds and a floor cones installed under the pumps improved conditions entering the pumps, but did not fully minimize rotation entering the pumps, which resulted in excessive pre-swirl values.
3. Installing four vanes within the suction tubes / shrouds reduced rotation entering the pumps and stabilized pre-swirl values.
4. Model observations showed a significant reduction in air entering the pumps when operating at the revised pump off levels. The modifications were effective at improving conditions within the pumps. With the modifications installed, pre-swirl as well as velocity and turbulence variations were within HI criteria.
5. The recommended water levels are presented below and represent the pump off elevations

Pump 7 Off – El. 61.0-ft
Pump 6 Off – El. 59.0-ft
Pump 5 Off – El. 57.0-ft
Pump 4 Off – El. 54.0-ft
Pump 3 Off – El. 51.0-ft
Pump 1 Off – El. To Be Determined

Table 5-2 summarizes the modification testing. Figures 5-1 and 5-2 show the recommended modification details and Photos 5-5 and 5-6 show the modifications in place.

Table 5-2 Summary of Modification Tests

<table>
<tr><td>Mod</td><td>Prototype Flow</td><td colspan="5">Vortex Activity
(I = Intermittent C = Constant)</td><td colspan="3">Velocity & Turbulence
(Vel = % of average)</td><td>Pre-Swirl</td></tr>
<tr><td>Test 1</td><td>(cfs)</td><td>Surface</td><td>Back wall</td><td>Side wall</td><td>Floor</td><td>Midflow</td><td>Min. Vel.</td><td>Max. Vel.</td><td>Max. Turb. %</td><td>Max (deg.)</td></tr>
<tr><td>Pump 1</td><td>450</td><td>none</td><td>none</td><td>none</td><td>none</td><td>none</td><td>-6.4</td><td>4.0</td><td>8.4</td><td>3.4</td></tr>
<tr><td>Pump 2</td><td>450</td><td>none</td><td>none</td><td>none</td><td>none</td><td>none</td><td colspan="3">No probe installed</td><td>1.9</td></tr>
<tr><td>Pump 3</td><td>450</td><td colspan="9">Flow withdrawn – no mods installed</td></tr>
<tr><td>Pump 4</td><td>450</td><td colspan="9">Flow withdrawn – no mods installed</td></tr>
<tr><td>Pump 5</td><td>0</td><td colspan="9"></td></tr>
<tr><td>Pump 6</td><td>450</td><td colspan="9">Flow withdrawn – no mods installed</td></tr>
<tr><td>Pump 7</td><td>450</td><td>none</td><td>none</td><td>none</td><td>none</td><td>none</td><td colspan="3">No probe installed</td><td>1.9</td></tr>
<tr><td>Pump 8</td><td>450</td><td>none</td><td>none</td><td>none</td><td>none</td><td>none</td><td colspan="3">No probe installed</td><td>2.5</td></tr>
<tr><td colspan="11">Comment: Water Level El. 61.0-ft – Revised 7 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds installed on ceiling under Pumps 1, 2, 7, and 8
Floor cones installed under Pumps 1, 2, 7, 8
Overall conditions remain unstable
Cones and shrouds improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed</td></tr>
</table>

Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 2	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	none	none	-2.6	4.8	9.8	1.6
Pump 2	450	none	none	none	none	none	No probe installed			2.2
Pump 3	0									
Pump 4	450	Flow withdrawn – no mods installed								
Pump 5	0									
Pump 6	0									
Pump 7	450	none	none	none	none	none	No probe installed			1.6
Pump 8	450	none	none	none	none	none	No probe installed			1.6

Comment: Water Level El. 57.0-ft – Revised 5 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds installed on ceiling under Pumps 1, 2, 7, and 8
Floor cones installed under Pumps 1, 2, 7, 8
Overall conditions remain unstable
Cones and shrouds improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed

Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 3	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	none	none	-4.2	9.6	10.4	12.3
Pump 2	450	none	none	none	none	none	No probe installed			9.9
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	450	none	none	none	none	none	No probe installed			6.2

Comment: Water Level El. 57.0-ft – Revised 5 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds installed on ceiling under Pumps 1, 2, 7, and 8
Floor cones installed under Pumps 1, 2, 7, 8
Overall conditions remain unstable
Cones and shrouds are less effective at this pump combination
Pre-swirl values are unstable and elevated
No vortex activity observed

Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 4	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	none	none	-4.9	5.1	9.9	0.3
Pump 2	0									
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	0									

Comment: Water Level El. 45.0-ft – Revised 1 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds installed on ceiling under Pumps 1, 2, 7, and 8
Floor cones installed under Pumps 1, 2, 7, 8
Overall conditions remain unstable
Cones and shrouds improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed

Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 5	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	none	none	-4.8	7.6	9.9	0.3
Pump 2	450	none	none	none	none	none	No probe installed			0.3
Pump 3	450	Flow withdrawn – no mods installed								
Pump 4	450	Flow withdrawn – no mods installed								
Pump 5	0									
Pump 6	450	Flow withdrawn – no mods installed								
Pump 7	450	none	none	none	none	none	No probe installed			0.3
Pump 8	450	none	none	none	none	none	No probe installed			0.3

Comment: Water Level El. 61.0-ft – Revised 7 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds installed on ceiling under Pumps 1, 2, 7, and 8
Floor cones installed under Pumps 1, 2, 7, 8
Four flow stabilizing vanes installed in the suction tubes / shrouds
Overall conditions remain unstable
Vanes further improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed

Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 6	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	none	none	-4.9	5.1	9.9	0.6
Pump 2	450	none	none	none	none	none	No probe installed			0.6
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	450	Flow withdrawn – no mods installed								
Pump 7	450	none	none	none	none	none	No probe installed			0.3
Pump 8	450	none	none	none	none	none	No probe installed			0.3

Comment: Water Level El. 57.0-ft – Revised 7 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds installed on ceiling under Pumps 1, 2, 7, and 8
Floor cones installed under Pumps 1, 2, 7, 8
Four flow stabilizing vanes installed in the suction tubes / shrouds
Overall conditions remain unstable
Vanes further improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed

Mod	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 7	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	none	none	-6.7	6.4	9.2	0.3
Pump 2	450	none	none	none	none	none	No probe installed			0.3
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	0									
Pump 7	0									
Pump 8	450	none	none	none	none	none	No probe installed			0.3
Comment: Water Level El. 51.0-ft – Revised 7 pump off (Sump Invert El. 20.0-ft.) Influent Flow Split: 50/50 Mods: Suction tubes / shrouds installed on ceiling under Pumps 1, 2, 7, and 8 Floor cones installed under Pumps 1, 2, 7, 8 Four flow stabilizing vanes installed in the suction tubes / shrouds Overall conditions remain unstable Vanes further improve flow entering the pumps Pre-swirl is stable No vortex activity observed										

The recommended modifications are shown in Figures 5-1 and 5-2 and in Photos 5-5 and 5-6.

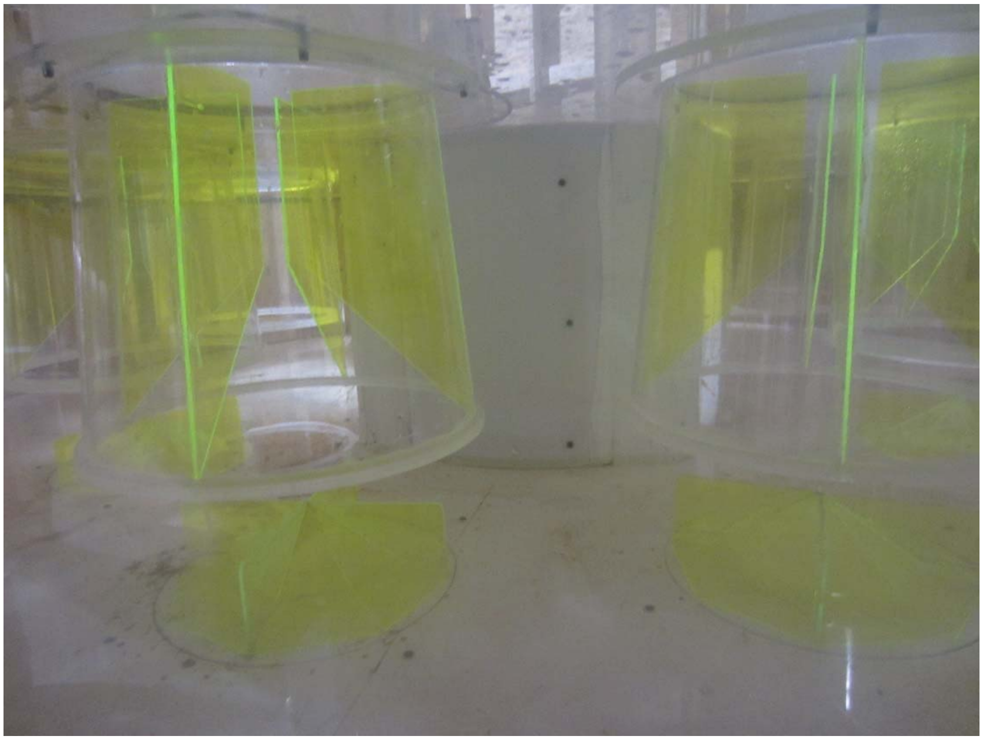


Photo 5-6 Suction Tubes / Shrouds with Vanes / Floor Cones

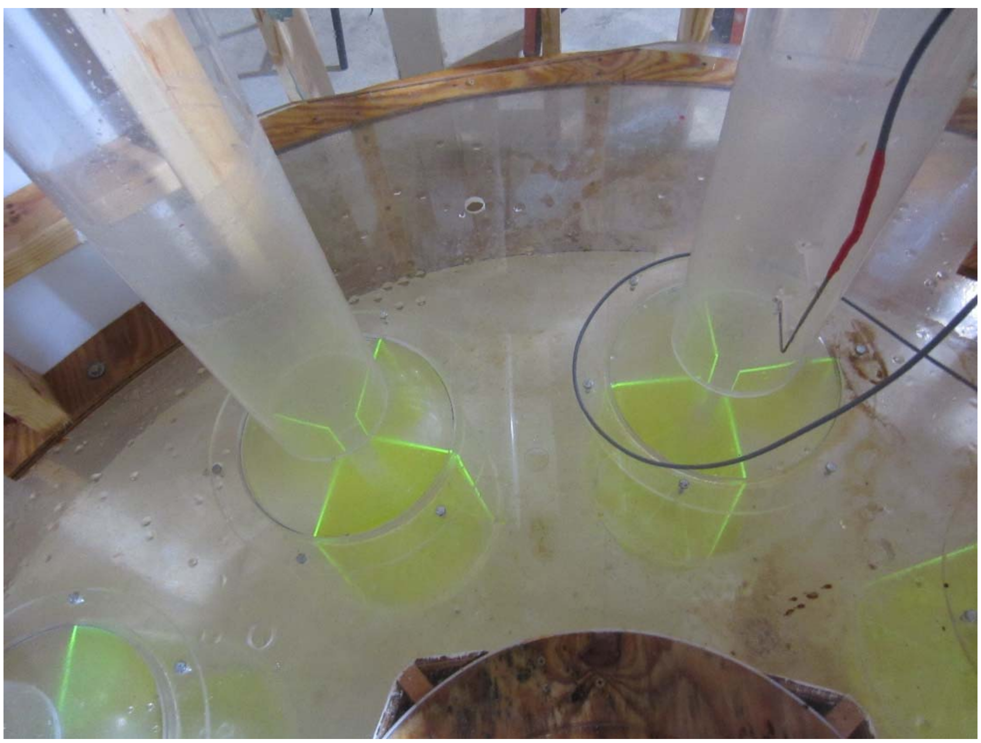
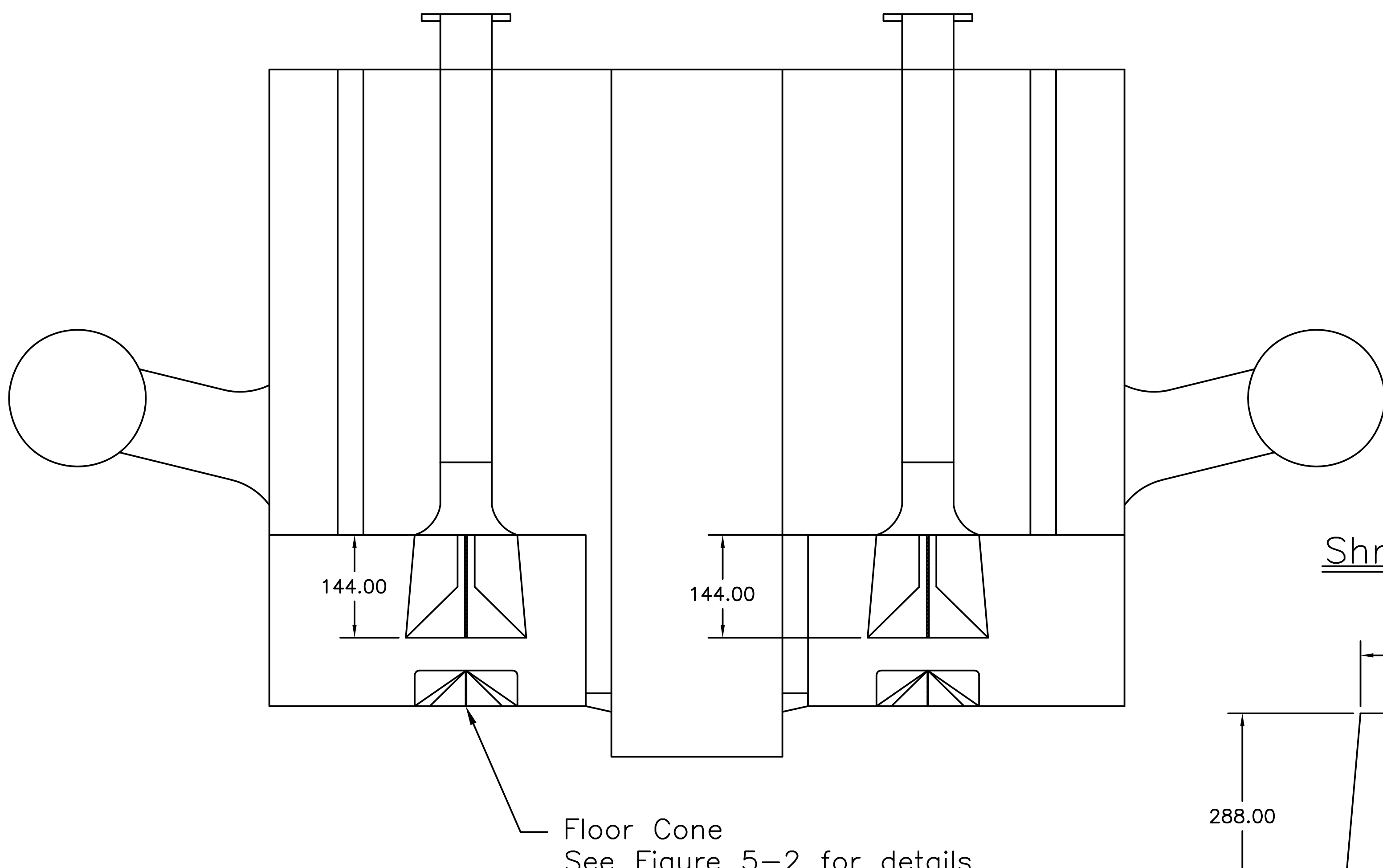
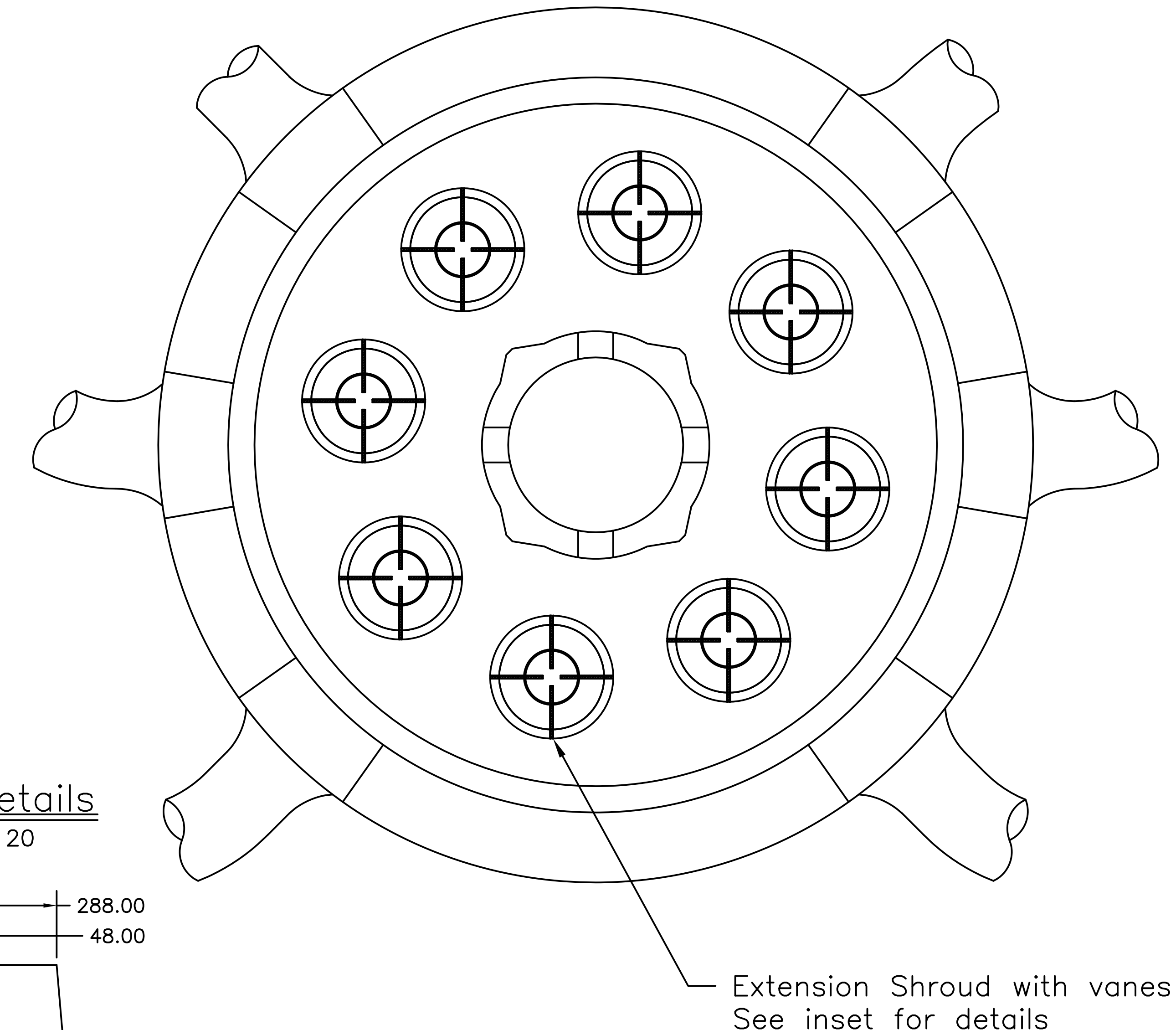


Photo 5-7 Suction Tube Vanes

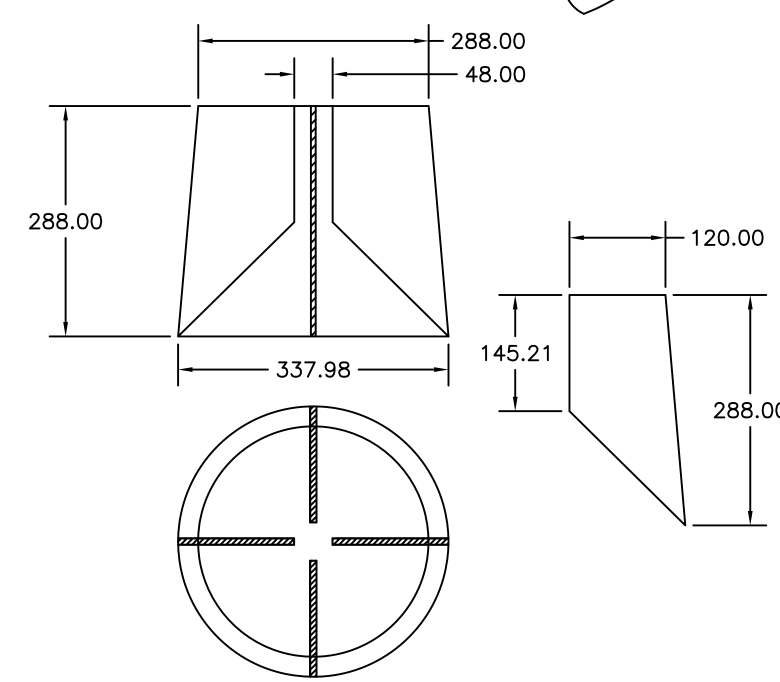
The following modifications are recommended:

1. Suction shrouds should be installed on the ceiling under each pump.
2. Four (4) vanes should be installed in each of the suction shrouds installed under the pumps.
3. Floor cones should be installed on the floor under each pump.





Shroud Details
Scale 1:120



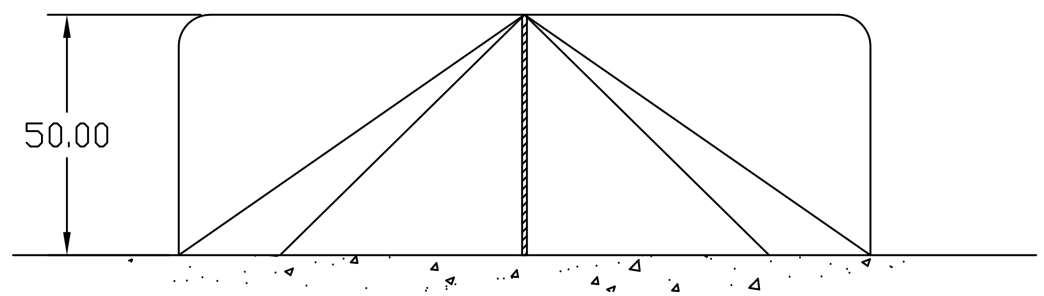
Note: Drawing intended for reference only. Not to be used as a construction drawing.

Note: 1. All dimensions given in prototype inches.
2. All elevations given in prototype feet.

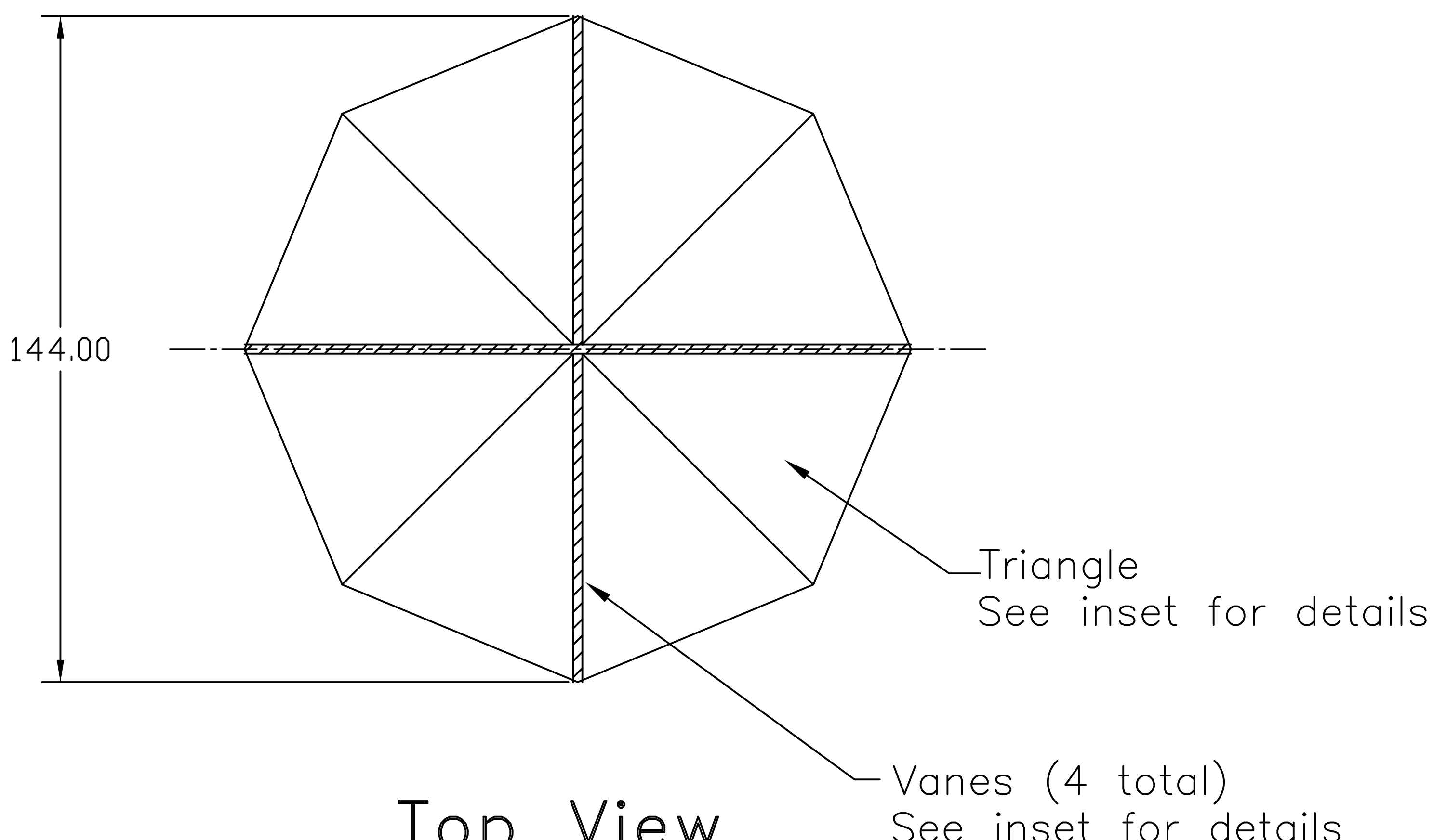
NO.	DATE:	REVISION	DRAWN:	CHK. BY:

DRAWING SCALE:	DRAWN: M. Havice	DATE: 2/12/2018	PROJECT NO:
1:240	FILE NO: SECTION	CHECKED:	

FIGURE 5–1
MODIFICATION DETAILS – OVERVIEW
FREUD STORM
ARCADIS

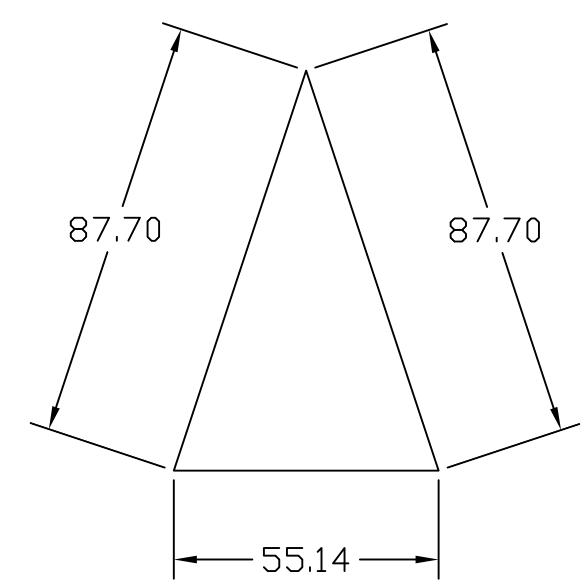


Notes:
1. All dimensions given in prototype inches
2. Cone Specifications:
   Fabricated out of 8 triangle pieces (see detail)
   Total Height = 50.0 in.
   Base Diameter = 144.0 in.
3. Structural analysis required for fabrication and attachment design

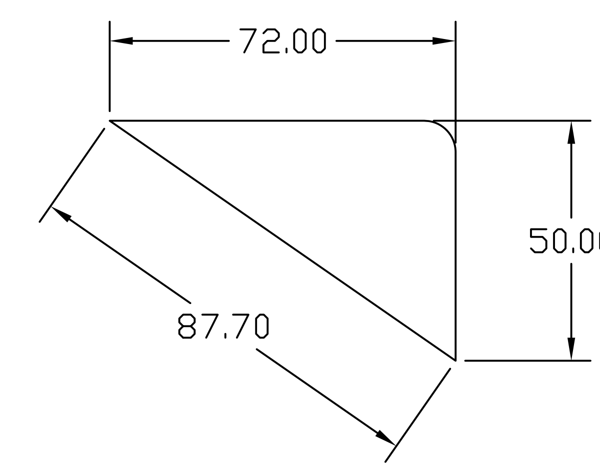


Top View

Triangle Details



Vane Details



Drawing to be used for reference only.
Not to be used as a construction drawing.

Note: Elevations given in prototype feet.
Dimensions given in prototype inches.

REVISION	DRAWN:	CHK. BY:	SCALE:	DRAWN: M. Havice	DATE: 2/9/2018	PROJECT NO:
			1:40	FILE NO:	CHECKED: D. Werth	

FIGURE 5-2
FLOOR CONE DETAILS
FREUD STORMWATER
ARCADIS

5.3 Witness Testing

A formal witness test was on Monday, February 19th with representatives from Arcadis as well as an owner's representative in attendance. During the witness test the model was demonstrated with and without modifications in place. Final documentation testing will be conducted after approval of this draft report. Video of baseline and final documentation testing will be included with the final report.

5.4 Final Documentation Testing

After approval of the draft report, final documentation tests were conducted for various operating conditions. The following modifications were implemented:

- Floor cones were installed under each pump.
- Suction tubes / shrouds with flow stabilizing vanes were installed on the ceiling under each pump.
- The "pump off" levels were revised as shown:

Pump 7 Off – El. 61.0-ft
Pump 6 Off – El. 59.0-ft
Pump 5 Off – El. 57.0-ft
Pump 4 Off – El. 55.0-ft
Pump 3 Off – El. 51.0-ft
Pump 2 Off – El. 49.0-ft
Pump 1 Off – El. 45.0-ft

Table 5-3 shows the final documentation test data.

Table 5-3 Summary Final Documentation Testing

Note: Pump numbers were revised to match prototype designations. Velocity probe is still in the same location.

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 1	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	450	none	none	none	none	none	No probe installed			0.3
Pump 2	0									
Pump 3	450	none	none	none	none	none	No probe installed			0.3
Pump 4	450	none	none	none	none	none	No probe installed			0.3
Pump 5	450	none	none	none	none	none	No probe installed			0.3
Pump 6	450	none	none	none	none	none	-7.4	5.8	7.2	0.3
Pump 7	450	none	none	none	none	none	No probe installed			0.3
Pump 8	450	none	none	none	none	none	No probe installed			0.3

Comment: Water Level El. 61.0-ft – Revised 7 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds (with internal vanes) installed on ceiling under all pumps
Floor cones installed under all pumps
Overall conditions remain unstable – air entrainment is minimized
Vanes further improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 2	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	450	none	none	none	none	none	No probe installed			0.3
Pump 4	450	none	none	none	none	none	No probe installed			0.3
Pump 5	450	none	none	none	none	none	No probe installed			0.6
Pump 6	450	none	none	none	none	none	-5.1	6.6	8.6	0.6
Pump 7	450	none	none	none	none	none	No probe installed			0.3
Pump 8	450	none	none	none	none	none	No probe installed			0.3

Comment: Water Level El. 59.0-ft – Revised 6 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds (with internal vanes) installed on ceiling under all pumps
Floor cones installed under all pumps
Overall conditions remain unstable – air entrainment is minimized
Vanes further improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 3	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	0									
Pump 4	450	none	none	none	none	none	No probe installed			0.3
Pump 5	450	none	none	none	none	none	No probe installed			0.6
Pump 6	450	none	none	none	none	none	-5.9	4.0	8.7	0.6
Pump 7	450	none	none	none	none	none	No probe installed			0.3
Pump 8	450	none	none	none	none	none	No probe installed			0.3

Comment: Water Level El. 57.0-ft – Revised 5 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds (with internal vanes) installed on ceiling under all pumps
Floor cones installed under all pumps
Overall conditions remain unstable – air entrainment is minimized
Vanes further improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 4	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	0									
Pump 4	450	none	none	none	none	none	No probe installed			0.3
Pump 5	450	none	none	none	none	none	No probe installed			0.3
Pump 6	450	none	none	none	none	none	-8.7	8.1	8.6	0.3
Pump 7	450	none	none	none	none	none	No probe installed			0.3
Pump 8	0									

Comment: Water Level El. 55.0-ft – Revised 4 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds (with internal vanes) installed on ceiling under all pumps
Floor cones installed under all pumps
Overall conditions remain unstable – air entrainment is minimized
Vanes further improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 5	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	0									
Pump 4	0									
Pump 5	450	none	none	none	none	none	No probe installed			0.3
Pump 6	450	none	none	none	none	none	-9.7	6.3	8.8	0.3
Pump 7	450	none	none	none	none	none	No probe installed			0.3
Pump 8	0									

Comment: Water Level El. 51.0-ft – Revised 3 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds (with internal vanes) installed on ceiling under all pumps
Floor cones installed under all pumps
Overall conditions remain unstable – air entrainment is minimized
Vanes further improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 6	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	0									
Pump 4	0									
Pump 5	450	none	none	none	none	none	No probe installed			0.3
Pump 6	0									
Pump 7	450	none	none	none	none	none	No probe installed			0.3
Pump 8	0									

Comment: Water Level El. 49.0-ft – Revised 2 pump off (Sump Invert El. 20.0-ft.)
Influent Flow Split: 50/50
Mods:
Suction tubes / shrouds (with internal vanes) installed on ceiling under all pumps
Floor cones installed under all pumps
Overall conditions remain unstable – air entrainment is minimized
Vanes further improve flow entering the pumps
Pre-swirl is stable
No vortex activity observed

Doc	Prototype Flow	Vortex Activity (I = Intermittent C = Constant)					Velocity & Turbulence (Vel = % of average)			Pre-Swirl
Test 7	(cfs)	Surface	Back wall	Side wall	Floor	Midflow	Min. Vel.	Max. Vel.	Max. Turb. %	Max (deg.)
Pump 1	0									
Pump 2	0									
Pump 3	0									
Pump 4	0									
Pump 5	0									
Pump 6	450	none	none	none	none	none	-7.3	6.9	9.2	0.3
Pump 7	0									
Pump 8	0									
Comment: Water Level El. 45.0-ft – Revised 1 pump off (Sump Invert El. 20.0-ft.) Influent Flow Split: 50/50 Mods: Suction tubes / shrouds (with internal vanes) installed on ceiling under all pumps Floor cones installed under all pumps Overall conditions remain unstable – increased air entrainment observed Vanes further improve flow entering the pumps Pre-swirl is stable No vortex activity observed										

Note: Increased air entrainment was observed at this elevation. Pump 6 is in close proximity to the vertical shafts that connect to the larger supply lines. Operating a different pump (located further from the vertical shafts) would minimize air entrainment at this minimum level.

6.0 CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

Initial testing was conducted with 1-7 pumps in operation. These tests were conducted at the water level initially set at the pump off levels for the number of pumps operating during that test. Significant air entrainment occurred at these levels with large amounts of air entering the wet well and ultimately the pumps. The air entrainment occurred within the vertical shafts that transitioned flow from the influent pipes to the wet well. The amount of air observed with three of more pumps operating was significant and excessive. Vortex activity was generally minimal because the general turbulence within the wet well washed out vortices before they could become fully developed. Some highly mobile floor and occasional "mid-flow" vortices were observed forming off the floor and mid-flow near the suction bells but these were not well developed and dissipated quickly. Pre-swirl values were unstable, and very dependent of pump combinations. For some tests, overall values were well outside of criteria. Velocity and turbulence levels were generally in criteria, but again, depending on which pumps were in service, the turbulence levels did increase. The long suction tubes helped to condition the flow by providing time for the flow to stabilize prior to reaching the pump location. However, vortices and swirl clearly reached the pump impeller location.

Water levels were revised to minimize air entrainment and suction tubes / suction shrouds (similar to those on the Conner storm water pumps), were installed on the ceiling under each of the pumps. These forced the pumps to receive water from lower in the water column as opposed to along the wet-well ceiling which minimized the amount of air entering the pumps. Four vanes were installed in each of the suction tubes to reduce pre-swirl and rotation. With the modifications installed and the increased water levels in the drop shafts significantly less air entrainment was observed and conditions within the pumps were improved. Pre-swirl, velocity/turbulence and vortex activity was within HI criteria. It was noted that increased air entrainment was observed at El. 45-ft. Operating a pump located further from the vertical shafts would minimize air entrainment at this minimum level.

6.2 Recommendations

It is recommended that a floor cone be installed under each pump. In addition, suction tubes / shrouds should be installed on the ceiling under each of the pumps. Four vanes should also be installed in the suction tubes / shrouds. The "pump off" elevations should be revised as noted below and the recommended modifications can be seen on Figures 5-1 and 5-2.

Pump 7 Off – El. 61.0-ft
Pump 6 Off – El. 59.0-ft
Pump 5 Off – El. 57.0-ft
Pump 4 Off – El. 55.0-ft
Pump 3 Off – El. 51.0-ft
Pump 2 Off – El. 49.0 ft
Pump 1 Off – El. 45.0 ft

7.0 REFERENCES

Hydraulic Institute Standards, 2012. American National Standard for Pump Intake Design. Hydraulic Institute, Parsippany, New Jersey, 07054-3802

Sweeney, C.E. and G.E. Rockwell, 1982. Pump Sump Design Acceptance through Hydraulic Model Testing. Proc. of the International Association for Hydraulic Research: Symposium on Operating Problems of Pump Stations and Power Plants. Amsterdam, the Netherlands, pp. 13-17, September 1982.

A7 – Vacuum Priming System Evaluation, System Analysis and Condition Survey of Sewerage PS

Vacuum Priming System Evaluation, System Analysis and Condition Survey of Sewerage Pumping Stations

METCO

June, 2015

TABLE OF CONTENTS

Technical Memorandum No. 4 - Pump Station Capacity Analysis

EXECUTIVE SUMMARY

1.0 INTRODUCTION

During the recent heavy storm event in August, 11 of 2014, DWSD had experienced problems in putting the storm water pumps at Connor Creek Pump Station in service due to malfunctioning of the associated Vacuum Priming System. The outage of all pumps had resulted in a severe surcharge conditions in upstream sewers as well in the related service areas. To mitigate this situation, DWSD has initiated immediate efforts to identify the cause and implement appropriate corrective measures so as to restore the desired level of reliability to the operation of storm water pumps at Connors Creek Pump Station.

To address the issue and also to optimize the utilization of the storm water pumping stations and the CSO basin, DWSD had contracted the services of METCO Services, Inc. (METCO) by Task order No. 36 under Contract CS-1499.

2.0 OBJECTIVES

The primary objectives of this Study Report are as below:

- Enhance the operational reliability of Connor Creek Pump Station
- Develop Operational Strategy to optimize the utilization of Connor Creek CSO basin and associated CSO control facilities
- Determine the optimum level of Pumping capacity required at Freud, Connor Creek and Fairview Pump Stations
- Condition assessment and identify required repair/upgrades to major equipment at Freud and Connor Creek Pump Stations

3.0 SCOPE OF TASKS

To meet the above objectives, the following tasks were assigned as scope of services for this project.

- Evaluation and preliminary design of upgrade/ replacement of Vacuum Priming System at Connors Creek Pump Station

- System Hydraulic Analysis and Develop Operational Strategy for optimization of CSO facilities
- Capacity analysis of Freud, Connor Creek and Fairview Pump Stations
- Condition assessment survey and identify repairs/upgrades to major equipment at Connor Creek and Freud Pump Stations

4.0 REPORT ORGANIZATION

This Report is organized into Four (4) Technical Memorandums with each addressing the requirements of below listed specific scope item:

- *Technical Memo No.1:* *Vacuum Priming System Evaluation– Connor Creek Pump Station*
- *Technical memo No.2:* *Condition Assessments – Freud and Connor Creek Pump Stations*
- *Technical Memo No.3:* *System (Connor Creek Drainage District) Hydraulic Analysis*
- *Technical Memo No.4:* *Freud, Connor Creek and Fairview Pump Station Capacity Analysis*

5.0 METHODOLOGY

The following approach was used in performing each task.

5.01 Evaluation of Vacuum Priming System – Connor Creek Pump Station

In the evaluation of Vacuum priming System, heavy reliance was placed upon the review of relevant engineering reports, drawings, O&M Manual and historical operating data of the pumps. In addition, field inspections and assessments were conducted along with maintenance personnel to obtain information on the current condition of the system.

The evaluation process included developing and analyzing different alternatives using criteria such as reliability, ease of operation and maintenance and the constructability.

5.02 Condition Assessment of Freud and Connor Creek Pump Station Equipment

For the condition assessment of the Pump Stations, prior to performing the field condition survey, the existing record drawings and the O&M Manual of the facility were obtained and reviewed. Subsequent to that, field inspections and assessments were performed to obtain information in sufficient detail to provide means of evaluating and determining the renewal and/or replacement of each major system/equipment.

The condition observations included the visual inspections, comments, assumptions and discussions with DWSD O&M personnel.

As part of our condition assessment process for each equipment, the following factors as applicable to each specific equipment were used.

- Age of equipment/ year of installation
- Corrosion
- Evidence of wear
- Inability to perform designed duty
- Excessive vibration/noise
- Leaks
- Accessibility to O&M Personnel
- Structural Integrity
- Code compliance
- Safety

5.03 System Hydraulic Analysis and Pump Station Capacity Analysis:

The Hydraulic Analysis and Pump Station Capacity analysis was performed primarily utilizing the existing GDRSS model as made available to METCO by DWSD. The relevant part of the model attributed to the Project service area was extracted from the overall system model and was enhanced to better represent the current conditions with the following improvements.

- Verify invert elevations and ground elevations from the as-built drawings and update as required.
- Verify and add all missing pipes upstream of the outfalls.
- Update Outfall geometry to reflect existing conditions.
- Subdivide the area into even smaller sub-areas to improve the model resolution.

As the re-calibration of this model is not within the scope of the project, the model was essentially used as calibrated earlier. However, additional validation of the model was performed by comparing the simulation results for earlier specific storm events with the available operating data from DWSD of the pump stations for that event.

The enhanced model was then used to simulate hydraulic responses under various Operational Scenarios for the design storm (10 year-1 Hour) event and also for establishing peak flow to various pump stations under the design storm condition.

6.0 EVALUATION OF ALTERNATIVES

A. Vacuum Priming System Evaluation – Connor Creek Pump Station

Subsequent to construction of CSO facility, the discharge channel of the Connor Creek Storm Water Pump Station is completely dewatered. This results in breaking seal of the siphon block and prevents the pump from priming with the operation of current vacuum priming system. Some of remedial measures such as construction of low head weir in the discharge channel did not prove to be effective in developing the siphon in discharge flume. The resultant condition is that the storm pumps are not able to be primed before starting thus rendering the pump station completely non-functional during storm events.

To address this condition and to improve the utilization of the Connor Creek PS during the wet weather events, the following Alternatives were considered as potential solutions:

A-1 Install flap valve at the end of the pump discharge line to replace the existing siphon arrangement to control the backflow and modify the existing vacuum priming system configuration for minimum four pumps.

A-2 Consider raising the dam in the pump station discharge channel to a level of 91'.0' to ensure the submergence of the siphon block.

A-3 Replace the existing mix flow, vertical, dry pit centrifuge pumps with vertical, wet pit turbine pumps and eliminate the priming system requirement.

After applying various criteria such as reliability, ease of operation and maintenance and the constructability of the above alternatives, the Alternative A-3 was found to be the preferred solution.

B. Condition Assessments – Connor Creek and Freud Pump Station

Our approach in this task included evaluation of two following alternatives as potential solution to address the deficiencies as determined from the condition assessment at these facilities.

- Repair or rehabilitation to the existing system / major equipment
- Replacement of the system/equipment

The evaluation included applying various assessment factors to the equipment as applicable and identifies the best approach that would provide a high level of reliability with ease of maintenance and operation.

C. System (Connor Creek Sewerage District) Hydraulic Analysis

In order to identify the operational strategy that will achieve the objectives of this task, the following three Alternative Operating Scenarios were evaluated by utilizing the Hydraulic Model simulations.

In conjunction with the controls under each Operating Scenario as described below, it was also assumed that none of the Pumps at Connor Creek Pump Station are operational due to inability to prime the pumps for the reasons detailed in Technical Memorandum No.1.

Accordingly, the model simulation run for the 10-Year, 1-Hour storm event under each scenario was performed with the no storm pumps being available at Connor Creek Pump station during wet weather events.

The operating strategies that were considered include:

C-1 Operating Scenario-I

This alternative represents the operating protocol currently being practiced by DWSD during the dry and wet weather conditions. This was developed primarily based upon our discussions with the DWSD operating personnel at their System Control Center. The hydraulic responses under this option were essentially utilized as the base line reference in our evaluation process.

C-2 Operating Scenario-II

This alternative represents modified operating protocol that DWSD had submitted to MDEQ as part of "Detroit WWTP-Wet Weather Operational Plan". This was developed in response to the NPDES permit mandate to provide general protocol for operating the Detroit WWTP during the wet weather periods. This was submitted on January 1, 2015 to comply with permit requirements.

C-3 Operating Scenario-III:

This alternative represents modifications to the existing operating protocol recommended by METCO in order to maximize the utilization of Connor Creek CSO basin and other associated Pump Station and control facilities. This was developed in conjunction with the evaluation of operational reliability of Connor Creek and Freud Pump Stations.

The evaluation criteria applied in our analysis included hydraulic responses in the upstream sewers and their impacts on the potential flooding at various locations within the service area. The criteria used for evaluating flood potential was to maintain minimum of 10 feet between the finished ground level and the hydraulic grade lines.

D. Capacity Analysis – Freud, Connor Creek and Fairview Pump Stations

The Evaluation process included determination of peak inflow rates to each pump station under the design storm event (10 year-1 hour storm) and corresponding hydrographs representing the inflow during dry weather and the design storm event as derived from the hydraulic model simulation runs.

The firm capacity and the installed capacity with “N+1” level of redundancy was determined to be aligned with the flow characteristics into the wet well at each Pump Station during the design wet weather event.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.01 Vacuum Priming System Evaluation – Connor Creek Pump Station

To make the operation of the vacuum priming system more reliable and efficient and also to improve the utilization of storm water pumps at Connor Creek PS and based upon our evaluation of various options as above, the Alternative A-3 as described under is recommended as the preferred approach.

- Remove and replace the two existing Pumps No.4 & 8 with wet pit, vertical turbine pumping units under the initial phase. In the event of priming the remaining pumps experience problem even with the new pumps on line, it is recommended two more new pumps shall be added to match the firm capacity of this pump station required to be consistent with the existing operating protocol and associated hydraulic analysis

- Maintain the existing siphon block in the discharge pipe to function as the check valve to control the back water from the discharge channel

The primary advantage of this option would be elimination of the need for any priming system. In addition, the new pumps could also be designed to meet the hydraulic conditions imposed due to construction of Connor Creek CSO Basin and thus would allow greater utilization of the Connors Creek Pump Station.

Typical arrangement of the proposed system is illustrated in the Sketch SK-03 and the preliminary pump curves from Flow Serve and Ebara are attached as SK-04.

7.02 Condition Assessment of Freud & Connor Creek Pump Station Equipment

7.02.01 Freud Pump Station

Based on our condition assessments of major equipment, the following Table provides the summery of recommended improvements for Freud Pump Station.

RECOMMENDED IMPROVEMENTS – FREUD PUMP STATION
1.0 PUMPING SYSTEM
1.1 Modify the all existing storm pumps with new mechanical seal and new self-lubricated bearings
1.2 Evaluate suction hydraulics, resize and relocate the existing two (2) sanitary pumps to the intermediate bearing floor level
1.3 Install stop logs at the inlet of the wet well for isolation purposes
1.4 Modify the discharge channel to eliminate the pumping restrictions
2.0 ELECTRICAL
2.1 Replace all three (3) Primary Power Transformers and associated controls
2.2 Upgrade the existing lighting system to provide required elimination level at the different floors
3.0 HVAC SYSTEM
3.1 Replace the existing two (2) boilers, condensate pumps and associated piping and valves
3.2 Replace the existing heaters and ventilation fans
4.0 MISCELLANEOUS
4.1 Resurface the existing driveway
4.2 Modify the existing access stairs to comply with ADA requirements

7.02.02 Connor Creek Pump Station

Based on our condition assessments of major equipment, the following Table provides the summery of recommended improvements

RECOMMENDED IMPROVEMENTS – CONNOR CREEK PUMP STATION
***1.0 STORM WATER PUMPING SYSTEM**
1.1 Perform detailed inspection of the internal components for the existing storm pumps
1.2 Convert existing six (6) slip ring synchronous motors into brushless type
1.3 Install machine safety guards for six pumps
2.0 ELECTRICAL
2.1 Replace two (2) Primary Power Transformers and associated controls
2.2 Upgrade the existing lighting system to provide required elimination level at the different floors
3.0 HVAC SYSTEM
3.1 Replace the existing boilers, condensate pumps and associated piping and valves
3.2 Replace the existing heaters and ventilation fans
4.0 MISCELLANEOUS
4.1 Resurface the existing driveway
4.2 Repair and seal crack between Pump building
4.3 Replace roofing system for the Storm Water Pump building

***The replacement of existing two pumps is not included; Refer to Tech memo No.1 for details**

7.03 System (Connor Creek Sewerage District) Hydraulic Analysis

Based upon evaluation of various operating scenarios and corresponding hydraulic responses, the following Wet Weather Operational Protocol as described under Scenario #3 is recommended to optimize the utilization of existing CSO control facilities relating to Connor Creek Sewerage District during wet weather events.

SYSTEM FACILITIES	RECOMMENDATIONS
Fairview Pump Station	Maintain at dry weather pump level
Freud Pump Station	No change to pump operations
Connor Creek Storm pumps	Operation begin when the level in discharge channel reaches 95’
Forebay Regulator Gates	Close when DRI level reaches 0.8D
Conner Sewer Backwater Gates	No change in operation (open at 95’ in the Forebay OR when regulator gates close)
CSO Basin Effluent Launder Weir	Lower weir level to 96’ (was 98’) – river elevation analysis
CSO Basin ERGs	Open at 96.5’ (was 98.5’); still 0.5’ above effluent weirs

By implementing the above operating protocol, the following potential benefits are anticipated and listed below:

RECOMMENDATIONS	POTENTIAL BENEFITS
Lower the level of the Conner Creek CSO Basin discharge weir	Lowering the discharge level will lower the HGL in the Conner Sewer and allow more discharge out of the CSO Basin (as one of the two ways to relieve the system in the area; it is important to be able to allow the most amount of water to leave the system).
Keep Fairview Pump Station running at dry weather level during wet weather events	As the second of two ways to relieve the system, allowing Fairview to maintain operation (at dry weather flows) will provide some relief to the DRI and allow for the storm water stored in the CSO Basin/Conner Sewer to be effectively dewatered as quick as possible.

RECOMMENDATIONS	POTENTIAL BENEFITS
Allowing the level in the Connor Creek Discharge Channel to reach 95' before staring the Storm pumps	By allowing the level in the discharge channel to rise, the siphon blocks at Connor Creek will be submerged enough to allow the vacuum priming system to prime the pumps effectively to allow relief of Connor Creek Wet Well, and the East & West Jefferson Relief Sewers.

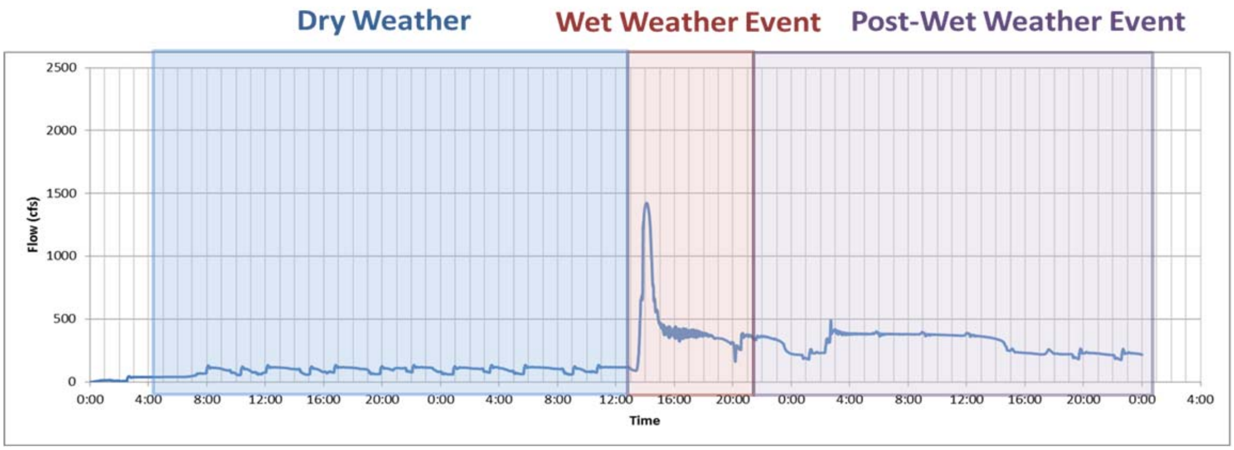
In order to realize the full benefits of the above recommendations, the following improvements are required to be implemented at different pump stations as below:

Connor Creek Pump Station	
Install minimum two (2) new vertical wet pit storm pumps (refer to Tech Memo #1 for details)	Vertical wet pit pumps will bypass the need for vacuum priming system, thus allowing those pumps to start without having to wait for the discharge level to reach the required height for the vacuum priming system
Freud Pump Station	
Modify the existing triple barrel discharge channel to remove the existing constraint and increase transport capacity	This will allow for more pumps to be run at Freud and will help relieve the sewers upstream of Freud and bring down the HGL

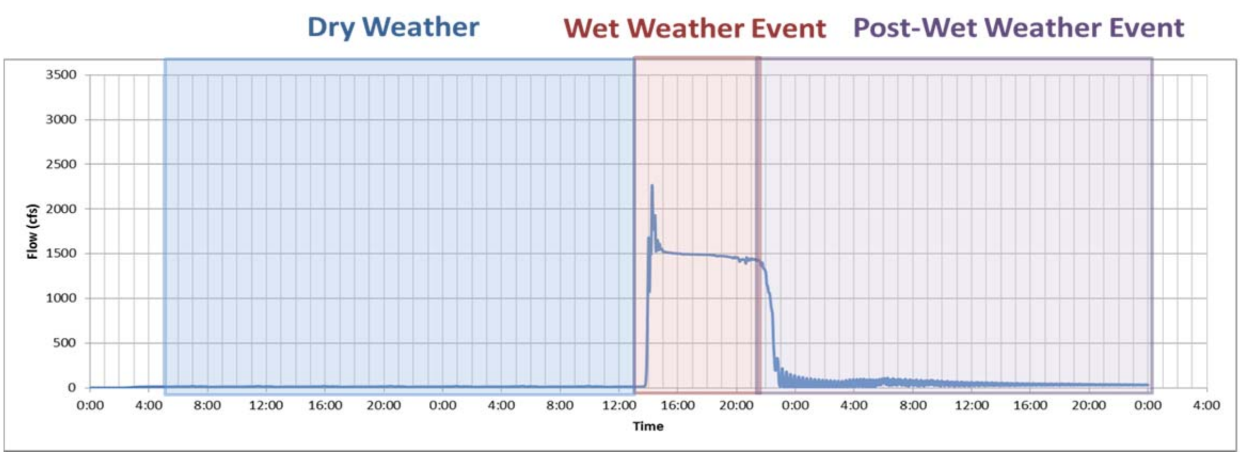
7.04 Capacity Analysis – Freud, Connor Creek and Fairview Pump Stations

The peak inflow to each pump station under the design storm event (10 year-1 hour storm) and corresponding hydrographs representing the inflow during dry weather and the design storm event were derived from the hydraulic model simulation runs. The Graphs below illustrate the peak inflow flow distribution to the wet well at each of the Pump station.

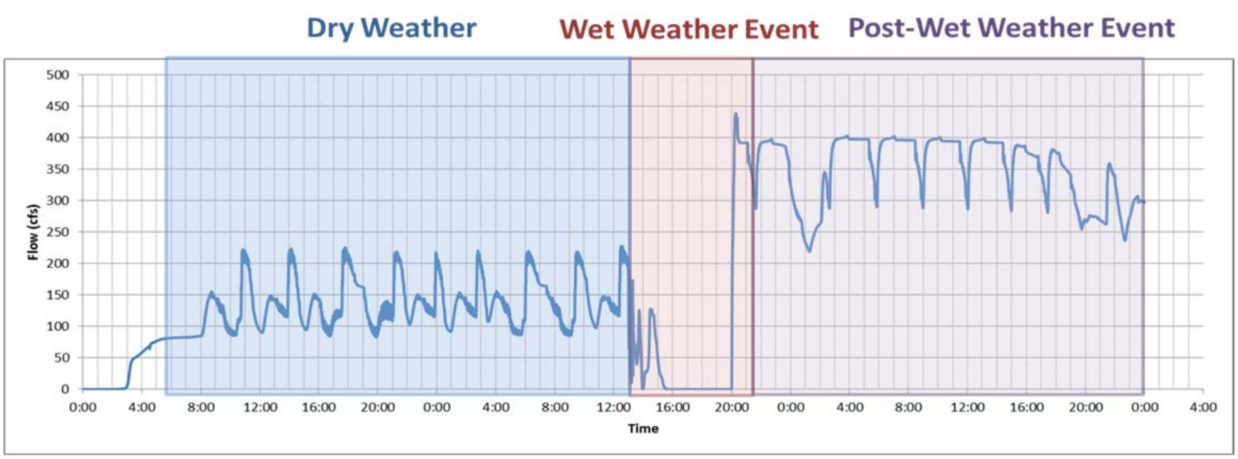
A. <u>*Connor Creek Pump Station Wet Wells Inflows*</u>



B. <u>*Freud Pump Station Wet Wells Inflows*</u>



C. <u>*Fairview Pump Station Wet Wells Inflows*</u>



The above peak flow distribution was utilized in determining the associated firm pumping capacity at each pump station such that hydraulic gradient at the upstream sewers will be minimum 10 feet below the grade level elevation. Applying these criteria, the following installed and firm capacity at each pump station is recommended.

FACILITY	PEAK FLOW	INSTALLED CAPACITY	FIRM CAPACITY
Freud Pump Station	2,200 cfs	2,700 cfs (6x450 cfs)	2,250 cfs
Connor Creek Pump Station	2,000 cfs	2,500 cfs (5x500 cfs)	2,000 cfs
Fairview Pump Station	*225 cfs	525 cfs (1x75 cfs + 3x150 cfs)	375 cfs

Based on current operating protocol – Fairview pump station taken out of service during storm event

It should be noted that our recommendation assumes that the proposed improvements will be implemented to make Connor Creek Pump Station fully operational and also the required improvements will be constructed to eliminate the constraints at the discharge conduit of Freud Pump Station as recommended in our Technical Memorandum No. 1 and 3.

8.0 OPINION OF CONSTRUCTION COST ESTIMATES

The estimated construction cost to implement the recommended improvements to improve the operational efficiency and reliability is listed below:

8.01 Improvements to Vacuum Priming System at Connor Creek Pump Station

The order of magnitude of the construction costs of this option would be approximately in the range of $8.0 million for procurement and installation of two (2) vertical turbine pumps to replace the existing Pumps. The details of our preliminary estimate are attached at the end of this memorandum.

8.02 Improvements at Freud and Connor Creek Pump Stations

Based upon the condition assessments of major equipment at Freud and Connor Creek Pumps stations, the preliminary construction cost estimates associated with the recommended improvements are listed below:

RECOMMENDED IMPROVEMENTS – FREUD PUMP STATION	
PROJECT	**OPCC**
1.0 PUMPING SYSTEM	
1.1 Modify the existing storm pumps with new mechanical seal and new self-lubricated bearings	$ 1,200,000
1.2 Evaluate suction hydraulics, resize and relocate the existing sanitary pumps to the intermediate bearing floor level	$ 500,000
1.3 Install stop logs at the inlet of the wet well for isolation purposes	$ 1,300,000
1.4 Modify the discharge channel to eliminate the pumping restrictions	$ 2,500,000
2.0 ELECTRICAL	
2.1 Replace all three (3) Primary Power Transformers and associated controls	$ 3,600,000
2.2 Upgrade the existing lighting system to provide required elimination level at the different floors	$ 400,000
3.0 HVAC SYSTEM	
3.1 Replace the existing boilers, condensate pumps and associated piping and valves	$ 800,000
3.2 Replace the existing heaters and ventilation fans	$ 250,000
4.0 MISCELLANEOUS	
4.1 Resurface the existing driveway	$ 75,000
4.2 Modify the existing access stairs to comply with ADA requirements	$ 55,000
***TOTAL**	**$10,680,000**

RECOMMENDED IMPROVEMENTS - CONNOR CREEK PUMP STATION	
PROJECT	**OPCC**
***1.0 PUMPING SYSTEM**	
1.1 Perform detailed inspection of pump internal components	$ 300,000
1.2 Convert existing six (6) synchronous motors into brushless type	$ 750,000
1.3 Install machine safety guards for six pumps	$ 75,000
2.0 ELECTRICAL	
2.1 Replace two (2) Primary Power Transformers and associated controls	$ 1,800,000
2.2 Upgrade the existing lighting system to provide required illumination level at the different floors	$ 200,000
3.0 HVAC SYSTEM	
3.1 Replace the existing boilers, condensate pumps and associated piping and valves	$ 800,000
3.2 Replace the existing heaters and ventilation fans	$ 250,000
4.0 MISCELLANEOUS	
4.1 Resurface the existing driveway	$ 75,000
4.2 Repair and seal crack between Pump building	$ 100,000
4.3 Replace roofing system for the Storm Water Pump building	$ 200,000
****TOTAL**	**$ 4,750,000**

***The replacement of existing two pumps is not included; Refer to Tech memo No.1 for details**

****The above estimate should be considered as order of magnitude and needs to be refined based on further engineering of the recommended improvements**

TECHNICAL MEMORANDUM NO. 1

VACUUM PRIMING SYSTEM EVALUATION – CONNOR CREEK PUMP STATION

1.0 INTRODUCTION

During the recent heavy storm event in August, 11 of 2014, DWSD had experienced problems in putting the storm water pumps at Connor Creek Pump Station in service due to malfunctioning of the associated Vacuum Priming System. The outage of all pumps had resulted in a severe surcharge conditions in upstream sewers as well in the related service areas. To mitigate this situation, DWSD has initiated immediate efforts to identify the cause and implement appropriate corrective measures so as to restore the desired level of reliability to the operation of storm water pumps at Connors Creek Pump Station.

To address the issue and also to optimize the utilization of the storm water pumping stations and the CSO basin, DWSD had contracted the services of METCO Services, Inc. (METCO) by Task order No. 36 under Contract CS-1499. The scope of the task order primarily focused on the following critical issues:

A. Evaluation and Design of upgrade/ replacement of Vacuum Priming System at Connors Creek Pump Station
B. System Hydraulic Analysis
C. Develop Operational Strategy for optimization of CSO facilities
D. Capacity analysis and condition survey of major equipment at Pump Stations.

However, DWSD required the evaluation and design of upgrade to the existing Vacuum Priming System to the Storm Water Pump at Connors Creek PS to be performed as the top priority item in order to mitigate the surcharge conditions as soon as possible and preferably prior to the onset of next wet weather season.

Consistent with this imperative, METCO had initiated their efforts to develop and evaluate various options as potential solutions to ensure reliable operation of the vacuum priming system.

This Technical memorandum accordingly presents our observations, findings and recommendations to improve the performance of the existing vacuum priming System and to balance the utilization between Connors Creek PS and Freud PS during the wet weather events.

2.0 BACKGROUND/DESCRIPTION OF THE SYSTEM

The Connors Creek Pump Station was originally built in 1928 with Four (4) storm water pumps, each with a rated capacity of 225,000 GPM (500 CFS) at 27 feet Static Head. Each pump is of vertical, mix-flow, dry type, with an 84-inch impeller and equipped with 2300 HP, 4160V, 200 RPM Synchronous Motor. The pump station was subsequently expanded in the year 1940 with installation of four additional pumps of same type and capacity. As a result, the Pump Station is currently provided with an installed capacity of 4,000 cfs (8X500 cfs) and a firm capacity of 3,500 cfs.

Some of the critical design parameters of the pump installation as gathered from the available drawings and the pump shop drawings are as below:

- Bottom of Wet Well: 55.00 feet
- Bottom of the Suction Bells: 59.00 feet
- Pump Room Floor: 79.00 feet
- Pump Impeller Centerline: 83.60 feet
- Design Wet well Level: 65 to 77 feet
- Design Operating Level: 71 to 77 feet

The other key features of these pumps are the siphon discharges and the method of priming. Siphons were originally considered as an alternative to the discharge check valves to control the backflow. The valves of large size (96 inch) were not manufactured at the time of installation of these pumps. Instead, a lower siphon arrangement with unique priming method was incorporated.

Until the Connor Creek CSO Basin was constructed, the storm water pump discharge channel always has standing water at or above Detroit River level since the pumps discharge into the Detroit River freely without any backwater gates. The River levels generally range from 91 to 98 feet. Based upon the conditions, the discharge siphon control point was designed to 102’-0” with the bottom of the siphon block at 79’-0”. This arrangement ensured the siphon block to be always submerged with the river level being at 91’-0”.

The vacuum priming system was designed with the above design conditions with vacuum pump suction connections both to the top of the siphon (102’) and to the pump casing and to the bottom of the impeller on the suction side.

This unique priming method was successful till the discharge channel maintained a minimum water level of 91’-0” to ensure adequate submergence of the siphon block.

With the Connor Creek CSO basin in operation, the discharge channel is generally emptied to the invert elevation of 79’-0” along with the CSO basin after every storm event. As the elevation of the discharge channel within the siphon block is also at 79’-0”, the siphon block submergence would be unlikely. Under this condition, the vacuum priming system may not be able to prime due to the vacuum being broken.

Applied Science, Inc. (ASI) in their memo of 9/10/1999 had recommended a small dam with a top elevation of 80.5’ to be built in the pump station discharge channel. They had also concluded that the proposed elevation should be sufficient to submerge the siphon block and allow vacuum to form. By this, maintaining the water level to an elevation of 80.5’ in the discharge channel for submergence of the vacuum block appears to be the necessary condition for the vacuum priming system to be functional.

The recommended dam with the top elevation of 80.5’ was subsequently constructed in the year 2000, under Contract PC-739 as part of Connor Creek CSO Basin.

Also, in the year 2007, the original Vacuum Priming system was replaced with a new system under Contract PC-674 consisting of a vacuum pump at a rated capacity of 940 cfm along with vacuum priming tank and associated valves and with a PLC based control for each storm water pump. The vacuum system for each pump was interconnected with other pumps vacuum system to provide additional level redundancy. In addition, each vacuum Pump system was designed to operate with a PLC based controls for “Remote-Auto” mode of operation and monitoring. Typical schematic of the existing vacuum system as designed and installed under Contract PC-674 is illustrated in the attached Sketch SK-01.

3.0 DISCUSSION OF THE EXISITNG SYSTEM

Based upon the review of the record drawings, extensive field investigations and discussions with DWSD Mechanical Maintenance personnel, the following observations and conclusions were made.

- The existing priming system assumes the submergence of the siphon block which is a necessary condition for the vacuum priming of the pump. In the original design of the vacuum priming system, this condition was not a relevant factor due to free discharge into the river with the minimum water level at the PS discharge channel represents the river elevation of minimum 91’.0”. However, with the construction of the Connor Creek CSO Basin, the discharge channel remains empty till the CSO basin is filled up to the level of about 79’.0”.

- To ensure submergence of the siphon block, a low head weir with the top elevation of 80.5’ was built in the discharge channel. This remedial measure appears to be not effective in creating the required siphon block submergence. On the contrary the weir had led to accumulation of sludge in the PS discharge channel to its crest height as observed during our field inspection.

- The weir at 80.5’ also led to the condition with the total head of less than 10 feet, which puts the pump in the runout operating condition.

- Furthermore, it appears that the current operating protocol is designed to overcome the above issues by operating the Freud PS to fill the CSO basin during storm event to backup flow into Connors Creek PS discharge channel such that the submergence of siphon block is ensured prior to starting the pumps at Connors Creek PS. This results in a condition leading to underutilization of

Connor PS. The review of the Connors Creek pump station operating records for year 2013 and 2014 also supports this conclusion with very few pump run hours as summarized below.

	CON PMP 1 STATUS	CON PMP 2 STATUS	CON PMP 3 STATUS	CON PMP 4 STATUS	CON PMP 5 STATUS	CON PMP 6 STATUS	CON PMP 7 STATUS	CON PMP 8 STATUS
TOTAL # OF HOURS-2013	2.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
TOTAL # OF HOURS-2014	0.000	5.000	0.000	5.000	0.000	12.000	4.000	25.000

- It should be noted that the above available pump operating data indicate only the pump status which does not necessarily run without fully priming. This possible scenario is further corroborated by the fact that wet well levels remained at the highest elevation of 75'+ during the entire period between 7.00 PM and 11.00 PM on August11, 2014 when the status of these pumps are shown active as per the operating records.

Vacuum System Capacity

Since the “basis of design” of the existing vacuum system installed under PC-674 is not readily available to us, we have inferred from the available design drawings and the field observations that the existing vacuum Pumps might not be appropriately configured to create enough vacuum in the siphon block with the submergence to 80.5' water level in the discharge channel. This inference is further supported by the following observed conditions.

Siphon block submergence is designed with the water elevation at 80.5' which is just above the bottom of the siphon at 79.0'. This condition differs from the original design basis of this PS which reflects the minimum submergence of the siphon with the discharge channel water level at 91.0' (normal river level) prior to starting any pump. It appears unlikely that the design and configuration of the existing system adequately addresses the requirements imposed by the new hydraulic condition at the PS discharge channel due to construction of the Connor Creek CSO Basin.

Vacuum System Set up (Refer Sketch SK-01)

The priming tank in the current system is installed at an elevation of 112'-00" which is approximately 41' above the minimum water level of 71'-0" in the wet well. The priming tank is generally designed to isolate the suction side piping from the vacuum side. The existing height of water lift required by vacuum priming appears to be in excess of the maximum theoretical height of 34' up to which a perfect vacuum system can lift water.

The existing system configuration includes numerous pneumatic and hydraulic valves with their positions designed as permissive interlocks for the operation of the system. These solenoid operated valves allow themselves as several potential "points of failure" in the system.

The condition of the 8" vacuum pipe from the crest of the siphon block to the priming tank at El. 112'-0" which was installed in 1928 under original construction contract, might have deteriorated allowing air leakage in the piping. It should be noted that under PC-674, this piping was reconnected to the new priming tank and no assessment on the condition of this pipe appears to be done during the design and/or construction of the new system under PC-674.

It appears likely that any or a combination of the above factors could have contributed to the failure of the vacuum priming system.

In summary, the current arrangement does not satisfy the required submergence condition of the siphon block until the level in the discharge channel reaches to an elevation of 91.0'. It appears current operating protocol is attempting to achieve this condition by operating the Freud PS to fill up the Connor Creek CSO Basin such that the water level in the Connor PS discharge channel is maintained at Elev. 91.0. This has resulted in underutilization of storm water pumps at Connor Creek PS.

4.0 ALTERNATIVES

To address the above conditions, the following alternatives were considered as potential solutions. These options are organized into two categories – short term and long term solutions as below.

Our approach was focused on eliminating the need for the siphon block to make the priming of the existing pump more reliable and efficient. In addition, this would also enable DWSD to operate the pump station independent of the discharge channel level and thus would lead to improved utilization of the Connor PS during the wet weather events.

A-1 Install flap valve at the end of the pump discharge line to replace the existing siphon arrangement to control the backflow and modify the existing vacuum priming system configuration for minimum four pumps.

A-2 Consider raising the dam in the pump station discharge channel to a level of 91'.0' to ensure the submergence of the siphon block.

A-3 Replace the existing mix flow, vertical, dry pit centrifuge pumps with vertical, wet pit turbine pumps and eliminate the priming system requirement.

5.0 DISCUSSION OF ALTERNATIVES

A-1 This option involves following improvements to the existing pumping and vacuum system configuration. The conceptual schematic of this alternative is presented in the attached Sketch SK-2

- Install flap valve at the end of pump discharge to replace the existing siphon system as backwater control device. This arrangement will significantly reduce amount of air that needs to be extracted from the pump discharge pipe and thereby increase the reliability of the vacuum priming system.

- The proposed valve would be of approximately 120" diameter, corrosion resistant FRP polymer construction with stainless steel hardware components and neoprene seals. The proposed valve body would be reinforced to withstand minimum flow velocity of 10 fps and develop not more than 6-8 inch of head loss as ascertained from the valve manufacturer (Plasti-Fab). This will be considerably less than 2 feet of head loss due to the existing siphon arrangement. However, as the pumps would be starting against closed flap valve, the break horse power requirement during the starting would be slightly higher than being currently experienced by the motor. It is very likely that the existing motor for each pump needs to be replaced with new motor having torque characteristics compatible with requirements when pump is started under closed valve condition with the installation of flap valve at the pump discharge pipe.

- Installation of the proposed flap valve would require demolition of existing siphon block to facilitate adequate space for vale opening without any obstruction. The pump would then experience free discharge flow directly into the discharge channel. In addition, an entry hatch of minimum 10'X10' would be required for adequate access prior to start of construction of the above improvements.

- The proposed elimination of the siphon block under this alternative would also lead to the modification of the existing vacuum priming system such that vacuum system would be designed to extract air from pump suction piping, pump volute and pump discharge piping as shown in the Sketch SK-02. The resultant vacuum priming system would be more simple, reliable and easy to operate and maintain.

The modified system would include following key features:

- Dedicated Vacuum Priming System for each pump with no interconnection by eliminating additional valves.

- Reuse the existing Vacuum Pump, vacuum tank and associated valves and the suction/discharge piping to the extent feasible.

- Two new priming tanks with each dedicated to extract air from suction pipe / volute of the pump and to the discharge pipe respectively.

- Priming tank dedicated to create vacuum in the suction pipe/pump volute would be located at Gallery Floor Elev. 98.2’ thus requiring approximately 21’ lift of water by vacuum.

- Each priming tank would be provided with appropriately sized isolation and check valves.

- The design would also consider the tanks and valves to be installed at the elevation appropriate to provide easy access to the operating and maintenance personnel.

In conjunction with the above modifications/improvements, replacing the existing gland seal system at the pumps with mechanical seal arrangement to minimize the air leak should be considered.

Constructability Evaluation:

- Based upon the information available from original design drawings, the existing siphon blocks are located below the motor floor level and within the foot print of the motor floor. Hence the proposed hatch needs to be located at the motor floor level within the pump station in order to provide the intended access. The current available space is not adequate to accommodate the proposed hatch and would further require extensive relocation of some of equipment, panels, electrical conduits and vacuum piping embedded in the motor floor thereby making the constructability of this alternative highly unlikely.

  Further, it should be noted that the constructability evaluation of the above improvements is limited by following field constraints. The accurate validation of the location and the configuration of the existing siphon block is required prior to make the final determination on the constructability of this option. Currently, there is no access to the siphon block for accurate field verification of the details shown in the original drawings which is critical for identifying the challenges during the construction of the alternative. Therefore, in absence of access to the area encompassing the siphon block for each pump, the constructability of this option cannot be ascertained with high degree of confidence. This imposes several “Unknowns” which could adversely impact the cost and the feasibility of construction of this option.

Due to above uncertainty over the constructability of this alternative, we do not consider this concept as a viable solution.

A-2 Under this option, the proposed improvement includes raising the dam from the current elevation of 80.5’ as constructed under PC-739. Ideally, the top of any proposed dam should be at elev. 91.0’ so as to create the hydraulic profile in the PS discharge channel similar to the condition existed prior to the construction of the CSO basin. The proposed elevation of 91.0’ would match with the normal Detroit river level which was the original basis of design for the vacuum priming system for these pumps.

However, our preliminary hydraulic calculations indicate that the dam could be raised to elevation of 84.5’ without creating backwater effect or surcharge in the upstream section of the PS when running all eight pumps with a total PS discharge flow of 4000 CFS. Also, our initial calculations indicate that when the dam level is raised to elev. 91.0’, the maximum flow of 1700 CFS could be discharged in the channel without the risk of generating any backwater condition. Therefore, this approach would severely limit the total discharge of the PS to about 1700 CFS.

However, the major downside of this approach would be that dam of any height impedes free flushing resulting in the accumulation of sediments in the section of the discharge channel upstream of the dam. This is evident form our field inspection of 12/05/2014 that significant buildup of sludge of approximately of

18”-24” deep was observed in the discharge channel upstream of the existing dam.

Due to above considerations and constraints which outweighs the benefits, we do not consider this alternative to be a viable solution.

A-3 This alternative involves in replacing the existing pumps (two pumps under initial phase) with new wet pit, vertical turbine pumps, thus eliminating the need for the priming system. This would make the pump operation more reliable with no influence of the discharge channel level on the pump starting. The configuration of the proposed pumping system would include the existing siphon to control the backwater from the discharge channel. The new pumps would be specified to reflect the existing hydraulic condition imposed by the construction of the CSO basin and by the existing siphon block in the discharge line.

The conceptual schematic of the proposed arrangement of the new Pumps is presented in the attached Sketch SK-3.

It is anticipated that with two new pumps on line, the level in the discharge channel would insure submergence of the siphon block thereby allowing priming of the other pumps.

The proposed arrangement would be simple with no demolition of the siphon block involved.

As the installation of new pumps would be in the existing pump shaft, we do not anticipate any impact to the existing structure and therefore no significant impediments to the constructability of this concept are anticipated. Further, the existing pumps are approximately 85 years old and have outlasted their useful life and are due for replacement. The new pump system could also result in additional benefits of more maintenance friendly features such as mechanical seal, ball bearings in the pumps and brushless synchronous motors.

Furthermore, the major benefit of this Alternative A-3 would be the elimination of the priming system which should make the pump operation more reliable. This could ultimately lead to more balanced utilization of storm pumps between Connor Creek Pump Station and Freud Pump Station.

Due to above advantages of this approach, we recommend this alternative to be considered as the viable option despite the higher capital costs and long implementation time schedule.

6.0 CONCLUSIONS

To make the operation of the vacuum priming system more reliable and efficient and also to improve the utilization of storm water pumps at Connor Creek PS and based upon our evaluation of various options as above, we recommend the Alternative A-3 as described under to be the preferred approach

- Remove and replace the two existing Pumps No.4 & 8 with wet pit, vertical turbine pumping units under the initial phase. In the event of priming the remaining pumps experience problem even with the new pumps on line, it is recommended two more new pumps shall be added to match the firm capacity of this pump station required to be consistent with the existing operating protocol and associated hydraulic analysis

- Maintain the existing siphon block in the discharge pipe to function as the check valve to control the back water from the discharge channel

The new pumping system would not require any priming system. The new pumps should be designed to meet the hydraulic conditions imposed due to construction of Connor Creek CSO Basin and thus would allow greater utilization of the Connors Creek Pump Station. Typical arrangement of the proposed system is illustrated in the Sketch SK-03 and the preliminary pump curves from Flow Serve and Ebara are attached as SK-04.

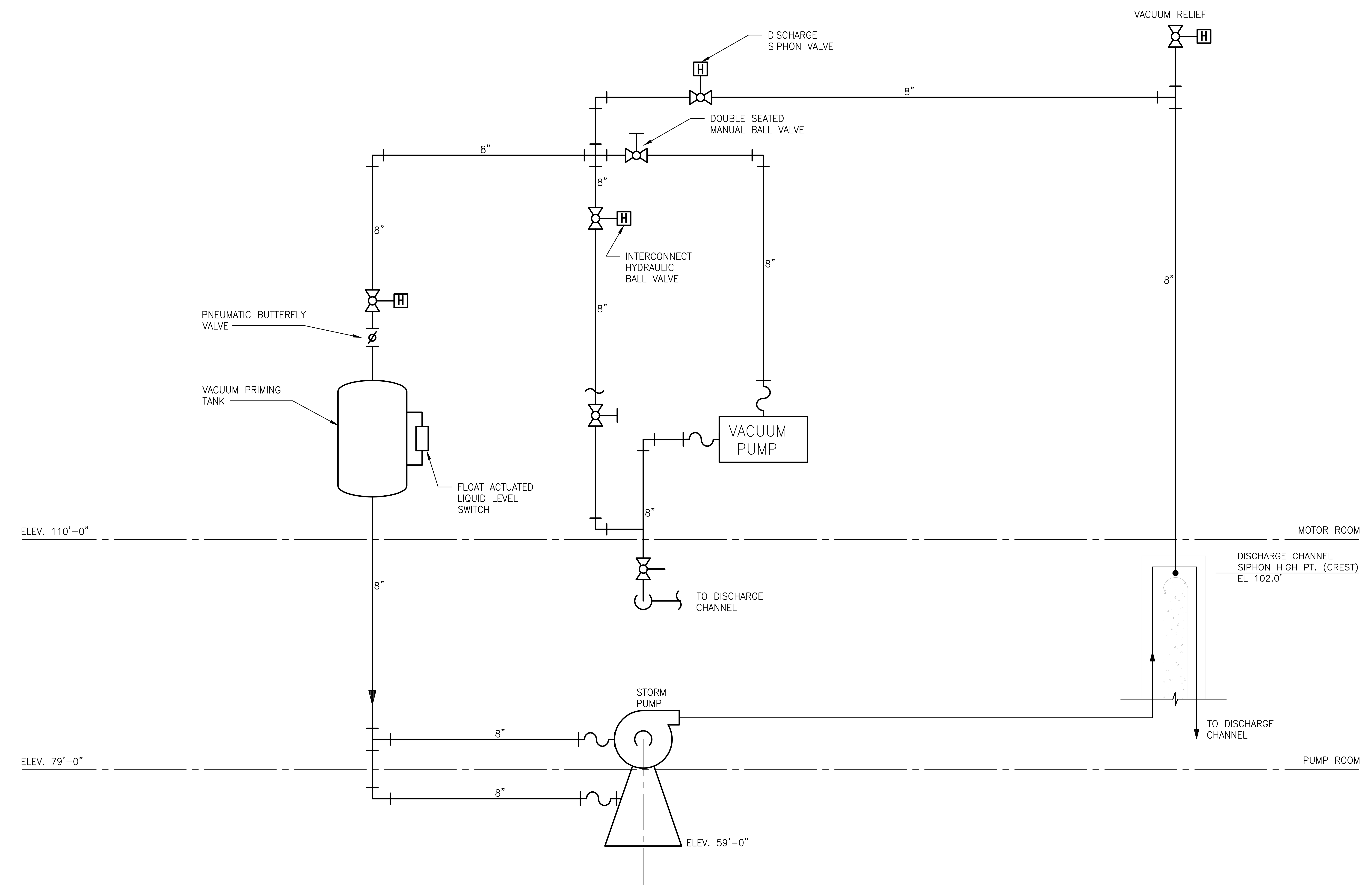
The order of magnitude of the construction costs of this option would be approximately in the range of $ 8.0 million for procurement and installation of two (2) vertical turbine pumps to replace the existing Pumps. The details of our preliminary estimate are attached at the end of this memorandum.

The implementation time schedule including design, bidding and construction would be approximately 32-40 months from the approval of the recommended concept and authorization to proceed with the design.

DETROIT WATER AND SEWERAGE DEPARTMENT
CS-1499 Task No. 36
Connors Creek PS - Pump/Priming System Modification
Preliminary Engineer's Opinion of Probable Construction Costs

Altenative A-3

Item	Unit	Quantity	Unit Cost	Total Cost
Division 1: GENERAL REQUIREMENTS				
Selective Demolition	ea	1	$ 100,000	$ 100,000
System Commissioning and Startup	ea	1	$ 50,000	$ 50,000
O&M Manuals	ea	1	$ 15,000	$ 15,000
Training	ea	1	$ 10,000	$ 10,000
			Subtotal Division 1 =	**$ 175,000**
Division 2: CIVIL/SITE WORK				
Site Clearance, Grading, Restoration	LS	1	$ 10,000	$ 10,000
			Subtotal Division 2 =	**$ 10,000**
Division 3: CONCRETE				
Miscellaneous Structural Concrete Work	LS	1	$ 150,000	$ 150,000
			Subtotal Division 3 =	**$ 150,000**
Division 5: METALS				
Misc Metals	LS	1	$ 25,000	$ 25,000
			Subtotal Division 5 =	**$ 25,000**
Division 6: WOOD AND PLASTIC				
			Subtotal Division 6 =	**$ -**
Division 9: FINISHES				
Misc Painting	LS	1	$ 20,000	$ 20,000
Refinish Motor Floor	LS	1	$ 50,000	$ 50,000
			Subtotal Division 10 =	**$ -**
Division 11: EQUIPMENT				
Vertical Turbine Pumps	ea	2	$ 700,000	$ 1,400,000
			Subtotal Division 14 =	**$ 1,400,000**
Division 15: MECHANICAL				
Discharge Pipe Modification	LS	1	$ 75,000	$ 75,000
Pump Installation	EA	2	$ 100,000	$ 200,000
			Subtotal Division 15 =	**$ 275,000**
Division 16: ELECTRICAL				
Medium Voltage Synchronous Motors	EA	2	$ 700,000	$ 1,400,000
MV Starters	EA	2	$ 100,000	$ 200,000
Electrical Cables and Conduit	LS	1	$ 50,000	$ 50,000
Electrical Installation and Modifications	LS	1	$ 125,000	$ 125,000
			Subtotal Division 16 =	**$ 1,775,000**
Division 17: INSTRUMENTATION AND CONTROLS				
I&C Modification	LS	1	$ 100,000	$ 100,000
			Subtotal Division 17 =	**$ 100,000**
			Subtotal Division 1 through 17 =	***$ 5,360,000***
General Conditions, mob/demob, bonds & insurance			15%	$ 804,000
			Subtotal - GCs	**$ 804,000**
Contigency			30%	$ 1,849,200
		Total		**$ 8,013,200**



H				
G				
F				
E				
D				
C				
B				
A				
	DESCRIPTION / REVISION	CHK'D	APPRVD	DATE

DESIGNED BY: R. VIJAYENDRAN, PE
DRAWN BY: N. EVANGELISTA
CHECKED BY:
APPROVED BY:

SYSTEM ANALYSIS AND CONDITION SURVEY
CONNORS STATION - VACUUM PRIMING SYSTEM
CS-1499, TASK 36

VACUUM PRIMING SYSTEM - STORM WATER PUMPS
EXISTING P & ID (TYP FOR EIGHT PUMPS)

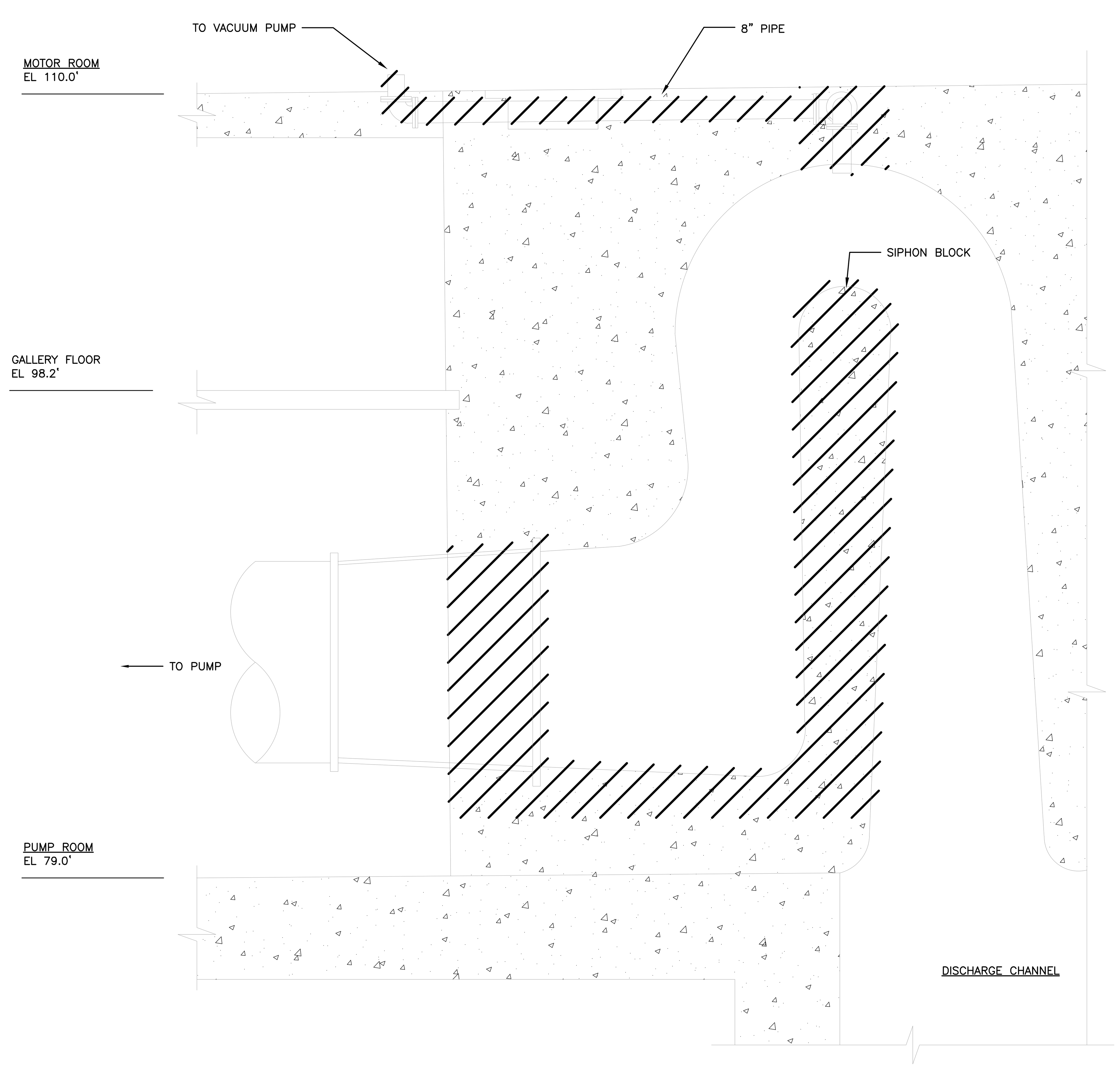
SCALE: NONE
DATE: NOV, 2014

METCO SERVICES, INC
1274 LIBRARY, DETROIT, MI. 48226
TEL - (313) 961-4560 * FAX (313) 961-1698
www.metcoservices.com

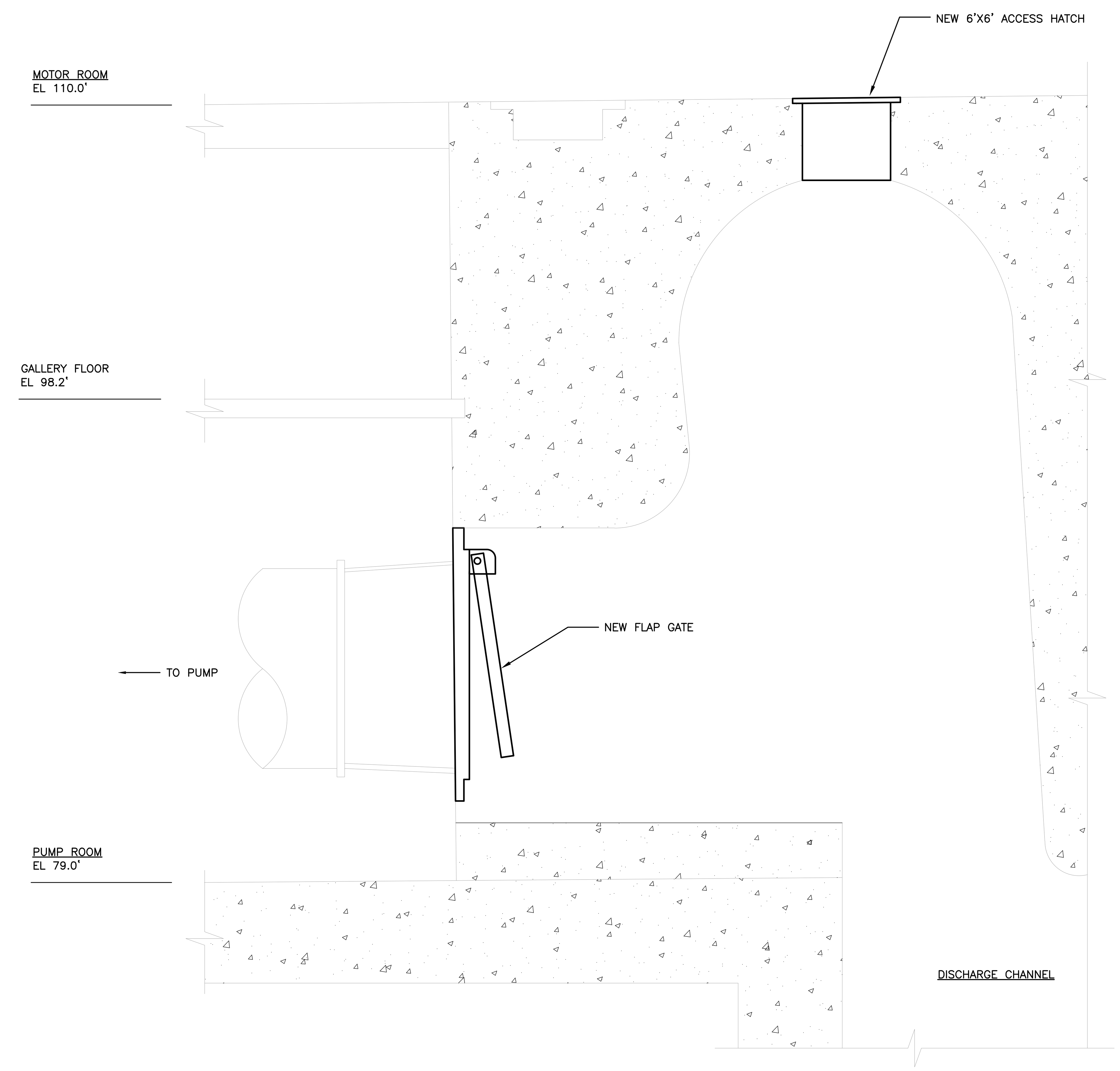
CITY OF DETROIT
WATER AND SEWERAGE DEPARTMENT
ENGINEERING DIVISION

SECTION MAP | TOWN | RANGE | SECTION | PORTION CODE | DRMS NO.

CONTRACT NO.
FILE NO.
PROJECT NO.
DRAWING NO.
SK-01



DEMOLITION
SECTION - SIPHON BLOCK
NOT TO SCALE



SECTION - FLAP GATE
NOT TO SCALE

	DESCRIPTION / REVISION	CHK'D	APPRVD	DATE
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DESIGNED BY: R. VIJAYENDRAN, PE
DRAWN BY: N. EVANGELISTA
CHECKED BY:
APPROVED BY:

SYSTEM ANALYSIS AND CONDITION SURVEY
CONNORS STATION - VACUUM PRIMING SYSTEM
CS-1499, TASK 36

VACUUM PRIMING SYSTEM
TYPICAL ARRANGEMENT (ALTERNATIVE A-1)

SCALE: NONE
DATE: NOV, 2014

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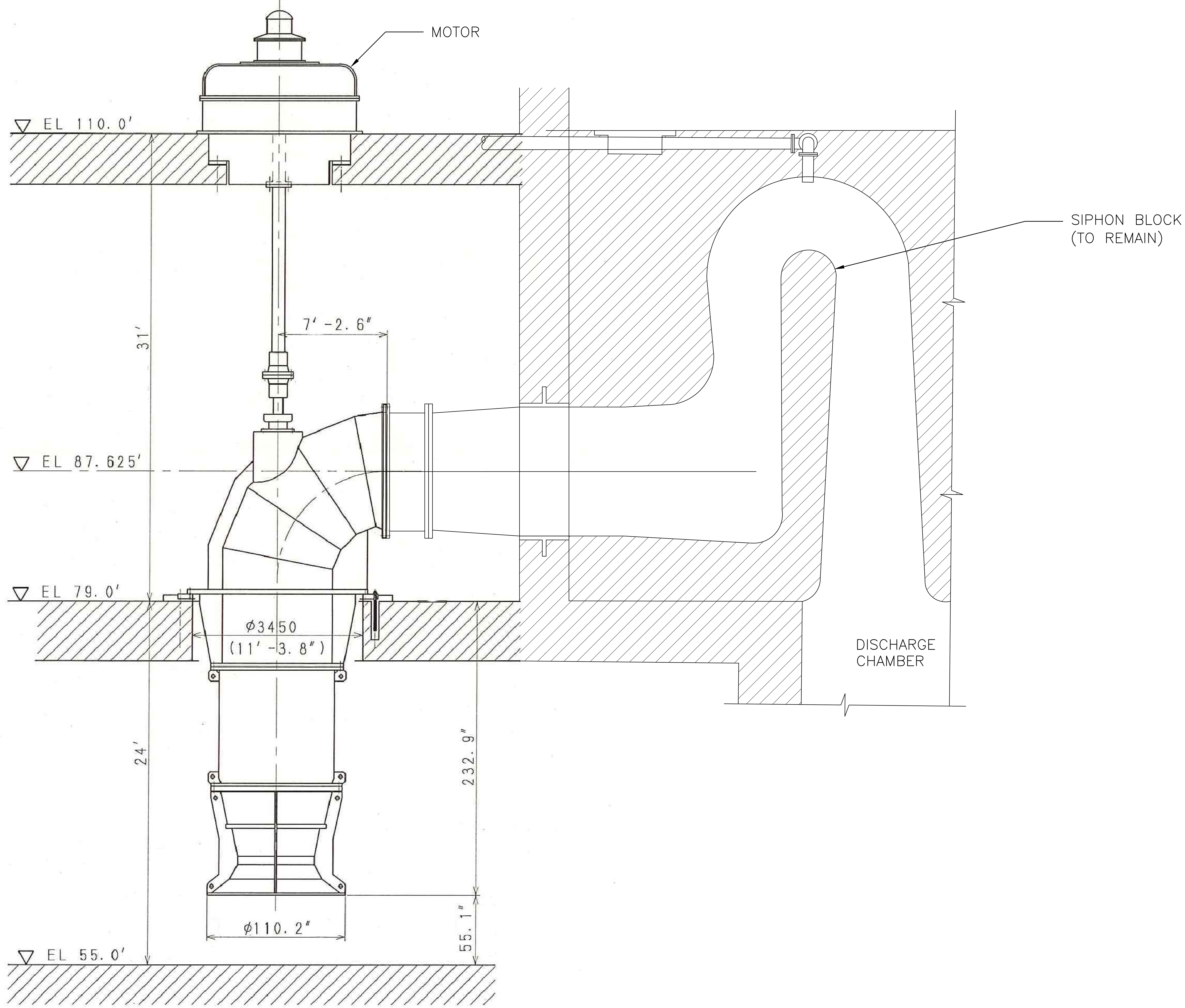
WATER AND SEWERAGE DEPARTMENT
ENGINEERING DIVISION

SECTION MAP	TOWN	RANGE	SECTION	PORTION CODE	DRMS NO.
- - - -	- -	- -	- - -	- - -	

CONTRACT NO.
FILE NO.
PROJECT NO.
DRAWING NO. SK-02

May. 5, 15 9:09:45 AM
Y:\1002 - General Engineering Services-CS-1499\1002-036 - Task 036 System Analysis and Condition Survey\6.0 Design\6.2 Drawings\62Dsgn\BOD\SK-02.dwg



DESIGNED BY: R. VIJAYENDRAN, PE
DRAWN BY: N. EVANGELISTA
CHECKED BY:
APPROVED BY:

	DESCRIPTION / REVISION	CHK'D	APPRV'D	DATE
H				
G				
F				
E				
D				
C				
B				
A				

SYSTEM ANALYSIS AND CONDITION SURVEY
CONNORS STATION - VACUUM PRIMING SYSTEM
CS-1499, TASK 36

TYPICAL VERTICAL TURBINE
PUMP ARRANGEMENT (ALTERNATE A-3)

SCALE: NONE
DATE: NOV, 2014

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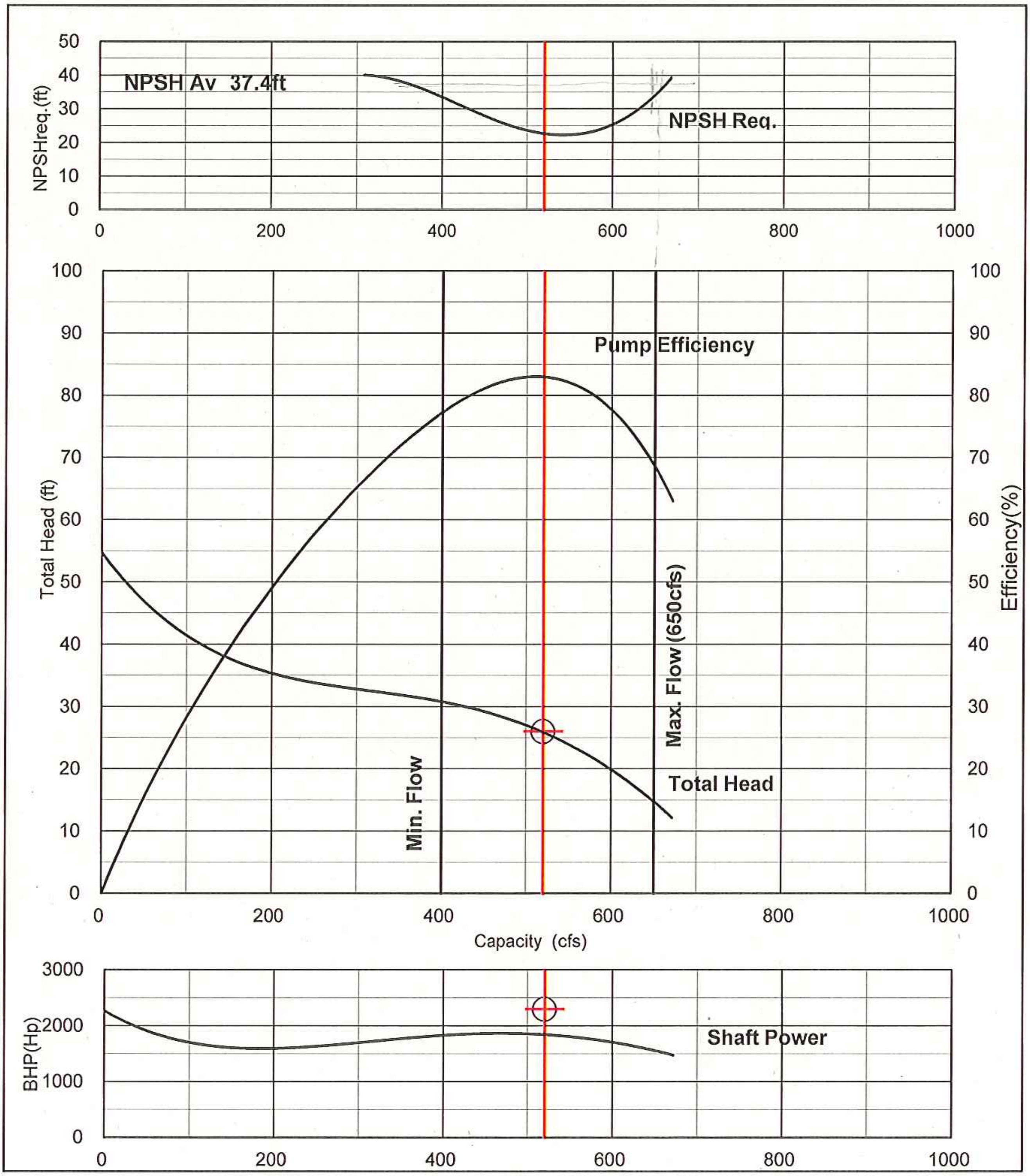
WATER AND SEWERAGE DEPARTMENT
ENGINEERING DIVISION

SECTION MAP	TOWN	RANGE	SECTION	PORTION CODE	DRMS NO.
- - - -	- -	- -	- - -	- - -	

CONTRACT NO.
FILE NO.
PROJECT NO.
DRAWING NO. SK-03

May. 5, 15 9:09:41 AM
Y:\1002 - General Engineering Services-CS-1499\1002-036 - Task 036 System Analysis and Condition Survey\6.0 Design\6.2 Drawings\620sgn\B00\SK-03.dwg

PUMP CHARACTERISTIC CURVE			DATE: 20-Nov-14
Item No.	-	Doc.No.	PB4B3421010-001
Customer	METCO SERVICES / DWSD	Service	Replacing storm water pumps
EBP Ser.No.	For proposal	Model	2400VZM
Specified Condition	520 cfs x 26 ft x 200 min-1 x 2300 Hp		
Liquid Handled	Storm water	Sp.Gr. 1.000	Temp. 10-40 °C Vis. 1.0 cP

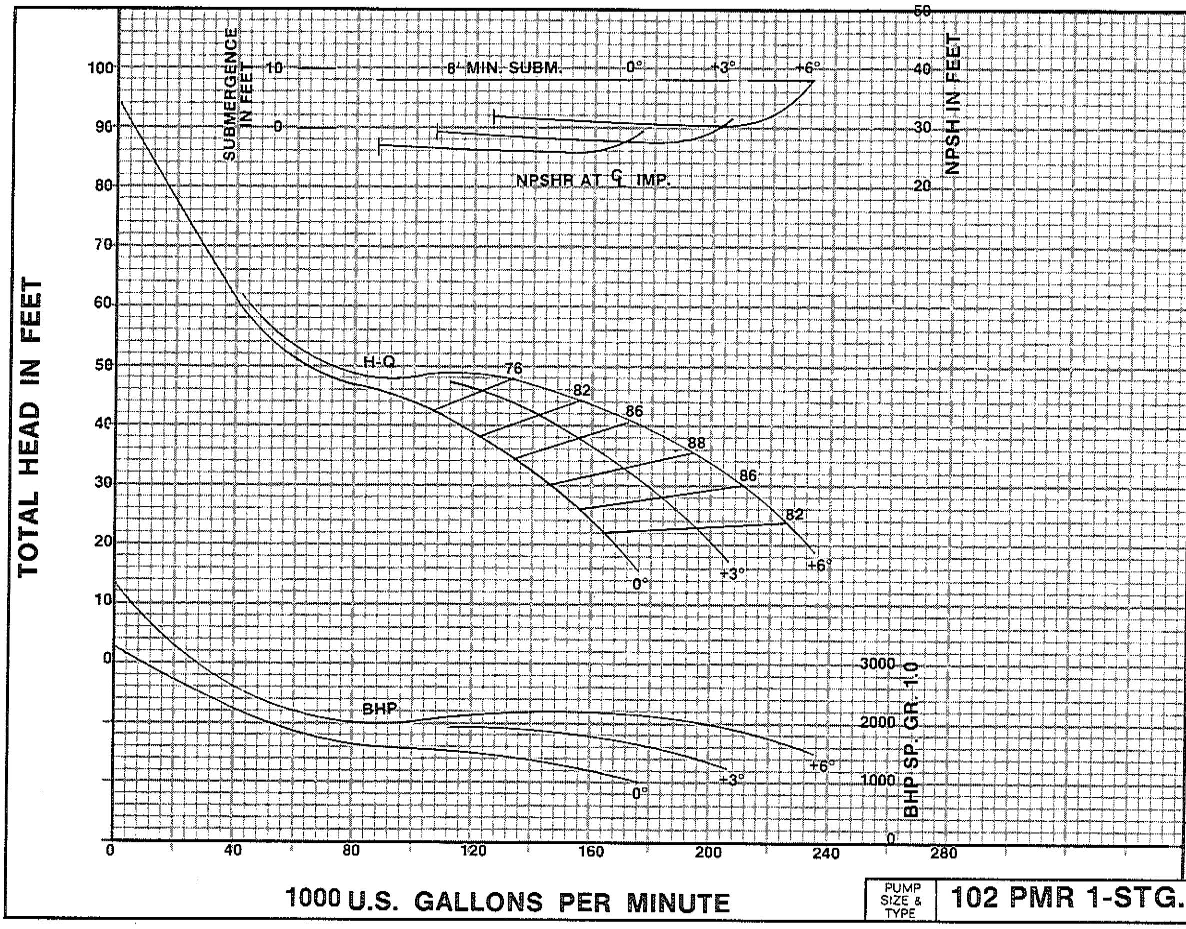


App'd by [signature] Nov. 25, 2014 Check'd by

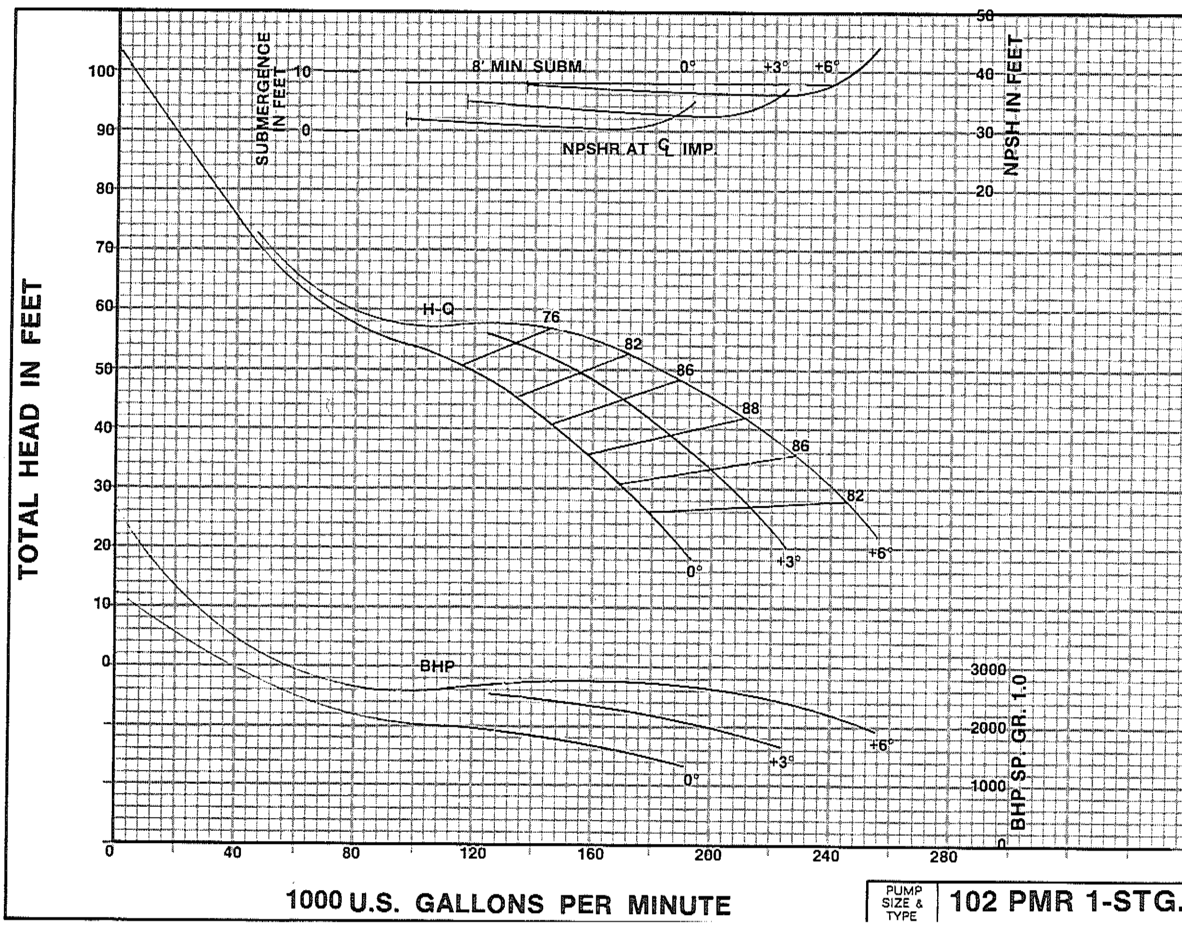
Prep'd by S. Yamasaki

EBARA CORPORATION

PMR



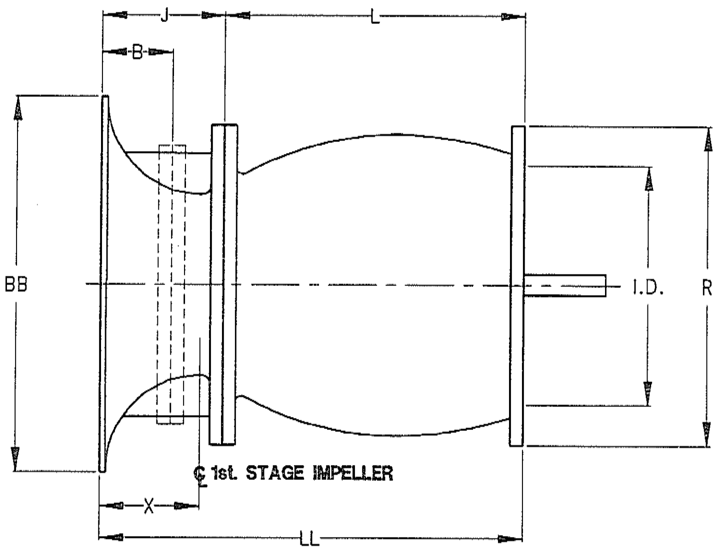
DRAWN BY	Y.K.
DATE	7 MAY 82
SUPERSEDES	
DATE	
BOWL DIA.	90 IN.
MINIMUM SUBMERGENCE	8 FT.
IMPELLER NO.	3833
N_S = PUMP SPECIFIC SPEED	8200
TYPE OF IMP.	☒ OPEN ☐ CLOSED
EYE AREA SQ. IN.	2500
U, FT./SEC.	79
RPM	270
BJ RATING NO.	2530-1
PUMP SIZE & TYPE	102 PMR 1-STG. VCT



DRAWN BY	Y.K.
DATE	7 MAY 82
SUPERSEDES	
DATE	
BOWL DIA.	90 IN.
MINIMUM SUBMERGENCE	8 FT.
IMPELLER NO.	3833
N_S = PUMP SPECIFIC SPEED	8200
TYPE OF IMP.	☒ OPEN ☐ CLOSED
EYE AREA SQ. IN.	2500
U, FT./SEC.	86
RPM	295
BJ RATING NO.	2992
PUMP SIZE & TYPE	102 PMR 1-STG. VCT

VERTICAL CIRCULATING PUMPS

Type PMR Bowl Data



PUMP SIZE	I.D.	R Max OD	L	B	J	BB[1]	LL	X	DATA: Weight[2] (Lbs.) 1st. Stage Complete	DATA: WR²[3] (Lbs-Ft²) 0°	DATA: WR²[3] (Lbs-Ft²) 11°	DATA: Thrust Factor[4] Peak	DATA: Thrust Factor[4] Closed Valve	DATA: Imp. Wt. (Lbs.)
20	15 5/8	19 1/2	10 3/4	–	8	23	18 3/4	6	316	4.40	5.36	45.5	42.5	50
26	19 1/2	25	14 1/2	–	11 1/2	35	26	9	776	16.15	19.7	78.0	72.8	110
30	22 1/2	29	16 1/8	–	12 1/8	39	28 1/4	10	937	30.9	37.7	103.9	96.9	150
32	25 1/4	30	18	7 1/2	13 1/2	40	31 1/2	11	1053	46.4	56.5	122.0	114.2	170
35	27 15/16	33 3/4	19 5/16	–	14 5/16	42	33 5/8	12	1294	69.8	85.2	146	136	210
38	30 13/16	36	21 1/4	–	16	48	37 1/4	13	1622	109.5	133.5	176	165	245
42	33 1/2	40	23 1/4	–	17 1/4	50	40 1/2	14	2210	183.3	223.2	210	197	330
46	36 1/4	43	25	11	19 1/2	55	44 1/2	15	2896	287	349	245	228	420
50	39.4	46 1/2	27 3/16	–	21 1/8	65	47 1/4	16	3150	424	516	290	270	500
52	41 1/4	46 1/2	24	11 3/8	20 1/4	68	44 1/4	16	3300	534	650	320	298	540
58	46 7/8	53	32 1/4	–	24 1/4	76	56 1/2	19	5977	902	1099	404	377	790
65	53 1/8	60	35 1/4	15 7/8	27 1/4	82	62 1/2	21	8291	1598	1948	504	471	1300
73	59	68	39 1/2	17 3/4	30 1/2	92	70	24	10,257	2800	3450	633	592	1950
81	65	73 1/4	44	19 3/4	34	103	78	27	12,770	4900	6000	784	732	2260
93	72	80	50	16 1/2	39	120	89	31	16,700	8200	10,600	988	922	3500
102	81 7/8	90	55	18	43	132	98	34	21,600	14,100	18,600	1236	1155	4640
114	90	100	62	21	49	132	111	39	28,500	24,800	32,900	1560	1455	6000

NOTES:
[1] Bell diameters shown are standard. Reduced or extended bell diameters can be furnished to suit a specific applications.
[2] Weights shown are for standard cast iron, bronze fitted bowl assembly.
[3] WR^2 values shown are for "wet" impellers with 0° and 11° vane angle respectively, and are to be used ordering drivers. For torsional analysis the exact "dry" value must be used. Contact the factory for this information.
[4] Thrust factors shown are based on full balanced impellers.

TECHNICAL MEMORANDUM NO.2

CONDITION ASSESMENT – FREUD AND CONNOR CREEK PUMP STATIONS

1.0 INTRODUCTION

During the recent heavy storm event in August, 11 of 2014, DWSD had experienced problems in putting the storm water pumps at Connor Creek Pump Station in service due to malfunctioning of the associated Vacuum Priming System. The outage of all pumps had resulted in a severe surcharge conditions in upstream sewers as well in the related service areas. To mitigate this situation, DWSD has initiated immediate efforts to identify the cause and implement appropriate corrective measures so as to restore the desired level of reliability to the operation of storm water pumps at Connor Creek Pump Station.

To address the issue and also to optimize the utilization of the storm water pumping stations and the CSO basin, DWSD had contracted the services of METCO Services, Inc. (METCO) by Task order No. 36 under Contract CS-1499. The scope of the task order primarily focused on the following critical issues:

A. Evaluation and Design of upgrade/ replacement of Vacuum Priming System at Connor Creek Pump Station
B. System Hydraulic Analysis
C. Develop Operational Strategy for optimization of CSO facilities
D. Capacity analysis and condition survey of major equipment at Pump Stations.

Consistent with these imperatives, METCO had initiated their efforts to develop and evaluate various options as potential solutions to the above issues

This Technical memorandum specifically presents our observations, findings and recommendations for a safe and reliable operation of Freud and Connor Creek Pump Stations. In developing some of the improvements to the facility, we have considered the findings and conclusions presented in Technical Memorandum no 1, 3 and 4 under this project.

2.0 METHODOLOGY

Prior to performing the field condition survey, the existing record drawings and the O&M Manual of the facility were obtained and reviewed. Subsequent to that, field inspections and assessments were performed to obtain information in sufficient detail to provide means of evaluating and determining the renewal and/or replacement of each major system/equipment.

The condition observations included the visual inspections, comments, assumptions and discussions with DWSD O&M personnel.

As part of our condition assessment process for each equipment, the following factors as applicable to each specific equipment were used.

- Age of equipment/ year of installation
- Corrosion
- Evidence of wear
- Inability to perform designed duty
- Excessive vibration/noise
- Leaks
- Accessibility to O&M Personnel
- Structural Integrity
- Code compliance
- Safety

3.0 FREUD PUMP STATION

3.01 BACKGROUND/DESCRIPTION OF THE SYSTEM

The Freud Pump Station was originally built in 1954 with eight (8) storm water pumps of Worthington make, each with a capacity of 201,500 GPM (450 cfs) at rated head of 45 feet. Each pump is of vertical, mix-flow, dry type, with 72-inch impeller and equipped with 3000 HP, 4160V, 200 RPM Synchronous Motor as manufactured by EM.

The pump station was subsequently added with two pumps (#9&10) which would primarily be operated as dewatering pumps as well as sanitary pumps during the dry weather period. The Pump No.9 is of mixed flow, centrifugal vertical type and designed for a capacity of 15,750 GPM (35 cfs) at rated head of 57 feet and fitted with 200 HP, 4160V Induction Motor. The pump No. 10 is also of mixed flow, centrifugal vertical type and designed for a capacity of 9,000GPM (20 cfs) at rated head of 36 feet and fitted with a 200 HP, 4160V Induction Motor.

The Pump Station is currently provided with installed storm water pumping capacity of 3,600 cfs and a firm capacity of 3,150 cfs. The smaller pumps are being operated as sanitary pumps at lower wet well level during the dry weather period.

This pumping station is designed essentially to handle the flows from Ashland Relief and Fox Creek Relief Sewers.

Some of the critical design parameters of the storm pump (No.1 thru 8) installation as gathered from the O&M manual and other documents are as below:

- Bottom of Wet Well for storm pumps: 20.00 feet
- Bottom of sump for Dewatering/Sanitary Pups: 13.00 feet
- Pump Impeller Centerline: 53.50 feet
- Design Operating Level: 68 to 75 feet

The operation of pumps are primarily controlled by the wet well levels with the first pump to be started at wet well level of 68’ and the subsequent pumps to be started at one foot interval thereof.

Two smaller pumps (No.9&10) are essentially operated to handle the dry weather sanitary flows and are again controlled by the wet well levels. The pump #10 is started normally 35’ and the pump #9 is started at wet well level of 45’. These pumps are not operated whenever the storm water pumps are put in service.

During the dry weather period, the Pumps # 9 & 10 are operated and the discharge flows into 5’ sewer along the Tennessee Street.

Under the current operating protocol, the storm water pumps are essentially operated first prior to the pumps at Connor Creek Pump Station. This is because of the inability to prime the pumps at Connor Pump Station until the water level in discharge channel of that pump station is high enough to ensure submergence of the vacuum siphon block prior to start of those pumps. As a result, reliability of this facility has become a critical element to the overall DWSD wet weather operational strategy during the heavy storm events.

3.02 DISCUSSION OF CONDITIONS OF MAJOR SYSTEM COMPONENTS

A. ***Methodology***

METCO has performed field visual inspection of this facility on January 14, 2014 along with the Operation and Mechanical maintenance personnel of DWSD to obtain information regarding the condition of major equipment in sufficient details to provide a reliable means of identifying the required improvements. In addition, we have also reviewed the existing system information available from O&M manual and other relevant drawings. These efforts were further supplemented with discussions with DWSD operators at SCC to obtain a good understanding of the operating protocol of this Pump station during dry and wet weather conditions.

B. Storm Water Pumping System Configuration

As indicated earlier, the existing storm water pumps are mixed flow, centrifugal, vertical pumps made by Worthington. Each pump is rated for 201,510 gpm at 45ft TDH and installed between years 1951-1954. The pumps are installed at elevation of 45.00’ and associated motors are installed at elevation 106.00’. The intermediate floors at elevation of 90.00’ and at 72.00’ are designed to provide access to the upper shaft bearing and lower shaft bearing of each pump.

Each pump is fitted with 72- inch, enclosed impeller. They are also provided with Babbitt bearings requiring oil cooling system. In addition, these pumps are provided with gland seal system with the stuffing box and an open seal water system.

The center line of pump casing is at 53.5’ and these storm water pumps are normally started with the wet level at 68’ and therefore requiring no priming system for these pumps to be operational.

The discharge pipe from each pump is tied to the three 14’X14’ box conduits which transports the flows from this pump station to the Connor Creek CSO Basin. The crown elevation of these conduits is approximately 95’ and the lowest ground elevation along these conduits varies from 100’ to 96’ allowing less than 10 feet between the finished ground level and the hydraulic grade line. This condition leads to potential surcharging and flooding along the discharge conduits.

With the current CSO operating protocol, the discharge conduits has been experiencing surcharge conditions whenever the CSO basin is filled to the overflow elevation of 98’and with more than three pumps operating in Freud Pump Station . This condition imposes serious limitations to the hydraulic capacity of the discharge conduits by the construction of CSO basin. Our inference is further validated by the operational experience of DWSD personnel who had observed serious surcharge condition in the conduit (by observing overflow of water into street from the manholes) when more than three pumps were to be operated during the storm event. The attached hydraulic profile below illustrates this potential surcharge condition. It is critical the above constraint to the overall operating capacity of this Pump station should addressed by further investigation and modification to the discharge conduit profile as required.

3.03 OBSERVATIONS AND FINDINGS

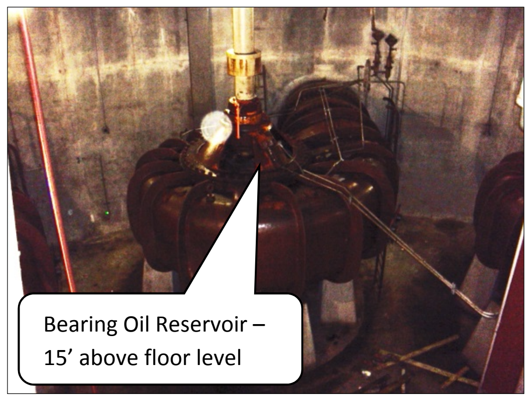
Based upon our field survey and the review of all available information, following are the brief discussion of our observations and findings:

A. __Storm Water Pumps__

- There is no means of isolating the wet well of this pump station from rest of the system for any inspection and/or maintenance. Due to this constraint, it appears the wet well has not been cleaned and / or inspected for a very long period. Further, the inlet to wet well is not provided with any bar screen mechanism leading to potential damage to pump impeller due to large debris during the wet weather flow during storm event.

- The existing pumps are operational and performing to the designed capacity and do not exhibit any major defects except for regular maintenance needs.

- However the current pump configuration does not provide easy and safe access to the maintenance personnel to perform periodic adjustment of gland packing. The pictures below illustrate the current arrangement, which does not allow easy approach to the existing gland packing system to the maintenance personnel. Similar constraint is being experienced by the personnel when replenishing the bearing cooling oil reservoir. In short, the existing pump arrangement is not very maintenance friendly.

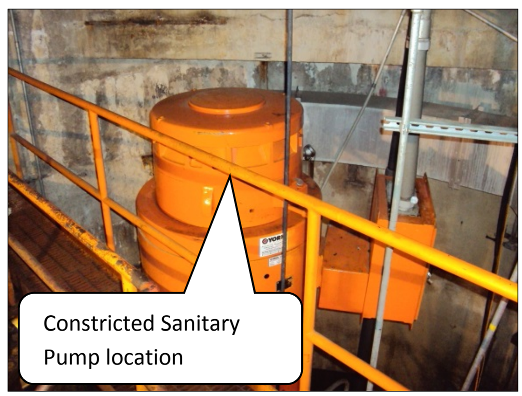


B. ***Sanitary/Dewatering Pumps***

- Currently, there are two sanitary and dewatering pumps installed to handle primarily the dry weather sanitary flow being received by this Pumping Station. Flow enters from two sources – Ashland relief and into the common wet well. Each discharges at the opposite end of the wet well. Therefore the flows from these relief sewers are not hydraulically connected during the dry weather conditions. The relative contribution from each relief sewer into the wet well can vary.

- These pumps are required to operate at the wet well level between 25' and 65'. The current sanitary pumps as designed do not appear to match the hydraulic conditions imposed by the existing flow pattern during dry weather conditions. It is likely there may be problems with vortices at the pump intakes due to non-uniformities in the approach flow to the pumps resulting in cavitation and excessive wear and tear. This is evidenced by frequent replacements of these pumps and most of the time within a period of one year.

- In addition to this issue, the existing two sanitary/dewatering pumps are installed at the elevation of 23.7' which is below the storm water pump floor elevation of 45.00'. This does not allow easy access for removal of these pumps and associated motors for regular maintenance requiring the removal of beams. The current arrangement of these pumps is illustrated in the following pictures.



C. ***<u>Motors</u>***

- The existing motors for the storm water pumps are slip-ring type synchronous type requiring periodic replacement of brush and cleaning of slip rings.

- Motors are about 60 years old and beyond the range of their general life period.

- The motors for the existing sanitary/dewatering pumps are 200 HP, vertical, Induction motor types and operate 4160 volt level. It is not common industry practice to operate motors of this capacity range at medium voltage (5 KV) level.

D. ***Electric Power***

- The primary power to this facility is currently fed from three 24 KV PLD feeders and is further stepped down to distribution voltage level of 4160V with the help of three (3) 6/7.5 MVA, 24KV-4.16KV Transformers. The low level of reliability of the PLD system and especially during the storm event(s) is a major issue of concern. However, this is partly mitigated by the installation of two (2) X2 MW Emergency diesel generators.

- The existing primary transformers are approximately 60 years old and outlived its useful life. The obsolescence of this equipment makes the maintenance of these transformers very difficult. Considering the criticality of this equipment, being the primary source of electrical power to the facility, it is important that these transformers are maintained to be consistent with the current technology for both reliability and efficiency.

- Most of the medium voltage switchgear and other electrical distribution transformer and panels are relatively new and in good working condition. However, we understood from our discussion with the DWSD personnel that there had been occasional ground fault being sensed in the existing 5 KV (pump) starter lineup. This would require further testing of the existing protective system at the starters and recalibration or replacement of those devices. The current arrangement of the existing primary transformers is illustrated in the following pictures:

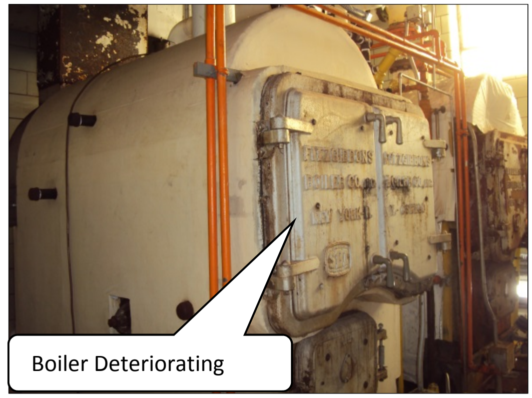
E. ***Lighting System***

- The existing lighting system consists of high bay HID lamps and at the time of our field inspection we have observed several of these lamps are not working. Also, we have noted that the illumination level at all levels of the pumping station is inadequate. The entire lighting system requires upgrading with new energy efficient fixtures to achieve sufficient level of illumination consistent with IES standards. Consistent with the current trend in the design of illumination system, serious consideration should be given to replacing the existing fixtures with comparable energy-efficient LED fixtures.

F. ***HVAC System***

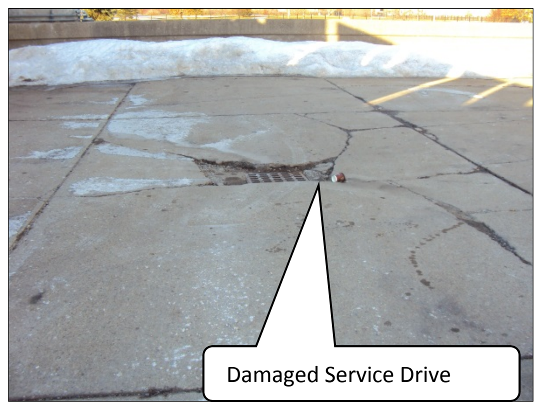
- Existing heating system consists of two gas fired, packaged hot water boilers with condensate receivers and pumps. The heating system also consists of hot water unit heaters installed at various locations in the motor room.

- Severe corrosion and damage were observed in the boilers as well in the hot water piping system. One of the existing boilers is not operational and the facility is currently served with only one boiler which also exhibits corrosion and insulation damage. The condensate pumps are also in poor condition requiring replacement. The current condition of the existing hot water boilers is illustrated in the following pictures:



G. ***<u>Miscellaneous</u>***

- The entrance driveway as well as the main stairs to the Pump Station are in advanced stages of deterioration and need to be replaced to comply with current ADA standards. The current condition of existing driveway and stairs are illustrated in the following pictures:



3.04 RECOMMENDED IMPROVEMENTS

Based on our condition assessments of major equipment, the following Table provides the summery of recommended improvements and associated OPCC for Freud Pump Station.

RECOMMENDED IMPROVEMENTS	
PROJECT	**OPCC**
1.0 PUMPING SYSTEM	
1.1 Modify the existing eight (8) storm pumps with new mechanical seal and new self-lubricated bearings	$ 1,200,000
1.2 Evaluate suction hydraulics, resize and relocate the existing two (2) sanitary pumps to the intermediate bearing floor level	$ 500,000
1.3 Install stop logs at the inlet of the wet well for isolation purposes	$ 1,300,000
1.4 Modify the discharge channel to eliminate the pumping restrictions	$ 2,500,000
2.0 ELECTRICAL	
2.1 Replace all three (3) Primary Power Transformers and associated controls	$ 3,600,000
2.2 Upgrade the existing lighting system to provide required illumination level at the different floors	$ 400,000
3.0 HVAC SYSTEM	
3.1 Replace the existing two (2) boilers, condensate pumps and associated piping and valves	$ 800,000
3.2 Replace the existing heaters and ventilation fans	$ 250,000
4.0 MISCELLANEOUS	
4.1 Resurface the existing driveway	$ 75,000
4.2 Modify the existing access stairs to comply with ADA requirements	$ 55,000
***TOTAL**	**$10,680,000**

***The above estimate should be considered as order of magnitude and needs to be refined based on further engineering of the recommended improvements**

4.0 CONNOR CREEK PUMP STATION

4.01 BACKGROUND/DESCRIPTION OF THE SYSTEM

The Connors Creek Pump Station was originally built in 1928 with Four (4) storm water pumps, each with a rated capacity of 225,000 GPM (500 CFS) at 27 feet Static Head. Each pump is of vertical, mix-flow, dry type, with an 84-inch impeller and equipped with 2300 HP, 4160V, 200 RPM Synchronous Motor. The pump station was subsequently expanded in the year 1940 with installation of four additional pumps of same type and capacity. As a result, the Pump Station is currently provided with an installed capacity of 4,000 cfs (8X500 cfs) and a firm capacity of 3,500 cfs.

- Bottom of Wet Well for storm pumps: 20.00 feet
- Bottom of sump for Dewatering/Sanitary Pups: 13.00 feet
- Pump Impeller Centerline: 53.50 feet
- Design Operating Level: 68 to 75 feet

The operation of pumps are primarily controlled by the wet well levels with the first pump to be started at wet well level of 68' and the subsequent pumps to be started at one foot interval thereof.

4.02 DISCUSSION OF CONDITIONS OF MAJOR SYSTEM COMPONENTS

A. ***Methodology***

METCO has performed field visual inspection of this facility on January 14, 2014 along with the Operation and Mechanical maintenance personnel of DWSD to obtain information regarding the condition of major equipment in sufficient details to provide a reliable means of identifying the required improvements. In addition, we have also reviewed the existing system information available from O&M manual and other relevant drawings. These efforts were further supplemented with discussions with DWSD operators at SCC to obtain a good understanding of the operating protocol of this Pump station during dry and wet weather conditions.

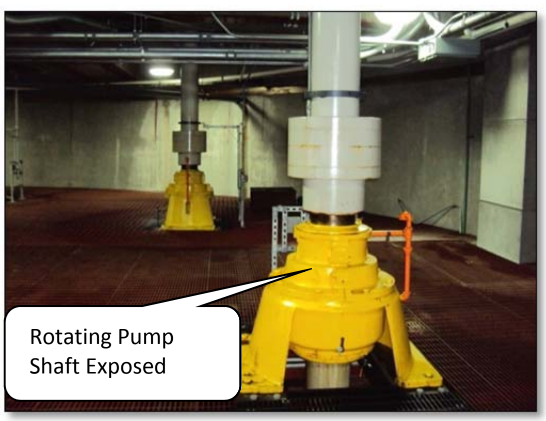
B. ***Storm Water Pumping System***

As indicated earlier, each pump is of vertical, mix-flow, dry type, with an 84-inch impeller and equipped with 2300 HP, 4160V, 200 RPM Synchronous Motor. These pumps were installed in the year 1929 (four (4) pumps) and in 1940 (four additional pumps) making the total installed capacity of 4,000 CFS.

The existing configuration of the storm water pumps requires priming before pumping. New Vacuum priming system and new motor starters were installed under Contract PC-674 for all storm water pumps. However, with the existing discharge flume operating as siphon, the existing vacuum priming system does not create enough priming such that current pumps are not functional rendering the pump station to be inoperative during the storm events. To mitigate this condition, improvements including replacing two of the existing pumps with new Pumps requiring no priming are being recommended in Technical Memorandum No.1.

Furthermore, these pumps are as originally installed in 1929 and are very old. The last inspection of the pump casing and the blades of some of these pumps were performed in 1998/2000. It is therefore preferable to have those pumps which are not proposed to be replaced, be inspected by the manufacturer for the structural integrity and for any pitting due to vibration and/or cavitation.

- The rotating shaft of the storm water pumps at the intermediate floor levels are exposed to contact by operating and maintenance personnel and are not provided with proper safety guard and thus create a safety hazard as shown in the figures below. This arrangement also does not meet the OSHA requirements and hence should be remedied with proper safeguards. The guards shall meet the requirements as set forth in American National Standards Institute, B15.1-1953 (R1958), Safety Code for Mechanical Power-Transmission Apparatus.



4.03 OBSERVATIONS AND FINDINGS

Based upon our field survey and the review of all available information, following are the brief discussion of our observations and findings on other major equipment/system.

A. Motors

- The existing motors for the storm water pumps are slip-ring type synchronous type requiring periodic replacement of brush and cleaning of slip rings.

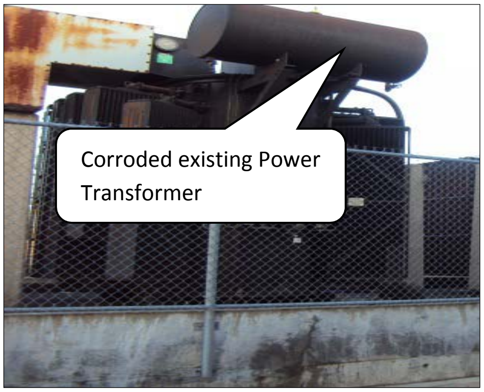
- Motors are about 85 years old and beyond the range of their general life period.

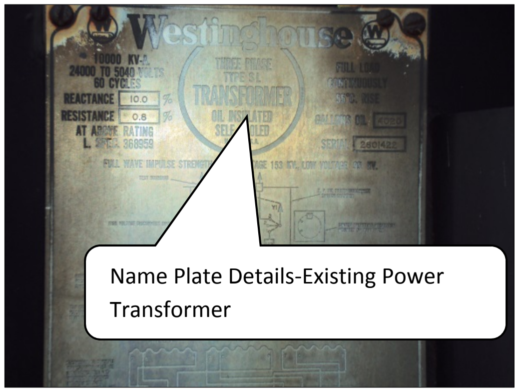
B. Electric Power

- The primary power to this facility is currently fed from two 24 KV PLD feeders and is further stepped down to distribution voltage level of 4160V with the help of two (2) 10MVA, 24KV-4.16KV Transformers. The low level of reliability of the PLD system and especially during the storm event(s) is a major issue of concern. However, this is partly mitigated by the installation of two (2) X2 MW Emergency diesel generators.

- The existing primary transformers are approximately 85 years old and outlived its useful life. The obsolescence of this equipment makes the maintenance of these transformers very difficult. Considering the criticality of this equipment, being the primary source of electrical power to the facility, it is important that these transformers are maintained to be consistent with the current technology for both reliability and efficiency.

- Most of the medium voltage switchgear and other electrical distribution transformer and panels are relatively new and in good working condition. The current arrangement of the existing primary transformers is illustrated in the following pictures:





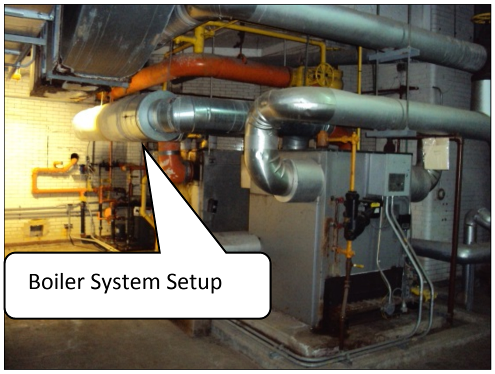
C. Lighting System

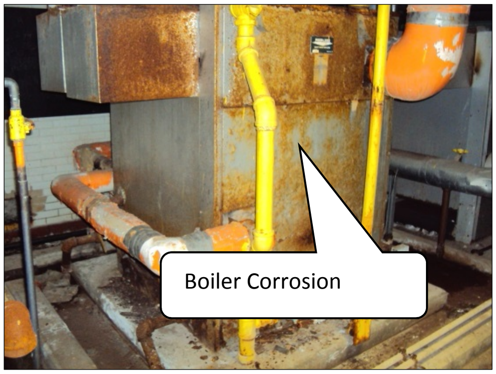
- The existing lighting system consists of high bay HID lamps and at the time of our field inspection we have observed several of these lamps are not working. Also, we have noted that the illumination level at all levels of the pumping station is inadequate. The entire lighting system requires upgrading with new energy efficient fixtures to achieve sufficient level of illumination consistent with IES standards. Consistent with the current trend in the design of illumination system, serious consideration should be given to replacing the existing fixtures with comparable energy-efficient LED fixtures

D. HVAC System

- Existing heating system consists of two gas fired, packaged boilers owith rated capacity of 1000-1250 Thousand BTU/Hr with condensate receivers and pumps. The heating system also consists of hot water unit heaters installed at various locations in the motor room.

- Severe corrosion and damage were observed in the boilers as well in the hot water piping system. One of the existing boilers is not operational and the facility is currently served with only one boiler which also exhibits corrosion and insulation damage. The condensate pumps are also in poor condition requiring replacement. The current condition of the existing boilers is illustrated in the following pictures:



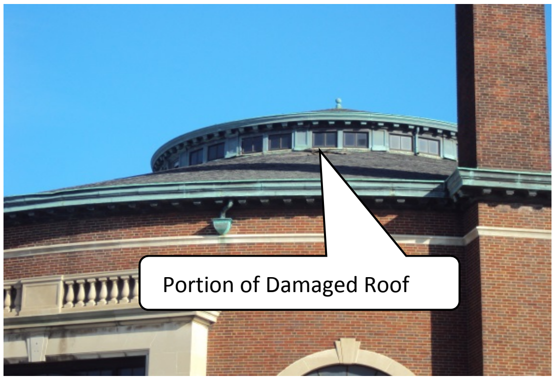


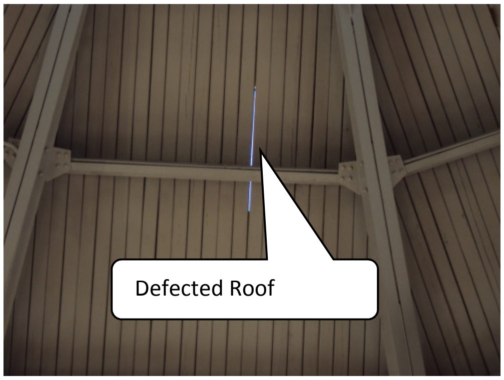
G. Civil/Structural

The following deficiencies were observed:

- Shingles on the roof of the storm water pumping station are missing at several places.

- Several cracks on the joints between sanitary and storm water pumping stations.





4.04 RECOMMENDED IMPROVEMENTS

Based on our condition assessments of major equipment, the following Table provides the summery of recommended improvements and associated OPCC for Freud Pump Station.

RECOMMENDED IMPROVEMENTS	
PROJECT	**OPCC**
1.0 PUMPING SYSTEM	
1.1 Perform detailed inspection of pump internal components for those six (6) pumps not replaced	$ 300,000
1.2 Convert existing six (6) slip ring synchronous motors into brushless type	$ 750,000
1.3 Install machine safety guards for six pumps	$ 75,000
2.0 ELECTRICAL	
2.1 Replace two (2) Primary Power Transformers and associated controls	$ 1,800,000
2.2 Upgrade the existing lighting system to provide required illumination level at the different floors	$ 200,000
3.0 HVAC SYSTEM	
3.1 Replace the existing boilers, condensate pumps and associated piping and valves	$ 800,000
3.2 Replace the existing heaters and ventilation fans	$ 250,000
4.0 MISCELLANEOUS	
4.1 Resurface the existing driveway	$ 75,000
4.2 Repair and seal crack between Pump building	$ 100,000
4.3 Replace roofing system for the Storm Water Pump building	$ 200,000
****TOTAL**	**$ 4,750,000**

***The replacement of existing two pumps is not included; Refer to Tech memo No.1 for details**

****The above estimate should be considered as order of magnitude and needs to be refined based on further engineering of the recommended improvements.**

TECHNICAL MEMORANDUM NO.3

SYSTEM (CONNOR CREEK DRAINGE DISTRICT) HYDRAULIC ANALYSIS

1.0 INTRODUCTION

During the recent heavy storm event in August, 11 of 2014, DWSD had experienced problems in putting the storm water pumps at Connor Creek Pump Station in service due to malfunctioning of the associated Vacuum Priming System. The outage of all pumps had resulted in a severe surcharge conditions in upstream sewers as well in the related service areas. To mitigate this situation, DWSD has initiated immediate efforts to identify the cause and implement appropriate corrective measures so as to restore the desired level of reliability to the operation of storm water pumps at Connor Creek Pump Station.

To address the issue and also to optimize the utilization of the storm water pumping stations and the CSO basin, DWSD had contracted the services of METCO Services, Inc. (METCO) by Task order No. 36 under Contract CS-1499. One of the work elements under the scope of the task order relates to perform Hydraulic Analysis of the System to determine the following:

- Develop an Operational Strategy to optimize the utilization of Connor Creek CSO basin and associated Connor Creek and Freud Pump Stations.
- To determine the optimal capacity of Fairview, Freud and Connor Creek Pump Stations that would be required under the revised Operating Protocol of the Connor Creek CSO System

Consistent with these imperatives, METCO had initiated the efforts by performing necessary hydraulic model simulations and subsequent analysis to determine the system hydraulic response under different operating scenarios.

This Technical memorandum presents our observations and findings along with recommendations that would eventually lead to optimum utilization of existing CSO assets with minimum adverse effects in the upstream sewers within the service area. It should be noted that some of the findings and conclusions presented in this tech memo were considered while developing recommendations for the Connor Creek and Freud Pump station improvements under technical memorandum No. 4.

2.0 OBJECTIVES

The primary objective of the task is to develop Operational Strategy to achieve the following:

- Optimization of Connor Creek CSO facility
- Balanced Utilization of Connor Creek and Freud Pump Stations
- Minimize the potential surcharge and flooding in the service areas during the 10 Year, 1 Hour storm event

3.0 METHODOLOGY

A. Existing SWMM Model

The model for the service area was extracted from the existing GDRSS model and was enhanced to better represent the current conditions with the following improvements to the existing SWMM model.

- Verify invert elevations and ground elevations from the as-built drawings and update as required.
- Verify and add all missing pipes upstream of the outfalls.
- Update Outfall geometry to reflect existing conditions.
- Subdivide the area into even smaller sub-areas to improve the model resolution.

As the re-calibration of this model is not within the scope of the project, the model was essentially used as calibrated earlier. However, additional validation of the model was performed by comparing the simulation results for earlier specific storm events with the available operating data from DWSD of the pump stations for that event.

B. Model Simulation

The Model simulations from the validated model was used to estimate peak flow rate and volume of flow for a typical 10 year – 1 hour design storm event at each of three pump stations – Freud, Connor Creek and Fairview and at the Connor Creek CSO Basin. Additional simulations were performed by applying different Operating strategies to predict the system responses and to identify the operating protocol that would satisfy the project objectives.

4.0 SYSTEM DESCRIPTION

The configuration of existing sewer network that transports flows during dry and wet weather conditions, to the Fairview, Freud and Connor Creek Pump stations and to the Connor Creek CSO basin is illustrated in the attached Figure No. 3-1. The sewer network also includes several weirs, gates and other control structures with their elevation designed to divert the flows to the WWTP or to CSO basin during wet and dry weather conditions in accordance with the established Operating protocol.

As evident from the Figure 3-1, the flows to the Connor Creek CSO basin are influenced by the operation of following facilities/ control structures.

- Fairview Pump Station
- Freud Pump Station
- Connor Creek Pump Station
- Forebay Regulator Gates
- Connor Sewer Backwater Gates
- Connor Creek CSO Basin Effluent Launder Gates
- Connor Creek CSO Basin Effluent Relief Gates

[redacted]

CONNORS CREEK PUMPING STATION

FLOW SCHEMATIC OF CONNORS-FREUD SYSTEM

SCALE

DATE NOV, 2014

METCO SERVICES, INC.
1274 LIBRARY, DETROIT, MI. 48226
TEL - (313) 961-4560 * FAX (313) 961-1898
www.metcoservices.com

CITY OF DETROIT
WATER AND SEWERAGE DEPARTMENT
ENGINEERING DIVISION

DRAWING NO. D-00-00-

FIGURE 3-1

Following is the summary of existing set of controls incorporated in the control strategy at the above facilities.

- Fairview Pump Station:
  - Current Capacity : One (1) 75 cfs & three (3) 150 cfs Pumps
  - Current Operating Control
    - On at 68'and maintain wet well level between 67' and 77'
    - All Pumps shut off at the onset of storm event

- Freud Pump Station:
  - Current Capacity :
    - Sanitary - one(1) 35 cfs & one (1) 18 cfs Pumps
    - Storm Water – Eight (8) X 450 cfs Pumps
  - Current Operating Control
    - Sanitary Pumps:
      - On at 25' and maintain wet well level between 25' and 45'
    - Storm Pumps:
      - On at 68' and maintain wet well level between 55' and 75'

- Connor Pump Station:
  - Current Capacity :
    - Sanitary – two (2) 110 cfs, one (1) 75 cfs & one (1) 60 cfs Pumps
    - Storm Water – Eight (8) X 500 cfs Pumps
  - Current Operating Control
    - Sanitary Pumps:
      - Maintain wet well level between 65' and 59'
    - Storm Pumps:
      - On at 71'and maintain wet well level between 66' and 75'

- Forebay Regulator gates:
  - Normally open; Closes when Freud PS is taken out of service off during storm event

- Connor Sewer Backwater gates:
  - Normally Closed; Open at 95’ elv in Forebay; Close at 87’ (falling level) in CSO Basin

- Connor Creek CSO Basin Effluent Launder Gates:
  - Normally Closed; Open to allow overflow over weir at elev. 98’ in CSO basin

- Connor Creek CSO Basin Effluent Relief Gates:
  - Normally Closed; Open at elev. 98.5’ in CSO basin; close at elev. 98’ (falling level) in CSO Basin

5.0 EVALUATION OF WET WEATHER OPERATIONAL STRATEGY

This section includes evaluation of current Operating procedure as practiced by System Control Center of DWSD and the modified operating protocol submitted to MDEQ by DWSD in their communication of December 19, 2014. In addition, a third alternate strategy which is recommended as the preferred option is also evaluated. Detailed hydraulic analysis using the relevant section of the existing GDRSS model was performed to evaluate the impacts on the utilization of CSO basin as well as the impacts to the Hydraulic Grade line in various sections of upstream sewers and the potential for surcharging and flooding.

The results of model simulation runs applying various operational strategies for the design storm event are summarized to highlight their ability to meet the objectives.

Description Alternative Operational Strategies

Operating Scenario-I

This alternative represents the operating protocol currently being practiced by DWSD during the dry and wet weather conditions. This was developed primarily based upon our discussions with the DWSD operating personnel at their System Control Center. The hydraulic responses under this option were essentially utilized as the base line reference in our evaluation process.

Operating Scenario-II

This alternative represents modified operating protocol that DWSD had submitted to MDEQ as part of "Detroit WWTP-Wet Weather Operational Plan". This was developed in response to the NPDES permit mandate to provide general protocol for operating the Detroit WWTP during the wet weather periods. This was submitted on January 1, 2015 to comply with permit requirements.

Operating Scenario-III:

This alternative represents modifications to the existing operating protocol recommended by METCO in order to maximize the utilization of Connor Creek CSO basin and other associated Pump Station and control facilities. This was developed in conjunction with the evaluation of operational reliability of Connor Creek and Freud Pump Stations.

6.0 EVALUATION OF ALTERNATIVES

General

The following is the brief description of critical control parameters of existing Operating Protocol being practiced by DWSD operators during Pre-Storm and Storm periods.

In conjunction with the controls under each Operating Scenario as described below, it was also assumed that none of the Pumps at Connor Creek Pump Station are operational due to inability to prime the pumps as detailed in Technical Memorandum No.1.

Accordingly, the model simulation run for the 10-Year, 1-Hour storm event under each scenario was performed with no storm pumps being available at Connor Creek Pump Station during wet weather events. This assumption closely reflects the existing condition as corroborated by review of pump operating hours during the last few significant storm events (Refer to technical memorandum No.1).

Description of Controls - Scenario-1

Fairview Pump Station:

- When a wet weather event is imminent, all pumps at Fairview PS are shut down
- Pumps are re-started when the level in the DRI downstream of Fairview PS has lowered and DRI has enough capacity to pump from Fairview PS

Conner Creek Pump Station-Sanitary:

- When wet weather event occurs, sanitary pumps are shut down.

Conner Creek Pump Station-Storm:

- When wet weather event occurs, sanitary pumps are shut down. The level in the wet well is allowed to rise and the storm pumps are started when level in the wet well reaches 71’
- After the rain event, storm pumps are turned off when level in the wet well falls below 66’ at which point the sanitary pumps are turned back on.

Freud Pump Station- Sanitary:

- When wet weather event occurs, sanitary pumps are shut down.

Freud Pump Station- Storm:

- The level in the wet well is allowed to rise and the storm pumps are started when level in the wet well reaches 68’

- After the rain event, storm pumps are turned off when level in the wet well falls below 50’ at which point the sanitary pumps are turned back on.

Forebay Regulator Gates and Conner Backwater Gates:

- As wet weather approaches, Forebay Regulator Gates are closed and the level in the Forebay is allowed to rise
- When the level in the Forebay reaches 95’, the backwater gates are opened to allow flow from the Conner Creek Sewer to the CSO Basin
- After the wet weather event, one or two of the regulator gates are opened to help dewater the CSO basin by gravity back to the DRI
- When the level in the Forebay falls below 67’ the Backwater gates are closed to allow all flow from the Conner Creek Sewer to go to the DRI

CSO Basin Effluent Launder Gates:

- Effluent Launder gates are set to open when the level in the CSO basin reaches 90’ (allows time to open gates for discharge over the effluent weir at 98’)

CSO Basin Effluent Relief Gates:

- When the level in the basin rises to above 98.5’, the Effluent Relief Gates are opened to allow discharge into the Detroit River
- When the level in the CSO Basin falls back down to below 98’ (level of the effluent weir), the relief gates are closed

Hydraulic Responses – Scenario 1

The hydraulic responses as represented by Hydraulic Gradient Line (HGL) at various sewers within system for the design storm condition is graphically illustrated in the attached Figure 3-2 in the following pages.

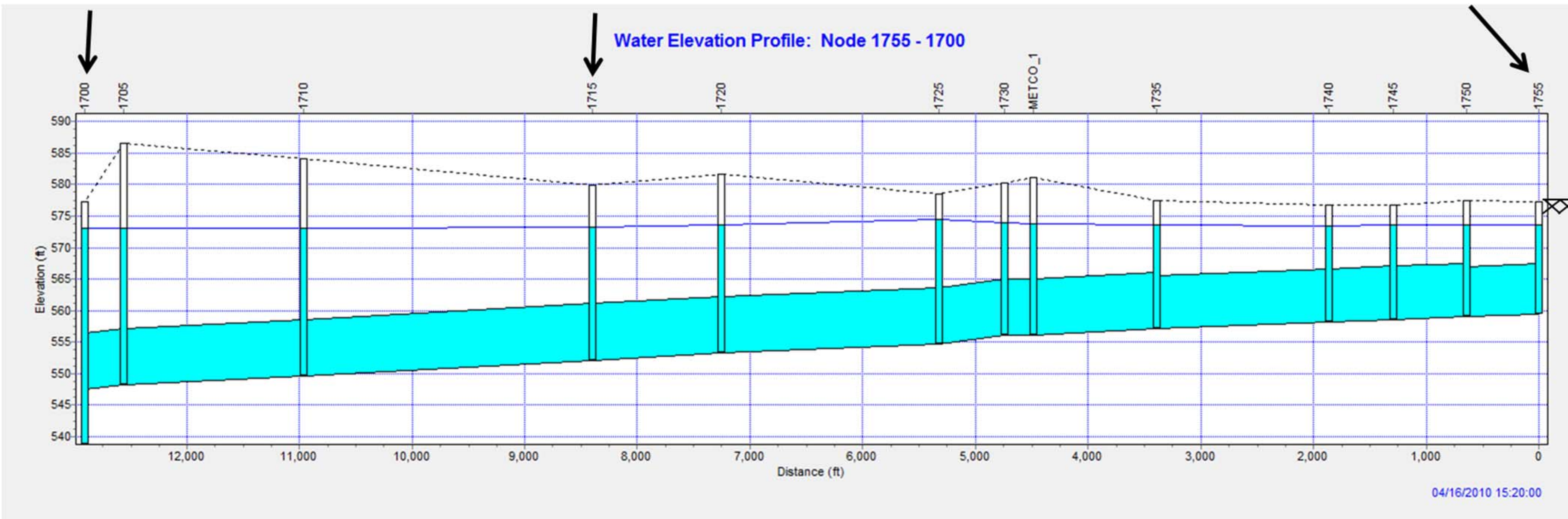
The following the summary description of the hydraulic responses:

Detroit River Interceptor (DRI)	Peak HGLs show significant surcharge in the DRI leading to levels about 4'-15' below grade. Potential for basement flooding.
Conner Creek Sewer	Peak HGL shows surcharge in the sewer with levels about 6' below grade. Potential for basement flooding.
West Jefferson Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 7'-13' below grade. Potential for basement flooding, particularly at the upstream end (where the ground surface is at a lower elevation)
East Jefferson Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 5'-12' below grade. Potential for basement flooding, particularly past 1/4 mile upstream of Connor Creek PS (where the ground surface is at a lower elevation)
Ashland Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 2'-25' below grade. Potential for basement flooding, particularly along Kercheval and Algonquin (where the ground surface is at a lower elevation)
Fox Creek Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 3'-10' below grade. Potential for basement flooding, particularly along Manistique and Freud (where the ground surface is at a lower elevation)
Connor Creek/Forebay Discharge Triple Barrel	Peak HGL shows levels near the top of the discharge triple barrel, which is about ground surface.

Freud Discharge Triple Barrel	Peak HGL shows levels above the top of the discharge triple barrel (about 3 feet below grade)
Conner Creek CSO Basin	The level in the CSO Basin rises to just over 98.5' allowing discharge from the CSO Basin through the launder gates and effluent relief gates.

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



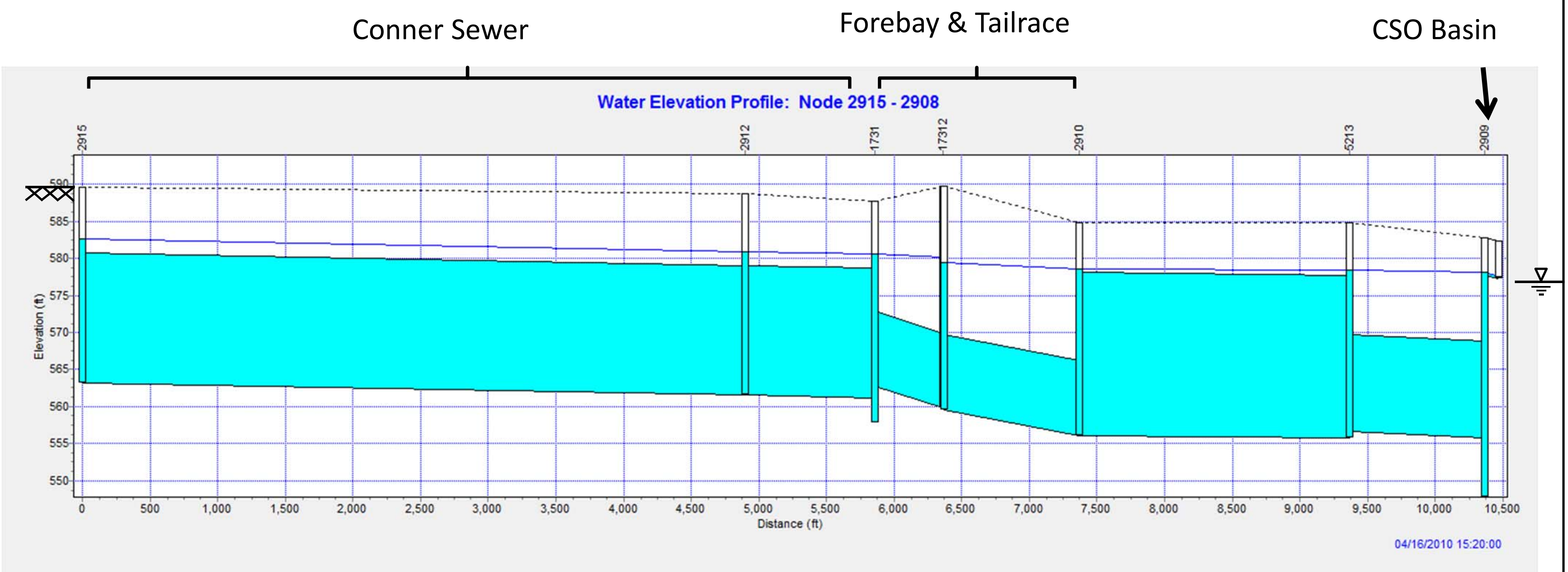
Detroit River Interceptor (DRI)

Scenario 1: Current Wet Weather Operating Protocol

FIGURE 3-2

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



Conner Sewer to CSO Basin Outfall

Scenario 1: Current Wet Weather Operating Protocol

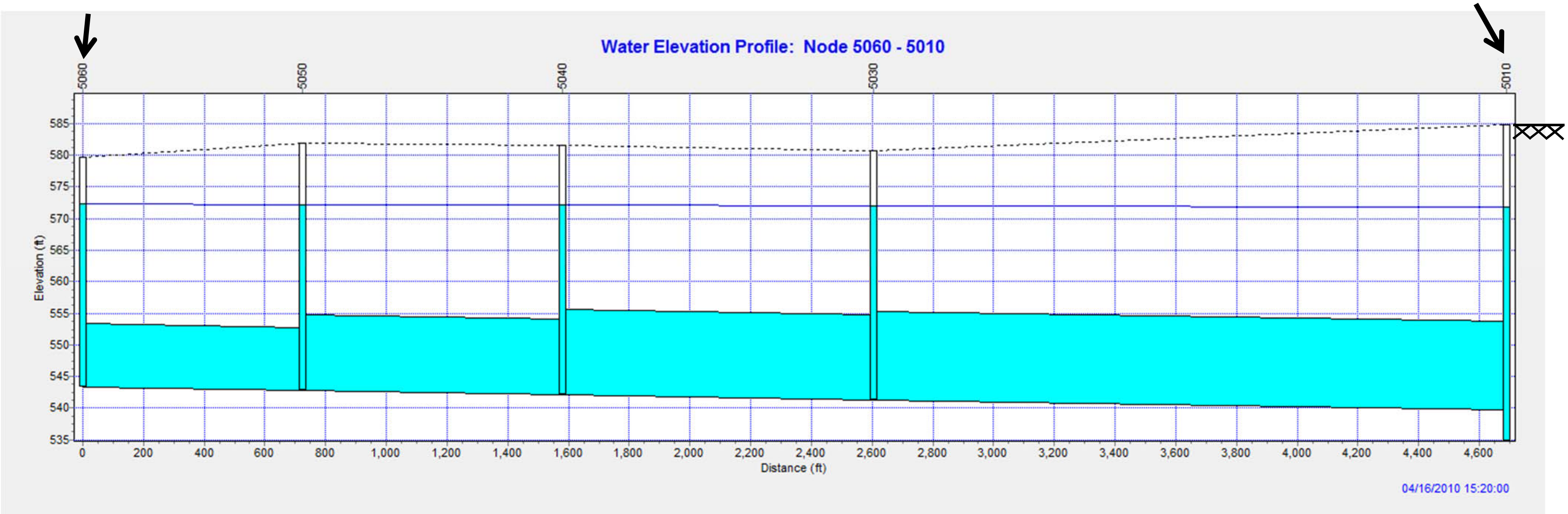
FIGURE 3-2

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)

Overflow from DRI

Connors Creek PS



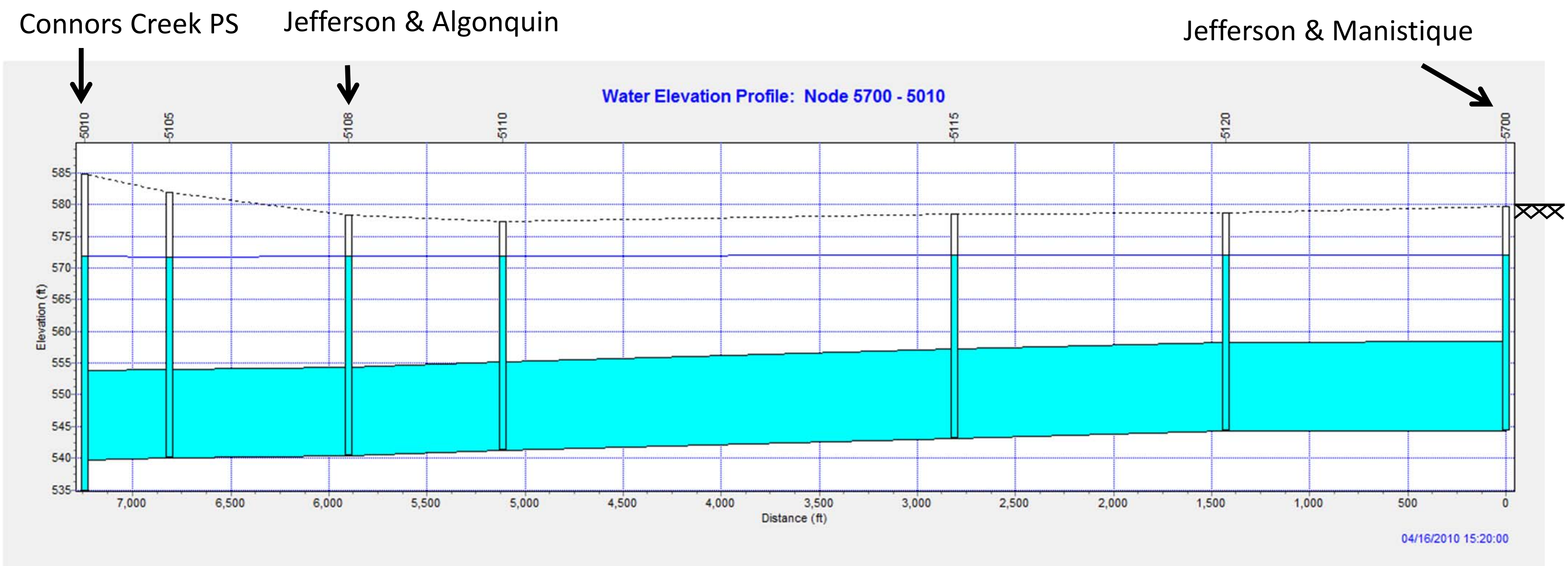
West Jefferson Relief Sewer

Scenario 1: Current Wet Weather Operating Protocol

FIGURE 3-2

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



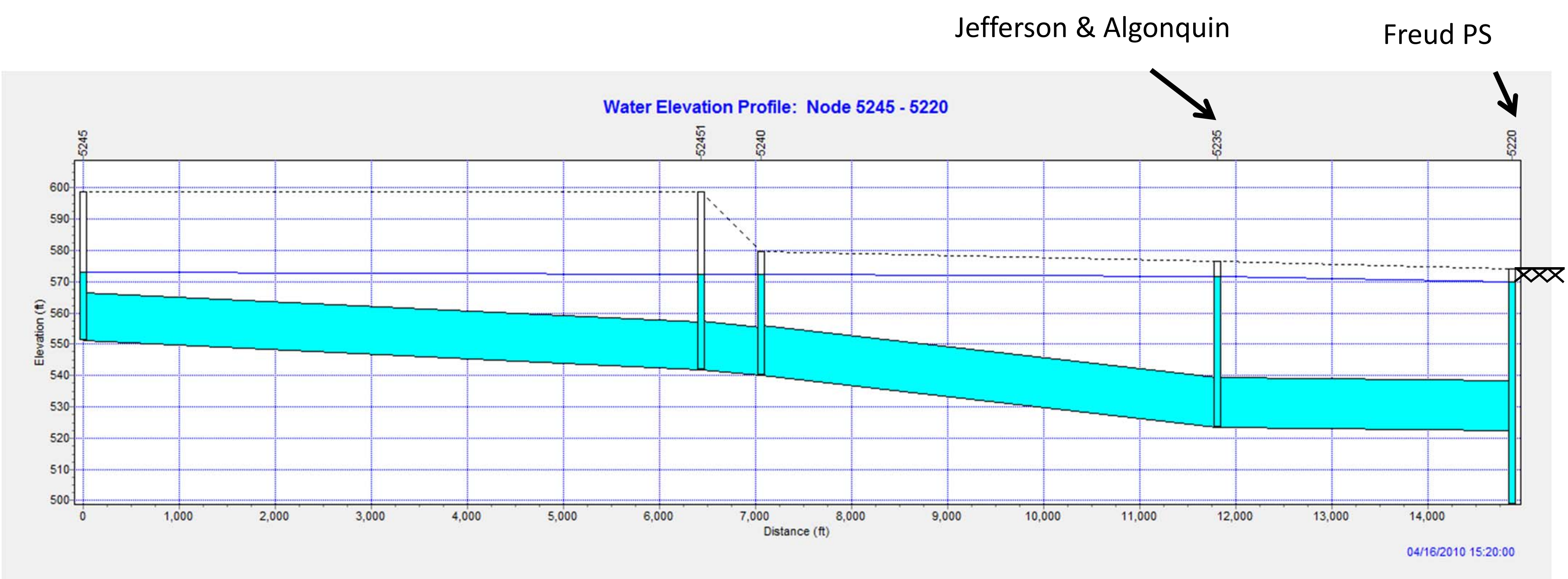
East Jefferson Relief Sewer

Scenario 1: Current Wet Weather Operating Protocol

FIGURE 3-2

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



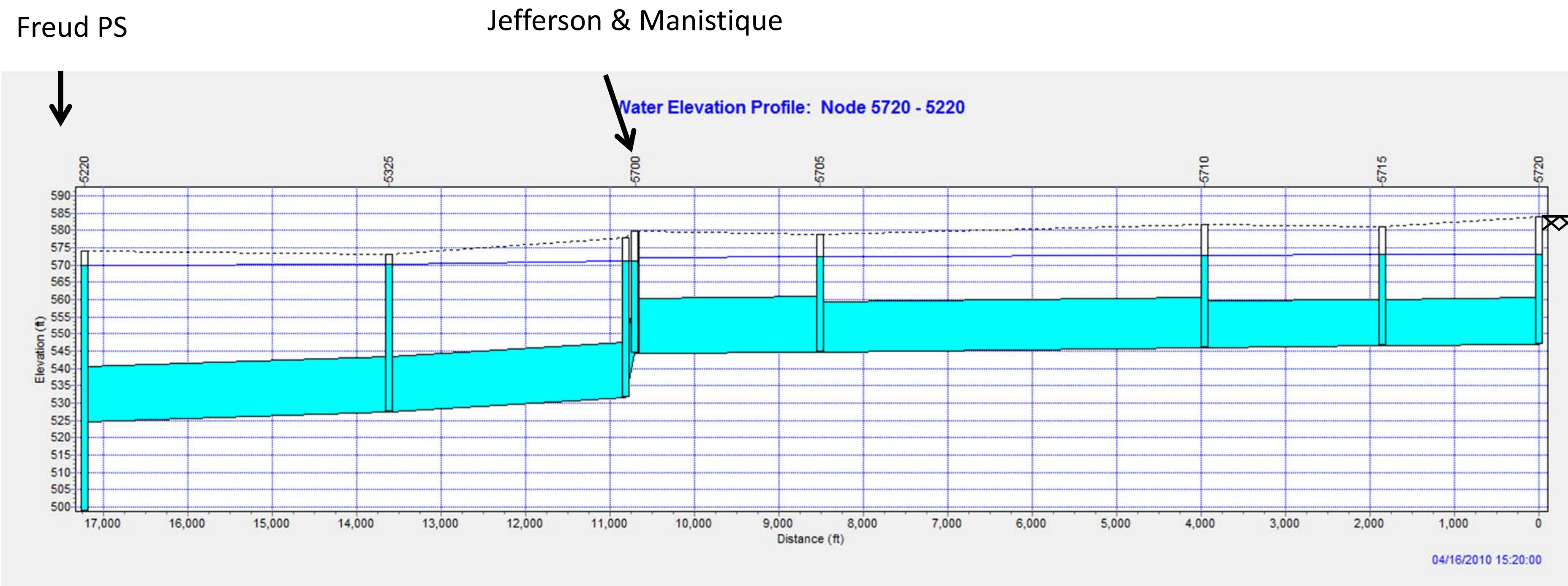
Ashland Relief Sewer

Scenario 1: Current Wet Weather Operating Protocol

FIGURE 3-2

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



Fox Creek Relief Sewer

Scenario 1: Current Wet Weather Operating Protocol

FIGURE 3-2

Description of Controls – Scenario 2

Fairview Pump Station - Same as Scenario 1

Conner Creek Pump Station – Sanitary - Same as Scenario 1

Conner Creek Pump Station - Storm:

- Storm pumps are turned on when the level in the wet well reaches 75'.
- Additional pumps are turned on based the level in the wet well.

Freud Pump Station – Sanitary - Same as Scenario 1

Freud Pump Station - Storm:

- Storm pumps are turned on when the level in the wet well reaches 72'.
- Additional pumps are turned on based the level in the wet well.

Forebay Regulator Gates and Conner Backwater Gates:

- Two criteria for the closing of the Forebay Regulator Gates: when the level in the Connor Creek wet well reaches 72' (likely to occur first), OR when the level in the CSO Basin reaches 96' (simultaneous with Backwater Gates opening)
- Backwater gates are closed during dry weather and are opened when the level in the CSO Basin reaches 96' (also triggering the closure of the regulator gates)

CSO Basin Effluent Launder Gates - Same as Scenario 1

CSO Basin Effluent Relief Gates:

- Effluent Relief Gates are opened when the level in the CSO Basin reaches 99' (1' above the effluent weir), and close when the level falls below 98'

Hydraulic Responses – Scenario 2

The hydraulic responses as represented by Hydraulic Gradient Line (HGL) at various sewers within system for the design storm condition is graphically illustrated in the attached Figures 3-3 in the following pages.

The following the summary description of the hydraulic responses:

Detroit River Interceptor (DRI)	Peak HGLs show significant surcharge in the DRI leading to levels less than 6'-15' below grade. Potential for basement flooding.
Conner Creek Sewer	Peak HGL shows surcharge in the sewer with levels about 1'-2' below grade. Potential for street and basement flooding
West Jefferson Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 9'-14' below grade. Potential for basement flooding, particularly at the upstream end (where the ground surface is at a lower elevation)
East Jefferson Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 6'-13' below grade. Potential for basement flooding, particularly past 1/4 mile upstream of Connor Creek PS (where the ground surface is at a lower elevation)
Ashland Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 3'-26' below grade. Potential for basement flooding, particularly along Kercheval and Algonquin (where the ground surface is at a lower elevation)
Fox Creek Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 4'-11' below grade. Potential for basement flooding, particularly along Manistique and Freud (where the ground surface is at a lower elevation)

Connor Creek/Forebay Discharge Triple Barrel"	Peak HGL shows levels above the top of the discharge triple barrel, which is about ground surface.
Freud Discharge Triple Barrel	Peak HGL shows levels above the top of the discharge triple barrel (about 3 feet below grade) Note: this peak occurs much later than in the other scenarios
Conner Creek CSO Basin	The level in the CSO Basin rises to just over 98.5' allowing discharge from the CSO Basin through the launder gates and effluent relief gates

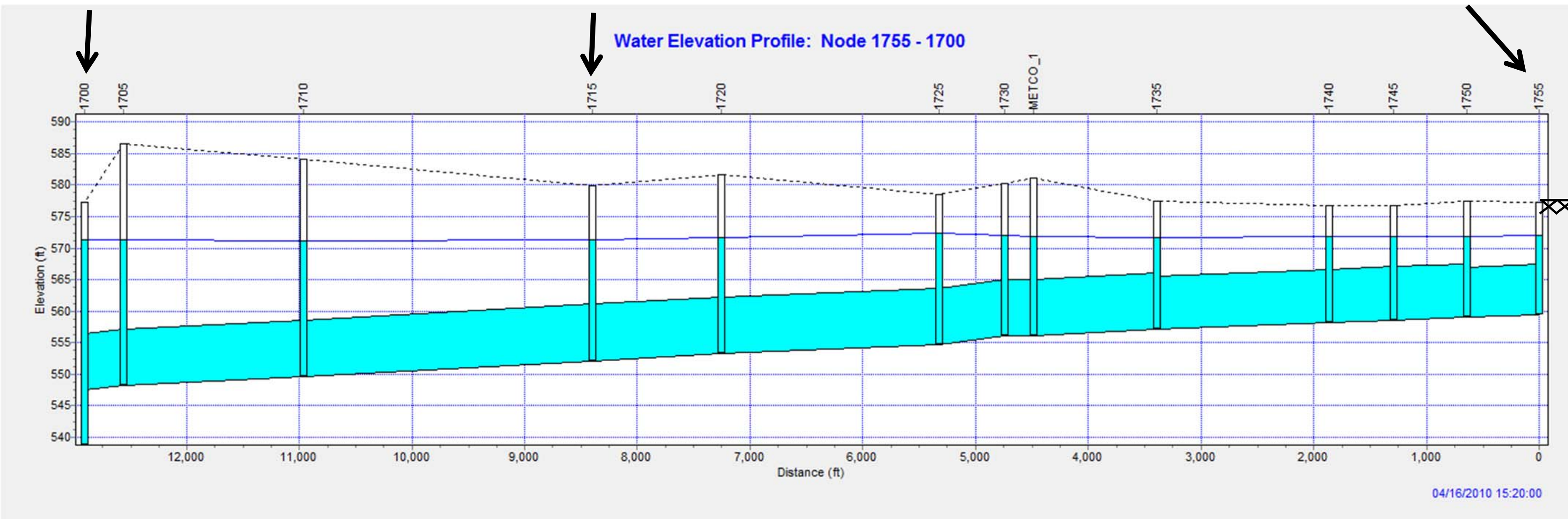
Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)

Fairview PS Wet Well

Overflow into EJR

Jefferson & Manistique



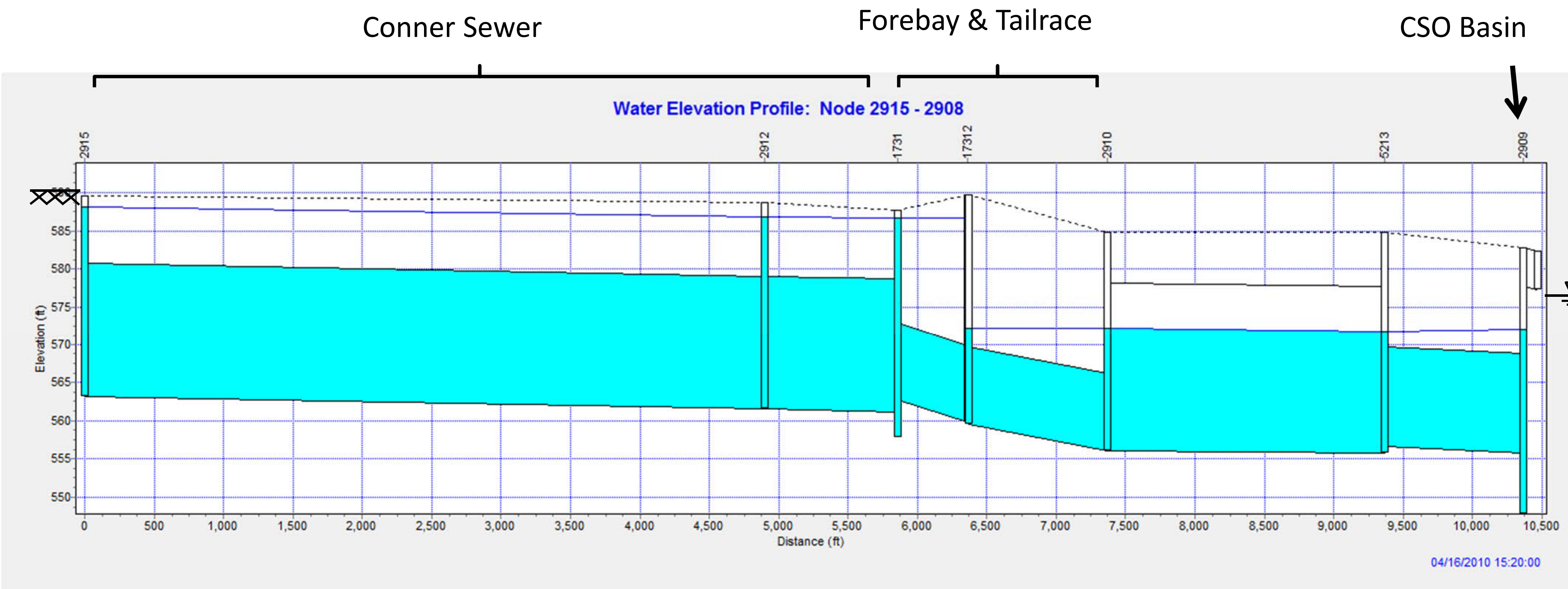
Detroit River Interceptor (DRI)

Scenario 2: DWSD Revised Wet Weather Operating Protocol

FIGURE 3-3

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



Conner Sewer to CSO Basin Outfall

Scenario 2: DWSD Revised Wet Weather Operating Protocol

WATER & SEWERAGE DETROIT DEPT.

METCO

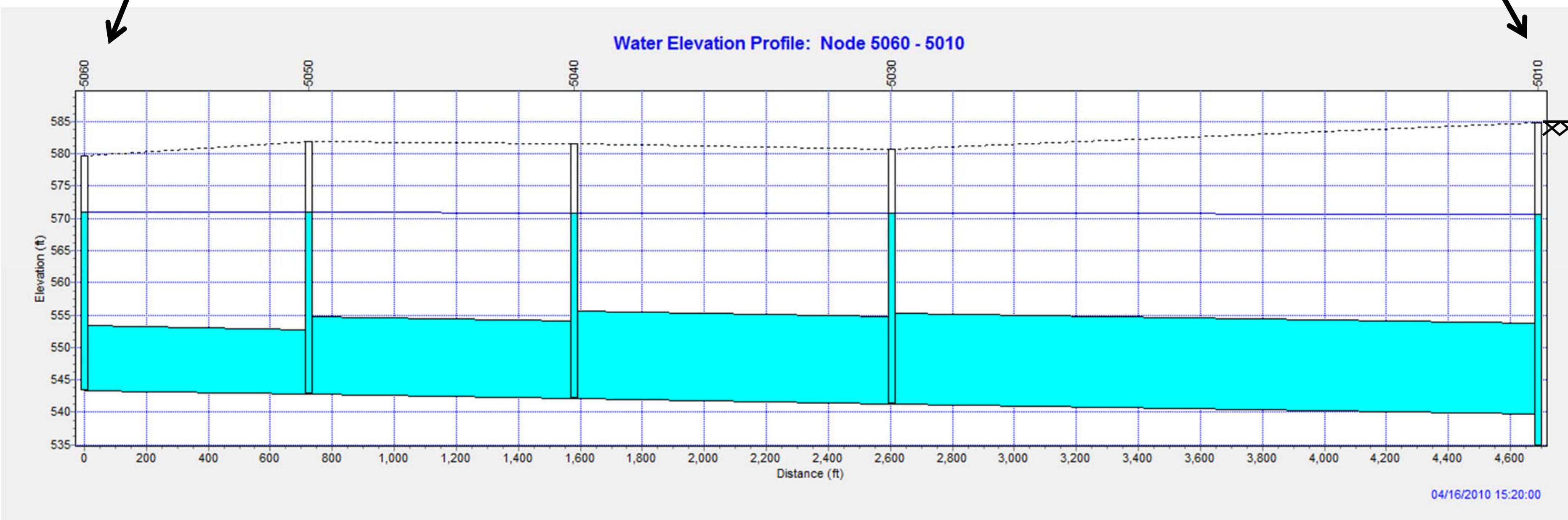
FIGURE 3-3

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)

Overflow from DRI

Connors Creek PS



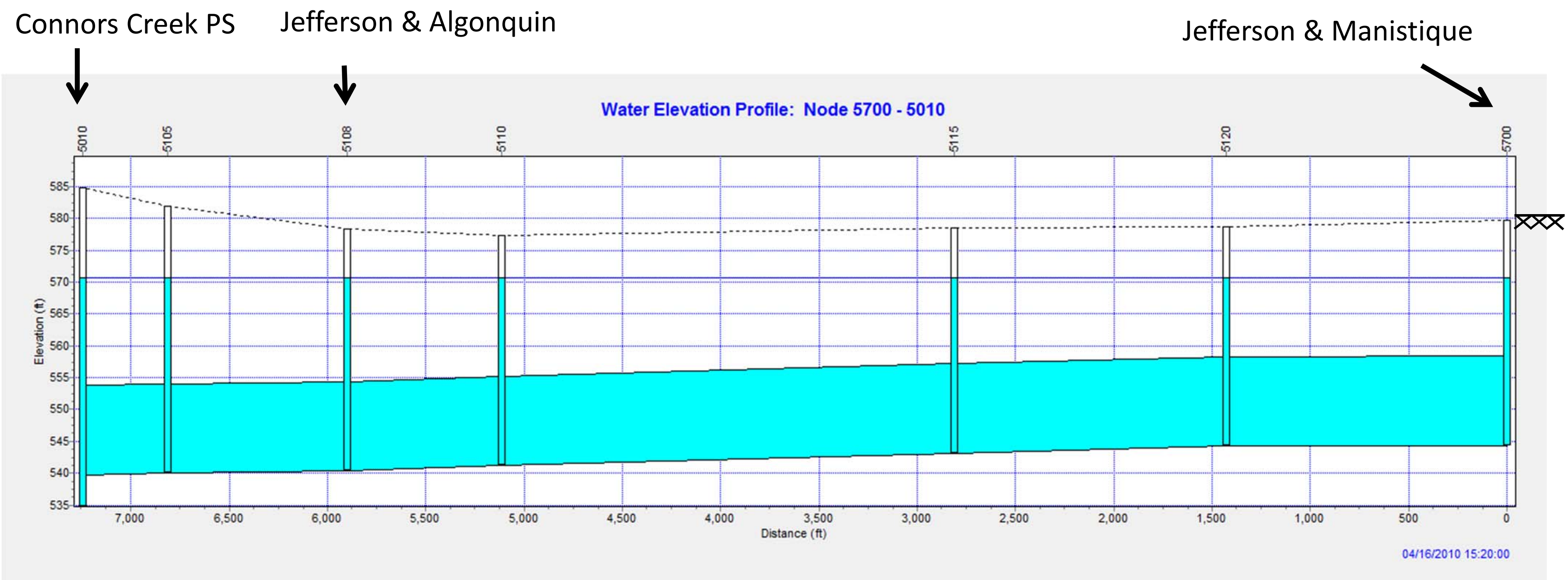
West Jefferson Relief Sewer

Scenario 2: DWSD Revised Wet Weather Operating Protocol

FIGURE 3-3

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



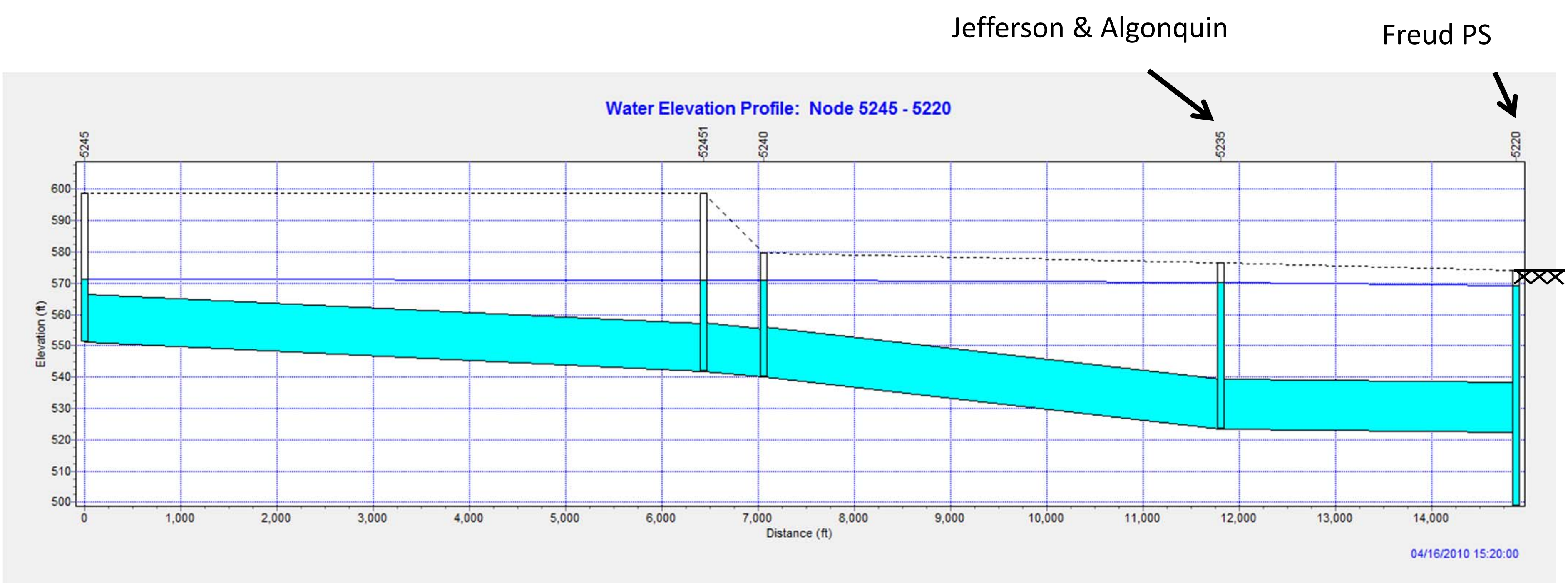
East Jefferson Relief Sewer

Scenario 2: DWSD Revised Wet Weather Operating Protocol

FIGURE 3-3

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



Ashland Relief Sewer

Scenario 2: DWSD Revised Wet Weather Operating Protocol

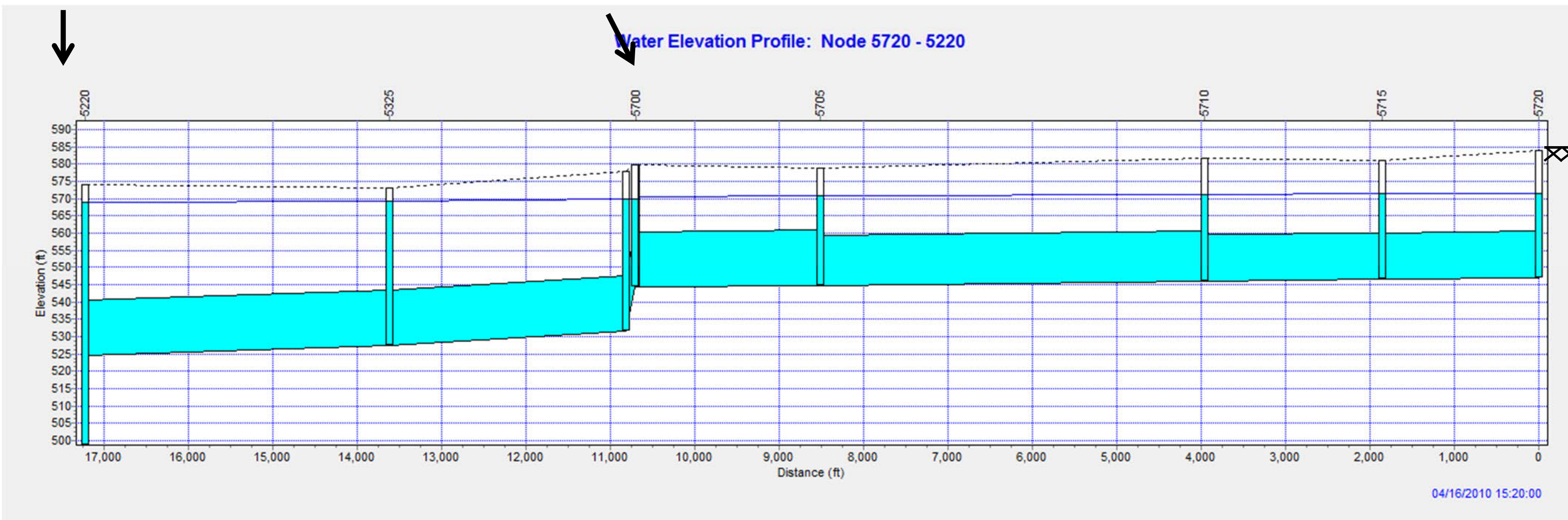
FIGURE 3-3

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)

Freud PS

Jefferson & Manistique



Fox Creek Relief Sewer

Scenario 2: DWSD Revised Wet Weather Operating Protocol

FIGURE 3-3

Description of Controls – Scenario 3

Fairview Pump Station:

- Dry weather operation of pumps is maintained throughout the wet weather event

Conner Creek Pump Station – Sanitary - Same as Scenario 1

Conner Creek Pump Station - Storm:

- Storm pumps are turned on when the level in the wet well reaches 71' AND only when the level in the discharge channel reaches 95' (in order to allow the vacuum priming system to prime the pumps).
- A maximum of 4 pumps are allowed to run at Connor Creek.

Freud Pump Station – Sanitary - Same as Scenario 1

Freud Pump Station – Storm - Same as Scenario 1

Forebay Regulator Gates and Conner Backwater Gates: Same as Scenario 1

CSO Basin Effluent Launder Gates:

- As the CSO Basin fills, the Effluent Launder Gates are opened and the overflow discharge starts to occur with the Effluent weir is set at 96'(lowered from 98' to 96') triggering the basin overflow at lower level.

CSO Basin Effluent Relief Gates:

- Effluent Relief Gates are opened when the level in the CSO Basin reaches 96.5' (0.5' above the effluent weir). ERGs are closed when CSO Basin level falls below 96'

Hydraulic Responses – Scenario 3

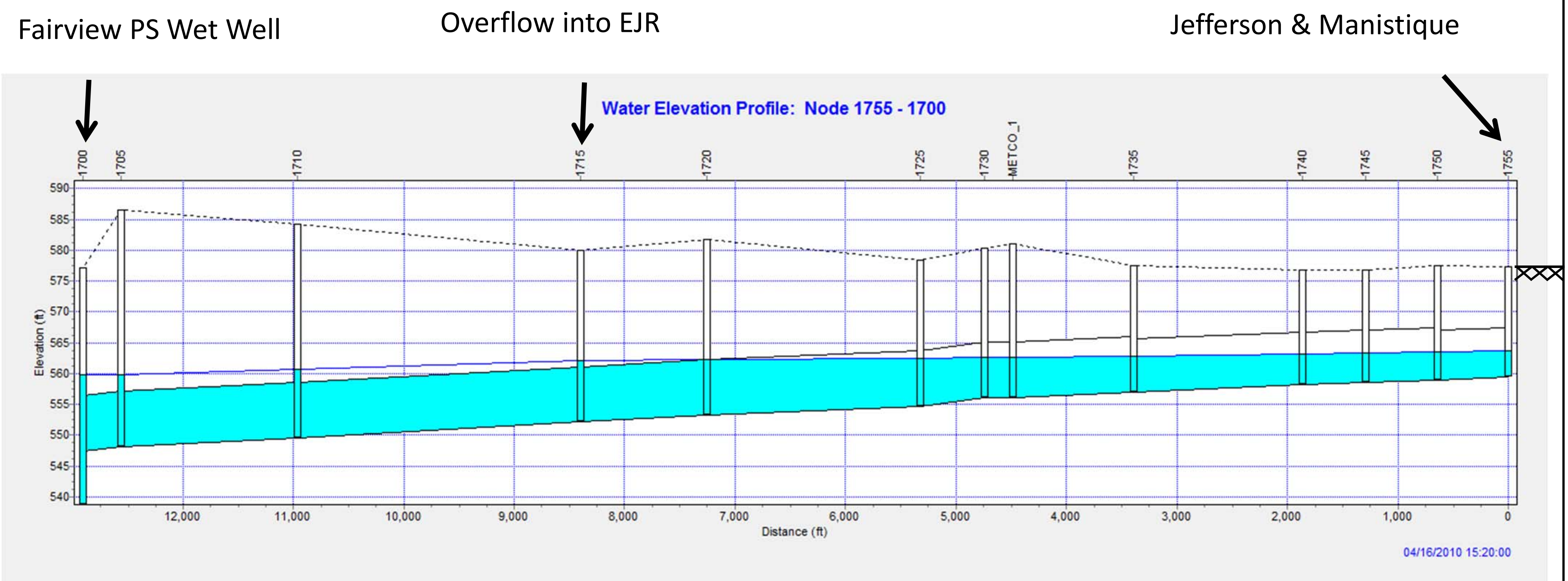
The hydraulic responses as represented by Hydraulic Gradient Line (HGL) at various sewers within system for the design storm condition is graphically illustrated in the attached Figures 3-4 in the following pages. The following the summary description of the hydraulic responses:

Detroit River Interceptor (DRI)	Peak HGL shows minimal surcharge in the DRI with level remaining greater than 13' below grade.
Conner Creek Sewer	Peak HGL shows surcharge in the sewer with levels about 8' below grade. Potential for basement flooding.
West Jefferson Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 16'-20' below grade.
East Jefferson Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 12'-19' below grade.
Ashland Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 5'-28' below grade. Potential for basement flooding, particularly along Kercheval and Algonquin (where the ground surface is at a lower elevation)
Fox Creek Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 8'-15' below grade. Potential for basement flooding, particularly along Manistique and Freud (where the ground surface is at a lower elevation)
Connor Creek/Forebay Discharge Triple Barrel"	Peak HGL shows levels above the top of the discharge triple barrel, which is about ground surface.
Freud Discharge Triple Barrel	Peak HGL shows levels above the top of the discharge triple barrel at ground level

Conner Creek CSO Basin	The level in the CSO Basin rises to just over 96.5' allowing discharge from the CSO Basin through the launder gates and effluent relief gates

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



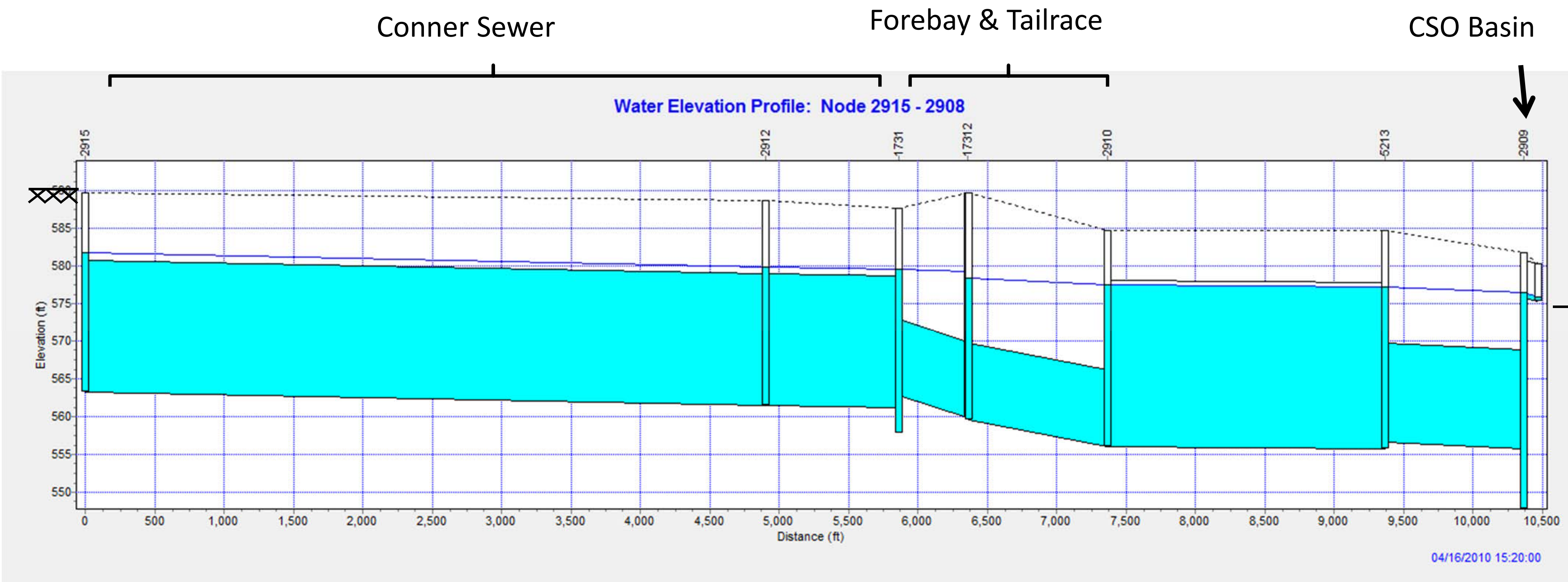
Detroit River Interceptor (DRI)

Scenario 3: METCO Recommended Wet Weather Protocol

FIGURE 3-4

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



Conner Sewer to CSO Basin Outfall

Scenario 3: METCO Recommended Wet Weather Protocol

METCO

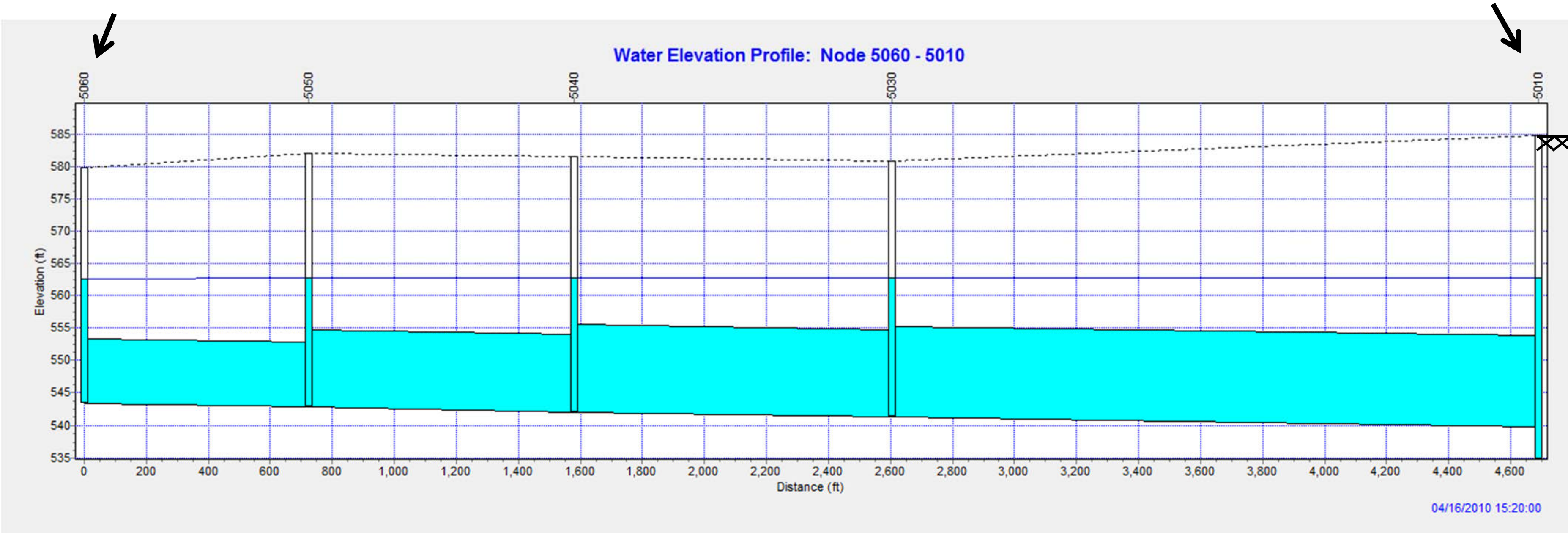
FIGURE 3-4

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)

Overflow from DRI

Connors Creek PS



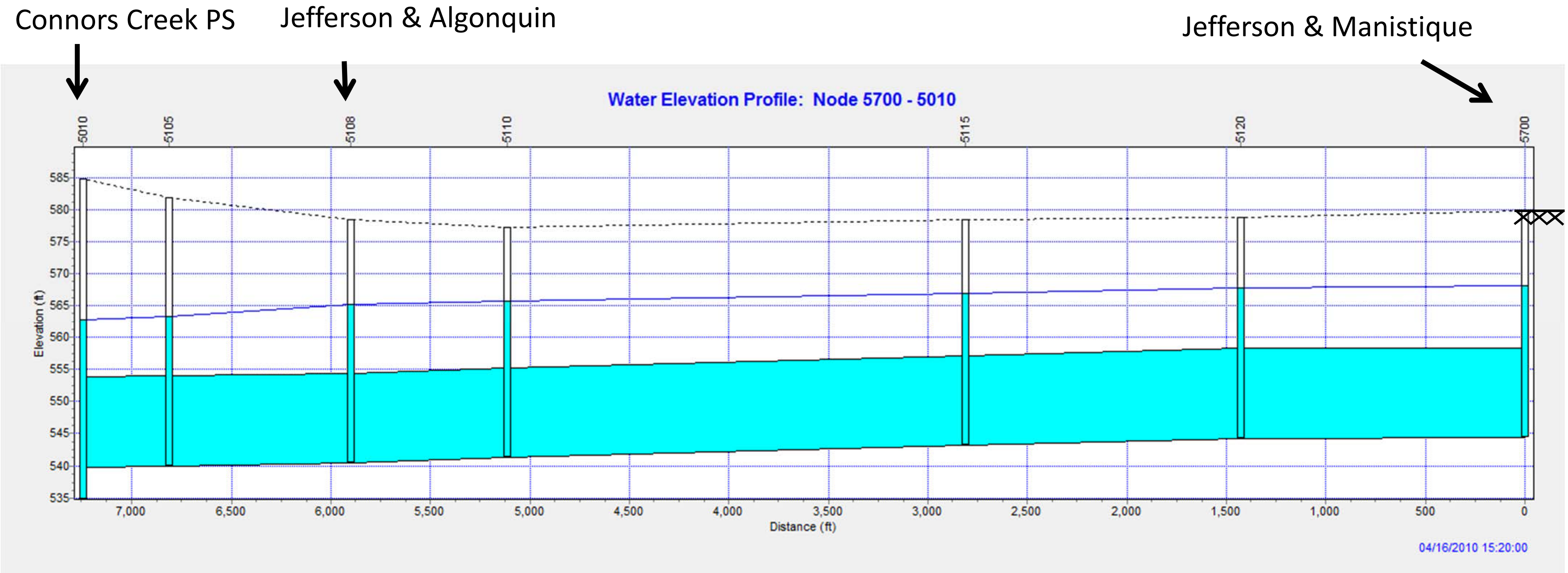
West Jefferson Relief Sewer

Scenario 3: METCO Recommended Wet Weather Protocol

FIGURE 3-4

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



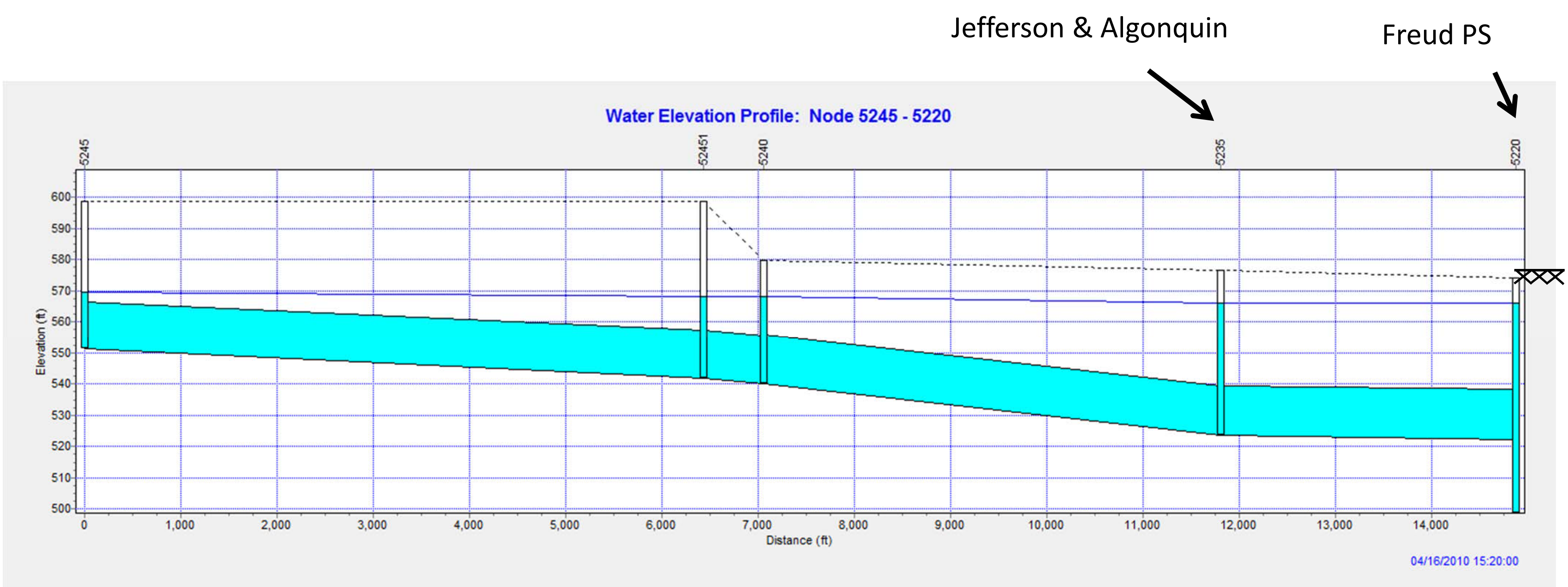
East Jefferson Relief Sewer

Scenario 3: METCO Recommended Wet Weather Protocol

FIGURE 3-4

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



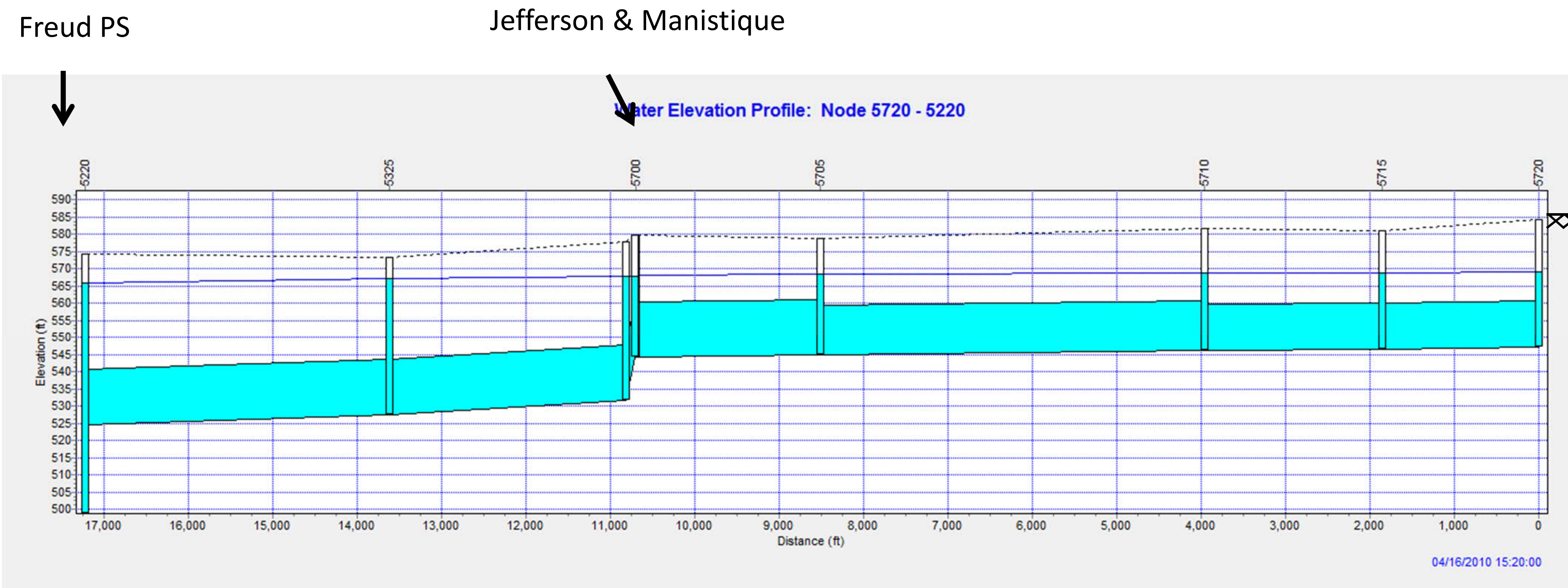
Ashland Relief Sewer

Scenario 3: METCO Recommended Wet Weather Protocol

FIGURE 3-4

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



Fox Creek Relief Sewer

Scenario 3: METCO Recommended Wet Weather Protocol

FIGURE 3-4

<u>Description of Controls – Scenario 3A</u>

Fairview Pump Station - Similar to Scenario 3

Conner Creek Pump Station – Sanitary - Similar to Scenario 1

Conner Creek Pump Station - Storm - Similar to Scenario 1

Freud Pump Station – Sanitary - Similar to Scenario 1

Freud Pump Station - Storm:

- Storm pumps are turned on when the level in the wet well reaches 68'.
- A maximum of 5 pumps are allowed to run at Freud PS.

Forebay Regulator Gates and Conner Backwater Gates - Similar to Scenario 1

CSO Basin Effluent Launder Gates - Similar to Scenario 3

CSO Basin Effluent Relief Gates - Similar to Scenario 1

Hydraulic Responses – Scenario 3A

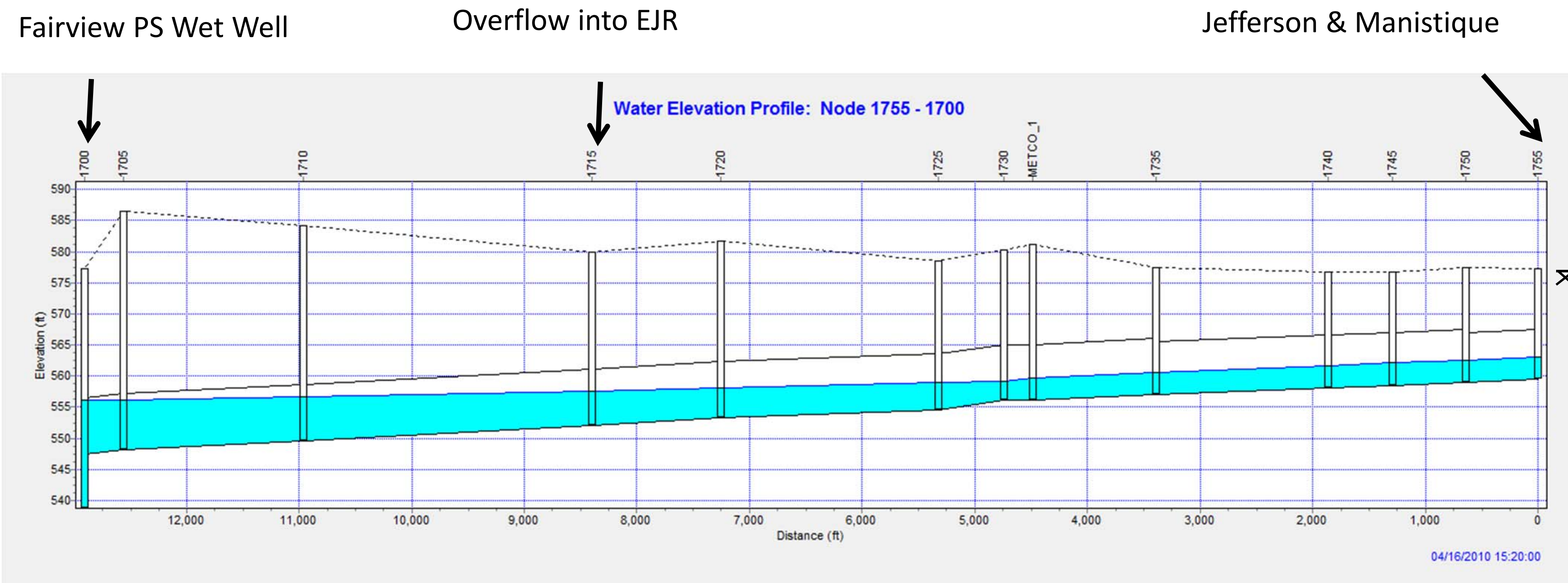
The hydraulic responses as represented by Hydraulic Gradient Line (HGL) at various sewers within system for the design storm condition is graphically illustrated in the attached Figures 3-5 in the following pages.

The following the summary description of the hydraulic responses:

Detroit River Interceptor (DRI)	Peak HGL shows minimal surcharge in the DRI with level remaining greater than 15' below grade.
Conner Creek Sewer	Peak HGL shows surcharge in the sewer with levels about 8' below grade. Potential for basement flooding.
West Jefferson Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 16'-20' below grade.
East Jefferson Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 13'-20' below grade.
Ashland Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 12'-33' below grade.
Fox Creek Relief Sewer	Peak HGL shows surcharge in the sewer with levels around 10'-17' below grade. Potential for basement flooding, particularly along Manistique and Freud (where the ground surface is at a lower elevation)
Connor Creek/Forebay Discharge Triple Barrel	Peak HGL shows levels above the top of the discharge triple barrel, which is about ground surface.
Freud Discharge Triple Barrel	Peak HGL shows levels above the top of the discharge triple barrel (about 3 feet below grade)
Conner Creek CSO Basin	The level in the CSO Basin rises to just over 96.5' allowing discharge from the CSO Basin through the launder gates and effluent relief gates

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



Detroit River Interceptor (DRI)

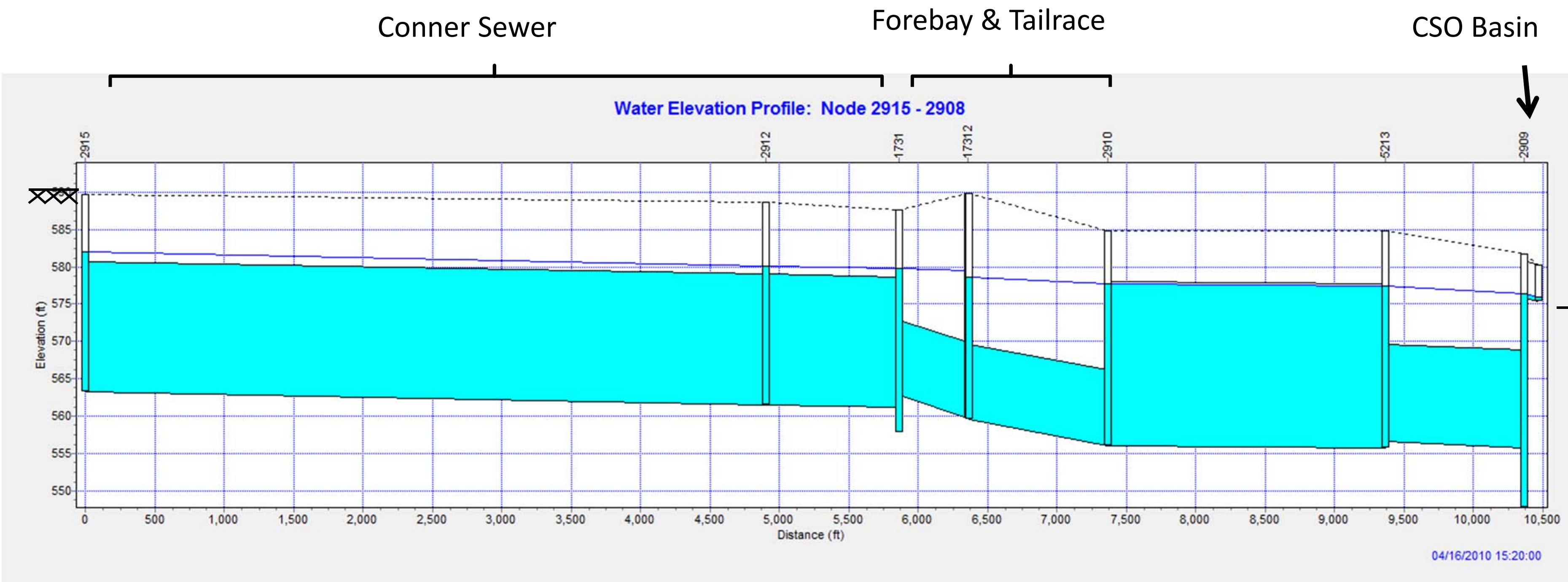
Scenario 3a: METCO Recommended Wet Weather Protocol
with 5 pumps running at Freud

METCO

FIGURE 3-5

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



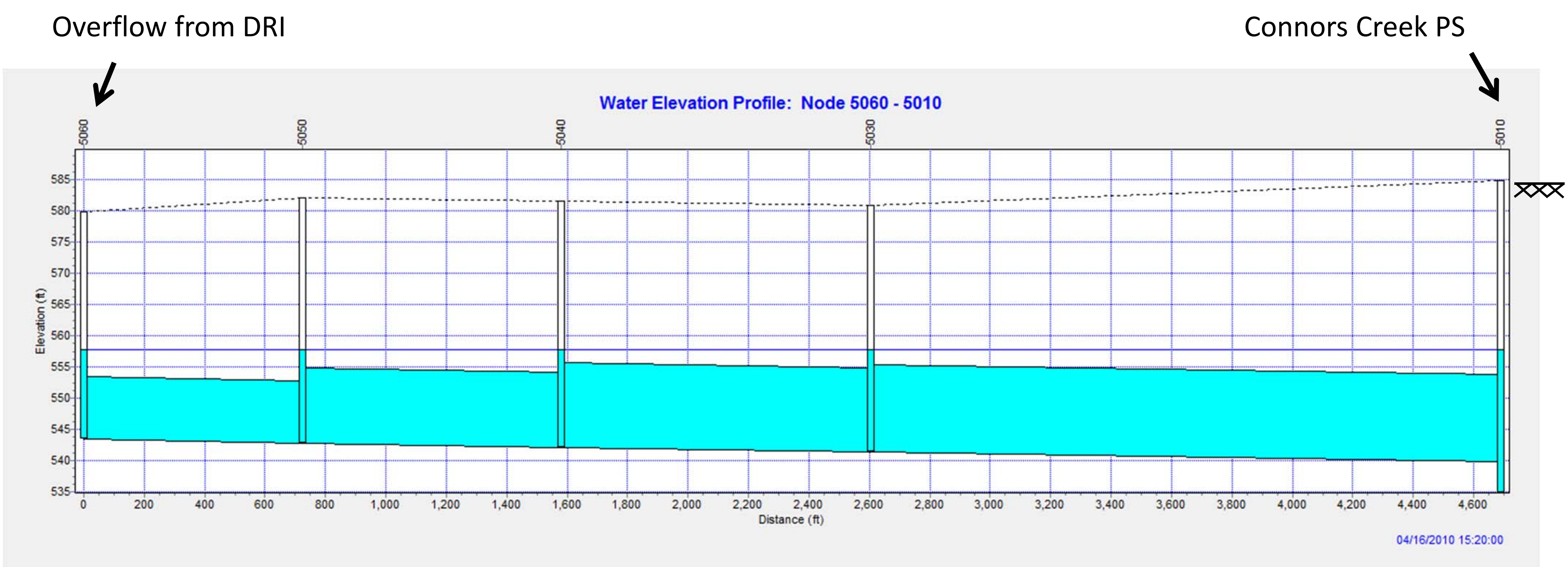
Conner Sewer to CSO Basin Outfall

Scenario 3a: METCO Recommended Wet Weather Protocol
with 5 pumps running at Freud

FIGURE 3-5

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



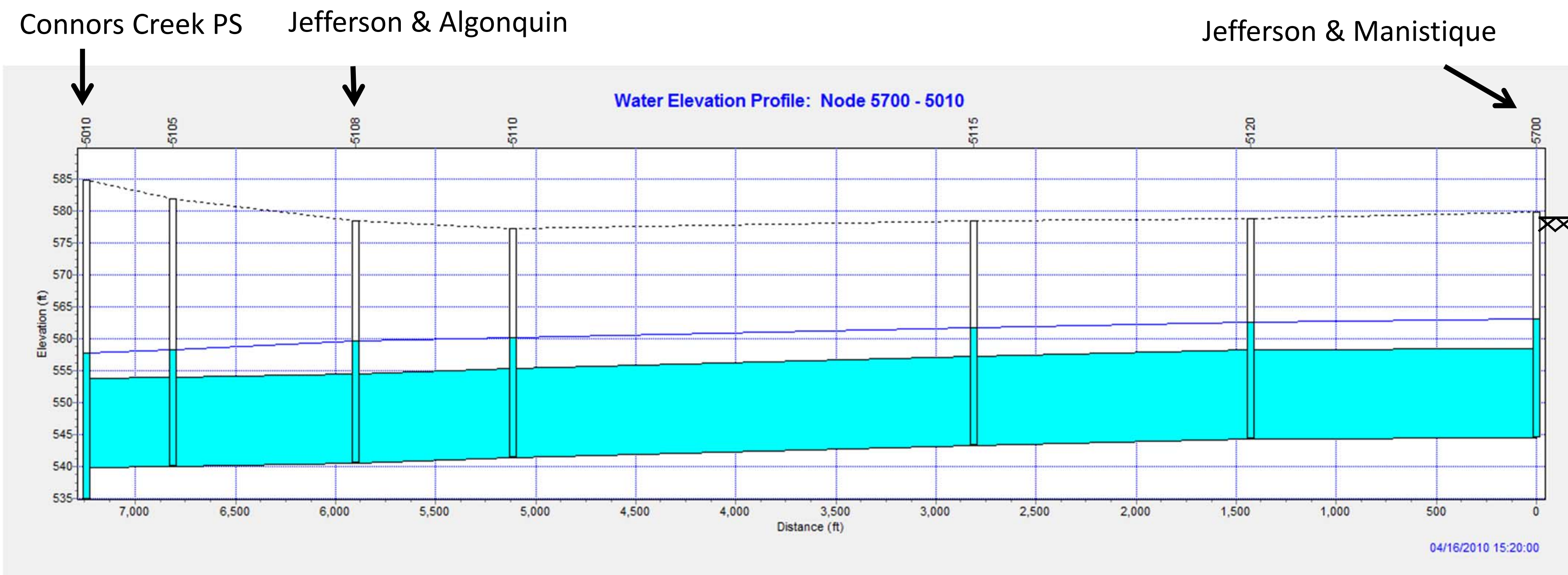
West Jefferson Relief Sewer

Scenario 3a: METCO Recommended Wet Weather Protocol
with 5 pumps running at Freud

FIGURE 3-5

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



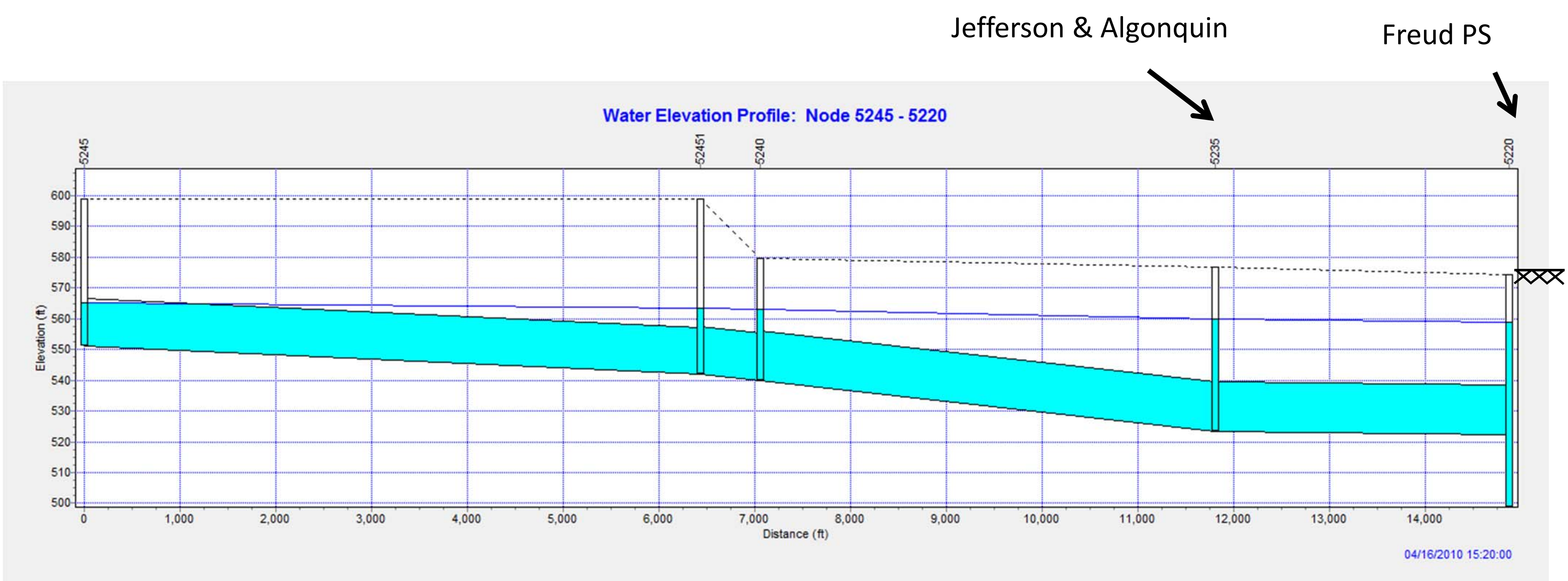
East Jefferson Relief Sewer

Scenario 3a: METCO Recommended Wet Weather Protocol
with 5 pumps running at Freud

FIGURE 3-5

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



Ashland Relief Sewer

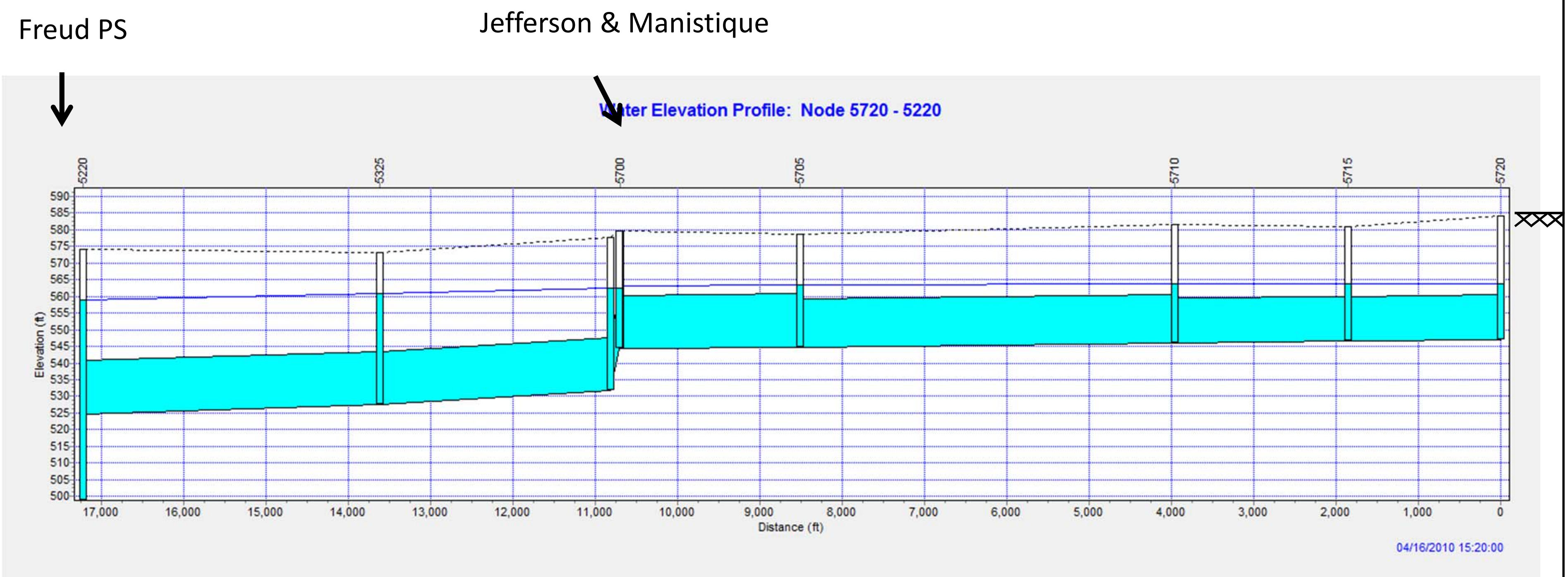
Scenario 3a: METCO Recommended Wet Weather Protocol
with 5 pumps running at Freud

METCO

FIGURE 3-5

Develop Operational Strategy for optimization of CSO Facilities

(10-year, 1-hour Storm Event)



Fox Creek Relief Sewer

Scenario 3a: METCO Recommended Wet Weather Protocol with 5 pumps running at Freud

METCO

FIGURE 3-5

The summary of the controls and the corresponding hydraulic responses for the above listed Operating Scenarios as derived the Hydraulic Model simulations are tabulated and presented in Figure 3-6 & 3-7.

Figure 3-6 - Model Scenarios and Controls Description

Facility	Installed Capacity	Current Dry Weather Protocol	Scenario 1: Current Wet Weather Operational Protocol	Scenario 2: DWSD Proposed Wet Weather Operational Protocol	Scenario 3: METCO Recommended Wet Weather Operational Protocol	Scenario 3a: METCO Recommended Wet Weather Operational Protocol w/ 5 pumps @ Freud
Fairview Pump Station	One (1) 75 cfs pump & three (3) 150 cfs pumps	Dry weather flows are pumped using a combination of the small pump and/or large pumps, maintaining a wet well level between 67' and 77'. No more than the small pump and two (2) large pumps should be operated at one time.	All Pumps are shut down when Wet Well level of PS-1 at WWTP reaches 85' (influent to WWTP exceeds 800 MGD); Pumps are restarted when influent to WWTP is sustained below 800 MGD	Same as Scenario 1	Dry weather operation of pumps is maintained througout the wet weather event	Same as Scenario 3
Connors Creek Pump Station - Sanitary	One (1) 40 cfs pump, one (1) 75 cfs pump, & two (2) 110 cfs pumps	Sanitary flows are pumped out of the sanitary wet well using a combination of the four pumps, maintaining a level between 59' and 65' in the wet well	Sanitary pumps are shut down when pumping has stopped at Fairview Pump Station.	Same as Scenario 1	Same as Scenario 1	Same as Scenario 1
Connors Creek Pump Station - Storm	Eight (8) 500 cfs pumps	Pumps are not operated during dry weather	Storm pumps are turned on when the level in the wet well reaches 71'. Additional pumps are turned on based the level in the wet well. Storm pumps are designed to maintain a wet well level between 66' and 75'. Note: Due to inability to prime, none of the storm water pumps could be put in service currently.	Storm pumps are turned on when the level in the wet well reaches 75'. Additional pumps are turned on based the level in the wet well. Note: Due to inability to prime none of the storm water pumps could be operated	Storm pumps are turned on when the level in the wet well reaches 71' AND only when the level in the discharge channel reaches 95' (in order to allow the vacuum priming system to prime the pumps). A maximum of 4 pumps are allowed to run at Connors Creek.	Same as Scenario 3
Freud Pump Station - Sanitary	One (1) 20 cfs pump & one (1) 35 cfs pump	Sanitary pumps are used to maintain a wet well level between 35' and 55', with the small pump operating between 35' and 45' in the wet well and the large pump oerating between 45' and 55' in the wet well	Sanitary pumps are shut down when pumping has stopped at Fairview Pump Station.	Same as Scenario 1	Same as Scenario 1	Same as Scenario 1
Freud Pump Station - Storm	Eight (8) 450 cfs pumps	Pumps are not operated during dry weather	Storm pumps are turned on when the level in the wet well reaches 68'. Additional pumps are turned on based the level in the wet well. Storm pumps are designed to maintain a wet well level between 55' and 75'. Note: Maximum three (3) storm pumps could be operated due to constricted discharge conduit leading to surcharge conditions.	Storm pumps are turned on when the level in the wet well reaches 72'. Additional pumps are turned on based the level in the wet well. Note: Maximum three (3) storm pumps could be operated due to constricted discharge conduit leading to surcharge conditions.	Same as Scenario 1	Storm pumps are turned on when the level in the wet well reaches 68' A maximum of 5 pumps are allowed to run at Freud PS. (Assumption: Improvements would be made to remove the existing constraint in the discharge conduit to allow for more than three pumps to operate without any surface surcharging)
Forebay Regulator Gates	Three (3) gates	Gates remain open at all times during dry weather	Forebay Regulator Gates are closed when pumping has stopped at Fairview Pump Station. The gates are re-opened when Fairview pumps resume and there is capacity in the DRI	Two criteria for the closing of the Forebay Regulator Gates: when the level in the Connors Creek wet well reaches 72' (likely to occur first), OR when the level in the CSO Basin reaches 96' (simultaneous wih Backwater Gates opening)	Same as Scenario 1	Same as Scenario 1
Conner Sewer Backwater Gates	Nine (9) gates	Gates remain closed at all times during dry weather	Resulting from the closure of the Regulator Gates, the level in the Forebay is allowed to rise. The gates are opened when the level in the Forebay reaches 95'. The gates are typically closed when the level in the Conner Creek CSO Basin falls to 87' during the dewatering process	Backwater gates are closed during dry weather and are opened when the level in the CSO Basin reaches 96' (also triggering the closure of the regulator gates)	Same as Scenario 1	Same as Scenario 1
Conner Creek CSO Basin Effluent Launder Gates	Sixteen (16) gates	Gates remain closed at all times during dry weather	As the CSO Basin fills in, the Effluent Launder Gates are opened and the overflow discharge starts to occur with discharge weir set 98' (level at basin reaches or exceeds the level at 98')	Same as Scenario 1	As the CSO Basin fills, the Effluent Launder Gates are opened and the overflow discharge starts to occur with the Effluent weir is set at 96'(lowered from 98' to 96') triggering the basin overflow at lower level.	Same as Scenario 3
Conner Creek CSO Basin Effluent Relief Gates	Sixteen (16) gates	Gates remain closed at all times during dry weather	Effluent Relief Gates are opened when the level in the CSO Basin reaches 98.5' (0.5' above the effluent weir). ERGs are closed when CSO Basin level falls below 98'	Effluent Relief Gates are opened when the level in the CSO Basin reaches 99' (1' above the effluent weir), and close when the level falls below 98'	Effluent Relief Gates are opened when the level in the CSO Basin reaches 96.5' (0.5' above the effluent weir). ERGs are closed when CSO Basin level falls below 96'	Same as Scenario 3

Figure 3-7 - Model Scenarios and Hydraulic Conditions

Sewer Component	Description	Dry Weather	Final Scenario 1: Existing Conditions with Current Wet Weather Operational Protocol	Final Scenario 2: Existing Conditions with DWSD Proposed Wet Weather Operational Protocol	Final Scenario 3: METCO Recommended Wet Weather Operational Protocol	Final Scenario 3a: METCO Recommended Wet Weather Operational Protocol w/ 5 Pumps @ Freud
Detroit River Interceptor (DRI)	8'-9' sewer running along Jefferson down to Fairview PS - primarily carries sanitary flow	HGLs remain within the pipe throughout the whole stretch to Fairview PS	Peak HGLs show significant surcharge in the DRI leading to levels about 4'-15' below grade. Potential for basement flooding.	Peak HGLs show significant surcharge in the DRI leading to levels less than 6'-15' below grade. Potential for basement flooding.	Peak HGL shows minimal surcharge in the DRI with level remaining greater than 13' below grade.	Peak HGL shows minimal surcharge in the DRI with level remaining greater than 15' below grade.
Conner Creek Sewer	Double (2) 12' x 17.5' barrel sewer from the north along Conner to the Forebay - carries little sanitary flow (gets diverted to the DRI at the Forebay) but significant storm flow	HGLs remain well within the double barrel, with depths consistantly around 1'	Peak HGL shows surchage in the sewer with levels about 6' below grade. Potential for basement flooding.	Peak HGL shows surchage in the sewer with levels about 1'-2' below grade. Potential for street and basement flooding	Peak HGL shows surchage in the sewer with levels about 8' below grade. Potential for basement flooding.	Peak HGL shows surchage in the sewer with levels about 8' below grade. Potential for basement flooding.
West Jefferson Relief Sewer	10'-14' sewer running along Jefferson from the west to Connors Creek PS wet well - some sanitary flow but primarily for storm water	HGLs remain well within the sewer, with depths ranging between 1' and 5'	Peak HGL shows surcharge in the sewer with levels around 7'-13' below grade. Potential for basement flooding, particularly at the upstream end (where the ground surface is at a lower elevation)	Peak HGL shows surcharge in the sewer with levels around 9'-14' below grade. Potential for basement flooding, particularly at the upstream end (where the ground surface is at a lower elevation)	Peak HGL shows surcharge in the sewer with levels around 16'-20' below grade.	Peak HGL shows surcharge in the sewer with levels around 16'-20' below grade.
East Jefferson Relief Sewer	14' sewer running along Jefferson from the east to Connors Creek PS wet well - some sanitary flow but primarily for storm water	HGLs remain well within the sewer, with depths ranging between 2' and 5'	Peak HGL shows surcharge in the sewer with levels around 5'-12' below grade. Potential for basement flooding, particularly past 1/4 mile upstream of Connors Creek PS (where the ground surface is at a lower elevation)	Peak HGL shows surcharge in the sewer with levels around 6'-13' below grade. Potential for basement flooding, particularly past 1/4 mile upstream of Connors Creek PS (where the ground surface is at a lower elevation)	Peak HGL shows surcharge in the sewer with levels around 12'-19' below grade.	Peak HGL shows surcharge in the sewer with levels around 13'-20' below grade.
Ashland Relief Sewer	15.5'-16' sewer from the north along Kercheval, Algonquin, and Frued to Freud PS wet well - some sanitary flow but primarily for storm water	HGLs remain well within the sewer, with depths ranging between 1' and 5'	Peak HGL shows surcharge in the sewer with levels around 2'-25' below grade. Potential for basement flooding, particularily along Kerchecal and Algonquin (where the ground surface is at a lower elevation)	Peak HGL shows surcharge in the sewer with levels around 3'-26' below grade. Potential for basement flooding, particularily along Kerchecal and Algonquin (where the ground surface is at a lower elevation)	Peak HGL shows surcharge in the sewer with levels around 5'-28' below grade. Potential for basement flooding, particularily along Kerchecal and Algonquin (where the ground surface is at a lower elevation)	Peak HGL shows surcharge in the sewer with levels around 12'-33' below grade.
Fox Creek Relief Sewer	14.5'-16' sewer running from the northeast along Kercheval, Manistique, and Frued to Freud PS wet well - weir at Manistique and Jefferson diverts sanitary flow to East Jefferson Relief, storm flow reaches Frued during wet weather	HGLs remain well within the sewer to Jefferson, with depth ranging between 2' and 4'. No water in the sewer from Jefferson to Freud PS	Peak HGL shows surcharge in the sewer with levels around 3'-10' below grade. Potential for basement flooding, particularily along Manistique and Freud (where the ground surface is at a lower elevation)	Peak HGL shows surcharge in the sewer with levels around 4'-11' below grade. Potential for basement flooding, particularily along Manistique and Freud (where the ground surface is at a lower elevation)	Peak HGL shows surcharge in the sewer with levels around 8'-15' below grade. Potential for basement flooding, particularily along Manistique and Freud (where the ground surface is at a lower elevation)	Peak HGL shows surcharge in the sewer with levels around 10'-17' below grade. Potential for basement flooding, particularily along Manistique and Freud (where the ground surface is at a lower elevation)
Connors Creek/Forebay Discharge Triple Barrel	Triple (3) 18.5' x 21.75' barrel carrying storm flow from Connors Creek storm pumps and Forebay towards the CSO Basin	No water in the discharge channels during dry weather	Peak HGL shows levels near the top of the discharge triple barrel, which is about ground surface.	Peak HGL shows levels above the top of the discharge triple barrel, which is about ground surface.	Peak HGL shows levels above the top of the discharge triple barrel, which is about ground surface.	Peak HGL shows levels above the top of the discharge triple barrel, which is about ground surface.
Frued Discharge Triple Barrel	Triple (3) 14' x 14' barrel carrying storm from from Freud PS storm pumps towards the CSO Basin	No water in the discharge channels during dry weather	Peak HGL shows levels above the top of the discharge triple barrel (about 3 feet below grade)	Peak HGL shows levels above the top of the discharge triple barrel (about 3 feet below grade) Note: this peak occurs much later than in the other scenarios	Peak HGL shows levels above the top of the discharge triple barrel at ground level	Peak HGL shows levels above the top of the discharge triple barrel (about 3 feet below grade)
Conner Creek CSO Basin	30 million gallon storage capacity with discharge 16 discharge launders/weirs set to discharge at 98' (with relief gates that open at 98.5'). Dewatering system drains the basin to the DRI.	No water in the CSO Basin during dry weather	The level in the CSO Basin rises to just over 98.5' allowing discharge from the CSO Basin through the launder gates and effluent relief gates	The level in the CSO Basin rises to just over 98.5' allowing discharge from the CSO Basin through the launder gates and effluent relief gates	The level in the CSO Basin rises to just over 96.5' allowing discharge from the CSO Basin through the launder gates and effluent relief gates	The level in the CSO Basin rises to just over 96.5' allowing discharge from the CSO Basin through the launder gates and effluent relief gates

7.0 RECOMMENDED WET WEATHER OPERATIONAL PROTOCOL – (SCENARIO 3)

Based upon evaluation of various operating scenarios and corresponding hydraulic responses, the following is recommended wet weather operational protocol as described under Scenario #3:

SYSTEM FACILITIES	RECOMMENDATIONS
Fairview Pump Station	Maintain at dry weather pump level
Freud Pump Station	No change to pump operations
Connor Creek Storm pumps	Operation begin when the level in discharge channel reaches 95’
Forebay Regulator Gates	Close when DRI level reaches 0.8D
Conner Sewer Backwater Gates	No change in operation (open at 95’ in the Forebay OR when regulator gates close)
CSO Basin Effluent Launder Weir	Lower weir level to 96’ (was 98’) – river elevation analysis
CSO Basin ERGs	Open at 96.5’ (was 98.5’); still 0.5’ above effluent weirs

By implementing the above operating protocol, the following potential benefits are anticipated and listed below:

RECOMMENDATIONS	POTENTIAL BENEFITS
Lower the level of the Conner Creek CSO Basin discharge weir	Lowering the discharge level will lower the HGL in the Conner Sewer and allow more discharge out of the CSO Basin (as one of the two ways to relieve the system in the area; it is important

RECOMMENDATIONS	POTENTIAL BENEFITS
	to be able to allow the most amount of water to leave the system).
Keep Fairview Pump Station running at dry weather level during wet weather events	As the second of two ways to relieve the system, allowing Fairview to maintain operation (at dry weather flows) will provide some relief to the DRI and allow for the storm water stored in the CSO Basin/Conner Sewer to be effectively dewatered as quick as possible.
Allowing the level in the Connor Creek Discharge Channel to reach 95' before staring the Storm pumps	By allowing the level in the discharge channel to rise, the siphon blocks at Connor Creek will be submerged enough to allow the vacuum priming system to prime the pumps effectively to allow relief of Connor Creek Wet Well, and the East & West Jefferson Relief Sewers.

In order to realize the full benefits of the above recommendations, the following improvements are required to be implemented at different pump stations as below:

Connor Creek Pump Station	
Install minimum two (2) new vertical wet pit storm pumps (refer to Tech Memo #1 for details)	Vertical wet pit pumps will bypass the need for vacuum priming system, thus allowing those pumps to start without having to wait for the discharge level to reach the required height for the vacuum priming system
Freud Pump Station	
Modify the existing triple barrel discharge channel to remove the existing constraint and increase transport capacity	This will allow for more pumps to be run at Freud and will help relieve the sewers upstream of Freud and bring down the HGL

TECHNICAL MEMORANDUM NO.4

PUMP STATION CAPACITY ANALYSIS

1.0 INTRODUCTION

During the recent heavy storm event in August, 11 of 2014, DWSD had experienced problems in putting the storm water pumps at Connors Creek Pump Station in service due to malfunctioning of the associated Vacuum Priming System. The outage of all pumps had resulted in a severe surcharge conditions in upstream sewers as well in the related service areas. To mitigate this situation, DWSD has initiated immediate efforts to identify the cause and implement appropriate corrective measures so as to restore the desired level of reliability to the operation of storm water pumps at Connors Creek Pump Station.

To address the issue and also to optimize the utilization of the storm water pumping stations and the CSO basin, DWSD had contracted the services of METCO Services, Inc. (METCO) by Task order No. 36 under Contract CS-1499. One of the work elements under the scope of the task order relates to perform Hydraulic Analysis of the System to determine the following:

- Develop an Operational Strategy to optimize the utilization of Connor Creek CSO basin and associated Connor Creek and Freud Pump Stations.

- To determine the optimal capacity of Fairview, Freud and Connor Creek Pump Stations that would be required under the revised Operating Protocol of the Connor Creek CSO System

Consistent with these imperatives, METCO had initiated the efforts by performing necessary hydraulic model simulations and subsequent analysis to determine the system hydraulic response under different operating scenarios.

This Technical memorandum presents our evaluation and recommendations for optimum pumping capacity required at each of the following three (3) pump stations:

- Freud Pump Station
- Connor Pump Station
- Fairview Pump Station

It should be noted that some of the recommendations presented in this tech memo were developed in conjunction with other recommended improvements listed in Technical Memorandum No. 1 thru 3.

2.0 OBJECTIVES

The primary objective of the task is to identify the optimum pumping capacity at each facility that would provide required level of reliability with N+1 redundancy level.

3.0 METHODOLOGY

Our evaluation of the required level of pump station capacity was done by simulation of the hydraulic model applying the controls defined under recommended wet weather operating protocol (refer Tech Memo No. 3).

In our hydraulic analysis, we have considered the influence of the pumping rate on the peak inflow to each pump station. Accordingly the hydrographs of the inflow to the wet well of each pump station was derived from hydraulic model simulation

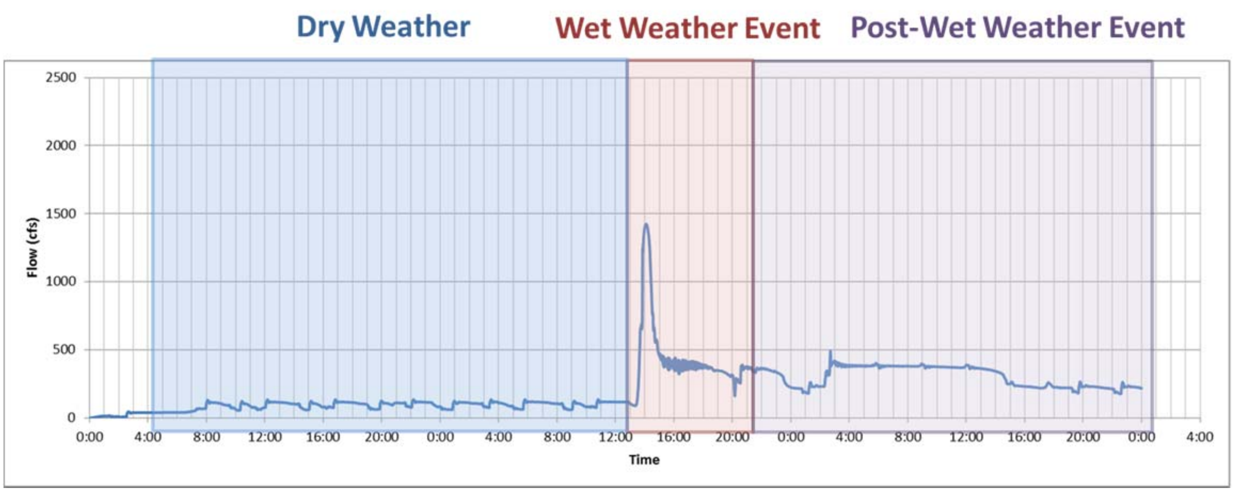
4.0 EXISTING STORM WATER PUMPING CAPACITY

FACILITY	INSTALLED CAPACITY	FIRM CAPACITY
Freud Pump Station	3,600 cfs (8x450 cfs)	3,150 cfs
Connor Creek Pump Station	4,000 cfs (8x500 cfs)	3,500 cfs
Fairview Pump Station	525 cfs (1x75 cfs + 3x150 cfs)	375 cfs

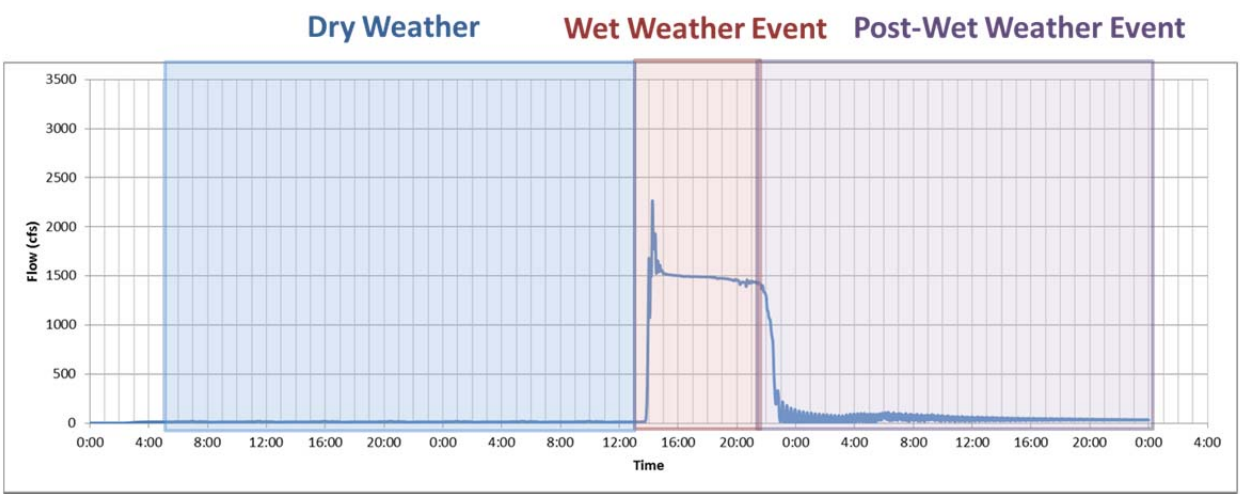
5.0 EVALUATION

This section includes determination of peak inflow to each pump station under the design storm event (10 year-1 hour storm) and corresponding hydrographs representing the inflow during dry weather and the design storm event as derived from the hydraulic model simulation runs.

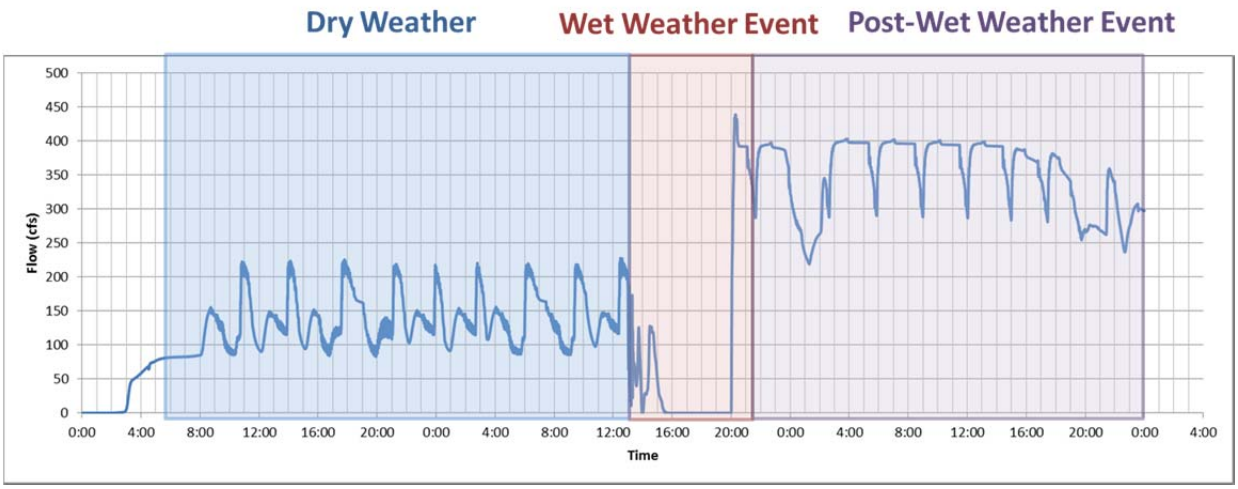
D. <u>Connor Creek Pump Station Wet Wells Inflows</u>



E. <u>Freud Pump Station Wet Wells Inflows</u>



F. ***Fairview Pump Station Wet Wells Inflows***



6.0 CONCLUSION AND RECOMMENDATIONS

Based on our hydraulic analysis, we have identified the peak inflow to the wet well and associated firm pumping capacity at each pump station such that hydraulic gradient at the upstream sewers will be minimum 10 feet below the grade level elevation. Applying this criteria, the recommended installed and firm capacity at each pump station is listed below:

FACILITY	PEAK FLOW	INSTALLED CAPACITY	FIRM CAPACITY
Freud Pump Station	2,200 cfs	2,700 cfs (6x450 cfs)	2,250 cfs
Connor Creek Pump Station	2,000 cfs	2,500 cfs (5x500 cfs)	2,000 cfs
Fairview Pump Station	*225 cfs	525 cfs (1x75 cfs + 3x150 cfs)	375 cfs

Based on current operating protocol – pump station not operational during storm event

It should be noted that our recommendation assumes that the proposed improvements are implemented to make Connor Creek Pump Station fully operational and also to eliminate the constraints at the discharge conduit of Freud Pump Station as recommended in our Technical Memorandum No. 1 and 3.

A8 – Freud and Connors Creek PS Improvements Study and Design

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Technical Memorandum

Prepared for: Great Lakes Water Authority

Project No.: GLWA-CS-120

Project Title: Freud and Conner Creek Pump Station Improvements Study and Design

Technical Memorandum No. 1

Subject: Existing Pumping Hydraulics and Operations Assessment

Date: October 17, 2017

To: Mini Panicker, P.E.; GLWA Project Manager

From: Jeff Swartz, P.E.; Arcadis
Richard Vendlinski, P.E.; Brown and Caldwell
Donnie Stallman, P.E.: Brown and Caldwell

Review by: David Nitz, P.E.; Brown and Caldwell

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List of Abbreviations

ANSI	American National Standards Institute
BC	Brown and Caldwell
BEP	Best Efficiency Point
BGD	Billion Gallons per Day
CSO	Combined Sewer Overflow
CCCSO	Conner Creek Combined Sewer Overflow Facility
CCPS	Conner Creek Pumping Station
DWWTP	Detroit Wastewater Treatment Plant
EL	Elevation
FPS	Freud Pumping Station
FSPS	Fairview Sewage Pumping Station
GLWA	Great Lakes Water Authority
HI	Hydraulic Institute
HMI	Human-Machine Interface
HP	Horsepower
MGD	Million Gallons per Day
NPSH	Net Positive Suction Head
POR	Preferred Operating Range
PS-1	Pump Station No. 1
RTB	Retention Treatment Basin
TM1	Technical Memorandum No. 1

Executive Summary

Technical Memorandum 1 (TM1) provides a review of the existing pumping systems at the Freud Pump Station (FPS) and the Conner Creek Pump Station (CCPS), as well as an assessment of operational procedures and pump performance characteristics. It also provides an overview of the connectivity between the FPS, CCPS, the Conner Creek Combined Sewer Overflow (CCCSO) Facility, and the Fairview Sewage Pumping Station (FSPS). The material presented in TM1 will be used to inform modeling efforts and alternatives analysis related to *GLWA-CS-120: Freud and Conner Creek Pump Station Improvements Study and Design.*

The major findings from this evaluation are presented in the list below.

1. Freud Dewatering Pump Station
   a. Pumps are not being operated to the control elevations defined in the O&M manual.
   b. No ability to isolate the wet well.
   c. Pumps are not equipped with discharge isolation valves or check valves.
   d. Pumps can discharge to E. Jefferson Relief Sewer or the storm discharge channel depending on whether valves at the discharge chamber are open or closed.
   e. HMI screen only shows discharge to storm channel (missing discharge to E. Jefferson Relief Sewer).
   f. Pump Nos. 9 and 10 are sometimes run at the same time, risking surcharge of receiving sewer.
   g. Pump Nos. 9 and 10 are operated outside of their preferred operating range (POR). This will significantly reduce the reliability and life span of pumping equipment.
   h. The wet well is not routinely drawn down below 48' EL.
2. Freud Storm Pump Station
   a. No ability to isolate the wet well.
   b. Pumps are not equipped with suction/discharge isolation valves which would promote safe maintenance.
   c. Pump start elevations in O&M manual differ from start elevations in Wet Weather Operating Plan.
   d. Pumps are not being operated at the control elevations defined in the O&M manual.
   e. Pump Nos. 5 and 7 appear to have been out of service in 2015 and 2016.
   f. Pumps operate to the right of the best efficiency point (BEP) and often outside of their POR.
   g. Pumps operate over a wide range of wet well levels, resulting in large flow variations even when the number of pumps on is constant. One possible outcome of this is the appearance of an overall flow reduction/restriction as the wet well level decreases the number of pumps.
   h. Further investigation of possible air binding and or grit build-up in the discharge channel should be performed.
3. Conner Sanitary Pump Station
   a. Sanitary wet well level data is offset from storm wet well level data at times when the two are hydraulically connected, possibly indicating an improperly calibrated level sensor.
   b. Pumps are not being operated to the control elevations defined in the O&M manual.
   c. Pumps run outside of their POR when wet well levels are high.
   d. NPSH margin is near the minimum recommended by the HI for pumps 9 and 11 at lower wet well levels.
   e. Suction intake conditions are known to be poor based on previous studies. These studies did not account for basket strainers nor the use of the third wet well inlet (from the storm wet well). It is anticipated that the basket strainers will negatively impact pump operation.
4. Conner Storm Pump Station
   a. There is no run time or discharge elevation data for the storm pumps between January 2015 and May 2016.

b. Pumps are not equipped with isolation valves or check valves.
c. HMI screen shows all eight (8) pumps as “NOT READY”.
d. An operator must be on site to monitor the vacuum priming system when storm pumps are started.
e. The wet well control levels outlined in the O&M manual indicate that the pumps operate within their POR.
f. Pumps operate over a wide range of wet well levels, resulting in large flow variations even when the number of pumps running is constant.
g. A connection between the Conner Discharge Channel and the Conner Gravity Sewer is currently left open to assist with keeping the Conner Storm Pump Siphon outlet submerged. It is presumed that this gate is closed once the either the Freud Storm or Conner Storm pumps are put into operation.

Section 1: Introduction

1.1 Purpose

Technical Memorandum 1 (TM1) provides review of the existing pumping systems at the Freud Pump Station (FPS) and the Conner Creek Pump Station (CCPS), as well as an assessment of operational procedures and pump performance characteristics. It also provides an overview of the connectivity between the FPS, CCPS, the Conner Creek Combined Sewer Overflow (CCCSO) Facility, and the Fairview Sewage Pumping Station (FSPS). The material presented in TM1 will be used to inform modeling efforts and alternatives analysis related to *GLWA-CS-120: Freud and Conner Creek Pump Station Improvements Study and Design.*

1.2 Background

The Freud and Conner Creek pumping systems are key components in relaying wastewater and stormwater generated in the eastern portion of Detroit to the Fairview Sewage Pump Station (FSPS), and ultimately, to the Detroit Wastewater Treatment Plant (DWWTP). The operation of these facilities is critical to prevent flooding of stakeholders' premises but they also protect the water quality in the Detroit River and ultimately the drinking water supply for Detroit. The conveyance system is very complex involving at least eight interceptors/sewers, multiple regulating structures, three large pump stations, and a CSO treatment system. The conveyance system has grown and been modified numerous times over the past 100-years with the last major improvement being the construction of the Conner Creek CSO Basin and Treatment system which was placed into operation in 2005. A schematic of this area of the collection system is presented in Figure 1-1.

The CCPS was originally constructed in 1928 to handle the flows from the East and West Jefferson Relief Sewers. It consists of two distinct components, the sanitary pump station and the stormwater pump station, along with the ancillary support appurtenances (emergency generators, switch house and backwater gates). The stormwater pumping station has a firm capacity of 2.2 billion gallons per day (bgd), and the sanitary pump station has a firm capacity of 147 million gallons per day (mgd).

The FPS was constructed in 1954 primarily to handle the overflows from the CCPS. When the capacity of the CCPS is exceeded, the East Jefferson Relief Sewer overflows to the Fox Creek and Ashland Relief Sewers. The original concept was for the FPS and the Fox Creek and Ashland Relief Sewers to store approximately 20 million gallons for return to the CCPS through the East Jefferson Relief sewer when the CCPS could handle the flow. The operational concept for Freud was changed when the CCCSO Facility was placed into operation. The change was made so that the Freud stormwater pumps would fill up the Conner outfall, thereby facilitating the priming of the Conner stormwater pumps. FPS also has two smaller pumps that pull from the same wet well as the storm pumps. These were originally intended as dewatering pumps, but now also handle dry weather sanitary flows. The FPS storm pumps have a firm capacity of 2.0 (bgd), and the sanitary pumps have a firm capacity of 13 mgd.

GLWA-CS-120 is meant to study the overall performance of both the pumping stations and develop and design an operation strategy to optimize the utilization of interconnected piping and operation between these two pumping stations and the Conner Creek Retention and Treatment Basin (also referred to as the CCCSO).

Figure 1-1. Collections System Schematic

Section 2: Overall Conner Basin Operations

2.1 System Overview

The interconnected nature of the collection system in the vicinity of the FPS and CCPS is illustrated in Figure 1-1 at the beginning of this TM. Figures 2-1A and 2-1B provide a profile view of the interconnected facilities in this part of the collections system and call out important elevations. Attachment A provides collection system reference drawings from GLWA that were used to develop this figure. Note that all elevations presented in this TM are based on the City of Detroit Datum

In dry weather the FPS receives flows from the Ashland and Mack Avenue Relief Sewers, and pumps to the E. Jefferson Relief Sewer, which then flows to the CCPS. The CCPS sanitary pump station receives flow from both the E. and W. Jefferson Relief Sewers and pumps to the Detroit River Interceptor (DRI). Flows from the Connors Creek Sewer enter the Forebay structure (located between FPS and CCPS, see Figure 1-1 for location) and are diverted into the DRI through the dry weather diversion gates. During dry weather the FPS and CCPS storm pumps are off, and the CCCSO does not receive any flow from the upstream collection system.

During wet weather events the FPS, CCPS, CCCSO, and Fairview Sewage Pumping Station (FSPS) must work in tandem according the _Wet Weather Operating Plan January 2015 Update_ to manage the increase in flow.

The following excerpts from the _Wet Weather Operating Plan January 2015 Update_ are relevant to the facilities illustrated in Figures 2-1A and 2-1B.

Fairview Pumping Station

> *Reduce or stop pumping when total influent DWWTP flows reach and exceed 800 mgd. If Fairview PS wet well levels are able to receive flow, sanitary flow from Conner Pumping station will continue until full capacity in Fairview wet well is reached (this maximizes in-system storage tributary to Fairview PS).*

Conner Sanitary and Wet Weather Pump Station; including some protocols for VR- 2, also known as "Forebay Regulator Gates"

a. *After Fairview pumps are stopped, reduce or stop all Conner PS sanitary pumps depending on available capacity at Fairview PS.*

b. *Sequentially close each of the three VR-2 (Forebay) dry weather diversion gates (1 at a time) when Conner PS wet well reaches El 72.0 feet to divert flow in Conner Gravity Sewer to the Conner Creek RTB (see other conditions that apply for these gates under 9, below).*

c. *When flow in the station's main wet well reaches El 75.0 feet, start storm pumps for discharge to Conner Creek RTB.*

Freud Pumping Station

a. *After Fairview pumps are stopped, reduce or stop all Freud sanitary pumps.*

b. *When the level in the station's wet well reaches El 72.0 feet, start storm pumps for discharge to Conner Creek RTB.*

Conner Creek RTB, Outfall 104; including some protocols for VR-2

a. *When level in the basin reaches El 96.0 ft, open each of the nine of the Conner Sewer Gates (3 at a time) and simultaneously close each of the three VR-2 (Forebay) gates, 1 at a time (see other conditions that apply for these gates under 7, above).*

b. *When level in the basin reaches El 99.0 ft, begin opening of the Relief Gates.*

Note that according to the O&M manual, Freud storm Pump Nos. 1-4 are all scheduled to start below 72' EL., which is contradictory to the *Wet Weather Operating Plan January 2015 Update* shown above. During plant walkthroughs and interviews, GLWA staff have indicated that their intent is to start both Conner and Freud storm pump stations at EL 68.0 ft.

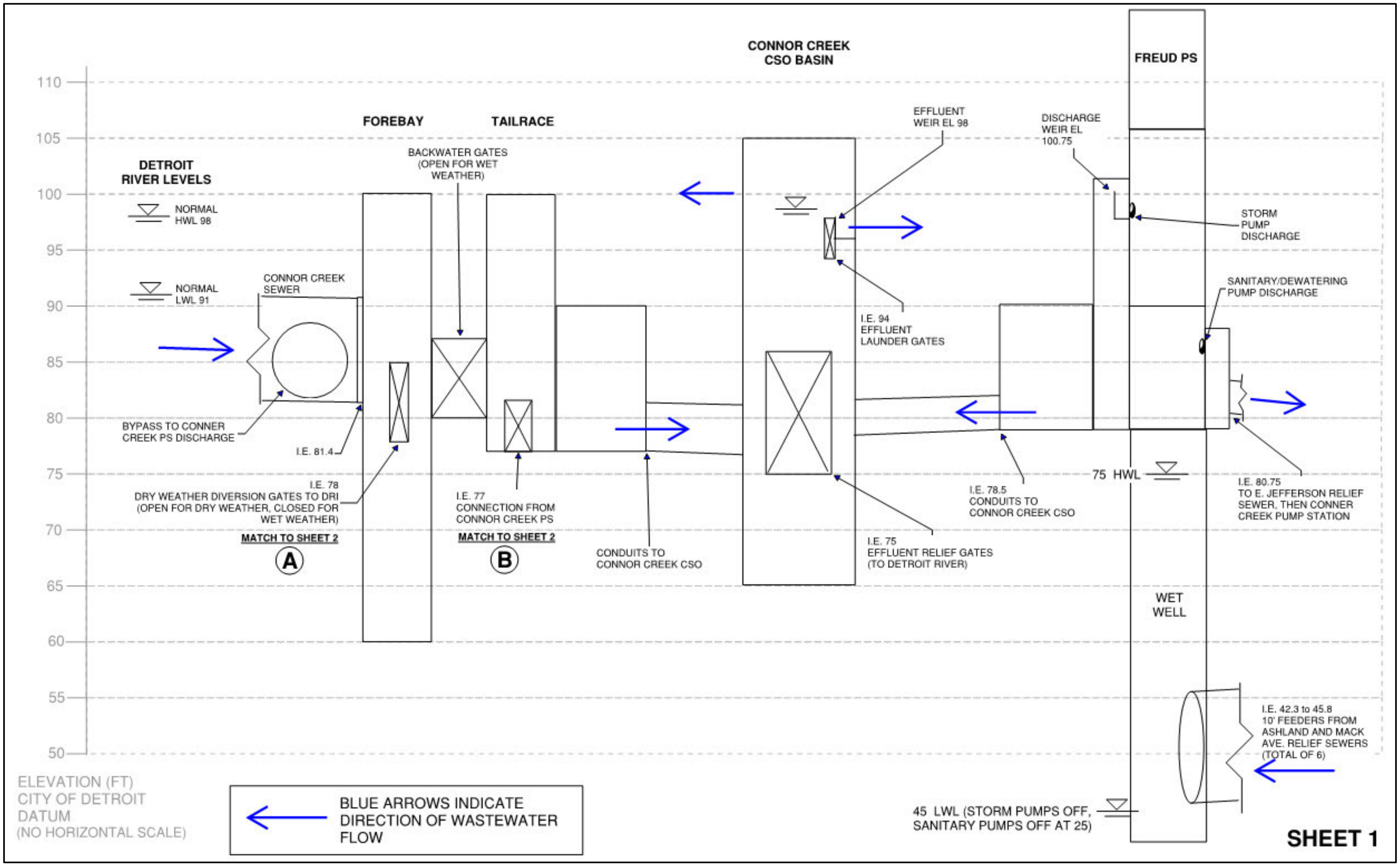

Figure 2-1A. Collection System Profile, Sheet 1 of 2

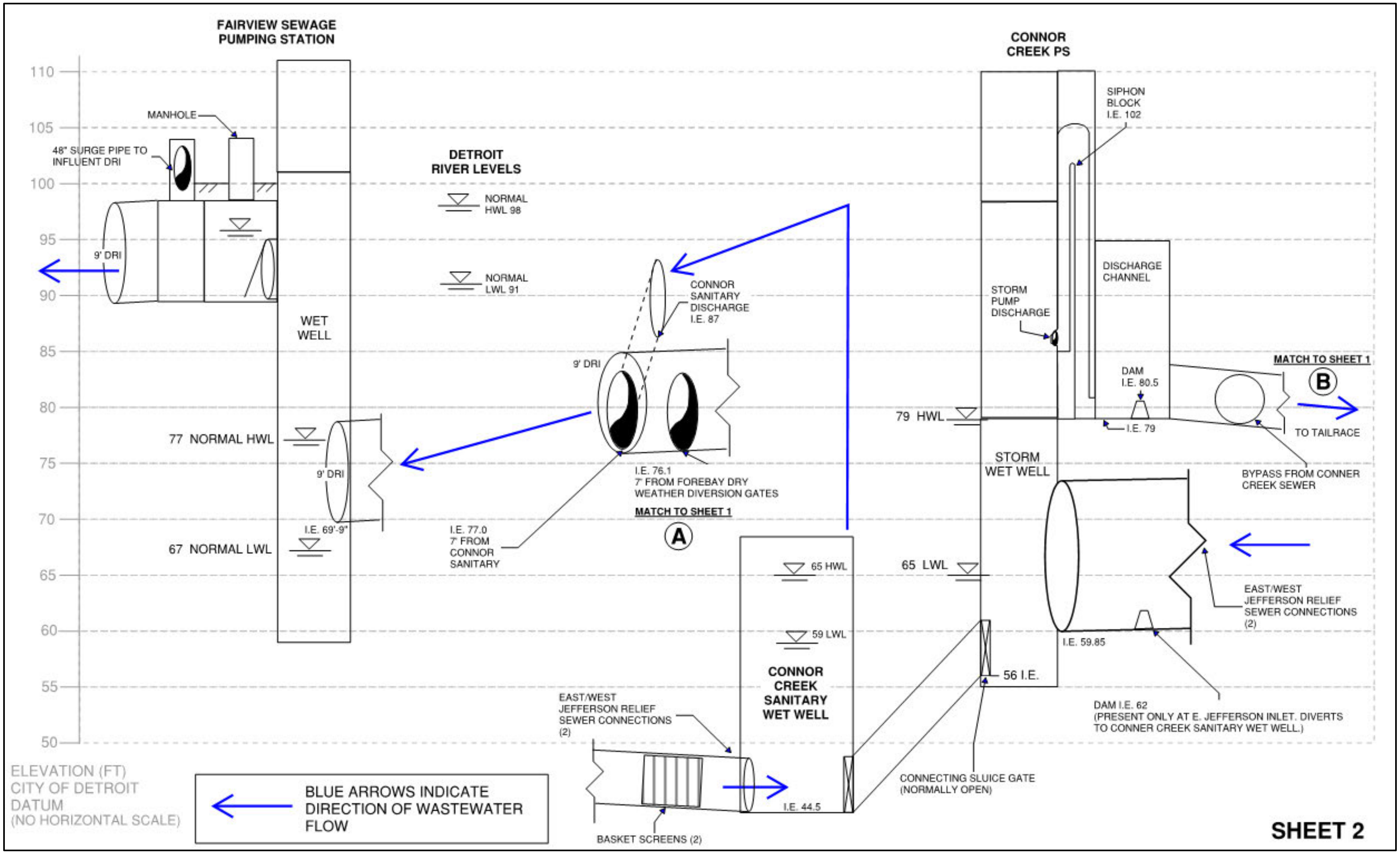

Figure 2-1B. Collection System Profile, Sheet 2 of 2

2.2 Wet Weather Data Review

Figure 2-2 and Figure 2-3 show flow and level data from two wet weather events that follow the Wet Weather Operational Plan and call out the operation of various collections system components during and after the storm events.

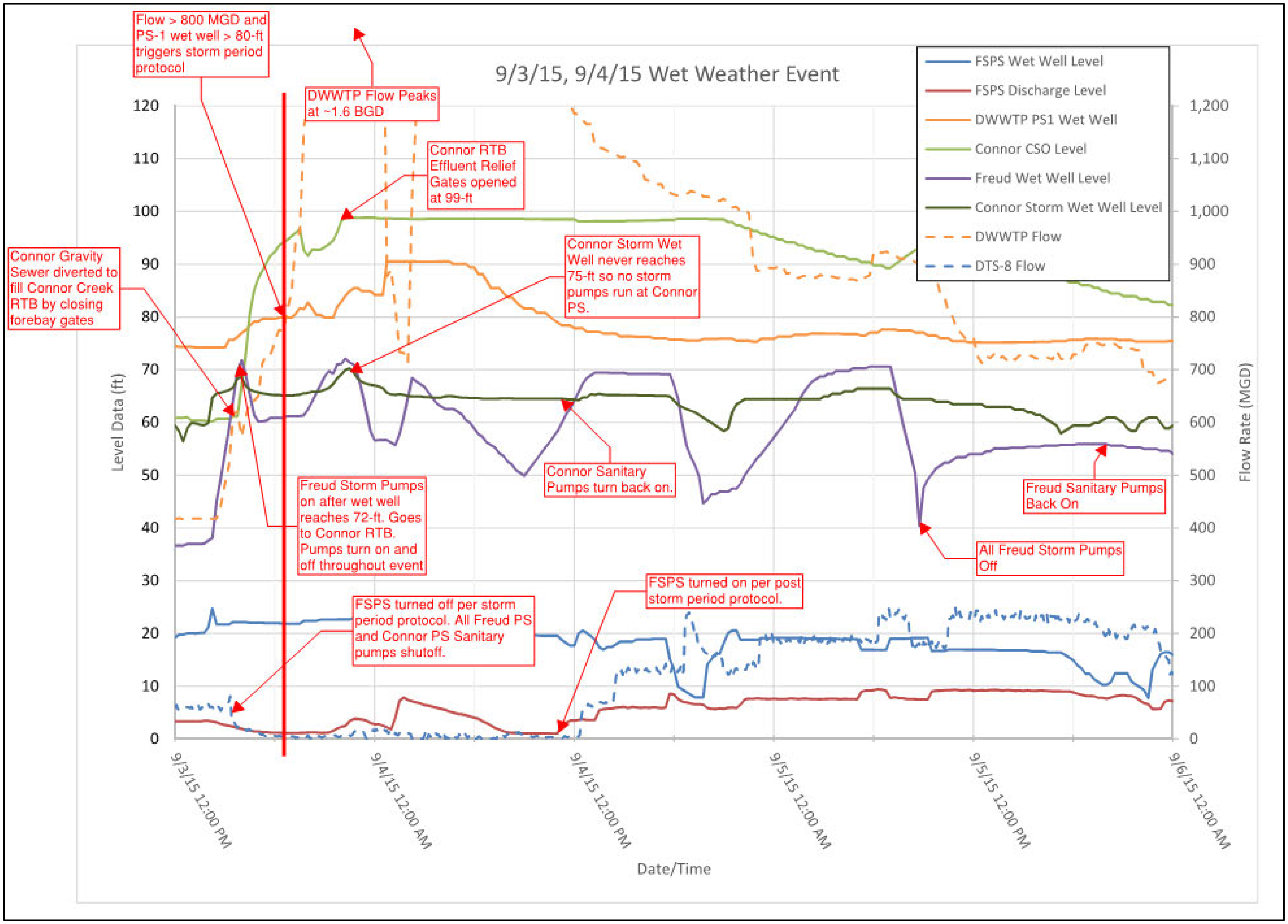

Figure 2-2. Wet Weather Event Data 9/3/15 – 9/4/15

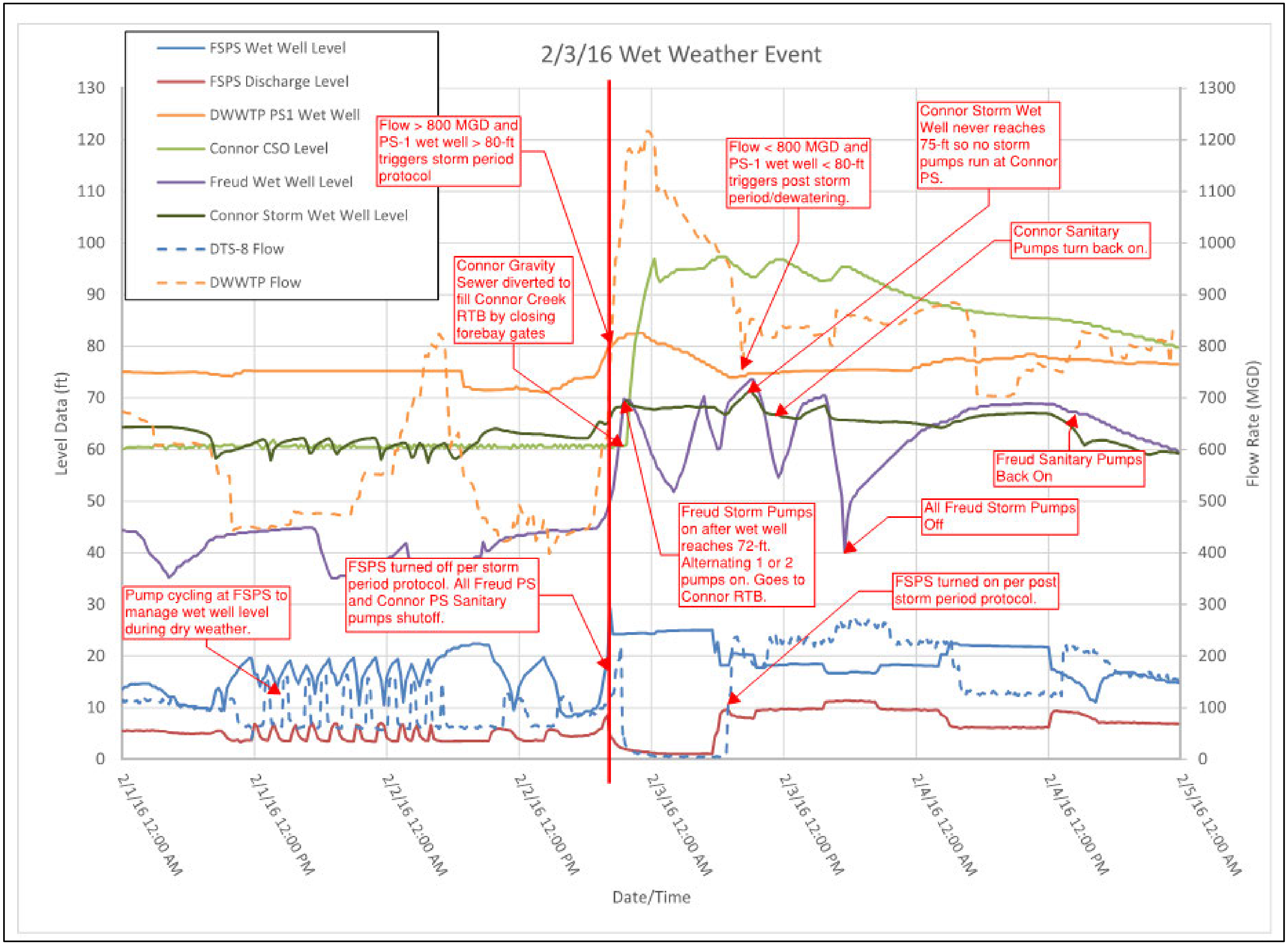

Figure 2-3. Wet Weather Event Data 2/3/16

In September 2016 (during preparation of this TM) it was reported that SCC altered the standard operating procedure for the FSPS, reverting back to the historical practice of running the FSPS throughout a wet weather event. Although not explicitly stated, it is assumed that this operating change was made as a result of flooding in the upstream Jefferson-Chalmers neighborhood during a wet weather event in July 2016.

During a rain event in late September 2016, an uncontrolled overflow occurred at FSPS while the pumps were running. It appeared the station was pumping flow beyond the capacity of the discharge channel/conduits. Figure 2-4 shows photos from this event.

Figure 2-4. Uncontrolled Overflow Event at FSPS September 2016

Operating data for this wet weather event was provided by GLWA and is summarized in Figure 2-5. The data confirms that the operating procedure changes were implemented (Conner sanitary and FSPS sanitary pumps operated during the wet weather event). The discharge surge chamber level data also confirms the overflow of the discharge flap gate structures during the event. Both Conner sanitary and FSPS wet well levels were elevated during this same period.

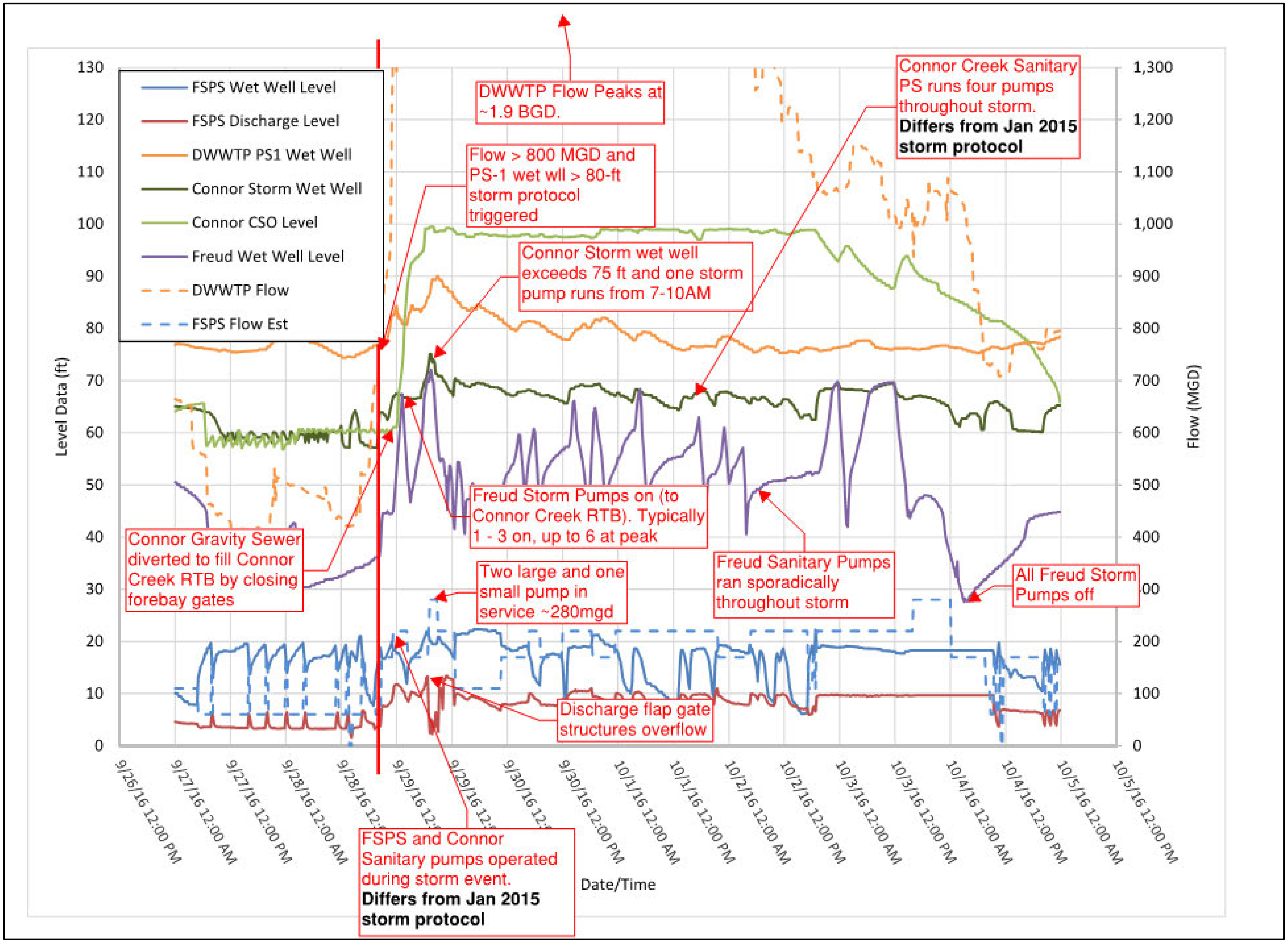

Figure 2-5. Wet Weather Event Data 9/29/16

Section 3: Freud Pump Station

3.1 Station Overview and Pump Design Criteria

A section view of the FPS is depicted in Figure 3-1. Both dewatering and storm pumping stations pull from the same wet well and pumping equipment for both are shown.

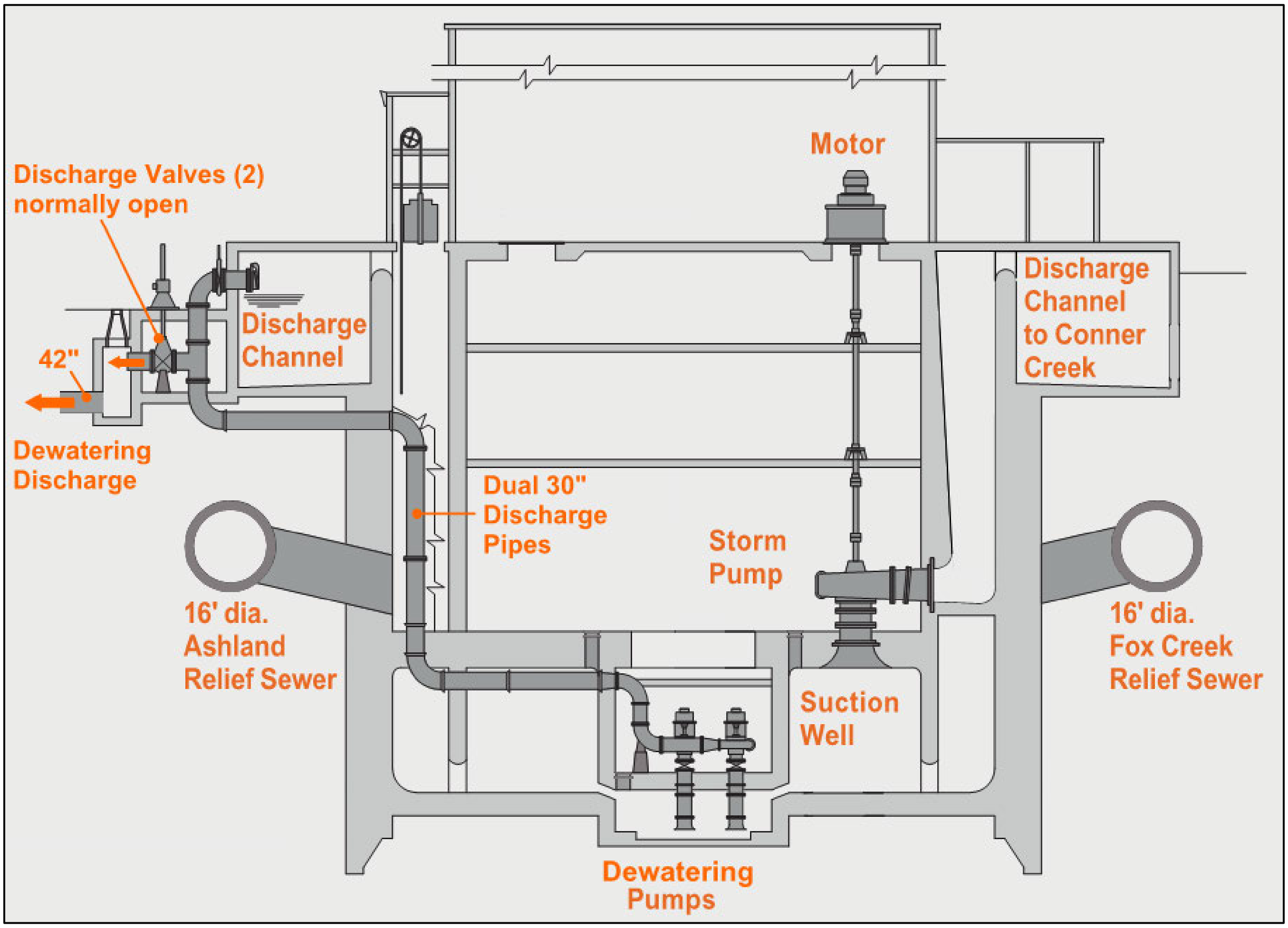

Figure 3-1. Existing Freud Pump Station

The dewatering pumps at FPS are shown at the bottom of Figure 3-1. The original function of the two pumps was to dewater the stormwater wet well, but they now also handle dry weather flow from the Fox Creek Sewer and Ashland Sewer. The O&M manual indicates that pump No. 9 is rated for 15,750 gpm at 36 feet TDH while Pump No. 10 is rated at 9,000 gpm at 57 feet TDH. According to the O&M manual, the pumps are not supposed to be operated in parallel because the flow would exceed the hydraulic capacity of the receiving sewer. Instead, one pump is to operate at high wet well levels and the other when the wet well is predominantly empty. The pumps discharge into a 42-inch line, which returns flow back to the East Jefferson Relief Sewer. The Freud O&M Manual from 1993 indicates that the dewatering pumps should not be operated when the storm pumps are operating. Design criteria for the dewatering pumps, as listed in the O&M manual, are shown in Table 3-1.

Table 3-1. Existing Freud Dewatering Pumps Design Criteria*			
Item	Unit	Value – Pump No. 9	Value – Pump No. 10
Manufacturer	-	ITT; Allis Chalmers	ITT; Allis Chalmers (Xylem)
Series and Model	-	-	-
Motor Size	hp	200	200
Motor Speed (constant)	rpm	585	885
Flow at BEP	gpm/mgd	17,250/25	8,900/13
Rated Capacity	gpm/mgd	15,750/23 (@ 36' TDH)	9,000/13 (@ 57' TDH)
TDH at BEP	ft	34	58
Suction/Discharge Size	in	24	16
Motor Voltage	V	4,160	4,160
Efficiency at BEP	%	82	86
Minimum Flow Rate	gpm/mgd	6,500/9 (@ 47' TDH)	3,000/4 (@ 72' TDH)
NPSHr at BEP	ft	17	16

**As listed in the FPS O&M Manual and manufacturer pump curves.*

There are eight stormwater pumps in the FPS. A representative section view of the storm pump configuration is shown in Figure 3-1 above. The Worthington pumps were originally rated for 201,510 gpm (290 mgd) at 45 feet TDH and are powered with 3,000-hp synchronous motors operating at 225 rpm. The stormwater pumps are not equipped with suction or discharge valves, nor do they have check valves. The Freud pumps are designed to operate with a flooded suction with individual overflow discharges. Design criteria for the storm pumps, as listed in the O&M manual, are shown in Table 3-2.

Table 3-2. Existing Freud Storm Pumps Design Criteria*		
Item	Unit	Value – Pump Nos. 1-8
Manufacturer	-	Worthington (Flowserve)
Series and Model	-	MIXFLO 72"
Motor Size	hp	3,000
Motor Speed (constant)	rpm	225
Flow at BEP	gpm/mgd	158,887/229
Rated Capacity	gpm/mgd	201,510/290 (@ 45' TDH)
TDH at BEP	ft	58
Suction/Discharge Size	in	72
Motor Voltage	V	4,000
Efficiency at BEP	%	85
Minimum Flow Rate	gpm/mgd	-
NPSHr at BEP	ft	-

**As listed in the FPS O&M Manual and manufacturer pump curves.*

3.2 Operations Assessment

BC reviewed available operating procedure documents in order to understand the past and present operation of the CCPS, FPS, and CCCSO Facility. Documents reviewed included:

- DWSD Connors Creek PS Operation and Maintenance Manual 2006.
- DWSD Freud Sewage PS Operation and Maintenance Manual 1993.
- Detroit WWTP Wet Weather Operational Plan (WWOP) January 2015 Update

The written operating procedures are compared to historical (SCADA) data from the System Control Center in subsequent sections.

HMI Screen

Figure 3-2 shows the HMI screen used to monitor and control the FPS. The HMI screen shows that storm pump Nos. 5 and 7 were "NOT READY" (presumably out of service) at the time this screen shot was taken. Also, note that "STATION FLOW RATE" is displayed, but it is unclear how the flowrate for the station is actually measured. And finally, the screen appears to be incomplete. According to record drawings, there are two (2) control valves that can be used to route dewatering discharge either to the stormwater discharge channel (not typical), or to the E. Jefferson Relief Sewer through a 42" receiving line (typical). However, the HMI screen indicates that discharge from the dewatering pumps is sent to the "CONNER CREEK DISCHARGE".

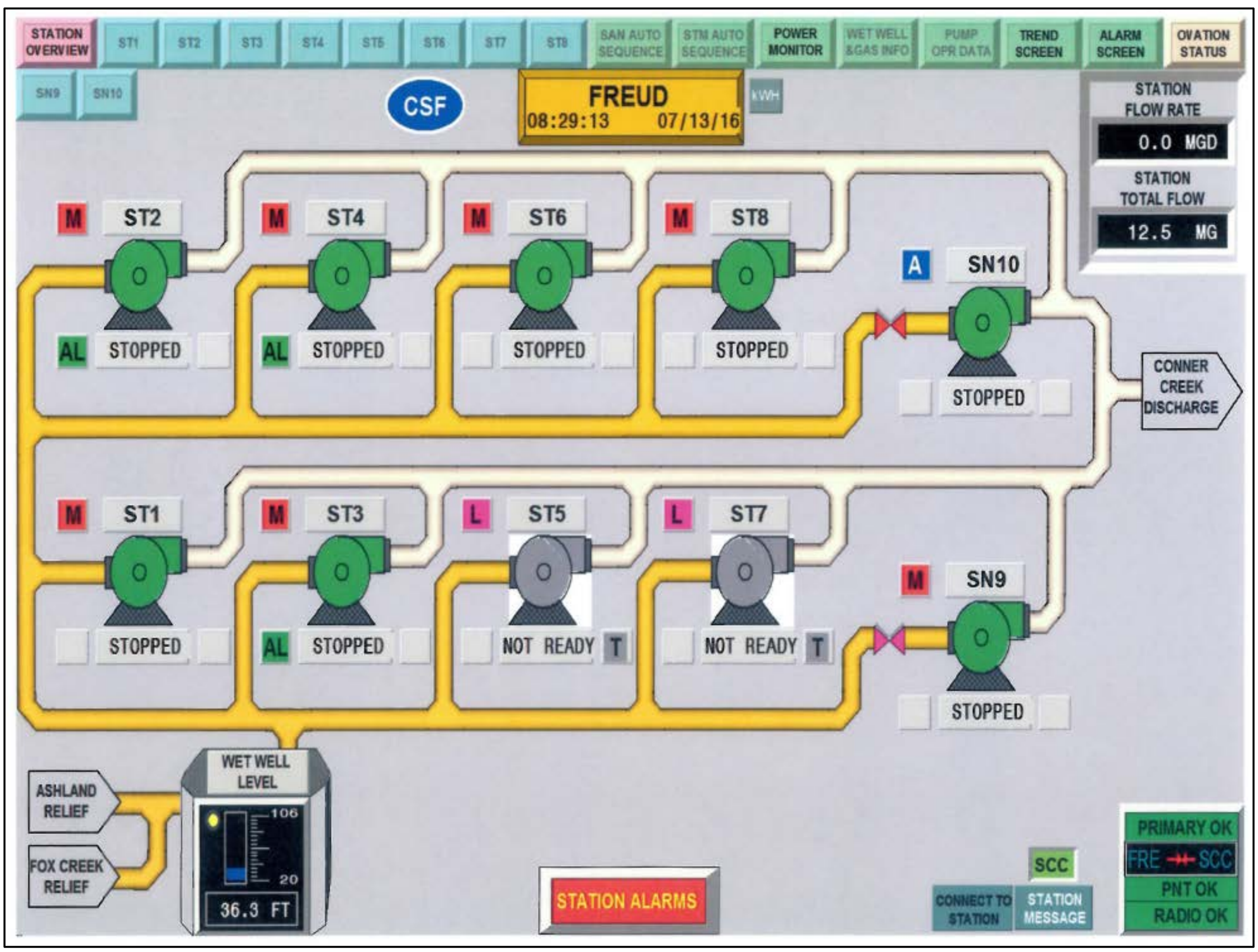

Figure 3-2. Existing Freud Pump Station HMI Screen

Wet Well Control Levels

During dry weather the FPS receives flow from the Ashland and Fox Creek Sewers and pumps to the E. Jefferson Relief Sewer, which runs to the CCPS. As shown in Table 3-3, the FPS wet well is supposed to be maintained between EL 25' and EL 65', during dry weather, according to the FPS O&M manual. Note that all elevations in this TM are based on the City of Detroit Datum.

The two dewatering pumps at FPS should never to be run in parallel because their pump performance curves are very different and were specifically selected to achieve "staged-pumping" rather than redundant or parallel pumping. In other words, Pump No. 9 should be utilized for higher wet well levels and Pump No. 10 for lower levels. Note however that the data analysis presented in below indicates that the pumps are sometimes run in parallel.

Table 3-3. Wet Well Control Levels for Freud Dewatering Pumps – Dry Weather*		
Pump	Start Elevation (ft)	Stop Elevation (ft)
No. 9 (24")	65	45
No. 10 (16")	45	25

As shown in the FPS O&M manual.

During a wet weather event the FPS storm pumps turn on and discharge flow to the CCCSO for retention and treatment. Table 3-4 provides the wet well control levels for the FPS storm pumps as defined in the FPS O&M manual.

Table 3-4. Wet Well Control Levels for Freud Storm Pumps – Wet Weather*		
Pumps	Start Elevation (ft)	Stop Elevation (ft)
No. 1	68	45
No. 2	69	47
No. 3	70	48
No. 4	71	49
No. 5	72	50
No. 6	73	51
No. 7	74	52
No. 8	75	53

As shown in the FPS O&M manual.

Wet well level and pump run data for the FPS dewatering pumps is shown in Figure 3-3. Data from May 2016 is presented because it represents a period in which the storm pumps were not run, and because a distinct diurnal dry weather pattern could be observed. The dewatering pumps do not appear to run as outlined in the control levels table from the O&M manual. The O&M manual indicates the Pump No. 9 start level is 65' EL, but the data shows that the actual pump starts vary from about 63' EL to 71' EL. It also appears that Pump No. 10 is periodically being run at wet well levels 5-15 ft higher than its intended "start elevation". Operation at these wet well levels results in a pump performance curve operating condition far off (to the right) of the allowable operating region of the pump curve. Operation at this condition is typically detrimental to the pumping equipment resulting in poor performance, reduced reliability, and significantly shortened equipment life. This data also indicates that the wet well is never drawn down below about 48', while the O&M manual calls for Pump No. 10 to stop at 25' EL. Figure 3-4 shows the wet well control levels from the O&M manual and the observed wet well levels overlaid on a drawing of the pump station.

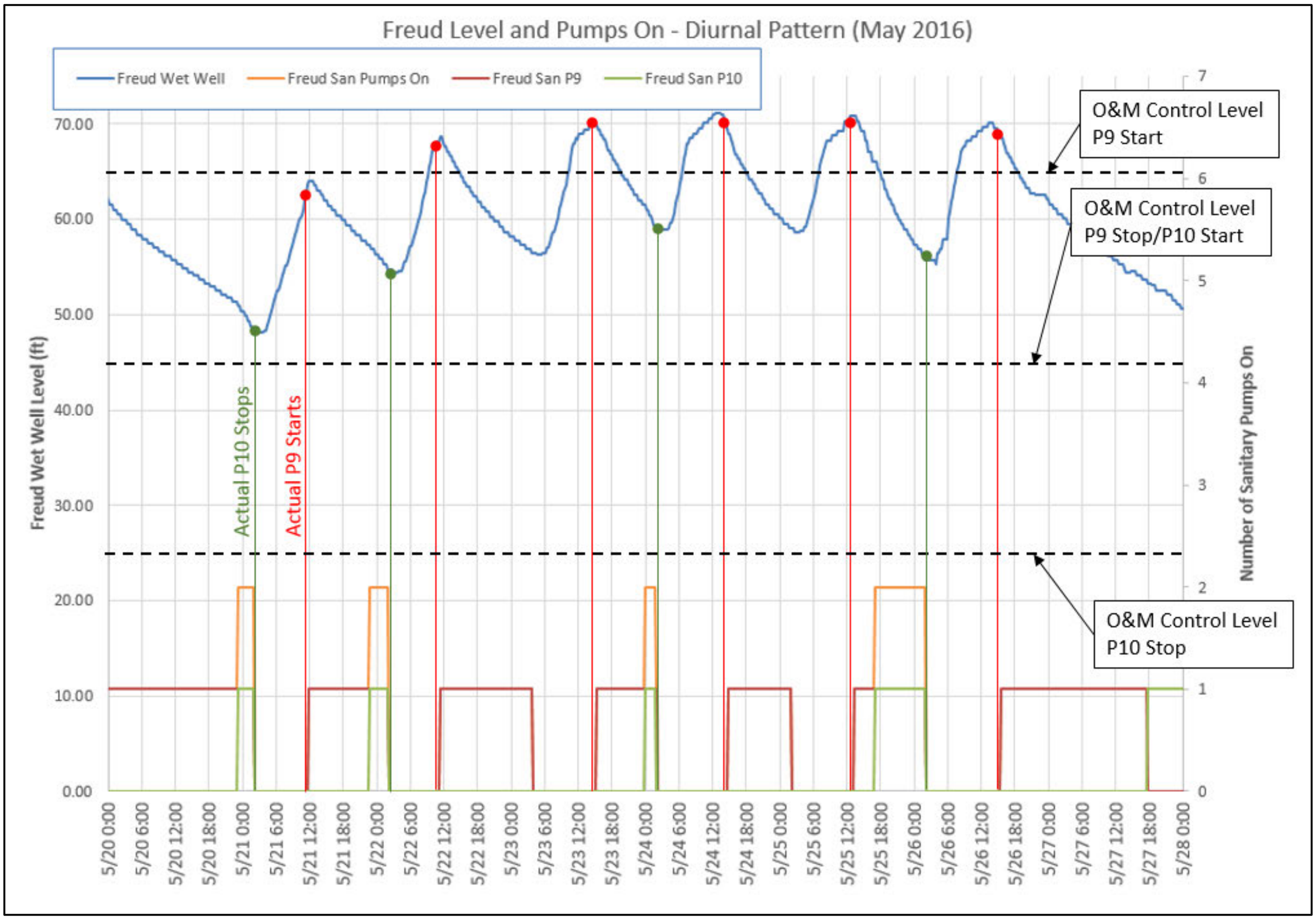

Figure 3-3. FPS Wet Well Level and Dewatering Pump Operation Data

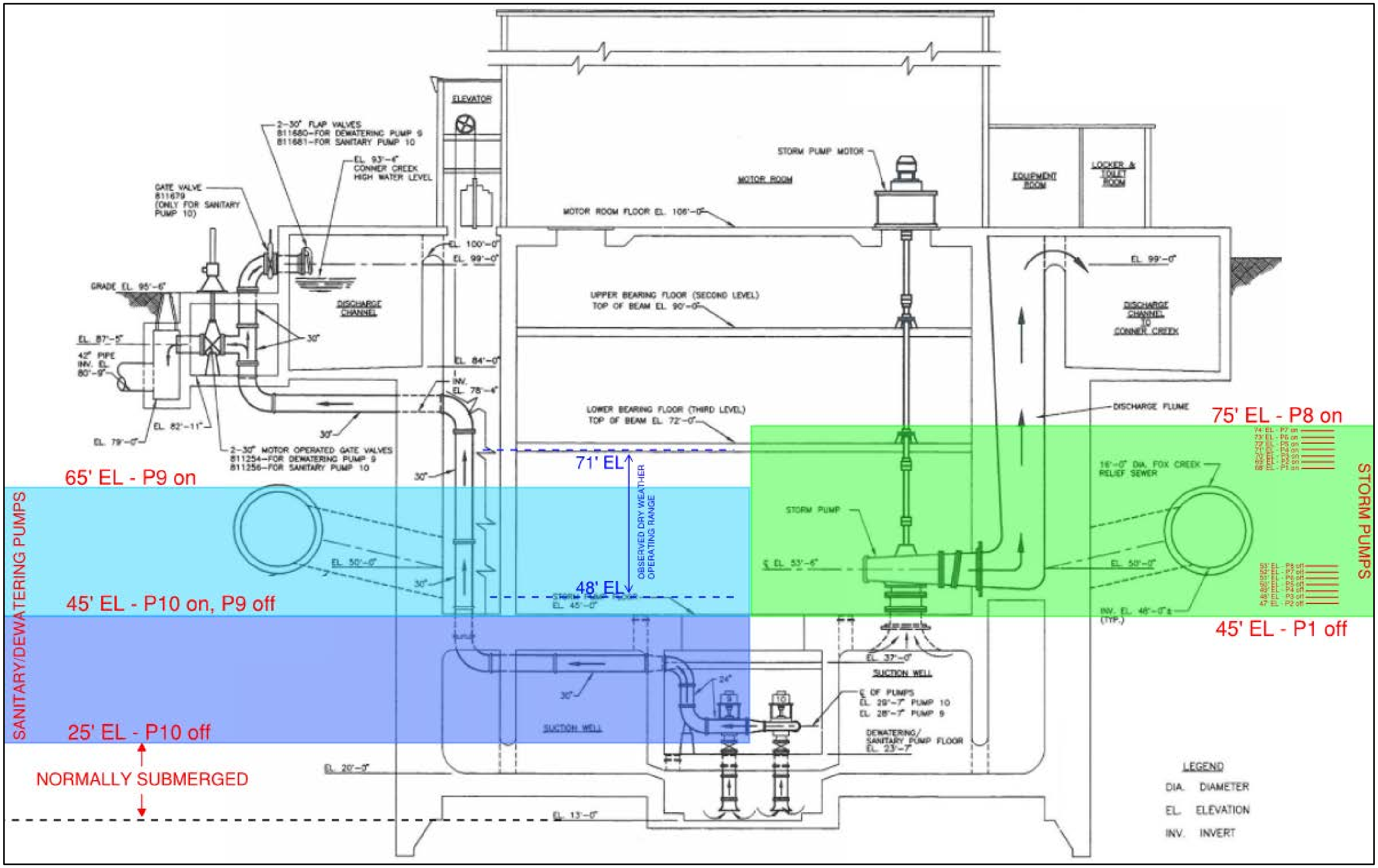

Figure 3-3. FPS Wet Well Control Levels and Observed Dry Weather Operating Range.

Figure 3-5 shows FPS wet well levels and number of storm pumps operating during the later part of March 2016. The start level listed in the O&M manual for the first pump is 68' EL. The start level listed in the *Wet Weather Operating Plan January 2015 Update* is 72' EL. Note from the figure that most of the first pump starts occur between these two values (the anomalous start-stop-start between 3/29 and 3/30 is the only outlier). The last pump, according to the O&M manual, should be shut off at 45' EL. The data shows that the last pump is actually shut off anywhere between 40' EL and 52' EL.

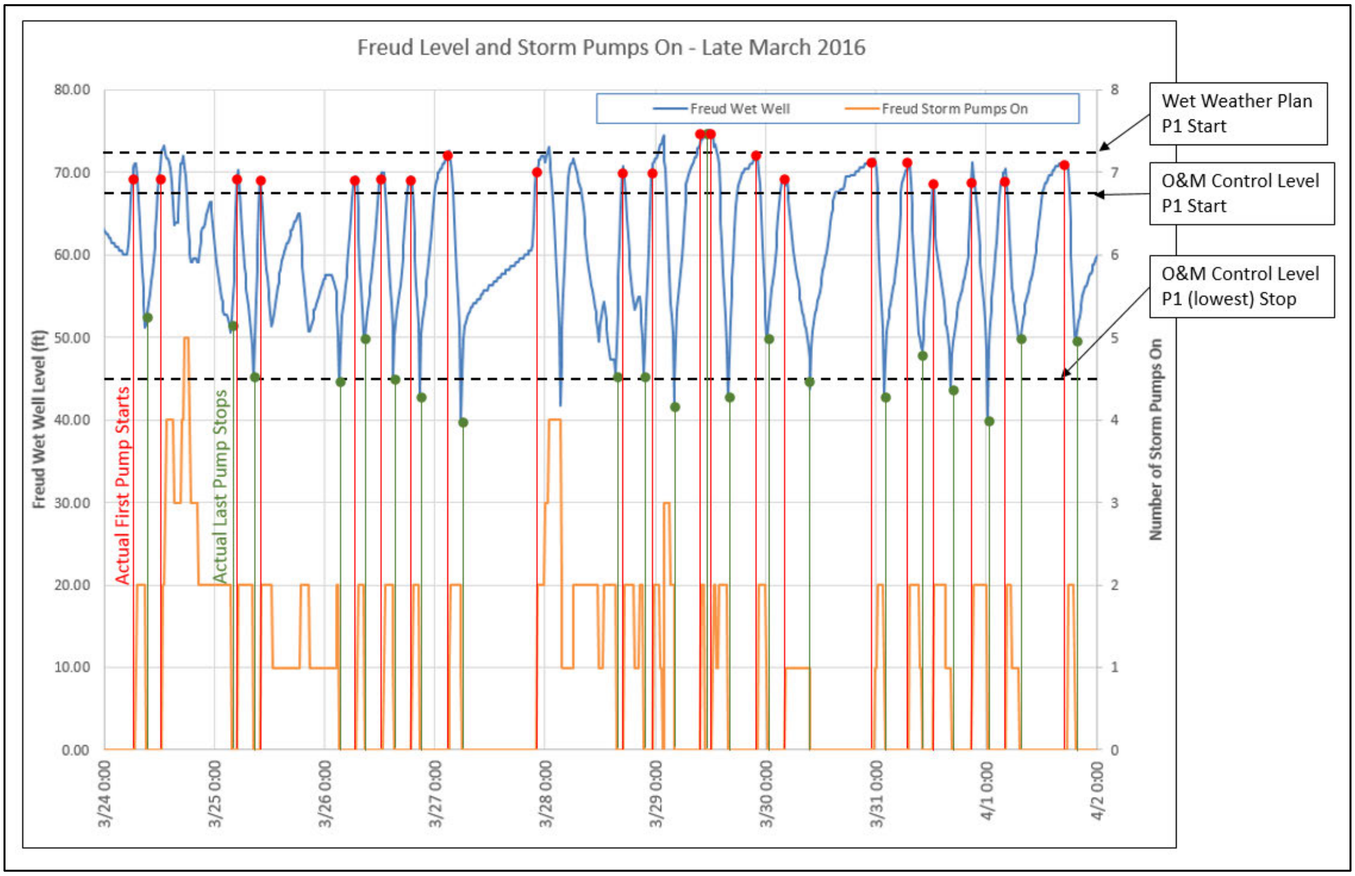

Figure 3-5. FPS Wet Well Level and Storm Pump Operation Data

Pump Run Time

Pump run times for FPS were generated using data from January 2015 to May 2016, and are shown in Tables 3-5, 3-6, 3-7, and 3-8. Table 3-5 shows that dewatering Pump Nos. 9 and 10 ran for a nearly equivalent number of hours during 2015, but that Pump No. 9 has about twice as many running hours than Pump No. 10 in 2016. This implies that some change in operational strategy was made between 2015 and 2016. Table 3-6 shows that the frequency of having both pumps running at once (which is contrary to guidance in the O&M manual) increased from 1 percent of the time in 2015 to 4 percent of the time in 2016.

FPS storm pump run times are shown in Table 3-7 and Table 3-8. These pumps run only 6 to 7 percent of the time, and run time is roughly balanced amongst all but pumps No. 5 and No. 7. Table 3-7 shows that Pump No. 5 did not run at all in 2015 or 2016, and Pump No. 7 did not run in 2016. These are the same two pumps that are labeled "NOT READY" in the HMI screen shots presented above.

Table 3-5. FPS Dewatering Pump Annual Runtime Data: January 2015 to May 2016			
Year	Pump Run Time (hours)		Out of Possible (hours)
	Pump No. 9	Pump No. 10	
2015	1,373	1,290	8,760
2016	1,434	727	4,656

Table 3-6. Number of FPS Dewatering Pumps in Operation: January 2015 to May 2016				
Year	Hours of Operation with Number of Pumps in Service			Out of Possible (hours)
	0 Pumps On	1 Pump On	2 Pumps On	
2015	6,180 (70%)	2,498 (29%)	83 (1%)	8,760
2016	2,678 (57%)	1,796 (39%)	183 (4%)	4,656

Table 3-7. FPS Storm Pump Annual Runtime Data: January 2015 to May 2016									
Year	Pump Run Time (hours)								Out of Possible (hours)
	Pump No. 1	Pump No. 2	Pump No. 3	Pump No. 4	Pump No. 5	Pump No. 6	Pump No. 7	Pump No. 8	
2015	138	152	141	98	0	105	88	111	8,760
2016	121	94	127	78	0	118	0	56	4,656

Table 3-8. Number of FPS Storm Pumps in Operation: January 2015 to May 2016										
Year	Hours of Operation with Number of Pumps in Service									Out of Possible (hours)
	0 Pumps On	1 Pump On	2 Pumps On	3 Pumps On	4 Pumps On	5 Pumps On	6 Pumps On	7 Pumps On	8 Pumps On	
2015	8,197 (94%)	335 (4%)	203 (2%)	16 (<1%)	8 (<1%)	2 (<1%)	1 (<1%)	0	0	8,760
2016	4,337 (93%)	95 (2%)	195 (4%)	17 (<1%)	6 (<1%)	1 (<1%)	5 (<1%)	0	0	4,656
Approx. Flow Rate (mgd)*	0	290	580	870	1,160	1,450	1,740	2,030	2,320	-

**Flow rate approximated by multiplying rated capacity of each pump by the number of pumps running.*

Pump and System Curves

Freud Dewatering Pump and System Curves

The existing pumping systems were modeled using BC's hydraulic modeling software, BC PumpPlots, to evaluate the existing operating conditions of the FPS and CCPS. The models were used to create system curves based on observed wet well operating levels and reference drawings provided by GLWA (see Attachment B: Pumping System Reference Drawings). Wet well control levels from the O&M manual are included on the graphs for comparison to the observed operating range. These curves were graphed with the factory test pump head-capacity curve to evaluate the current pump operating conditions. Original pump curve data sheets are provided in Attachment C.

Pump and system curves for the Freud dewatering pumps are shown in Figure 3-6 and Figure 3-7. Note that the current O&M manual sometimes refers to Pump No. 9 as the "sanitary pump" and Pump No. 10 as the "dewatering pump". For each of these pumps we have included two system curves, which correspond to the boundaries of operating range observed in the data analysis. Wet well control levels from the O&M manual are included on the graphs for comparison to the observed operating range.

Pump No. 9 operates to the left of the preferred operating range (POR) when wet well levels are below about 52' EL, and would operate even further from the POR if it were to stop at the elevation prescribed in the O&M manual. There is still significant overlap between the POR and the observed operating range for Pump No. 9 so the longevity of this pump may be improved simply by changing the control levels to match the POR.

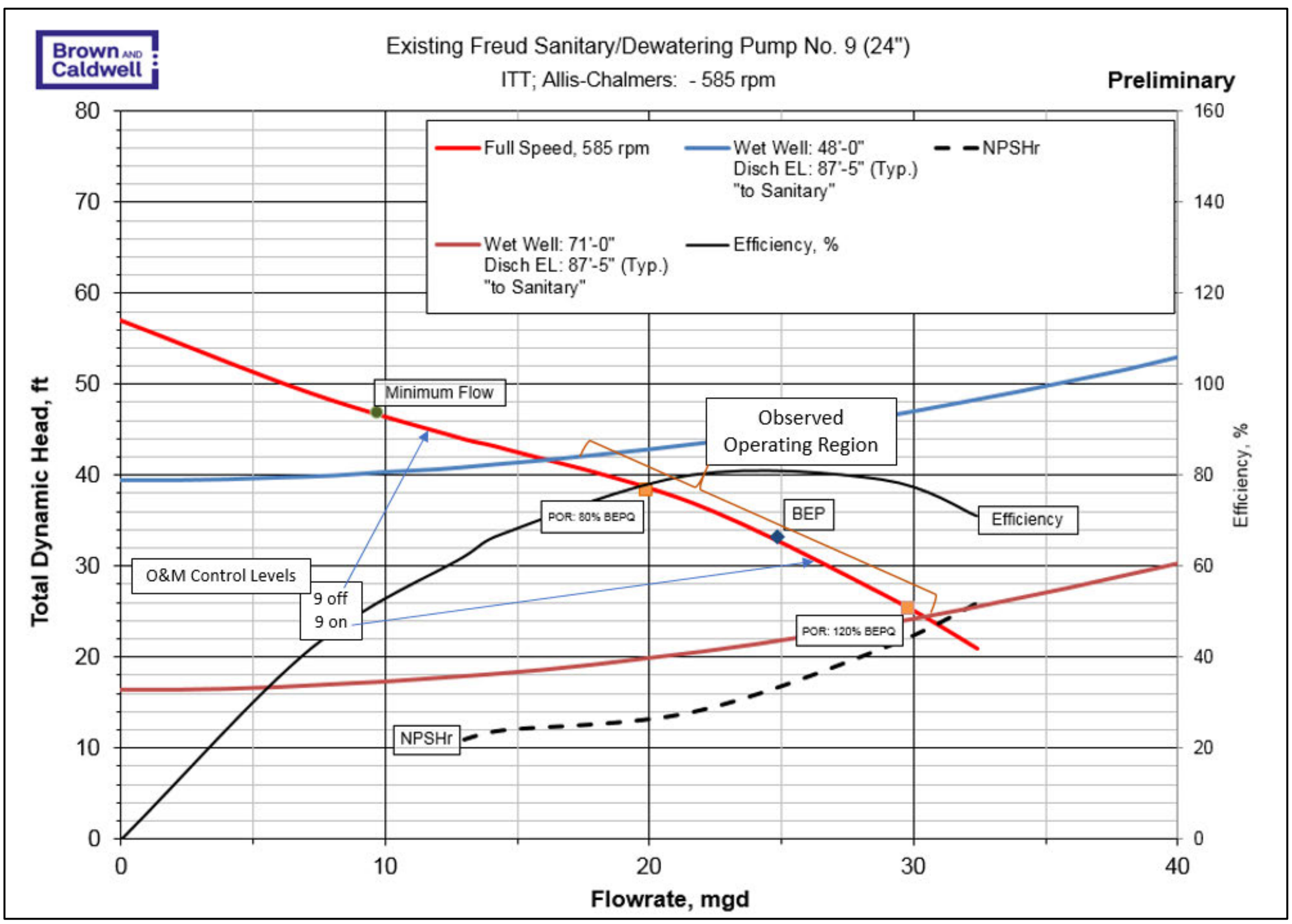

Figure 3-6. Pump and System Curves for Existing Freud Sanitary Pump No. 9

The recommended control levels from the O&M manual for Pump No. 10 match the pump's POR very well, however, review of the historical data shows that the pump is actually operating to the far right of the POR and off of the published curve. Operating the pump in this manner will result in poor efficiency, discharge recirculation, and cavitation, which will cause serious damage to the pump (reducing the reliability and lifespan of equipment).

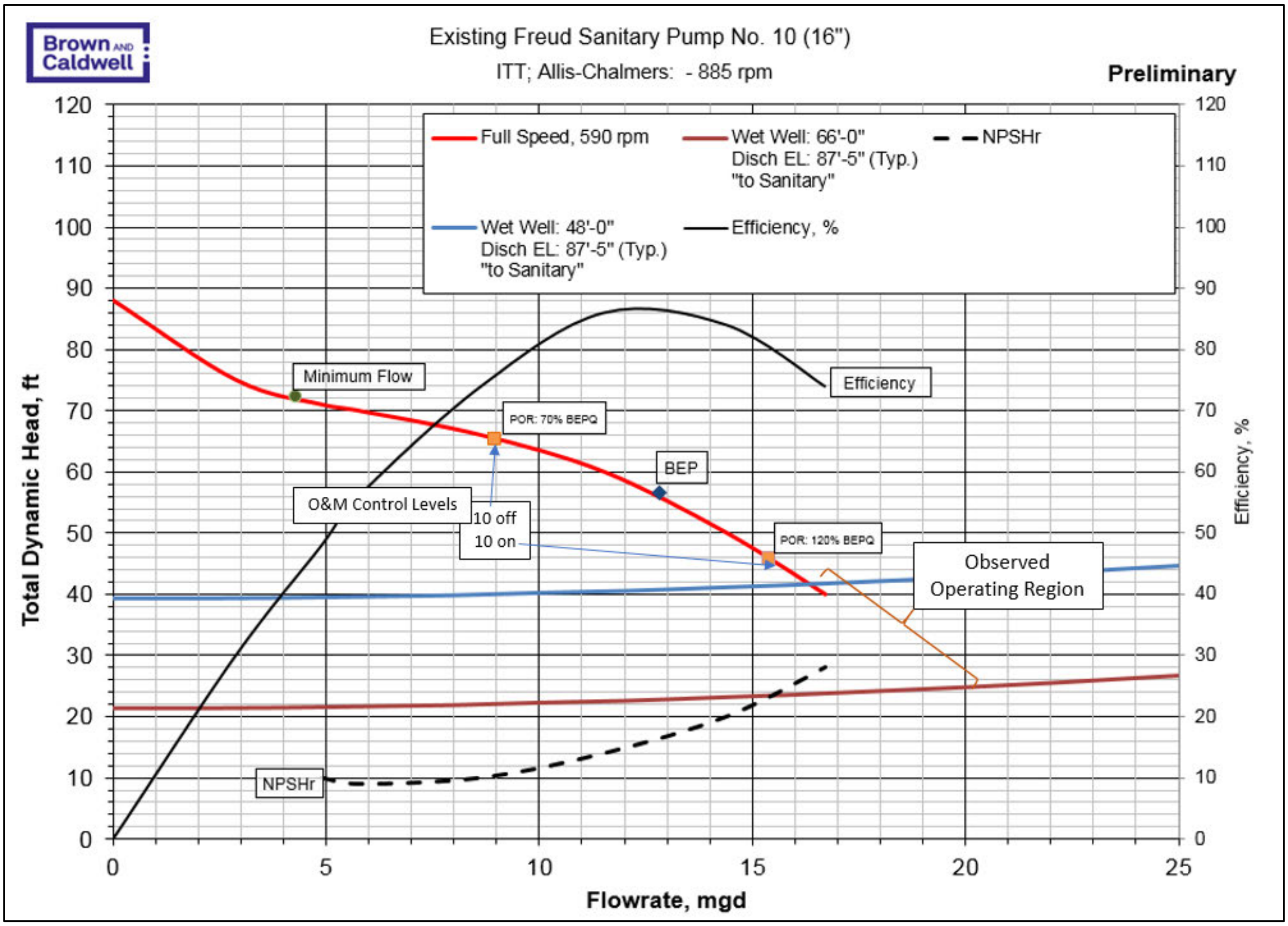

Figure 3-7. Pump and System Curves for Existing Freud Dewatering Pump No. 10

Freud Storm Pump and System Curves

For the FPS storm pumps, we have included two system curves, which correspond to the boundaries of operating range observed in the data analysis. Wet well control levels from the O&M manual are included on the graphs for comparison to the observed operating range. Pump and system curves for the Freud storm pumps are shown in Figure 3-8. In developing the system curve for this analysis, it was assumed there is no hydraulic influence on the pumps once the flow is pumped over the discharge weir. The data analysis shows that these pumps are operating far to the right of the best efficiency point (BEP) and often outside of the POR. Operating the pumps in this manner will result in poor efficiency, discharge recirculation, and cavitation, which will cause serious damage to the pump. Also, these pumps are operating over a very large range of wet well levels, so flow will vary significantly even if the number of pumps running stays constant (flow will increase at higher wet well levels and decrease at lower wet well levels). As an example, if Pump No. 8 starts according to the O&M control levels it will produce 340 mgd when it starts and 260 mgd just before it stops (approximately 25% reduction in flow across operating range).

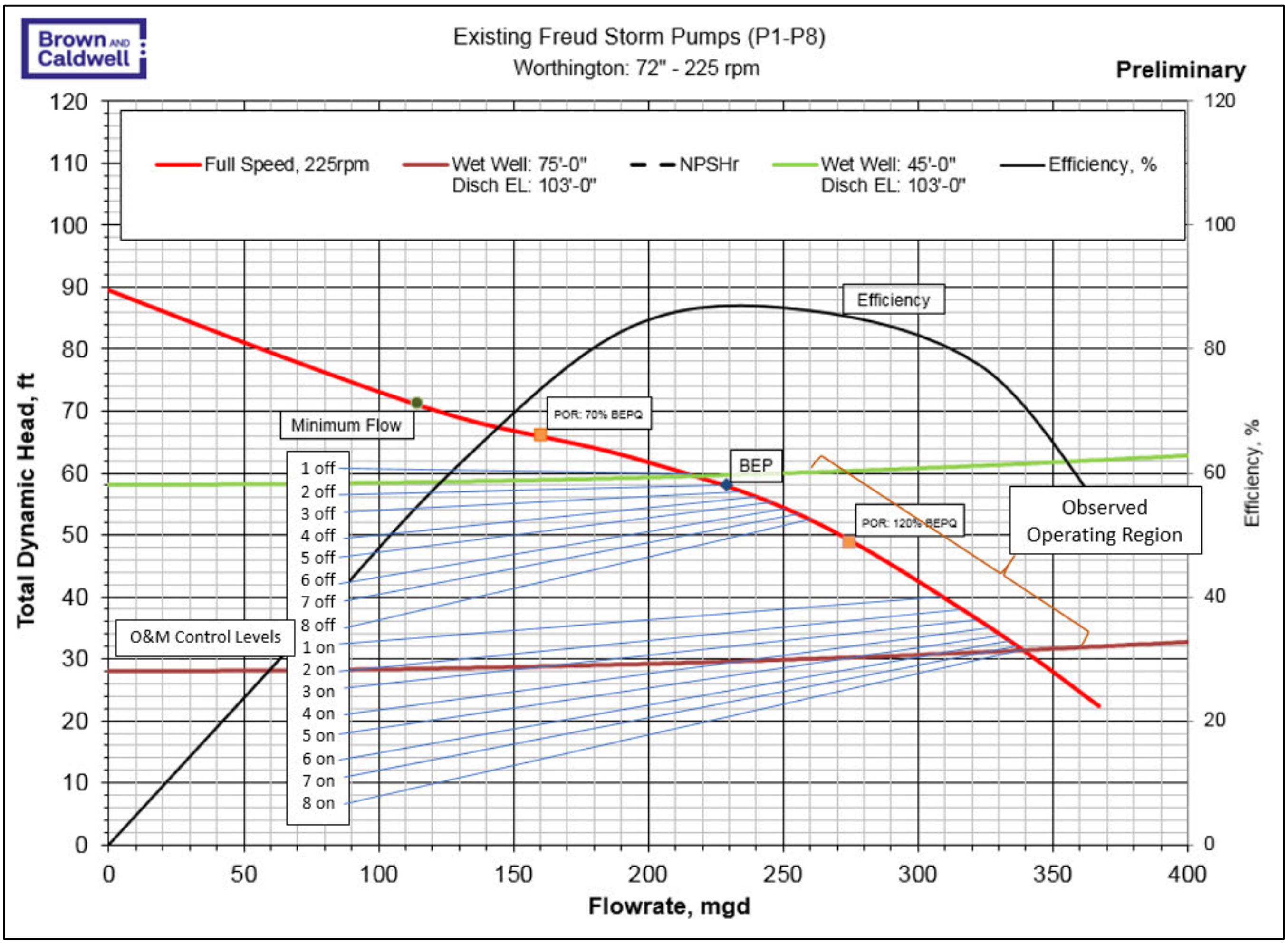

Figure 3-8. Pump and System Curves for Existing Freud Storm Pumps

NPSH Margin and Suction Intake Conditions

Per ANSI HI 9.6.1 – Guideline for NPSH Margin, the recommended minimum NPSH margin is 1.1 – 1.3 for large wastewater pumps. The NPSH margins for the existing dewatering pumps were evaluated at elevations that correspond to their observed operating ranges. NPSH margins could not be calculated for the storm pumps because NPSH3 data is not provided with the manufacturer's pump curve data.

The formulas used for the calculations are:

NPSH margin ratio = NPSHA / NPSH3

NPSHA = $h_{atm} + h_s + z_s - h_L - h_{vp} - SF$

Where:

NPSHA	= Net Positive Suction Head Available
NPSH3	= Net Positive Suction Head at which a 3% reduction in total head occurs
h_{atm}	= atmospheric pressure head
h_s	= suction head
z_s	= elevation head
h_L	= minor losses in suction piping
h_{vp}	= liquid vapor pressure head
SF	= safety factor (5-ft for wastewater).

Table 3-9 summarizes the NPSH margins for the FPS dewatering pumps.

Table 3-9. FPS NPSH Margins

Pump No.	Wet Well EL (ft)	NPSH Margin
9 (sanitary)	48	3.81
	71	2.99
10 (dewatering)	48	1.69
	66	NA*

NPSH3 data not available for this region of the pump curve.

There is sufficient NPSH margin under all conditions except for Pump No. 10 at high wet well levels. This level could not be evaluated because at this level the pump is operating outside of the published curve.

Suction intake conditions in the FPS wet well are also currently being evaluated through the use of laboratory physical hydraulic modeling.

3.3 Major Findings for Freud Pump Station

The major findings from this evaluation of the FPS are presented in the list below.

1. Freud Dewatering Pump Station
   a. Pumps are not being operated to the control elevations defined in the O&M manual.
   b. No ability to isolate the wet well.
   c. Pumps are not equipped with discharge isolation valves or check valves.
   d. Pumps can discharge to E. Jefferson Relief Sewer or the storm discharge channel depending on whether valves at the discharge chamber are open or closed.
   e. HMI screen only shows discharge to storm channel (missing discharge to E. Jefferson Relief Sewer).
   f. Pump Nos. 9 and 10 are sometimes run at the same time, risking surcharge of receiving sewer.
   g. Pump Nos. 9 and 10 are operated outside of their preferred operating range (POR). This will significantly reduce the reliability and life span of pumping equipment.
   h. The wet well is not routinely drawn down below 48' EL.
2. Freud Storm Pump Station
   a. No ability to isolate the wet well.
   b. Pumps are not equipped with suction/discharge isolation valves which would promote safe maintenance.
   c. Pump start elevations in O&M manual differ from start elevations in Wet Weather Operating Plan.
   d. Pumps are not being operated at the control elevations defined in the O&M manual.
   e. Pump Nos. 5 and 7 appear to have been out of service in 2015 and 2016.
   f. Pumps operate to the right of the best efficiency point (BEP) and often outside of their POR.
   g. Pumps operate over a wide range of wet well levels, resulting in large flow variations even when the number of pumps on is constant. One possible outcome of this is the appearance of an overall flow reduction/restriction as the wet well level decreases the number of pumps.
   h. Further investigation of possible air binding and or grit build-up in the discharge channel should be performed.

Section 4: Conner Creek Pump Station

4.1 Station Overview and Pump Design Criteria

A section view of the CCPS is depicted in Figure 4-1. Both sanitary and storm pumping stations are shown.

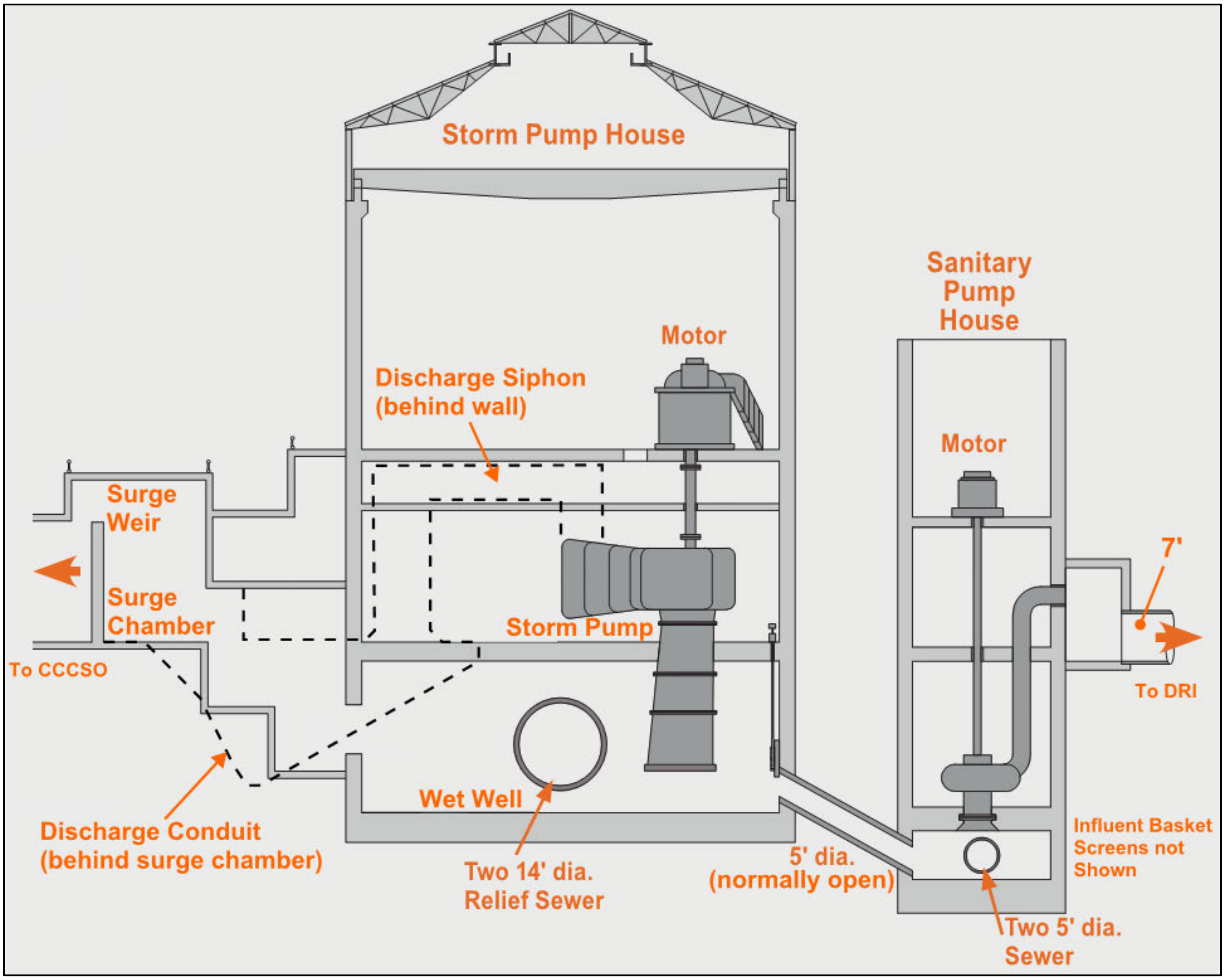

Figure 4-1. Existing Conner Creek Pump Station (Vacuum Priming System Not Shown)

The sanitary pump configuration at the CCPS is shown in Figure 4-1 above. Sanitary and low stormwater flows from the E. and W. Jefferson Relief Sewers enter the sanitary wet well on the east and west sides of the pump station. GLWA staff have indicated that significantly more flow enters from the E. Jefferson Relief Sewer than the W. Jefferson Relief Sewer. Flow passes through very coarse (12" clear) basket screens (Figure 4-2) on either side of the structure before entering the sanitary pump house wet well. They are then pumped into a discharge chamber that is connected to the DRI. Design criteria for each of the four sanitary pumps are shown in Table 4-1. It has been reported that there are times when all four pumps run to meet influent capacity requirements.

Figure 4-2. CCPS Influent Basket Screens Located at Both Inlets to the Sanitary Wet Well.

Table 4-1. Existing Conner Sanitary Pumps Design Criteria*				
Item	Unit	Value – Pump Nos. 9 and 11	Value – Pump No. 10	Value – Pump No. 12
Manufacturer	-	Morris Pumps (Grundfos)	Morris Pumps (Grundfos)	Morris Pumps (Grund-fos)
Series and Model	-	7100 MF 4242374V	7100 MF 3636324V	7100 MF 3030274V
Motor Size	hp	500	350	200
Motor Speed (constant)	rpm	400	450	514
Flow at BEP	gpm/mgd	43,000/62	30,000/43	19,000/27
Rated Capacity	gpm/mgd	49,000/71 (@ 28.5' TDH) 52,000/75 (@ 24' TDH)	33,500/48 (@ 28.5' TDH) 36,000/52 (@ 22' TDH)	17,500/25 (@ 28' TDH) 20,000/29 (@ 20' TDH)
TDH at BEP	ft	35	33	27
Suction/Discharge Size	in	42	36	30
Motor Voltage	V	4,600	4,600	4,600
Efficiency at BEP	%	88	88	87
Minimum Flow Rate	gpm/mgd	-	-	-
NPSHr at BEP	ft	16	12	-

**As listed in the CCPS O&M Manual and manufacturer pump curves.*

There are eight stormwater pumps in the CCPS. A representative section view of the storm pump configuration is shown in Figure 4-1 above. The pumps were originally rated for 220,810 gpm (318 mgd) at 27 feet TDH and are powered with 2,250 to 2,300-hp synchronous motors operating at 200 rpm. The stormwater pumps are not equipped with suction or discharge valves, nor do they have check valves. Isolation on the suction side was accomplished by installing the pumps above the system hydraulic grade and operating the pumps in a suction lift mode. Priming of the pumps is accomplished by a vacuum priming system. Typically, the storm discharge is flooded prior to priming by opening the bypass between the Conner Creek Sewer and the Conner Storm Discharge (see Figures 2-1A and 2-1B). Conner Storm Discharge isolation and backflow prevention is accomplished by individual discharge siphons on each pump. To achieve the rated stormwater capacities, the pumps require the siphons to operate to minimize the discharge head. Design criteria for the pumps are shown in Table 4-2.

Table 4-2. Existing Conner Storm Pumps Design Criteria*

Item	Unit	Value – Pump Nos. 1-8
Manufacturer	-	Worthington (Flowserve)
Series and Model	-	MIXFLO 84" E71418
Motor Size	hp	Pump Nos. 1-4 = 2300 Pump Nos. 5-6 = 2250 Pump Nos. 7-8 = 2300
Motor Speed (constant)	rpm	200
Flow at BEP	gpm/mgd	-
Rated Capacity	gpm/mgd	220,825/318 (@ 27' TDH)
TDH at BEP	ft	-
Suction/Discharge Size	in	84
Motor Voltage	V	4800
Efficiency at BEP	%	-
Minimum Flow Rate	gpm	-
NPSHr at BEP	ft	-

**As listed in the CCPS O&M Manual and manufacturer pump curves.*

4.2 Operations Assessment

HMI Screen

Figure 4-3 shows the HMI screen for the CCPS. The screen shows all eight (8) storm pumps as "NOT READY", possibly because the vacuum priming system must be activated before the storm pumps can be turned on. GLWA staff have reported that remote start of the CCPS storm pumps is not possible because someone must be at the station to start and monitor the vacuum priming system. There is also one sanitary pump (No. 9) in the "NOT READY" condition. As with FPS, flow rate is displayed, but it is unclear how the flow is measured.

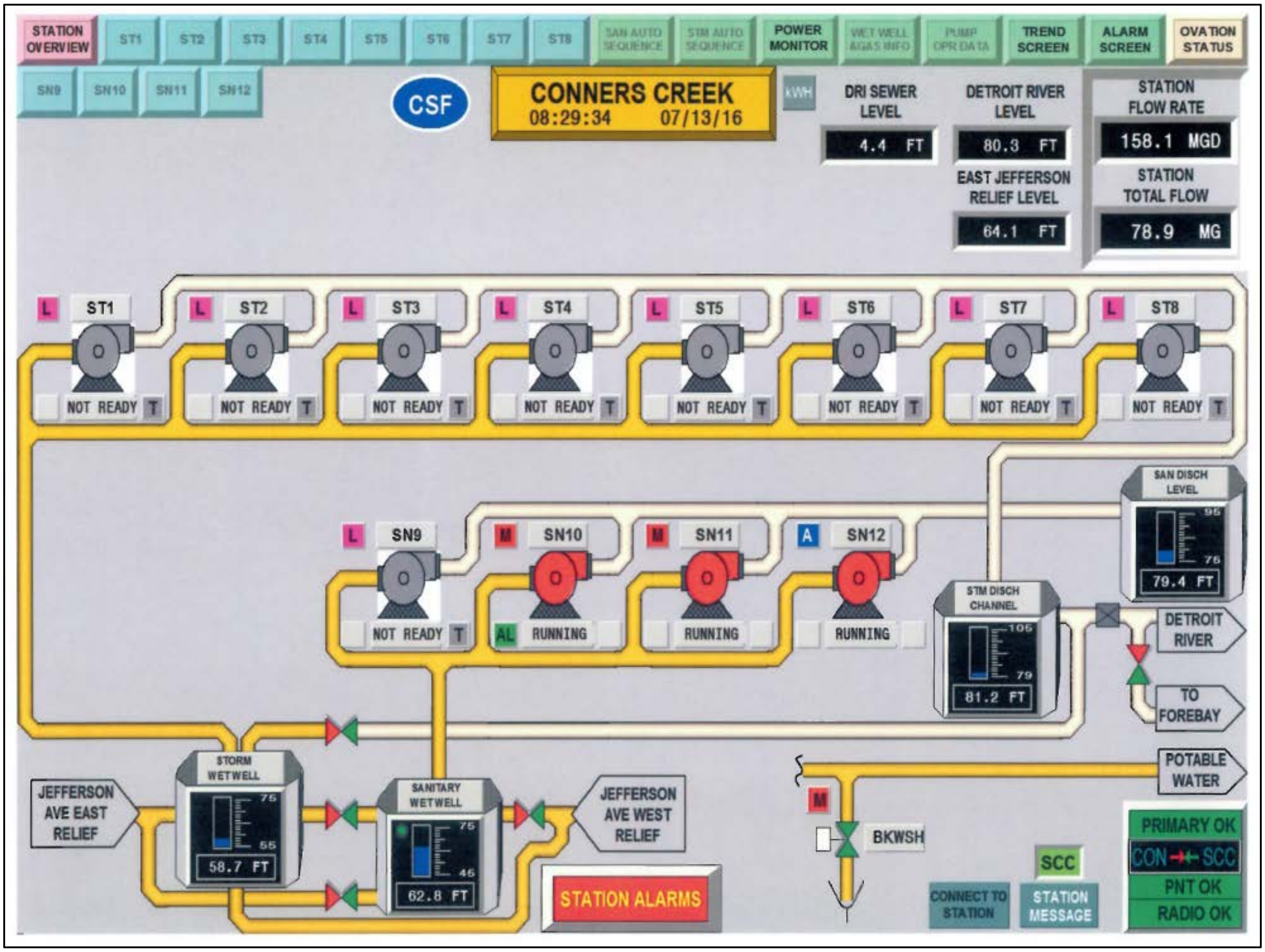

Figure 4-3. Existing Conner Pump Station HMI Screen

Wet Well Control Levels

During dry weather the CCPS receives flow from the E. Jefferson and W. Jefferson Relief Sewers and pumps to the DRI, which flows to the FSPS and ultimately the DWWTP.

CCPS sanitary wet well control levels from the O&M manual are shown in Table 4-3. Note that all elevations in this TM are based on the City of Detroit Datum. The level is maintained inside of a relatively narrow band between EL 59' and EL 65'. GLWA staff report that it is not uncommon for all four pumps to be running during dry weather. Also, contrary to the control levels shown in Table 4-3, GLWA staff have reported that they attempt to balance run time amongst these pumps, and that any pump can be started/stopped at any level deemed appropriate by the operator.

Table 4-3. Wet Well Control Levels for Conner Sanitary Pumps – Dry Weather*		
Pump	Start Elevation (ft)	Stop Elevation (ft)
No. 9 (42")	62	59
No. 10 (36")	63	60
No. 11 (42")	64	61
No. 12 (30")	65	62

As shown in the CCPS O&M manual.

During a wet weather event the CCPS storm pumps turn on and discharge flow to the CCCSO for retention and treatment. Table 4-4 provides the wet well control levels for the CCPS storm pumps as defined in the O&M manual.

Table 4-4. Wet Well Control Levels for Conner Storm Pumps – Wet Weather*		
Pumps	Start Elevation (ft)	Stop Elevation (ft)
No. 1	72	65
No. 2	73	66
No. 3	74	67
No. 4	75	68
No. 5	76	69
No. 6	77	70
No. 7	78	71
No. 8	79	72

As shown in the CCPS O&M manual.

CCPS wet well level and pump run data for the Conner sanitary pumps is shown in Figure 4-4. Data from May 2016 is presented because it represents a period in which the storm pumps were not run, and because a distinct diurnal dry weather pattern could be observed.

Note that changes in the storm and sanitary wet well levels track each other but are offset by about three (3) feet. When flow enters the CCPS it is diverted to the sanitary wet well by an overflow structure. When water levels exceed the height of the overflow structure sewage flows to both wet wells and they become hydraulically connected. The two wet wells are also connected by a 5-ft diameter pipe located between the two structures, which is reportedly normally open. The systematic difference between the two could be attributed to improper setup or calibration of a level sensor in one of the two wet wells.

The sanitary discharge levels were analyzed to determine whether there is a flow restriction at the CCPS sanitary discharge box. Figure 4-4 shows that discharge levels are typically between 76' EL and 84' EL. The ceiling of the discharge structure is at 92' EL so there does not appear to be a restriction in the sanitary discharge box even with all four pumps running.

Despite the control levels listed in the O&M manual, one of the goals of pump station operators is to balance run time between the sanitary pumps, and pumps may be initiated in any order. Also, as the data shows in Figure 4-4, it is not uncommon to have all pumps running under dry weather conditions.

The observed sanitary operating range is illustrated in Figure 4-5, which also shows the wet well control levels from the O&M manual overlaid on a drawing of the pump station. Sanitary control levels are shown in red text and represented graphically by the blue rectangle. The observed operating range is shown by the dashed blue lines. Storm pump control levels are depicted by the green rectangle. The O&M manual calls for the first sanitary pump to be turned on at a wet well level of 62' EL, and the last pump to be turned off at 59' EL. The data in Figure 4-4 shows, however, that most first pump starts are occurring when the wet well is between 68' EL and 72' EL., and most last pump stops are occurring between 65' EL and 67' EL. Actual wet well levels range from 52' EL to 72' EL during this period shown in the figure. This is a significant discrepancy that could be attributed to an incorrectly calibrated level sensor, or an undocumented change in operating procedure from what is in the O&M manual.

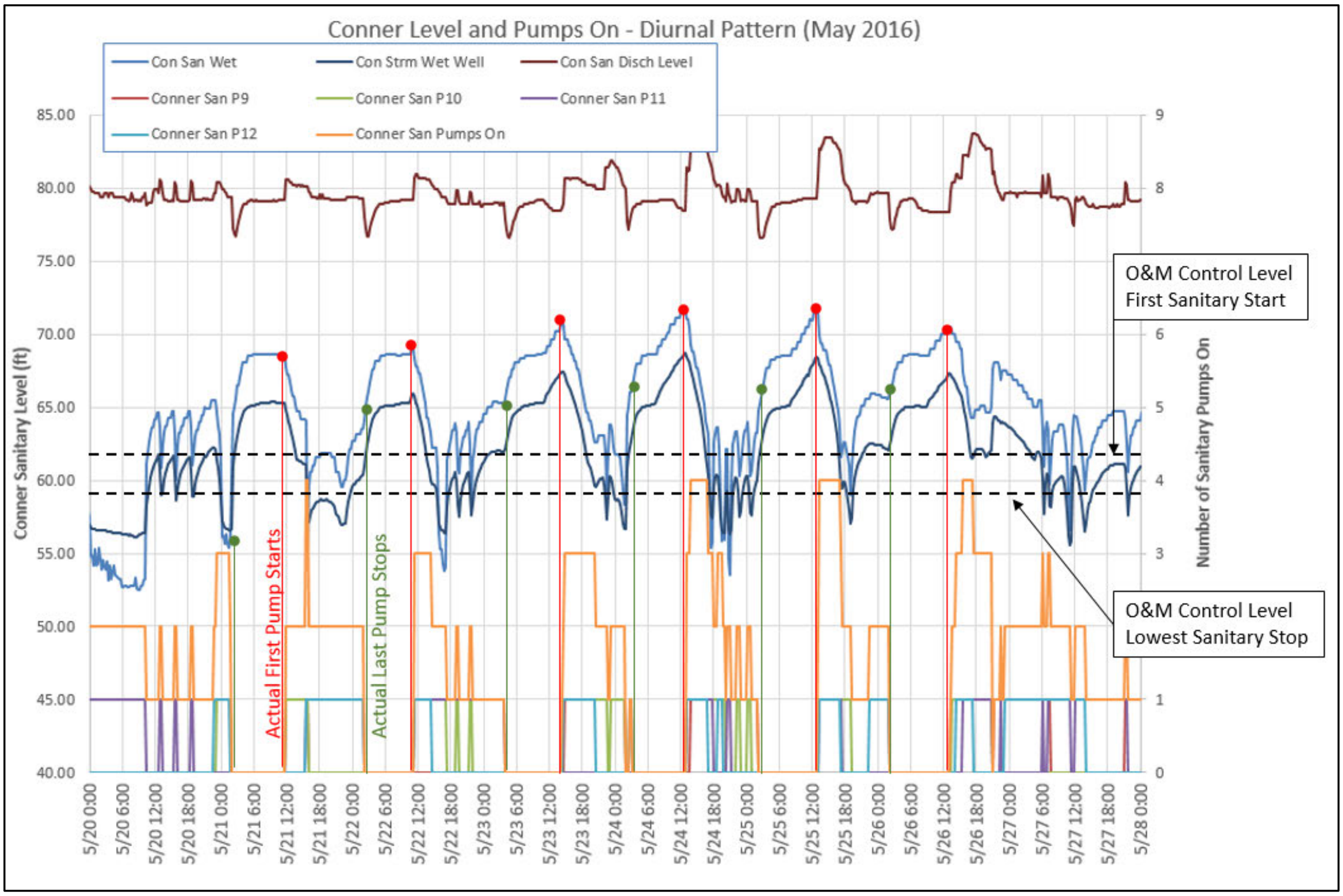

Figure 4-4. CCPS Wet Well Level, Discharge Level, and Sanitary Pump Operation Data

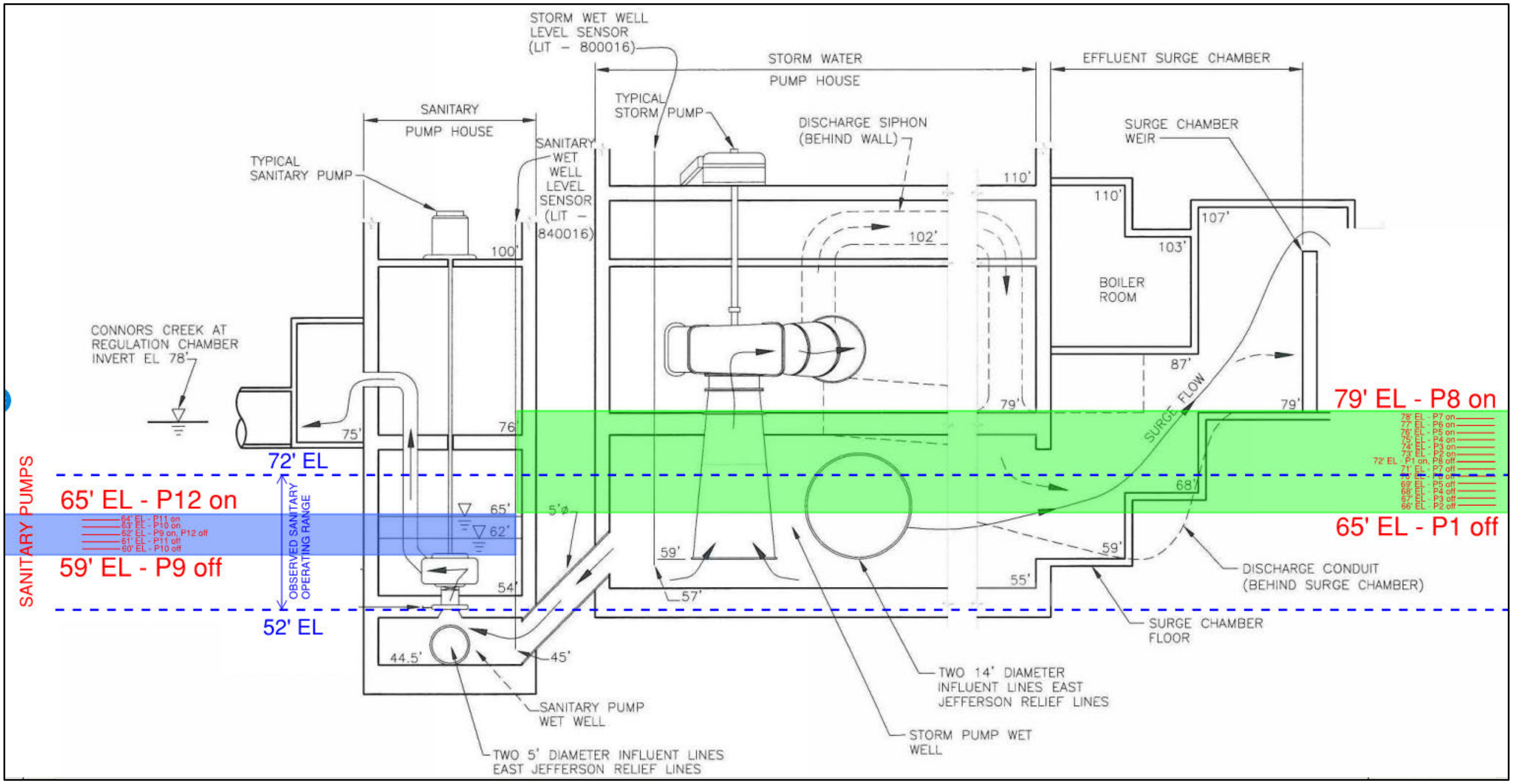

Figure 4-5. CCPS Wet Well Control Levels and Observed Sanitary Operating Range.

Neither run time data nor discharge elevation data were available for CCPS storm pumps. It is possible that the pumps were not run during the period from January 2013 to May 2016, but this should be confirmed by GLWA.

Pump Run Time

Run time data for the CCPS sanitary pumps is summarized in Tables 4-5 and 4-6. In 2015 Pump No. 9 received the least run time, Pump Nos. 10 and 11 received approximately twice as much each as Pump No. 9, and Pump No. 12 received the most run time (about 3 times as much as Pump No. 9). In 2016 Pump Nos. 9 and 10 received about 50 percent more run time than Pump Nos. 11 and 12.

Table 4-5. CCPS Sanitary Pump Annual Runtime Data: January 2015 to May 2016

Year	Pump Run Time (hours)				Out of Possible (hours)
	Pump No. 9	Pump No. 10	Pump No. 11	Pump No. 12	
2015	1,780	3,989	3,546	4,581	8,760
2016	2,643	2,226	1,659	1,596	4,656

Table 4-6. Number of CCPS Sanitary Pumps in Operation: January 2015 to May 2016

Year	Hours of Operation with Number of Pumps in Service					Out of Possible (hours)
	0 Pumps On	1 Pump On	2 Pumps On	3 Pumps On	4 Pumps On	
2015	833 (10%)	3393 (38%)	3242 (37%)	1149 (13%)	144 (2%)	8,760
2016	688 (15%)	1321 (28%)	1535 (33%)	715 (15%)	397 (9%)	4,656

Pump and System Curves

For the CCPS sanitary pumps, we have included two system curves, which correspond to the boundaries of the operating range observed in the data analysis. Wet well control levels from the O&M manual are included on the graphs for comparison to the observed operating range. Pump and system curves for the Conner sanitary pumps are shown in Figure 4-6 through Figure 4-8 below. The wet well control levels published in the O&M manual fall well within the POR for all the CCPS sanitary pumps. However, GLWA staff have reported that operators attempt to balance run time amongst these pumps, so any pump may be operating at any point on the observed operating region. The observed operating region includes parts of the pump curve to the right of the POR for all the pumps, so at times when wet well levels are highest the pumps operate outside of the POR.

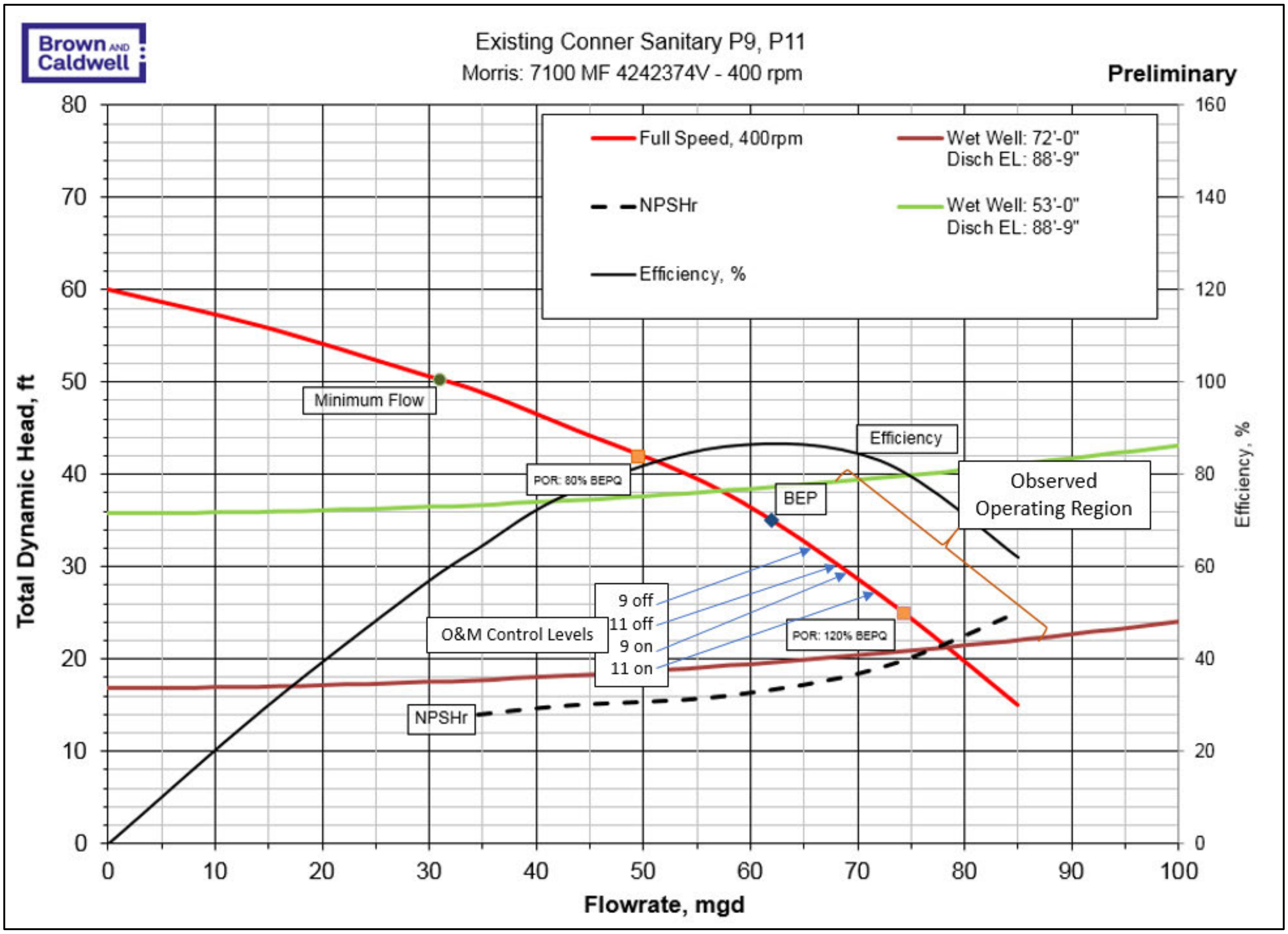

Figure 4-6. Pump and System Curves for Existing Conner Sanitary Pump Nos. P9 and P11

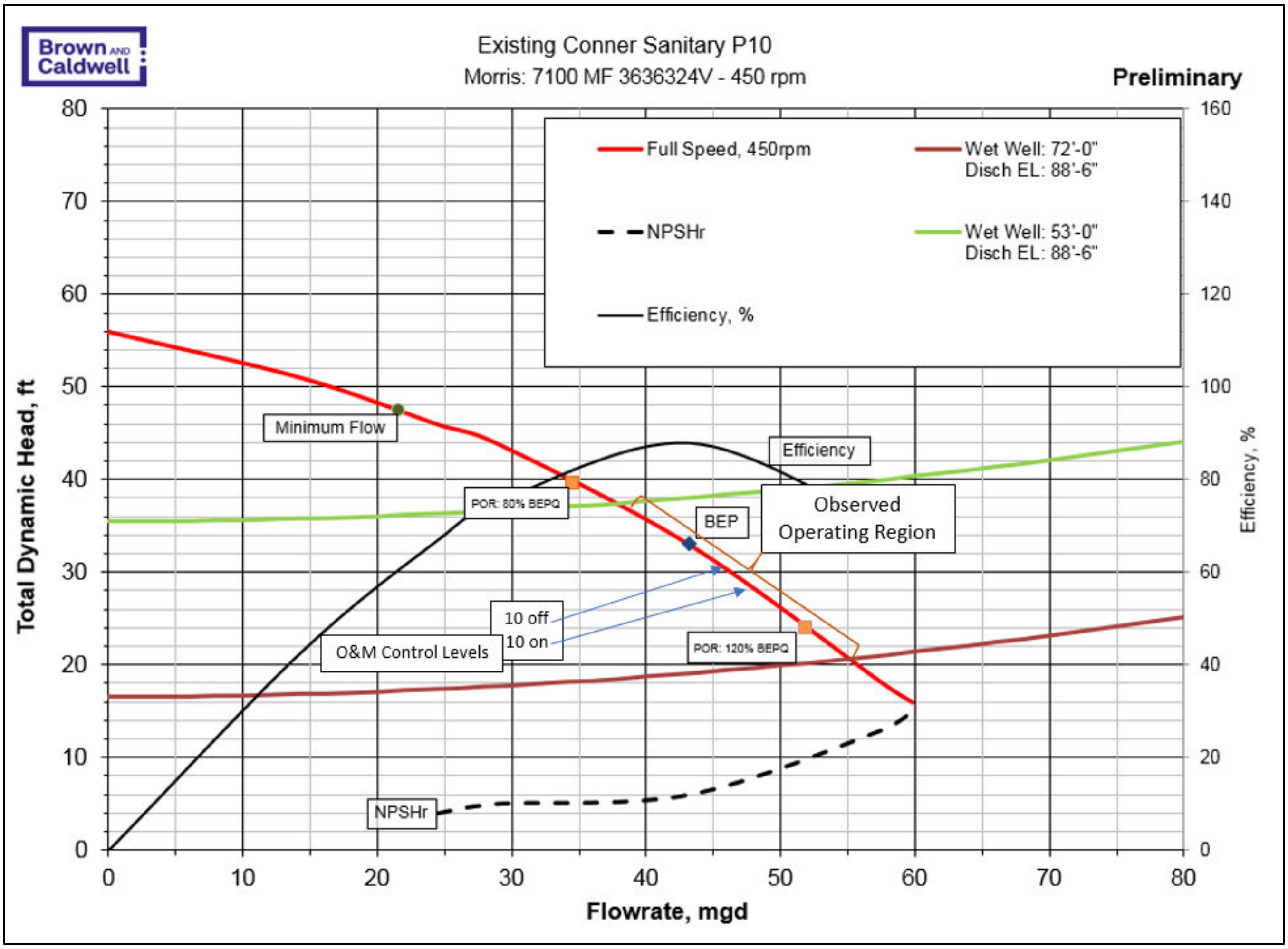

Figure 4-7. Pump and System Curves for Existing Conner Sanitary Pump No. P10

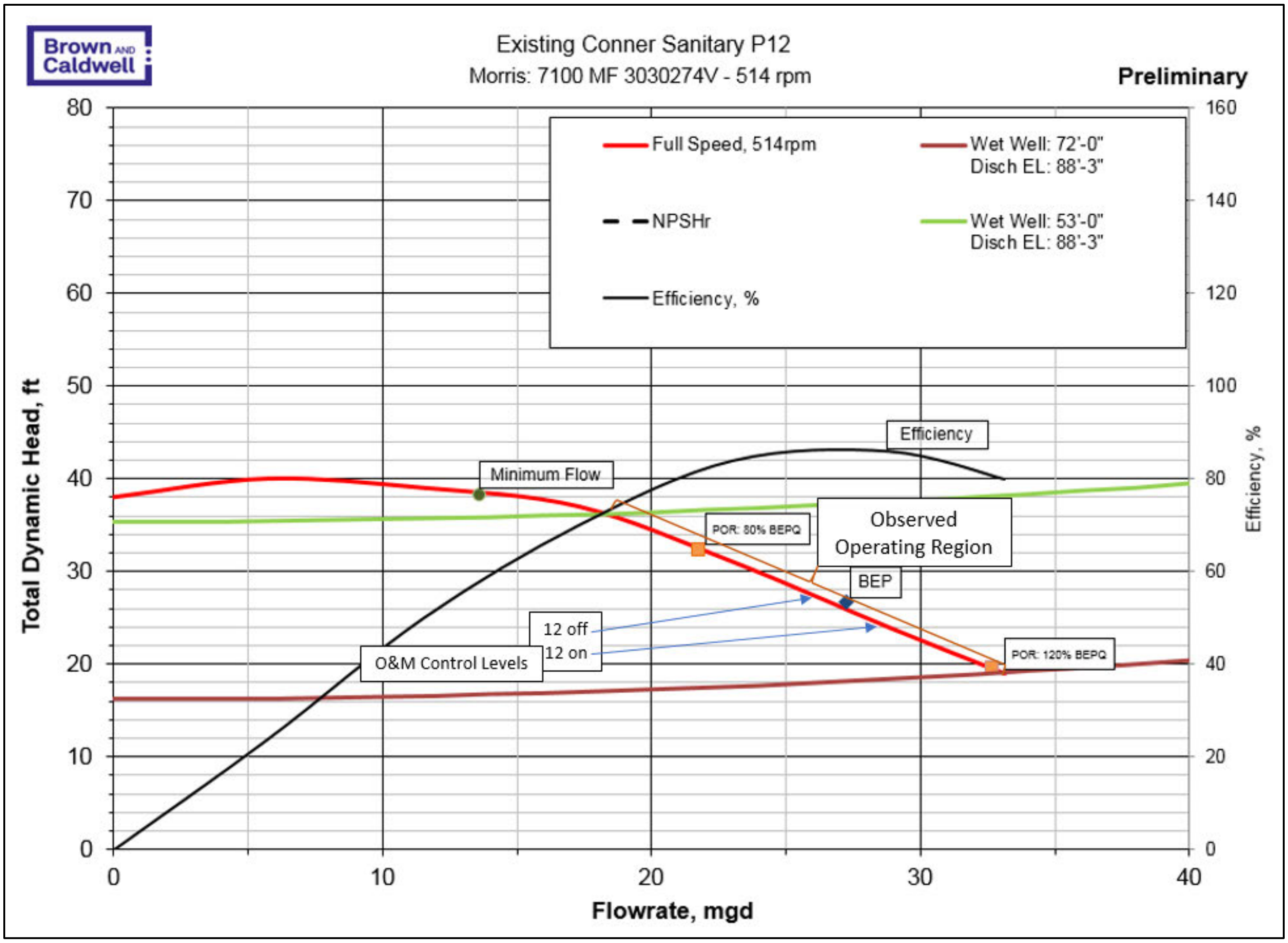

Figure 4-8. Pump and System Curves for Existing Conner Sanitary Pump No. P12

Pump operation data for the CCPS storm pumps was not available, so an observed operating range is not provided with Figure 4-9. There are four system curves presented; two that correspond to a scenario in which a siphon is established in the pump discharge conduit, and two that correspond to a scenario in which a siphon is not established. The assumed operating range corresponds to the wet well control levels provided in the O&M manual and presented on the graph below. Note that the pump curves provided by the manufacturer only graph the portion of the curve to the right of the BEP. Nevertheless, all control levels, except the Pump No. 8 “on” level fall within the POR. Similar to the Freud storm pumps, these pumps are operating over a large range of wet well levels, so flow will vary significantly even if the number of pumps running stays constant

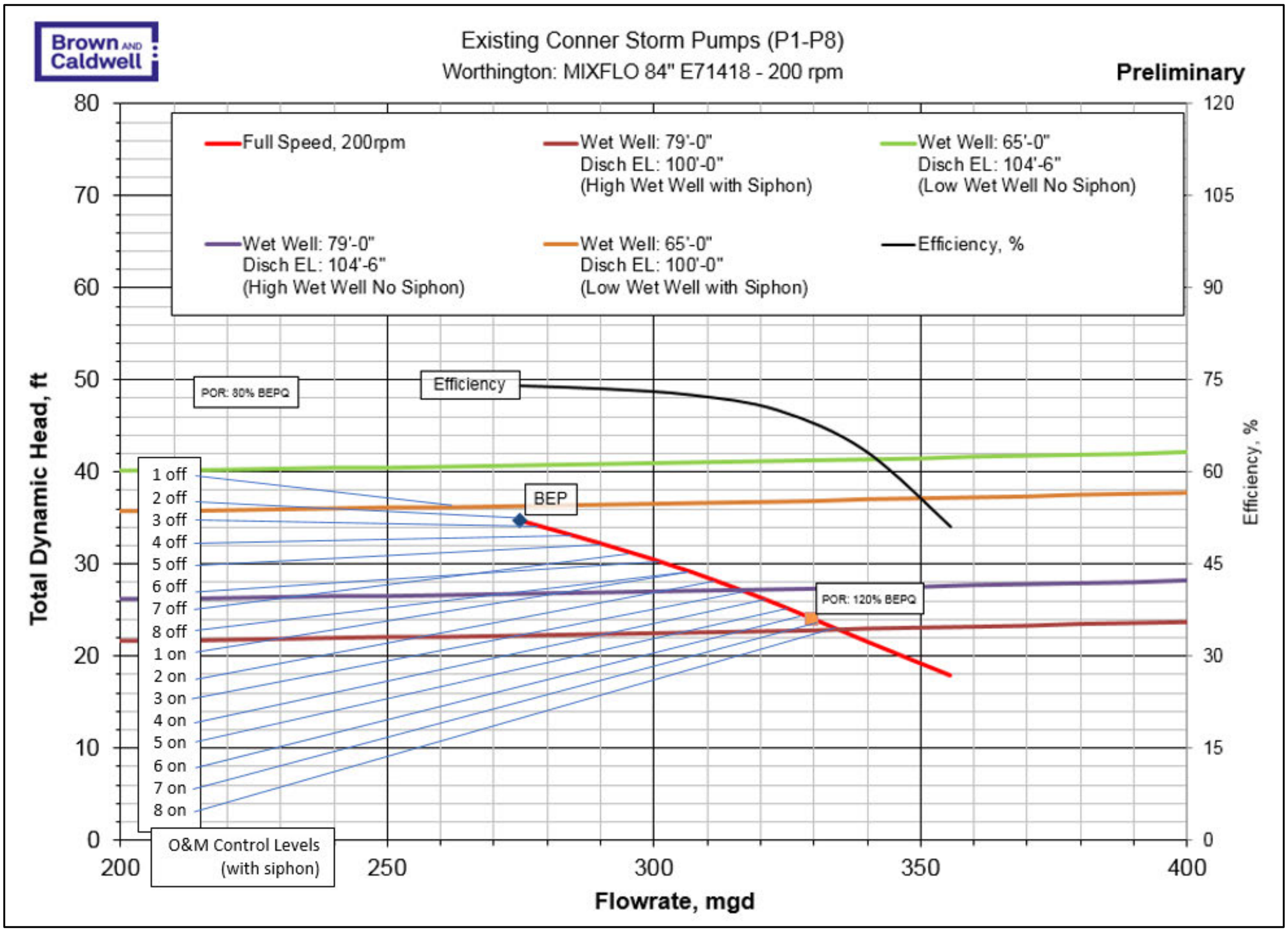

Figure 4-9. Pump and System Curves for Existing Conner Storm Pumps

Vacuum Priming System

The current operation of the vacuum priming system (based on the laminated instructions onsite) requires a minimum wet well elevation of 67 feet and a minimum discharge channel elevation of 83 feet. The storm water pumps have a discharge centerline elevation is 87.63 feet. In order to prime the pump at the minimum elevations noted, water must be lifted 20.6 feet on the suction side and/or 19 feet on the discharge side before the pump will prime. The current starting sequence is to turn the storm pump on first before initiating the vacuum priming pumps. Therefore, water is likely overflowing the siphon weir crest and cascading down the discharge flume into the rotating impeller before the water is fully lifted into the pump on the suction side. Priming from the discharge side with a rotating impeller is not ideal as it is likely causing vibration and producing a great deal of foam due to the agitation of the impeller and the low vapor pressure inside the pump. This scenario impedes the priming process. GLWA operations reports that the pumps do not have sufficient horsepower to prime if the vacuum priming system is actuated first and the pump started when the water is lifted to the impeller centerline elevation. As each subsequent pump is started, priming from the discharge side becomes easier as the water level in the discharge channel rises.

NPSH Margin and Suction Intake Conditions

Per ANSI HI 9.6.1 – Guideline for NPSH Margin, the recommended minimum NPSH margin is 1.1 – 1.3 for large wastewater pumps. The NPSH margins for existing sanitary pumps 9, 10, and 11 were evaluated at elevations that correspond to their observed operating ranges. NPSH margins could not be calculated for the Pump No. 12 nor the storm pumps because NPSH3 data is not provided with the manufacturer's pump curve data.

The formulas used for the calculations are:

NPSH margin ratio = NPSHA / NPSH3

NPSHA = $h_{atm} + h_s + z_s - h_L - h_{vp} - SF$

Where:

NPSHA = Net Positive Suction Head Available

NPSH3 = Net Positive Suction Head at which a 3% reduction in total head occurs

h_{atm} = atmospheric pressure head

h_s = suction head

z_s = elevation head

h_L = minor losses in suction piping

h_{vp} = liquid vapor pressure head

SF = safety factor (5-ft for wastewater).

Table 4-10 summarizes the NPSH margins for the CCPS sanitary pumps.

Table 4-10. CCPS NPSH Margins

Pump No.	Wet Well EL (ft)	NPSH Margin
9 and 11	53	1.18
	72	1.72
10	53	3.83
	72	3.18

There is sufficient NPSH margin under all conditions except for Pump Nos. 9 and 11 at low wet well levels. Pumps 9 and 11 are operating at the minimum recommended NPSH margin, making them more susceptible to pre-cavitation and cavitation phenomena. The narrow NSPH margin could also compound with poor intake conditions to exacerbate negative effects on the pump. GLWA staff have reported that Pump No. 9 is currently out of service and that the rotating assembly is severely damaged. This is consistent with a pump that is operating in poor hydraulic conditions.

A 1997 study of the sanitary wet well hydraulics is provided in Attachment D. This study was performed using a physical hydraulic model of the pump station, constructed at the University of Michigan. Testing showed that head loss at the inlets combined with the small wet well volume resulted in air entrainment and vortices throughout the wet well. It should be noted that the 1997 study did not investigate the impact of the third wet well inlet (to the storm wet well) nor the impact of basket strainers (neither clean or blinded condition).

Suction intake conditions in the CCPS wet well are being further evaluated with a new laboratory physical hydraulic model study.

4.3 Major Findings for Conner Creek Pump Station

The major findings from this evaluation of the CCPS are presented in the list below.

1. Conner Sanitary Pump Station
   a. Sanitary wet well level data is offset from storm wet well level data at times when the two are hydraulically connected, possibly indicating an improperly calibrated level sensor.
   b. Pumps are not being operated to the control elevations defined in the O&M manual.
   c. Pumps run outside of their POR when wet well levels are high.
   d. NPSH margin is near the minimum recommended by the HI for pumps 9 and 11 at lower wet well levels.
   e. Suction intake conditions are known to be poor based on previous studies. These studies did not account for basket strainers nor the use of the third wet well inlet (from the storm wet well). It is anticipated that the basket strainers will negatively impact pump operation.
2. Conner Storm Pump Station
   a. There is no run time or discharge elevation data for the storm pumps between January 2015 and May 2016.
   b. Pumps are not equipped with isolation valves or check valves.
   c. HMI screen shows all eight (8) pumps as “NOT READY”.
   d. An operator must be on site to monitor the vacuum priming system when storm pumps are started.
   e. The wet well control levels outlined in the O&M manual indicate that the pumps operate within their POR.
   f. Pumps operate over a wide range of wet well levels, resulting in large flow variations even when the number of pumps running is constant.
   g. A connection between the Conner Discharge Channel and the Conner Gravity Sewer is currently left open to assist with keeping the Conner Storm Pump Siphon outlet submerged. It is presumed that this gate is closed once the either the Freud Storm or Conner Storm pumps are put into operation.
   h. The priming system is complex and operationally unforgivingIt requires manual operation by GLWA staff during a storm event to make sure the pumps prime.
   i. Priming sequence is contributing to priming difficulties due to pump running as water fills the pump.
   j. Priming is occurring from the discharge side because the elevation difference between the water surface in the outlet channel to the siphon crest elevation is less than the elevation difference between the pump discharge centerline elevation and the suction well water surface elevation.

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Attachment A: Collection System Reference Drawings

[redacted]

	description	ckd.	apprv.	date
D	BID ISSUE			9-21-98
C	100% REVIEW			5-8-98
B	95% REVIEW			5-30-97
A	95% OWNER REVIEW			9/30/94
	revisions			

drawn by : NYS

checked by : JVH

project manager : RV

FOX CREEK BACKWATER GATE BUILDING
REHABILITATION PROJECT

STORM WATER PUMP HOUSE

SCHEMATIC OF CONNORS - FREUD SYSTEM

scale : NOT TO SCALE

date : 09/29/88

WATER AND SEWERAGE DEPARTMENT

ENGINEERING DIVISION

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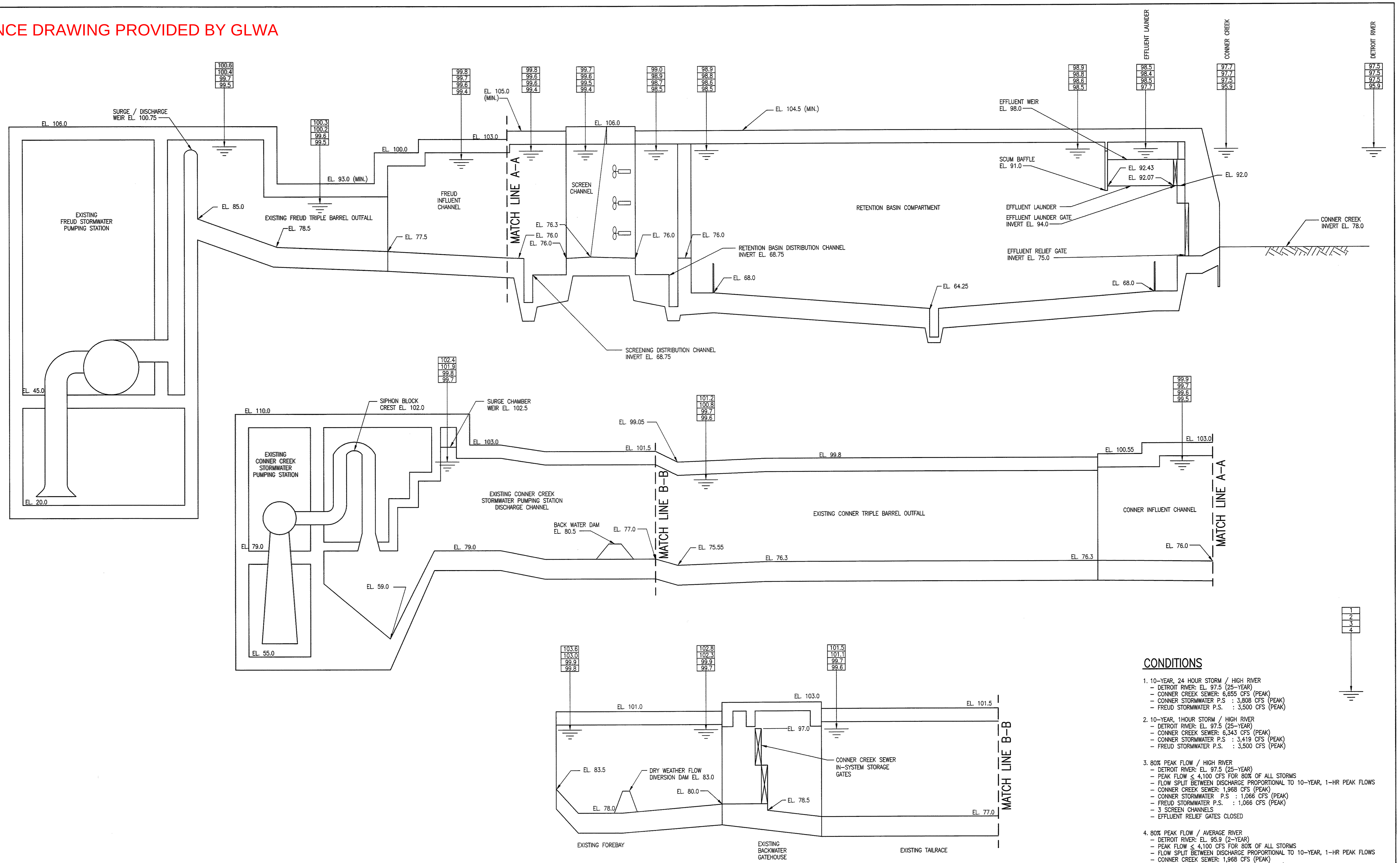
sheet no : D-94-12-12

REFERENCE DRAWING PROVIDED BY GLWA



CONDITIONS

1. 10–YEAR, 24 HOUR STORM / HIGH RIVER
   - DETROIT RIVER: EL. 97.5 (25–YEAR)
   - CONNER CREEK SEWER: 6,655 CFS (PEAK)
   - CONNER STORMWATER P.S : 3,808 CFS (PEAK)
   - FREUD STORMWATER P.S. : 3,500 CFS (PEAK)
2. 10–YEAR, 1HOUR STORM / HIGH RIVER
   - DETROIT RIVER: EL. 97.5 (25–YEAR)
   - CONNER CREEK SEWER: 6,343 CFS (PEAK)
   - CONNER STORMWATER P.S : 3,419 CFS (PEAK)
   - FREUD STORMWATER P.S. : 3,500 CFS (PEAK)
3. 80% PEAK FLOW / HIGH RIVER
   - DETROIT RIVER: EL. 97.5 (25–YEAR)
   - PEAK FLOW ≤ 4,100 CFS FOR 80% OF ALL STORMS
   - FLOW SPLIT BETWEEN DISCHARGE PROPORTIONAL TO 10–YEAR, 1–HR PEAK FLOWS
   - CONNER CREEK SEWER: 1,968 CFS (PEAK)
   - CONNER STORMWATER P.S : 1,066 CFS (PEAK)
   - FREUD STORMWATER P.S. : 1,066 CFS (PEAK)
   - 3 SCREEN CHANNELS
   - EFFLUENT RELIEF GATES CLOSED
4. 80% PEAK FLOW / AVERAGE RIVER
   - DETROIT RIVER: EL. 95.9 (2–YEAR)
   - PEAK FLOW ≤ 4,100 CFS FOR 80% OF ALL STORMS
   - FLOW SPLIT BETWEEN DISCHARGE PROPORTIONAL TO 10–YEAR, 1–HR PEAK FLOWS
   - CONNER CREEK SEWER: 1,968 CFS (PEAK)
   - CONNER STORMWATER P.S : 1,066 CFS (PEAK)
   - FREUD STORMWATER P.S. : 1,066 CFS (PEAK)
   - 3 SCREEN CHANNELS
   - EFFLUENT RELIEF GATES CLOSED

PHS–005.DWG 8/26/99 GV

	DESCRIPTION	CHECKED	APRVD	DATE
F				
E				
D				
C				
B				
A				
	REVISIONS			

DESIGN CDC
DRAFTING GV
CHECKED CSH
APPROVED AJV

DETROIT WATER AND SEWERAGE DEPARTMENT
WASTEWATER COLLECTION SYSTEM IMPROVEMENTS
CONNER CREEK PILOT CSO CONTROL FACILITY

HYDRAULIC PROFILE

SCALE: NONE   DATE: JULY, 2000

HAZEN AND SAWYER Environmental Engineers & Scientists
SIGMA
MALCOLM PIRNIE
HEC
Hamilton Anderson Associates Architecture Landscape Architecture Urban Design Planning

CITY OF DETROIT
WATER AND SEWERAGE DEPARTMENT
ENGINEERING DIVISION

SECTION MAPS	TOWN	RANGE
6 2 C 6 2 D	T 1 S T 2 S	R 1 3 E

M.D.P.H./D.N.R. PERMIT NO. SRF 5175–03
DRMS NO. 001799
CONTRACT NO. PC–739
DWG NO. D–99–03–403

Attachment B: Pumping System Reference Drawings

M F 1957

NOTED BY		DESCRIPTION	DR'N	CK'D	AP'VD	DATE
	G					
	F					
	E					
	D	4" DRAIN LINE (VALVE WELL) RELOCATED	L.H.	[illegible]	[illegible]	12/22/52
	C	DIMENSIONS FOR PIPING ADDED	L.H.	[illegible]	[illegible]	[illegible]
	B	REVISED PER BULL. 2-5	FSK	[illegible]	[illegible]	[illegible]
	(A)	EL. 96.5' CHANGED TO 95.5'	L.H.	[illegible]	[illegible]	[illegible]

REVISIONS

REFERENCE DRAWINGS

DESIGNED BY P. Perkins
DRAWN BY L. Hartzell
TRACED BY L. Hartzell
CHECKED BY [illegible]

APPROVED: [signature]
MECHANICAL ENGINEER [signature]
ASS'T. CITY ENGINEER [signature]
CITY ENGINEER

CITY OF DETROIT
DEPARTMENT OF PUBLIC WORKS
CITY ENGINEERS OFFICE
FOR
DEPARTMENT OF PUBLIC WORKS

FOX CREEK DISTRICT
FREUD STORM WATER PUMPING STATION
CASTINGS AND PIPING FOR PUMPS

DEWATERING PUMP PIPING

SCALE NOTED

SHEET 1 OF 4 SHEETS
JOB No. P W 1071-B4
DRWG No. M-1
DATE APRIL 28-1952

67IV B4

3BP 5/10/50
15BP 5/31/50
1BP 6-1-50
1BP 11/8/50
3BP 12/27/50
4BP 2/6/51
1BP 3/14/51
1BP 6/6/51

[redacted]

	G						REFERENCE DRAWINGS
	F						
	E						
	D						
	C	PUMPS NO'S. 9 & 10 RELOCATED	L.H.			6/5/51	
	B	PIPING FOR DEWATERING PUMPS REARRANGED	L.H.			6/5/51	
	A	GEN'L REVISION TO SUIT PUMP SUCTION DESIGN	J.S.	A.P.		7/5/50	
NOTED BY		DESCRIPTION	DR'N	CK'D	AP'VD	DATE	
		REVISIONS					

DESIGNED BY	
DRAWN BY	John Newman
TRACED BY	John Newman
CHECKED BY	

APPROVED:
MECHANICAL ENGINEER
ASS'T CITY ENGINEER
CITY ENGINEER

CITY OF DETROIT
DEPARTMENT OF PUBLIC WORKS
CITY ENGINEERS OFFICE
FOR
THE DEPARTMENT OF PUBLIC WORKS

FOX CREEK DISTRICT
ELECTRIC MOTOR DRIVEN PUMPS
FREUD STORM WATER PUMPING STATION

GENERAL ARRANGEMENT
DEWATERING PUMPING UNITS

SCALE: 1/2" = 1'-0"

SHEET 3 OF 7 SHEETS
JOB No. PW-1071-A
DRWG No. M-3
DATE APRIL 1950

M F 1952

[redacted]

						REFERENCE DRAWINGS
COOR'D	DESCRIPTION	DR'N	CK'D	AP'VD	DATE	

REVISIONS LOCATED BY COORDINATES ON SHEET

DESIGNED BY	P. Perkins	APPROVED: W. Ludd
DRAWN BY	L. Hartzell	MECHANICAL ENGINEER
TRACED BY	L. Hartzell	ASSISTANT CITY ENGINEER
CHECKED BY	D. Stettler	CITY ENGINEER

CITY OF DETROIT
DEPARTMENT OF PUBLIC WORKS
CITY ENGINEERS OFFICE
FOR
DEPARTMENT OF PUBLIC WORKS

FOX CREEK DISTRICT
FREUD STORM WATER PUMPING STATION
CASTINGS AND PIPING FOR PUMPS

DEWATERING PUMP PIPING DETAILS

SCALE NOTED

SHEET 2 OF 4 SHEETS
CONTRACT No. PW 1071 B-4
DRWG No. M-2
DATE APRIL 28-1952

67784

Rev. A	Replaced steel Sec B-B & Sec. C-C	EM	EM	EM	1-6-53
COOR'D	DESCRIPTION	DR'N	CK'D	APVD	DATE

REVISIONS LOCATED BY COORDINATES ON SHEET

REFERENCE DRAWINGS

DESIGNED BY E. Mitchell
DRAWN BY S.P. Gross
TRACED BY S.P. Gross
CHECKED BY E. Mitchell

APPROVED: ARCHITECTURAL ENGINEER; ASSISTANT CITY ENGINEER; G.R. Thompson, CITY ENGINEER

CITY OF DETROIT
DEPARTMENT OF PUBLIC WORKS
CITY ENGINEERS OFFICE
FOR
THE DEPARTMENT OF PUBLIC WORKS

FOX CREEK DISTRICT
FREUD STORM WATER PUMPING STATION
SUB-STRUCTURE

SECTIONS - PUMP DISCHARGE FLUME
SCALE AS NOTED

SHEET 23 OF 39 SHEETS
CONTRACT No. PW-1071-B2
DRWG No. S-23
DATE JUNE 1952

Discharge and surge weir elevations raised to 100.75' under PC-739

REFERENCE DRAWING PROVIDED BY GLWA

REVISIONS					
A	Changed Sewer Inlets	E.M.		E.M.	10-30-51

DESIGNED BY: L.F. KEYS
DRAWN BY: L.F. KEYS
TRACED BY: L.F. KEYS
CHECKED BY: E. Mitchell

APPROVED: ARCHITECTURAL ENGINEER; ASST. CITY ENGINEER; CITY ENGINEER

CITY OF DETROIT
DEPARTMENT OF PUBLIC WORKS
CITY ENGINEERS OFFICE
FOR
DEPARTMENT OF PUBLIC WORKS

FOX CREEK DISTRICT
FREUD STORM WATER PUMPING STATION
CAISSON

DEVELOPED INNER FACE AT SEWER INLETS

SHEET 6 OF 13 SHEETS
JOB No. PW-1071-B1
DRWG No. S-6
DATE FEB. 15, 1951

67 III B1

REFERENCE DRAWING PROVIDED BY GLWA

F:\PROJECTS\9821\STRUCT\STY-304.DWG

F					DESIGN SM
E					
D					DRAFTING JE
C					
B					CHECKED AG
A	1 PROJECT RECORD DRAWINGS	ES	PY	9/19/05	APPROVED AG
	DESCRIPTION	CHECKED	APRVD	DATE	
	REVISIONS				

DETROIT WATER AND SEWERAGE DEPARTMENT
WASTEWATER COLLECTION SYSTEM IMPROVEMENTS
CONNER CREEK PILOT CSO CONTROL FACILITY
FREUD STORMWATER PUMPING STATION
SURGE AND DISCHARGE WEIR MODIFICATIONS
SECTIONS

SCALE: AS SHOWN DATE: JULY 2000

HAZEN AND SAWYER Environmental Engineers & Scientists
SIGMA
MALCOLM PIRNIE
HEC
Hamilton Anderson Associates

CITY OF DETROIT
WATER AND SEWERAGE DEPARTMENT
ENGINEERING DIVISION

SECTION MAPS						TOWN						RANGE			
6	2	C	6	2	D	T	1	S	T	2	S	R	1	3	E

M.D.P.H./D.N.R. PERMIT NO. SRF 5175-03
DRMS NO. 001799
CONTRACT NO. PC-739
DWG NO. D-99-03-304

REFERENCE DRAWING FOR PW-1071-B2

REVISIONS					REFERENCE DRAWINGS
NOTED BY	DESCRIPTION	DR'N	CK'D	APV'D	DATE

DESIGNED BY	P. Perkins	APPROVED:	(signature) MECHANICAL ENGINEER
DRAWN BY	F. G. Dengler		(signature) ASST. CITY ENGINEER
TRACED BY	F. G. Dengler		(signature) CITY ENGINEER
CHECKED BY	(signature)		

CITY OF DETROIT
DEPARTMENT OF PUBLIC WORKS
CITY ENGINEERS OFFICE
FOR
THE DEPARTMENT OF PUBLIC WORKS

FOX CREEK DISTRICT
FREUD STORM WATER PUMPING STATION
CASTINGS AND PIPING FOR PUMPS

SUCTION CASTINGS & ASSEMBLY

SCALE: AS INDICATED

SHEET 3 OF 4 SHEETS
JOB No. PW 1071 B4
DRWG No. M-3
DATE APRIL 28-1952

JOB No. 67 IV B(2)

REFERENCE DRAWING PROVIDED BY GLWA

REFERENCE DRAWING FOR PW-1071-B2

REVISIONS		
NOTED BY	DESCRIPTION	DR'N / CK'D / AP'VD / DATE

REFERENCE DRAWINGS

DESIGNED BY P. Perkins
DRAWN BY L. Hartzell
TRACED BY L. Hartzell
CHECKED BY

APPROVED:
MECH. ENG'R.
ASS'T. CITY ENG'R.
CITY ENGINEER

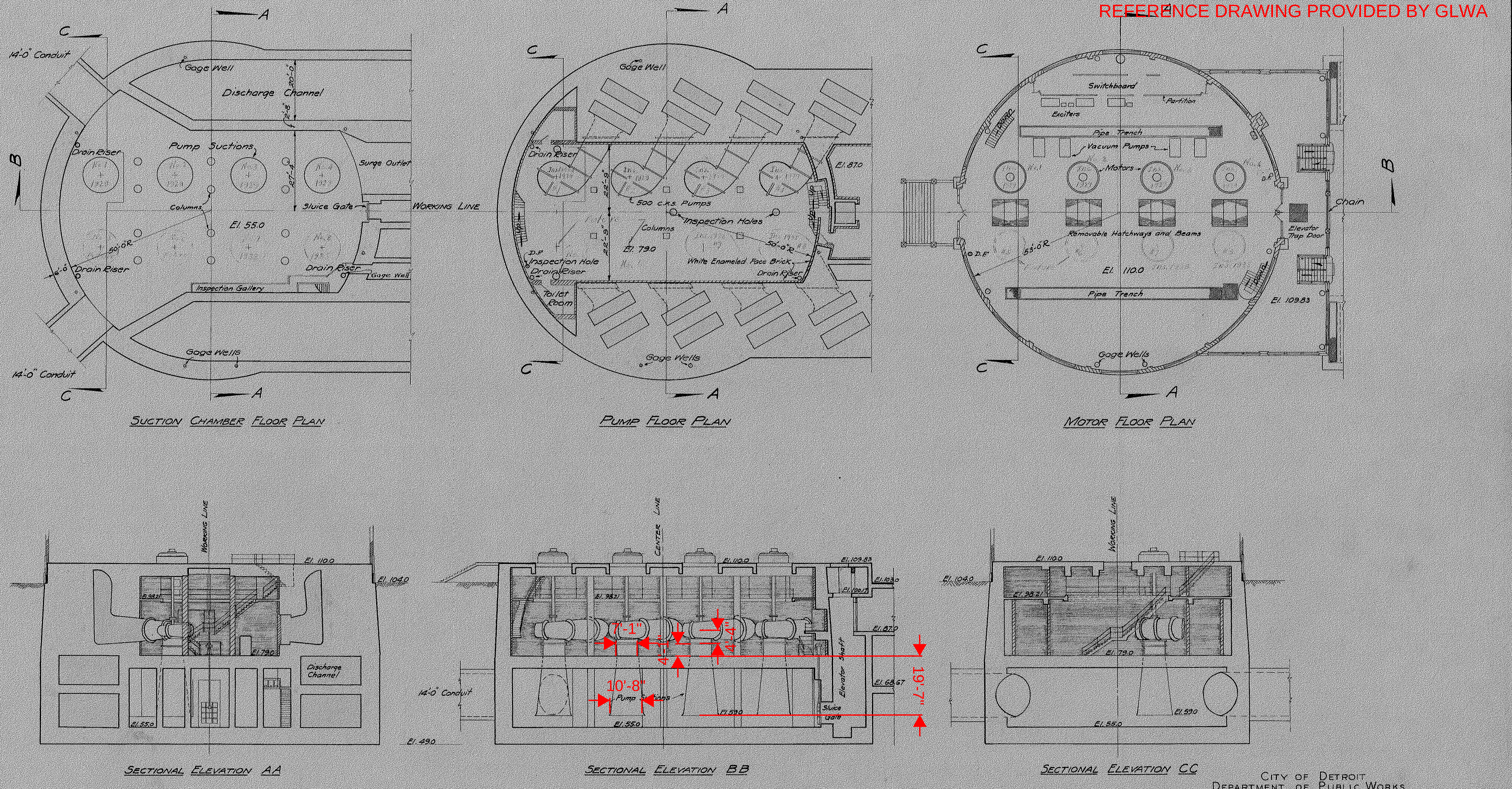
CITY OF DETROIT
DEPARTMENT OF PUBLIC WORKS
CITY ENGINEERS OFFICE
FOR
DEPARTMENT OF PUBLIC WORKS

FOX CREEK DISTRICT
FREUD STORM WATER PUMPING STATION
CASTINGS AND PIPING FOR PUMPS

DISCHARGE CASTINGS & ASSEMBLY

SCALE AS NOTED

SHEET 4 OF 4 SHEETS
JOB No. PW 1071 B4
DRWG No. M-4
DATE APRIL 28 - 1952



Approved:

M. F. Wagner
Assistant Engineer
Perry A. Fellows
City Engineer

REVISED AS PER LETTER OF OCT. 31ST 1928
JAN. 25, 1929 BY C.S.M.
CHECKED BY M.H.H.

City of Detroit
Department of Public Works
City Engineers Office

Connors Creek Storm Water Pumping Station
Main Building — Substructure
General Plan & Elevation

Scale – $\frac{1}{16}$" = 1'-0"   Date – August 1928

PREPARED BY AYRES, LEWIS, NORRIS & MAY

Sheet No. 2 of 108 Sheets

[redacted]

Scale $\frac{1}{8}$"=1'-0"

Scale $\frac{1}{8}$"=1'-0"

Note: See Sheet #97-98-99-100 for Heating Duct Details
See Sheet #23 for Steam Pipe Trenches in Main Floor
See Sheet #20 for Sections AA, BB, CC, DD, EE, FF, GG, HH.
See Sheet #19 for Sections II, KK, LL, MM, NN, OO, PP, QQ, RR

Approved:- M. F. Wagnitz
Assistant Engineer
Perry A. Fellows
City Engineer

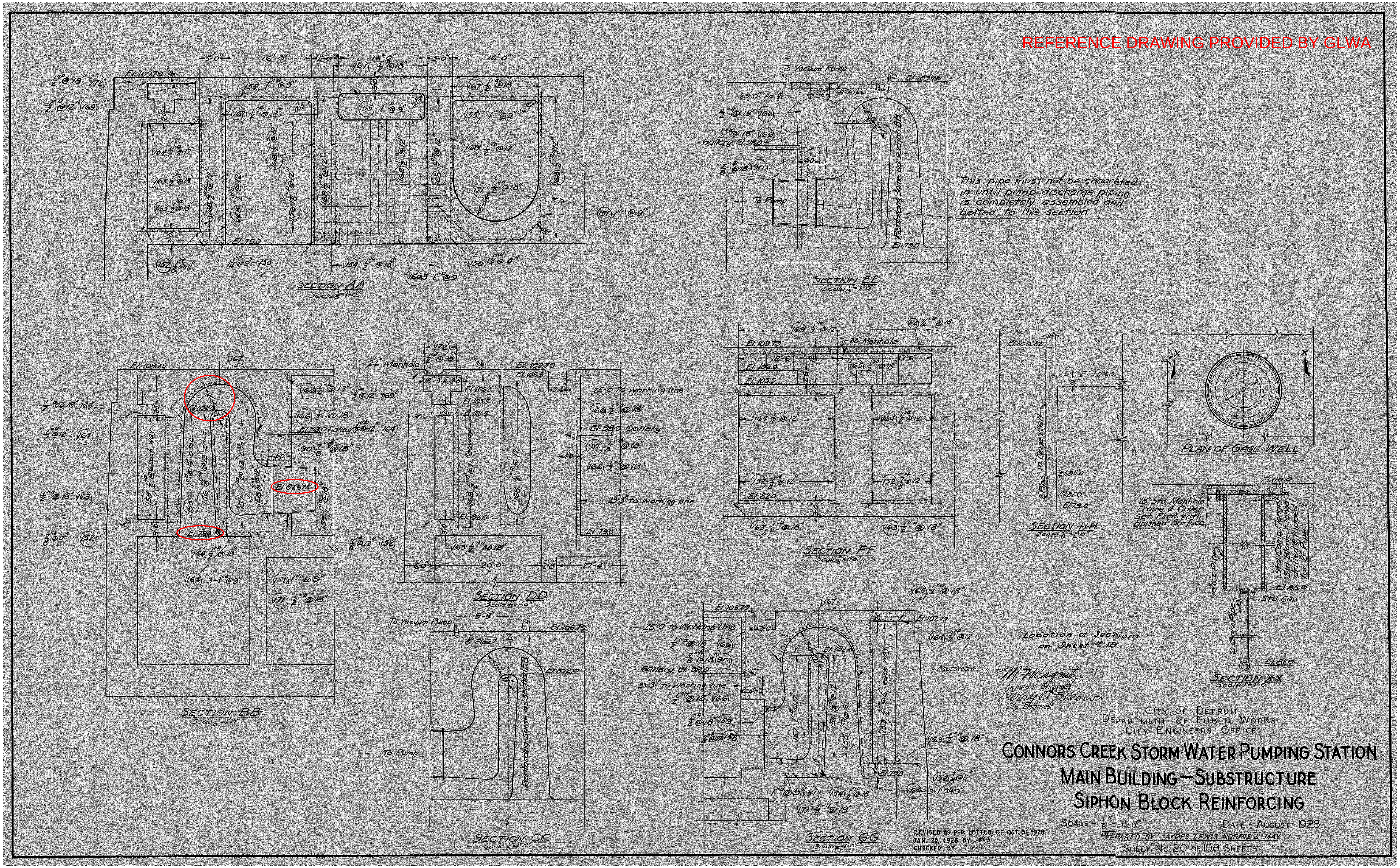
REVISED AS PER LETTER OF OCT. 31ST. 1928
JAN. 25, 1929 BY E. S. M.
CHECKED BY N. H. H.

CONNORS CREEK STORM WATER PUMPING STATION
MAIN BUILDING — SUBSTRUCTURE
SIPHON BLOCK REINFORCING

SCALE - $\frac{1}{8}$"= 1'-0" DATE - AUGUST 1928

PREPARED BY AYRES, LEWIS, NORRIS & MAY

SHEET No. 18 OF 108 SHEETS


REFERENCE DRAWING PROVIDED BY GLWA
SECTION AA
Scale 1/8"=1'-0"
SECTION EE
Scale 1/8"=1'-0"
This pipe must not be concreted in until pump discharge piping is completely assembled and bolted to this section.
To Vacuum Pump
8" Pipe
To Pump
Reinforcing same as section BB
SECTION BB
Scale 1/8"=1'-0"
SECTION DD
Scale 1/8"=1'-0"
SECTION FF
Scale 1/8"=1'-0"
SECTION HH
Scale 1/8"=1'-0"
PLAN OF GAGE WELL
SECTION XX
Scale 1"=1'-0"
18" Std. Manhole Frame & Cover set Flush with Finished Surface
Std. Comp. Flange Std. Blank Flange drilled & tapped for 2" Pipe
Std. Cap
SECTION CC
Scale 1/8"=1'-0"
SECTION GG
Scale 1/8"=1'-0"
Location of Sections on Sheet #18
Approved:
Assistant Engineer
City Engineer
City of Detroit
Department of Public Works
City Engineers Office
CONNORS CREEK STORM WATER PUMPING STATION
MAIN BUILDING – SUBSTRUCTURE
SIPHON BLOCK REINFORCING
Scale – 1/8" = 1'-0"
Date – August 1928
Prepared by Ayres Lewis Norris & May
Sheet No. 20 of 108 Sheets
Revised as per letter of Oct. 31, 1928
Jan. 25, 1928
Checked by

[redacted]

[redacted]

APPROVED:- M.F. Wagnitz
ENGINEER OF PUBLIC STRUCTURES

CITY ENGINEER G.R. Thompson

CONNORS CREEK PUMPING STATION

MECHANICAL DETAILS.

DRAWN BY E.A.M. TRACED BY J.ST.G. CHECKED BY R.H.S.

SCALE AS SHOWN AUG. 1937

SHEET 2 OF 9 SHEETS.

5217-A-2

D:\8737\100% REVIEW\8737-021.dwg Tue May 12 10:25:58 1998 DAN MARTEL

[redacted]

	description	ckd.	apprv.	date
F				
E				
D				
C	BID ISSUE			9/21/98
B	100% OWNER REVIEW			5/8/98
A	95% OWNER REVIEW			5/30/97
	revisions			

designed by : E.H.K.
drawn by : A.S.M.
checked by : E.H.K.
project manager : L.P.C.

approved by :

CONNORS STATION
AND
FOX CREEK BACKWATER GATE BUILDING
REHABILITATION PROJECT

SANITARY PUMP STATION
PUMP REPLACEMENT AND OTHER IMPROVEMENTS
SHEET 1 OF 2

scale : 3/16" = 1'-0"   date : 4/11/97

CITY OF DETROIT
WATER AND SEWERAGE
DEPARTMENT
ENGINEERING DIVISION

section map	town	range	section
25-L	S1	13	211

BEI
ARCHITECTS & ENGINEERS
601 West Fort Street
Detroit , Michigan 48226
(313) 963-2300

PROFESSIONAL

portion code	famis no.
662	448814

M.D.P.H. / D.N.R. permit no :
fed. ref. no :
contract no : PC-674
file no : 87075-2
sheet no : D-94-12-021

[redacted]

F					designed by : E.H.K.	approved by :	
E					drawn by : A.S.M.		
D					checked by : E.H.K.		
C	BID ISSUE			9/21/98	project manager : L.P.C.		
B	100% OWNER REVIEW			5/8/98			
A	95% OWNER REVIEW			5/30/97			
	description	ckd.	apprv.	date			
	revisions						

CONNORS STATION
AND
FOX CREEK BACKWATER GATE BUILDING
REHABILITATION PROJECT

SANITARY PUMP STATION
PUMP REPLACEMENT AND OTHER IMPROVEMENTS
SHEET 2 OF 2

scale : 3/16" = 1'-0"   date : 4/11/97

CITY OF DETROIT
WATER AND SEWERAGE
DEPARTMENT
ENGINEERING DIVISION

section map	town	range	section
25-L	S1	13	211

BEI
ARCHITECTS & ENGINEERS
601 West Fort Street
Detroit , Michigan 48226
(313) 963-2300

portion code	famis no.
662	448814

M.D.P.H. / D.N.R. permit no :
fed. ref. no :
contract no : PC-674
file no : 87075-2
sheet no : D-94-12-022

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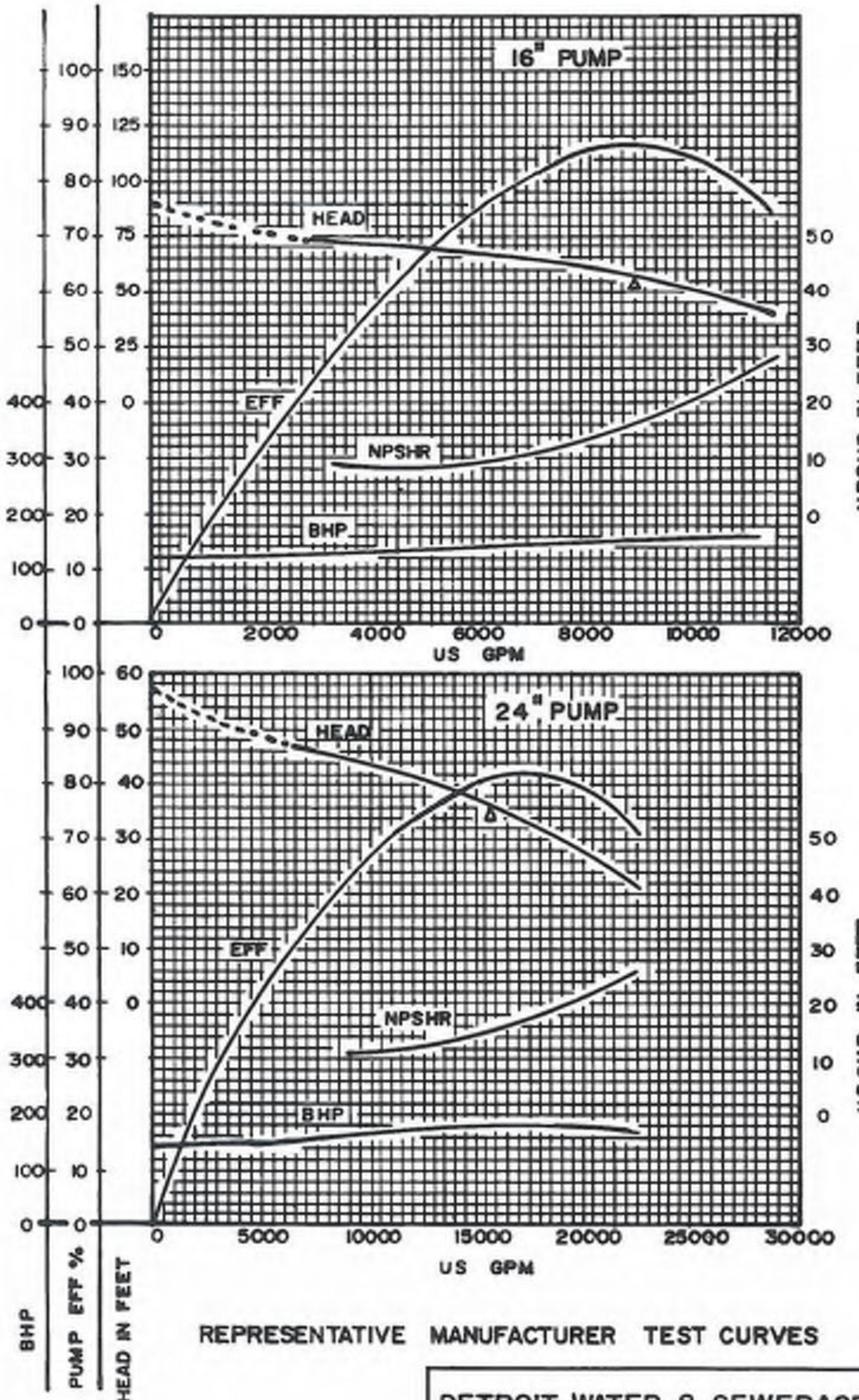
Attachment C: Original Manufacturer Pump Curves

Freud Sanitary/Dewatering Pump Curves



REPRESENTATIVE MANUFACTURER TEST CURVES

DETROIT WATER & SEWERAGE DEPARTMENT
CS-1188 O & M MANUALS

FREUD SEWAGE PUMPING STATION

MADISON
MADISON
INTERNATIONAL
OF MICHIGAN

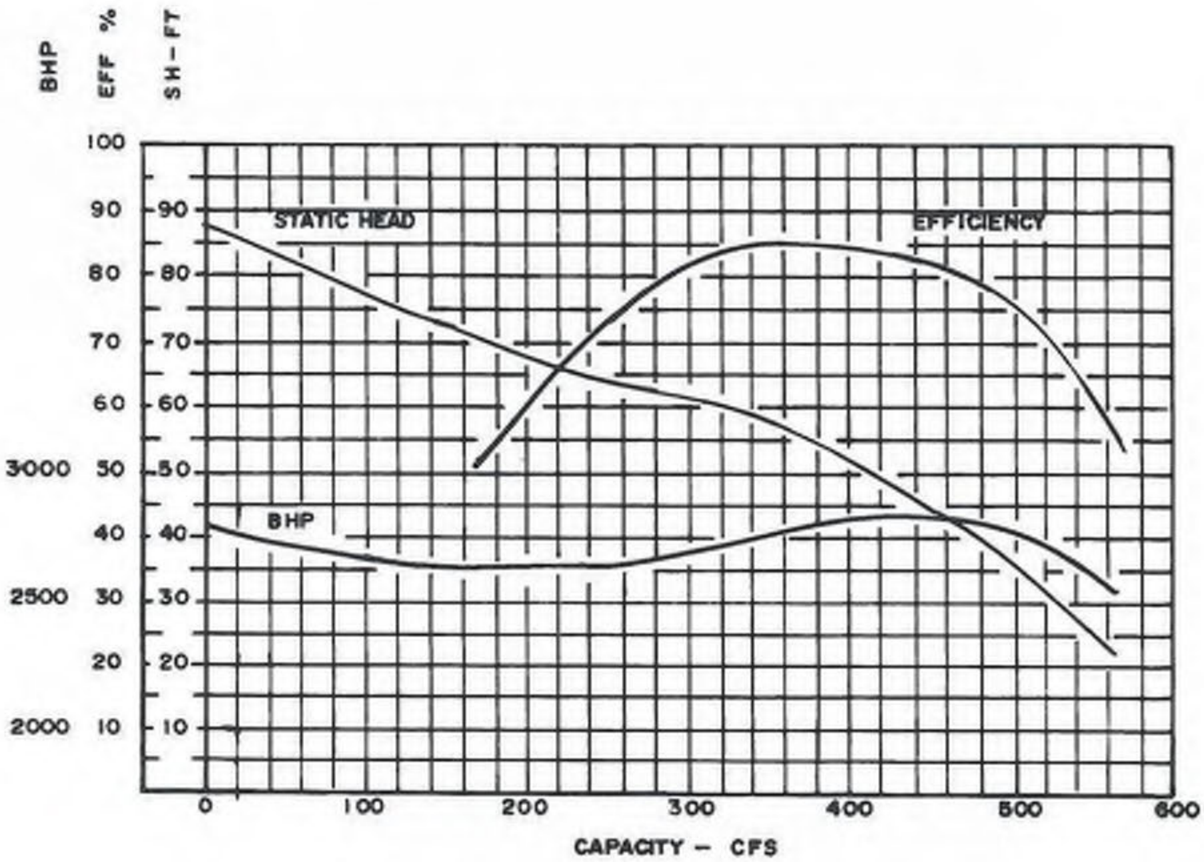
FIGURE: 2-8

16" & 24" PUMP CURVES

DATE: JUNE 93

510440

Freud Storm Pump Curves



REPRESENTATIVE MANUFACTURER TEST CURVE

DETROIT WATER & SEWERAGE DEPARTMENT CS-1188 O & M MANUALS	
MADISON MADISON INTERNATIONAL OF MICHIGAN	FREUD SEWAGE PUMPING STATION
	FIGURE: 2-6 72" PUMP CURVE
DATE: JUNE '93	

510440

Conner Sanitary Pump Curves

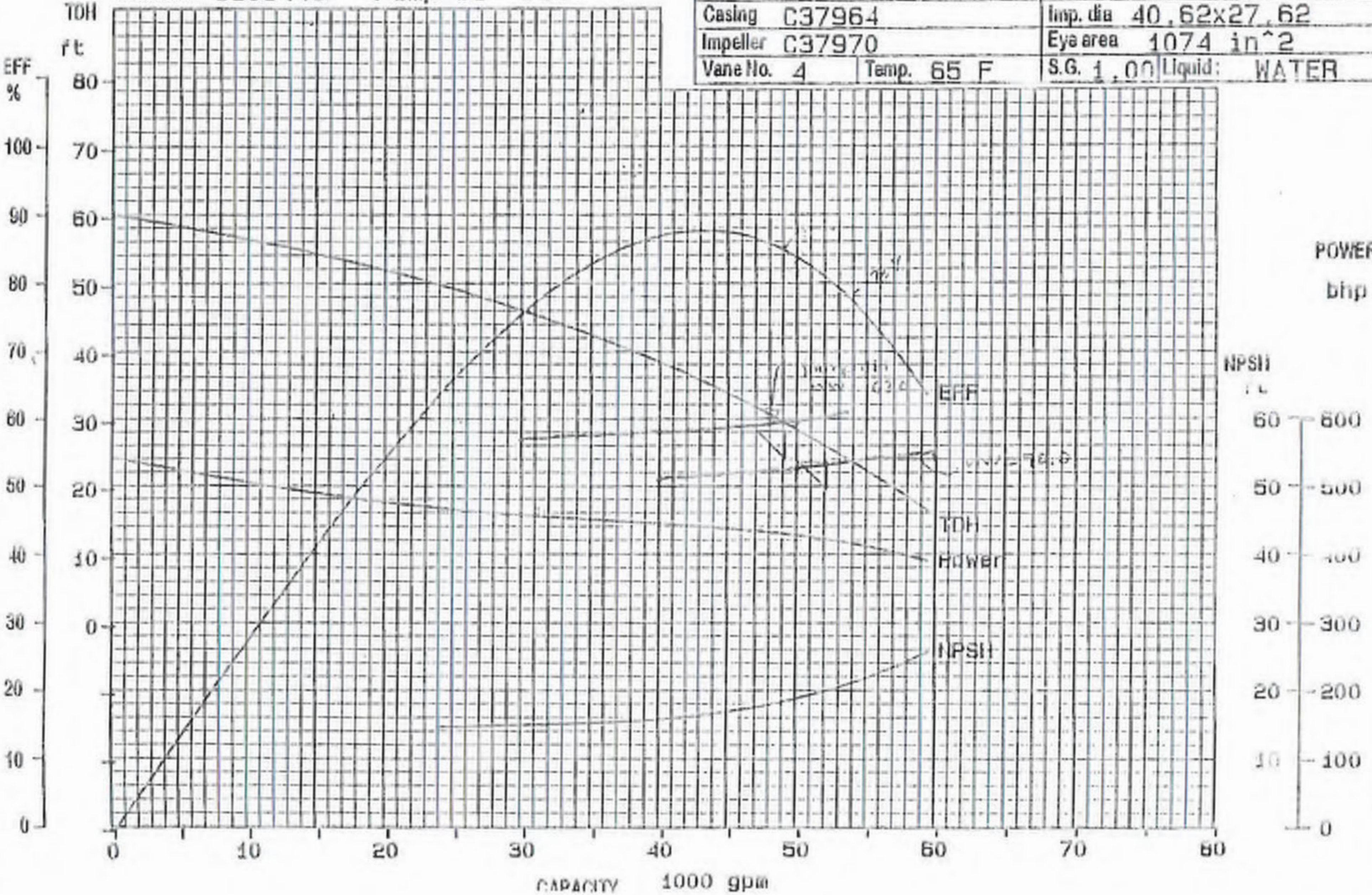
MORRIS PUMPS
Yeomans Chicago Corp.
Aurora, IL 60504

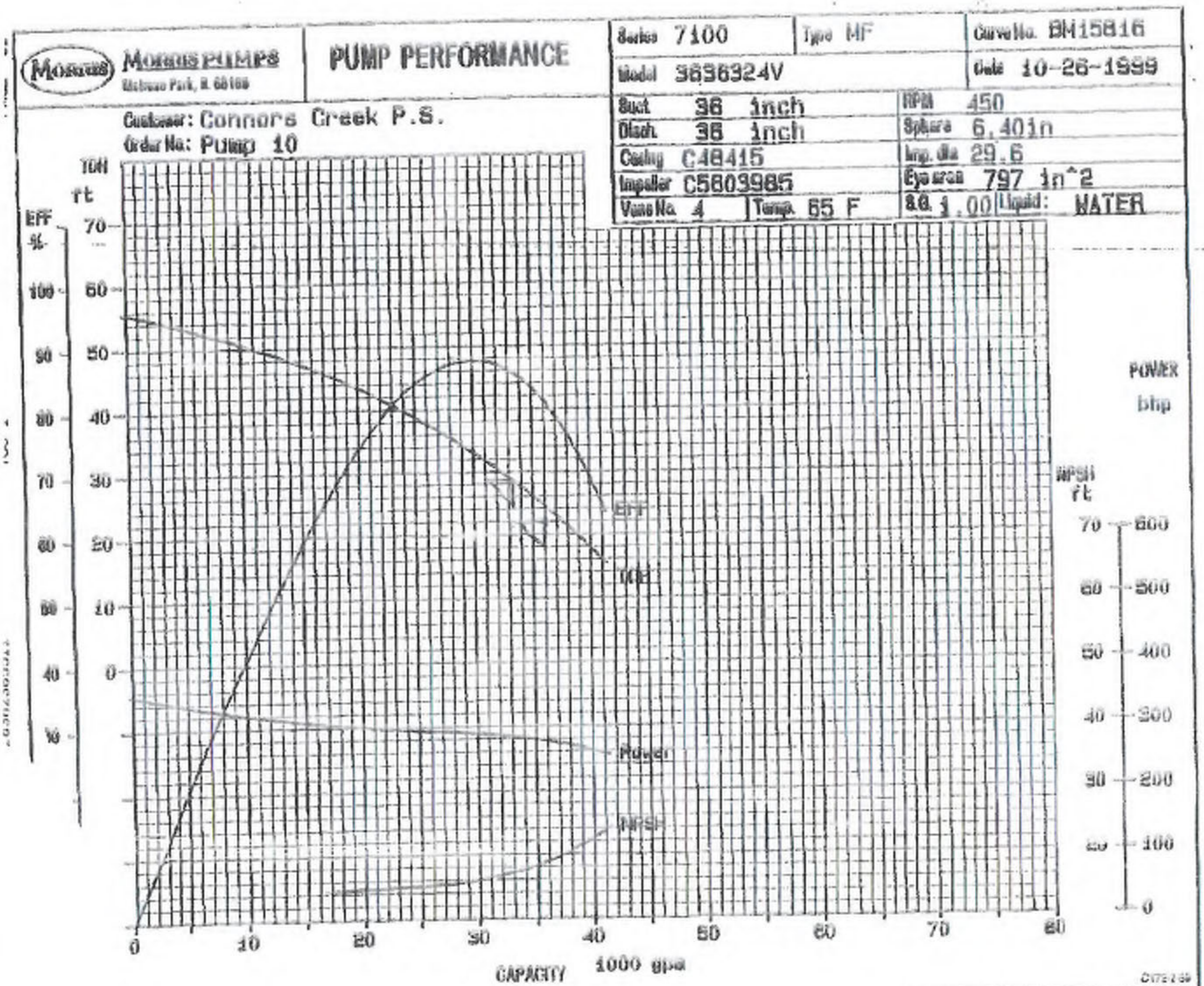
PUMP PERFORMANCE

Series 7100	Type MF	Curve No. BM15815
Model 4242374V		Date 11-13-2001

Customer: Weiss Constr Conners Creek
Order No.: 9806445 Pump #9 #11

Suct.	42 inch	RPM	(400) 315
Disch.	42 inch	Sphere	7.50 in
Casing	C37964	Imp. dia	40.62x27.62
Impeller	C37970	Eye area	1074 in^2
Vane No. 4	Temp. 65 F	S.G. 1.00	Liquid: WATER





Morris Pumps
Melrose Park, IL 60160
PUMP PERFORMANCE
Series 7100
Type MF
Curve No. BM15816
Model 3636324V
Date 10-26-1999
Suct. 36 inch
Disch. 36 inch
RPM 450
Sphere 6.40in
Casing C48415
Imp. dia 29.6
Impeller C5803985
Eye area 797 in^2
Vane No. 4
Temp. 65 F
S.G. 1.00
Liquid: WATER
Customer: Connors Creek P.S.
Order No: Pump 10
TDH ft
EFF %
EFF
TDH
Power
NPSH
NPSH ft
POWER bhp
CAPACITY 1000 gpm

MORRIS PUMPS Yeomans Chicago Corp. Aurora, IL 60504

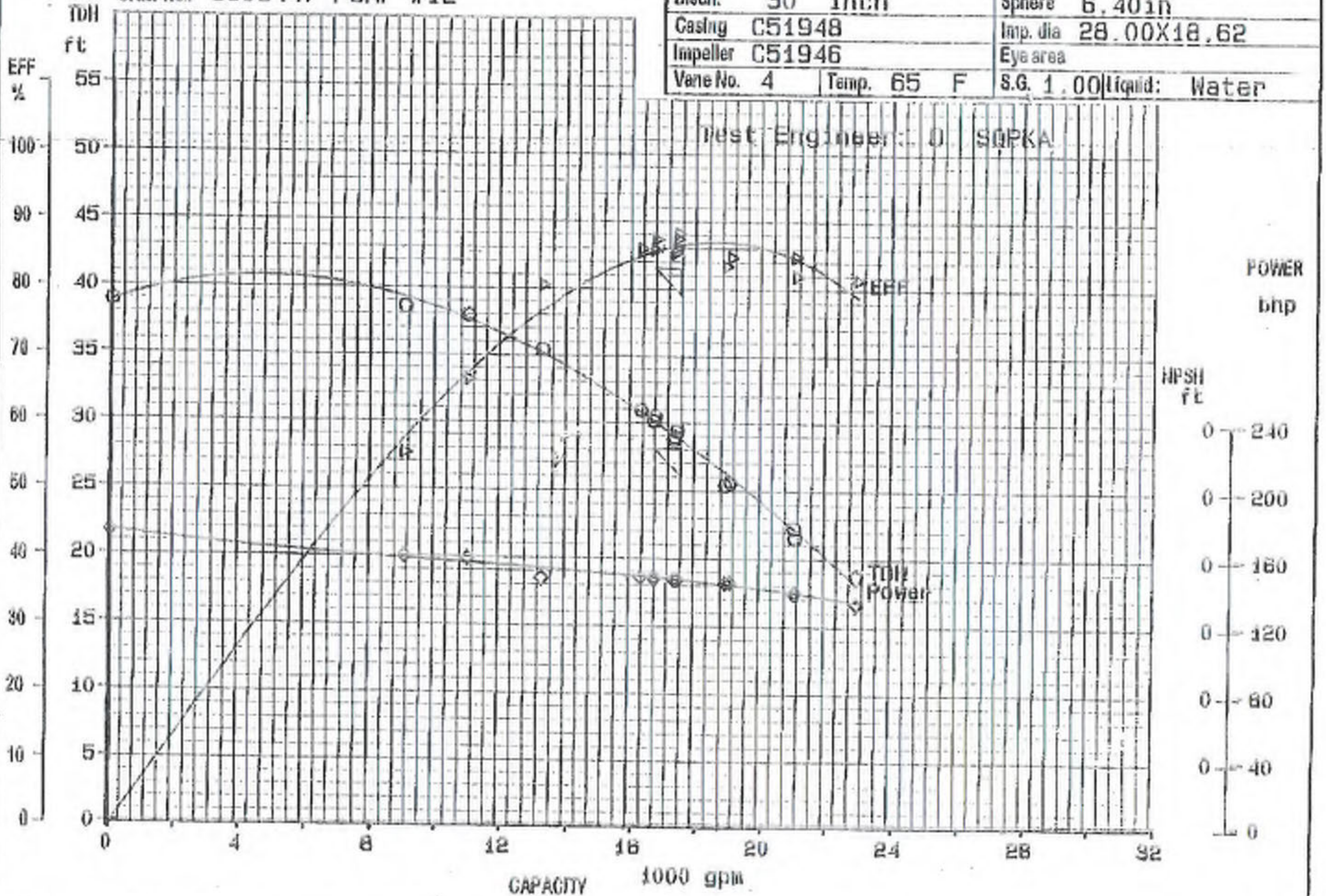
PUMP PERFORMANCE

PERFORMANCE TEST RESULTS

Series 7100	Type MF		Curve No. MF3067W
Model 3030274V			Date 01-15-2003
Suct. 30 inch		RPM 514	
Disch. 30 inch		Sphere 6.40in	
Casing C51948		Imp. dia 28.00X18.62	
Impeller C51946		Eye area	
Vane No. 4	Temp. 65 F	S.G. 1.00	Liquid: Water

Customer: WEISS CONSTR CONNORS STATION

Order No.: 9806447 PUMP #12



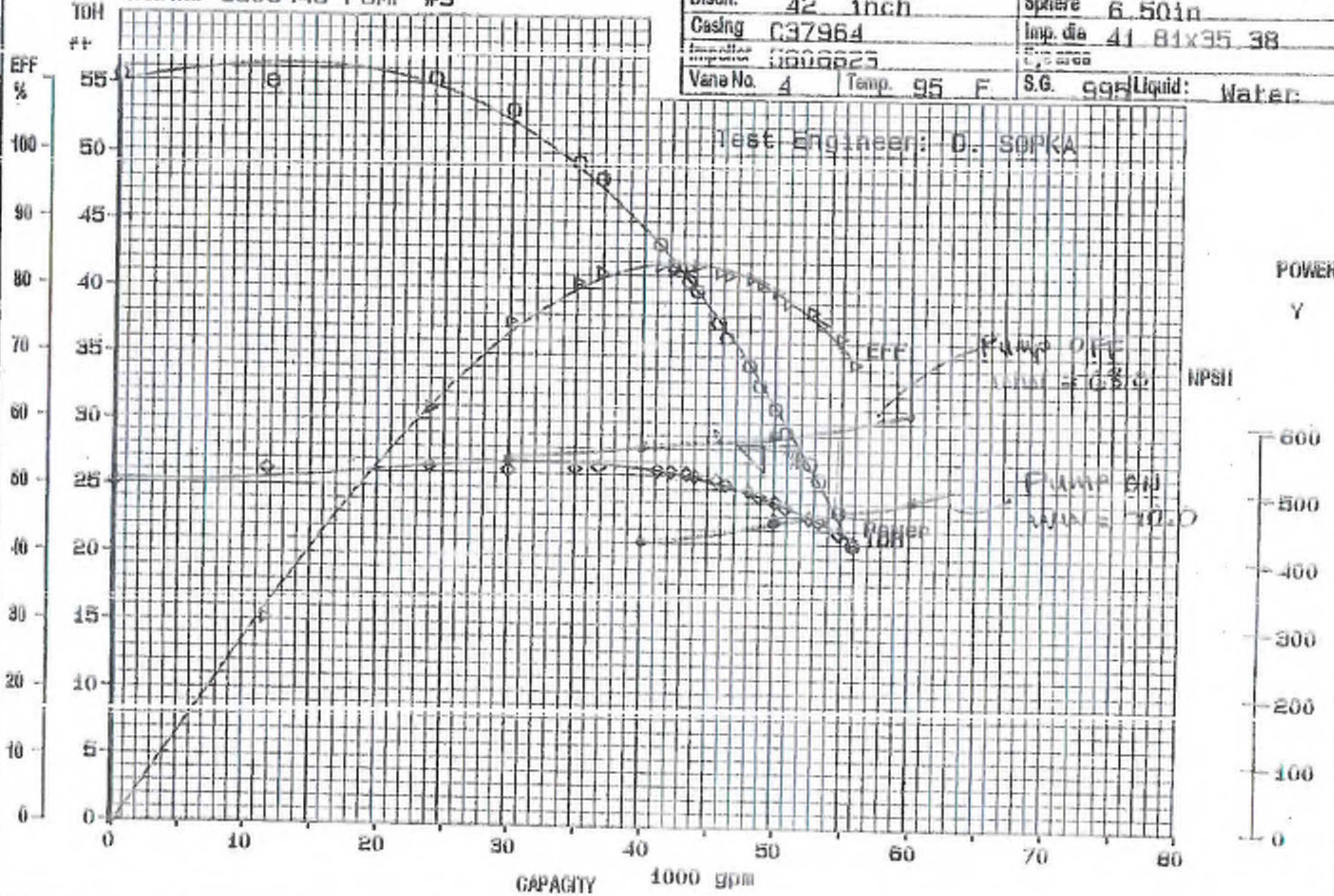
MORRIS PUMPS
Yeomans Chicago Corp.
Aurora, IL 60504

PUMP PERFORMANCE

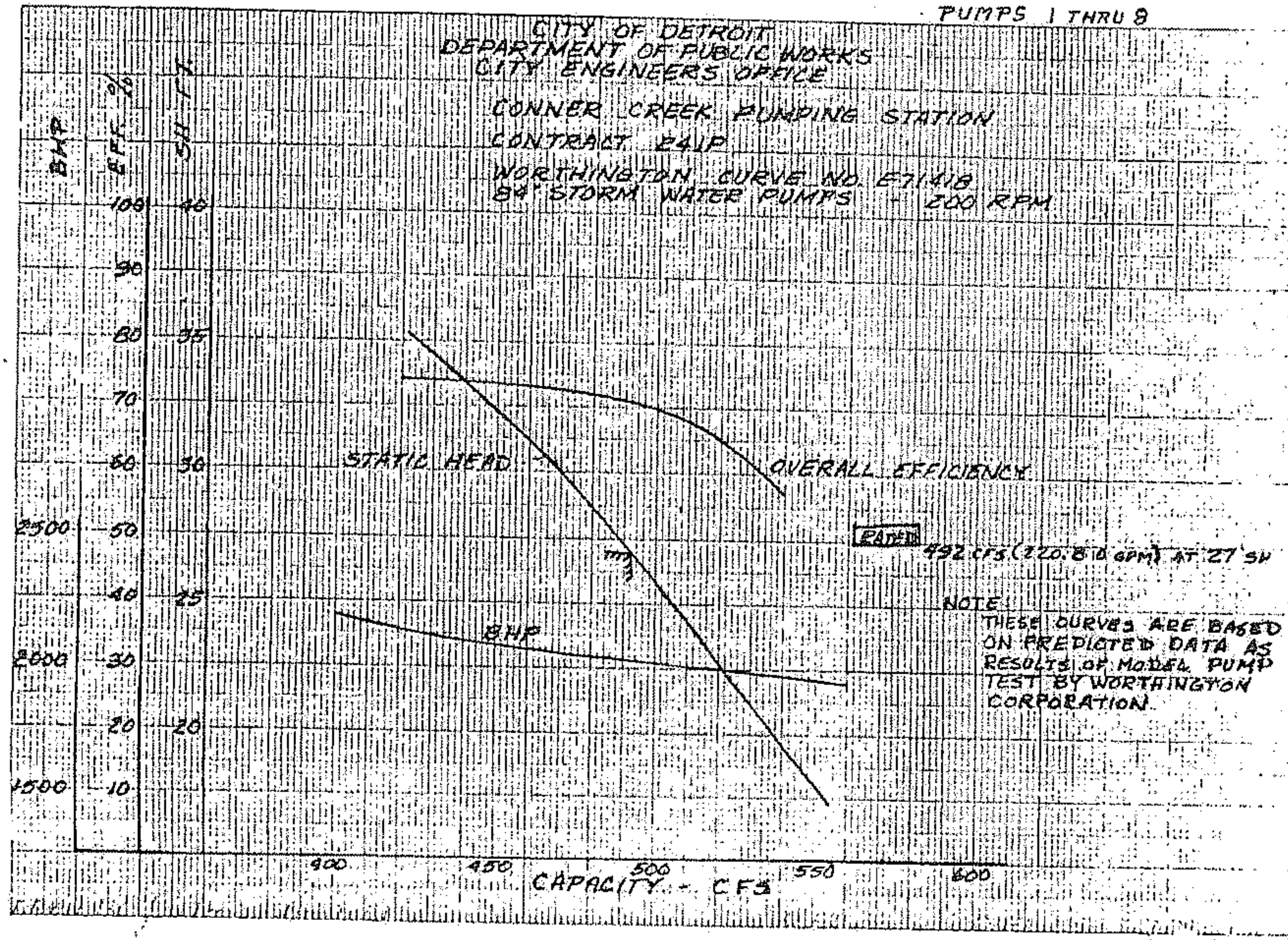
PERFORMANCE TEST RESULTS

Series	7100	Type MF	Curve No. MF42A04W
Model	4242424V		Date 07-22-2003
Suct.	42 inch	RPM	400
Disch.	42 inch	Sphere	6.50in
Casing	C37964	Imp. dia	41.81x35.38
Impeller	G806623	Eye area	
Vane No. 4	Temp. 95 F	S.G. .995	Liquid: Water

Customer: WEISS CONSTR CONNORS STATION
Order No.: 9806445 PUMP #9

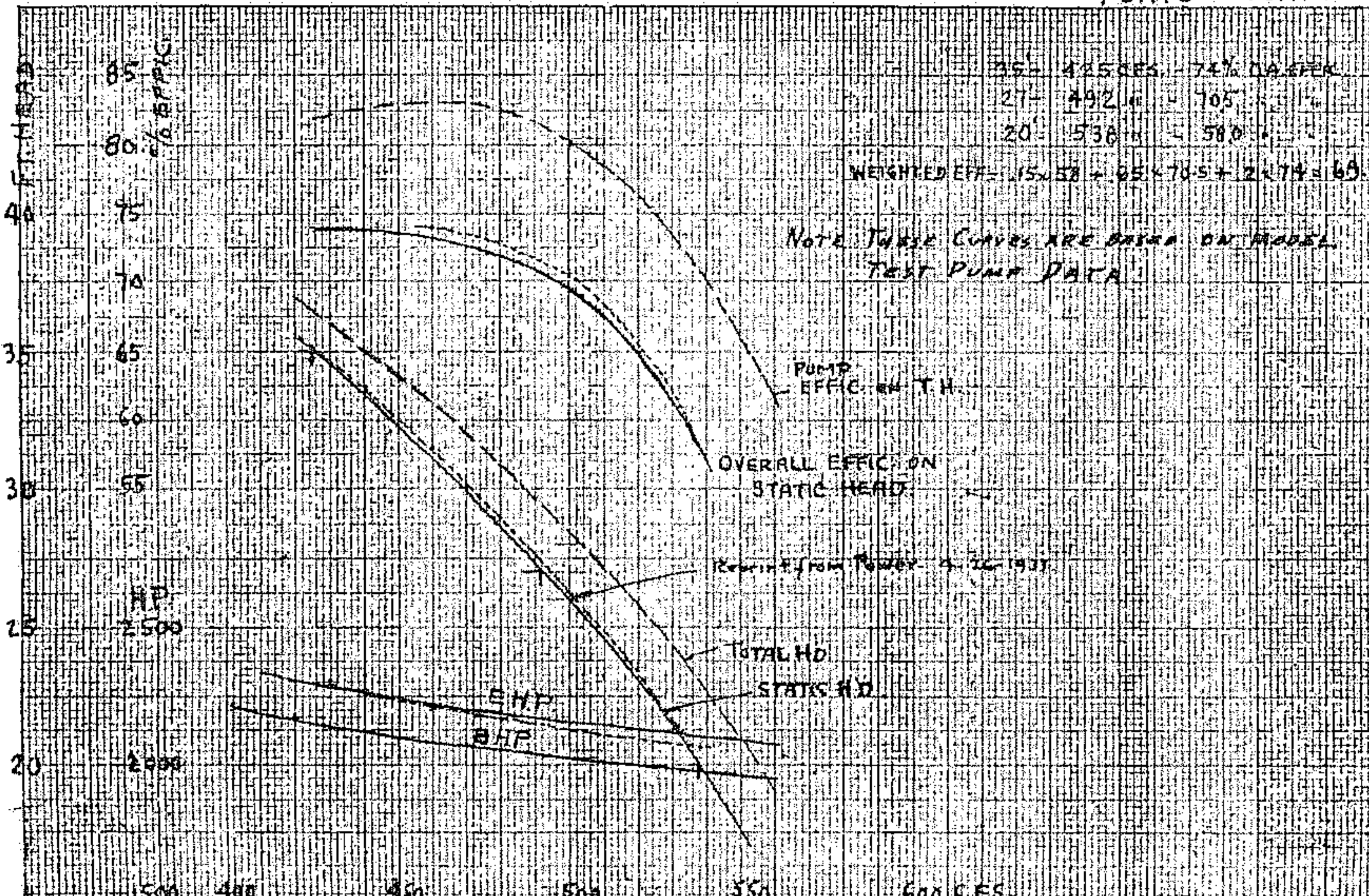


Conner Storm Pump Curves


PUMPS 1 THRU 8
CITY OF DETROIT
DEPARTMENT OF PUBLIC WORKS
CITY ENGINEERS OFFICE
CONNER CREEK PUMPING STATION
CONTRACT 241P
WORTHINGTON CURVE NO. E71418
84" STORM WATER PUMPS - 200 RPM
BHP
EFF. %
SH FT.
STATIC HEAD
OVERALL EFFICIENCY
RATED
492 cfs (220,810 GPM) AT 27 SH
NOTE:
THESE CURVES ARE BASED ON PREDICTED DATA AS RESULTS OF MODEL PUMP TEST BY WORTHINGTON CORPORATION.
BHP
400
450
500
550
600
CAPACITY - CFS

S/H. & P.HD. NOT AVAILABLE. CONNER CREEK STN.

84 MA-1 PUMPS PUMPS 1 THRU 8



HOW TESTED:	CAPACITY	DRIVER	SPEED	DRIVE

CURVE	WORTHINGTON PUMP AND MACHINERY CORPORATION NEW YORK					ORDER No.	TEST No.
1747	84	Vertical	MIXFLO	DETROIT	200		E 71418

Attachment D: CCPS Hydraulic Model Study

FINAL PROJECT REPORT
HYDRAULIC MODEL STUDY
Connors Creek Sanitary Pumping Station

Report UMCEE 97-21

By
Steven J. Wright
and
Glenn T. Wright

THE UNIVERSITY OF MICHIGAN
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
ANN ARBOR, MICHIGAN

December, 1997

For

Applied Science, Inc.
Edison Plaza Building
660 Plaza Drive, Suite 2000
Detroit, Michigan 48226-1207

TABLE OF CONTENTS

HYDRAULIC MODEL STUDY
Connors Creek Sanitary Pumping Station

EXECUTIVE SUMMARY

The City of Detroit is planning a rehabilitation of their existing Connors Creek Sanitary Pumping Station. The pump impellers in this station have suffered damage in the past, apparently due to cavitation. It has also been presumed that there may have been problems with vortices at the pump intakes due to nonuniformities in the approach flow to the pumps. A 1:7.5 scale model of the wet well, including the four pump intakes, and the inlets into the wet wells through the east and west drop shafts was constructed to study the hydraulics of the flow into and within the wet well as well as the flow at the individual pump intakes. An additional issue that was examined in the hydraulic modeling related to the proposed location of a level sensor to control pump operation. The objective was to determine whether the level sensor provides an appropriate measure of the hydraulic grade line within the wet well and to suggest alternate locations if the proposed location was not acceptable.

Flow enters into the wet well from one of two sources, the East Jefferson Relief Sewer or the West Jefferson Relief Sewer, each of which are fourteen feet in diameter. The primary entrance into the wet well from each relief sewer is through separate five foot diameter conduits, each of which discharges into a drop shaft at opposite ends of the wet wells. There is a third five foot diameter connection from the adjacent Storm Pump Station which receives any flow that does not enter the wet well. Current operating procedures do not utilize this third wet well entrance in which case the flow from the two relief sewers is not hydraulically connected during dry weather flow conditions. Therefore the relative contribution of wet well inflow from each relief sewer can vary although it appears that the larger contribution is normally derived from the East Jefferson Relief Sewer. In order to divert dry weather flows into the wet well, small check dams installed within each relief sewer are intended to force all flow

into the wet well. This fixes a maximum hydraulic grade line allowed in the wet well so as not to overtop the check dams during dry weather flows. During wet weather conditions, flow is allowed to overtop the check dams and continue to the Storm Pump Station at which point, a hydraulic connection between the two relief sewers can be established through the Storm Pump Station wet well.

Phase 1 Testing: The initial specifications for testing of dry weather flow conditions provided only generalized guidelines on wet well hydraulic grade lines and pumping conditions. No operational sequence was specified for the pumps and the wet well hydraulic grade lines were constrained only by the need to avoid pump cavitation at low wet well levels and to avoid overtopping the check dams in the relief sewer during dry weather flow conditions. During initial testing of the model, it was discovered that significant head losses were associated with the flow down through the drop shafts and into the wet well. Under these circumstances, it would be hydraulically impossible to operate the pumping station as planned. At intermediate flow rates that may be associated with dry weather flow conditions, it is not possible to maintain hydraulic grade line elevations low enough to prevent overtopping of the check dams in the relief sewers and provide sufficient system storage to allow reasonable pump cycle intervals.

Phase 2 Testing: Further consideration of this problem led to a decision to raise the level of the check dams in the relief sewers and attempt to utilize the storage present within the relief sewers to provide the desired pump cycle intervals. This consideration led to the development of a proposed sequence for pump operation and for on-off levels for each pump in the sequencing. This proposed set of conditions was tested in the physical model and found to be successful in the condition where the wet well inflow is uniformly distributed between the two relief sewers. However, in the case of a 75 percent contribution from the East Jefferson Relief Sewer, which may be more realistic of actual flow conditions, the system is unable to perform hydraulically at the proposed control levels for the pumps. The hydraulic grade line could be met only by raising the elevation of the check dam in the East Jefferson Relief Sewer to such an extent that the ability to pass storm water flows to the Storm Pump Station would be compromised.

Phase 3 Testing: As a result of the above findings, it appears that the only feasible method of operating the wet well is to pass some portion of dry weather flows to the Storm Pump Station and to utilize the third entrance into the Sanitary Pump Station. The physical model was not constructed with this prospect in mind and hydraulic testing for these conditions was not in the original scope of the model study. However, the physical model could be modified to accommodate flows from this third entrance and this additional hydraulic testing could be included in future studies. Although the third inlet could not be modeled, the existing model was used to more accurately define the hydraulics of the other two inlets. These hydraulic results are to be used in calculations to define the final pump operating scheme.

With regards to the major objective of the physical model study, a detailed investigation was performed to examine conditions at the pump intakes and a number of potential problems were discovered. In particular, a significant problem associated with air entrainment in the drop shafts was noted. At low wet well hydraulic grade line elevations, below the invert of the five foot diameter conduits from the relief sewers, the air entrainment occurs due to the water plunging onto the water surface within the drop shaft. However, a hydraulic grade line elevation this low will not generally be acceptable due to the lack of system storage for pump cycling. Water levels within the drop shafts must generally remain above the inverts of the inflow conduits and this type of air entrainment should therefore not be a problem, although it has probably contributed to problems with the pump station performance in the past. Air entrainment was observed even when the five foot conduits were completely submerged at their exit into the drop shafts. This air entrainment was generated by a pair of vortices that formed in each drop shaft due to the velocity in the inflow conduit. The design of the wet well forces this air to pass through the pumps leading to a possibility for a deterioration of pump performance and contributing to bearing wear. The amount of air entrained decreases as the wet well hydraulic grade line increases but never vanishes for the higher flow rates.

Subsurface vortices were observed in the wet well underneath the middle two pumps, Pump 10 and 11. The source of these vortices appears to be the high velocity inflow from each drop shaft in combination with the small wet well volume. These organized vortices are not observed under Pumps 9 and 12, apparently due to the inflows from the drop shafts sweeping out any organized motion in these areas. Due to the small wet well volume and associated high velocities, intermittent vortices were observed throughout much of the wet well, but these are not considered to be significant compared to the air entrainment and organized vortices under Pumps 10 and 11. These organized vortices can probably be largely eliminated by installing cones with vanes on the floor directly under the pump intakes. The use of the third inlet to conduct flow into the wet well will have the effect of reduction the inflow velocities in the other two inlets; this will result in a reduction in both air entrainment in the drop shafts and should reduce the strength of the submerged vortices as well

Testing to measure swirl angles in the pump intakes did not indicate a significant problem. Swirl angles less than 1.6 degrees were measured for all flow conditions tested. This was attributed to the presence of the swirl baffles installed on each pump intake. The swirl baffle was removed from pump 12 and the swirl angles in that pump ranged from 5.7 to 17.2 degrees for the same flow conditions. Visually, vortices in the flow entering the pump intakes were observable by the motion of the air entrained in the flow, but these were confined to one of the four quadrants constrained by the swirl baffle and apparently any organized pre-rotation of the flow was not allowed over the entire flow cross-section. The small swirl angles therefore may not be representative of excellent pump intake conditions, but the swirl baffles do improve the pre-rotation to an acceptable level.

The initial location of the wet well hydraulic grade line level sensor was located in a region where the organized floor vortices observed under Pumps 10 and 11 would have an impact on the sensor readings and in particular, large fluctuations in water levels were recorded in the model. Two alternate locations were suggested to replace this initial location and both seemed to be equally effective and acceptable for purposes of monitoring hydraulic grade line elevations within the wet well.

INTRODUCTION

The Connors Creek raw sewage pumping station has been in operation for a number of years. The existing pumps in this station have suffered damage in the past, apparently due to cavitation. Inspections of the facility have also indicated rough running conditions and loss of pump prime due to air ingestion. These problems have been due in large part to a lack of automatic control on pump operation. The pumps are scheduled to be replaced and alterations are planned for the operation of the pumping station, including the installation of hydraulic grade line sensors from which the operation of the pumps can be controlled. The purpose of the physical model study was to ensure that previous problems with station operation would be avoided. Particular emphasis was placed on the study of inlet conditions for the pumps.

Vortices and inlet swirl can have a detrimental effect on the operation of pumps, lowering efficiency and increasing wear. Severe vortexing can lead to pump vibration, cavitation and impeller pitting. The proposed testing sequence included the following components:

- Examination of surface vortex patterns (within the drop shafts)
- Examination of subsurface vortex patterns in the wet well
- Measurement of swirl in flow into individual pump suction lines
- Measurement of hydraulic grade line differences between the inlet conduits and the wet well.
- Investigation of the placement location for a proposed wet well hydraulic grade line level sensor to be used to automatically control pump operation.

GENERAL SYSTEM DETAIL

The wet well is rectangular in shape with plan dimensions of approximately 21 ft by 61.5 ft. The four pumps lift raw sewage through suction pipes mounted in the ceiling of the 7.5 ft high chamber. These pumps are arranged in a linear fashion along the 61.5 ft length of the wet well. Flow normally enters the wet well from 5 ft diameter inlet pipes at either end of the wet well which in turn conduct flow from the 14 foot diameter Jefferson Avenue relief sewer. Flows through either inlet flow down a drop shaft from the relief sewer before entering the pump station (the conduits connecting the drop shafts and the wet well are also five foot diameter. In order to avoid confusion in this report, the pipes connecting the 14 ft interceptors and the drop shafts will be referred to as *connecting* pipes while those between the drop shafts and the wet well will be called *inlet* pipes). The east drop shaft conducts flow from the East Jefferson Relief Sewer while the west drop shaft carries flow from the West Jefferson Relief Sewer. All dry weather flows in the relief sewers are intended to pass through the pumping station while storm flows from both are permitted to enter the adjacent Storm Pump Station A third inlet connects from the Storm Pump Station to the Sanitary Pump Station. Since this inlet was reported to be closed under normal operating conditions, it was not included in the hydraulic model. Figure 1 provides a plan view of the general layout of the two pumping stations and associated conveyance systems.

The pump capacities for the four pumps were reported to be approximately 49,000 gpm (each of two pumps), 33,500 gpm, and 17,500 gpm. The actual capacity of each pump depends on the hydraulic grade line elevation in the wet well and a range of elevations are possible during normal plant operation.

The physical model included all relevant detail of the wet well and pump suction bells up to the pump impellers, the two inlet pipes, and the connections to the relief sewer including the drop shafts. Details of the tests conducted in the model are described below. Testing was performed controlling the following variables:

- Different combinations of pumps in simultaneous operation
- Different splits of inflow into the wet well from the various inlets
- Different wet well hydraulic grade line elevations

MODEL DESCRIPTION

Modeling Criteria

Although the wet well itself was in a submerged condition, the drop shafts and inlets had free surface flow conditions. Physical models to examine flow patterns in free surface flow are performed using Froude number similarity, which fixes the relations between model and prototype conditions once the physical model scale has been selected. Dynamic similarity requires keeping all Froude numbers, defined by $V/(gL)^{1/2}$, equal in the model and prototype. Here, V refers to any representative fluid velocity, g the acceleration due to gravity, and L is any system length. The relations between prototype and model parameters are related to the scale ratio $\mathbf{L_r}$ which is the geometric ratio between any length in the model and the corresponding one in the prototype ($\mathbf{L_r} = \text{Length}_{model} / \text{Length}_{prototype}$). For a Froude scaled model, assuming the same fluid in model and prototype, the following relations must hold for the respective ratio between the model and prototype vaariable:

PARAMETER		RATIO
Length	L_r	L_r
Velocity	V_r	$L_r^{1/2}$
Discharge	Q_r	$L_r^{5/2}$
Time	T_r	$L_r^{1/2}$

The critical factors with respect to model testing facilities are the model size and discharge. If the scale ratio is too small, both surface tension and viscous effects may become too great in the model. This consideration generally fixes the minimum model size required to avoid distortion of the model flow due to the effects of viscosity. Padmanabhan and Hecker (1982) suggest from the results of model studies on pump intakes that a minimum Reynolds number of greater than 70,000 be maintained in the physical model to correctly reproduce the air intake and vortex strength. The Reynolds number is to be defined in terms of the flow in the suction pipe as $Re = UD/\nu$, with U the average flow velocity in the suction pipe, D intake diameter, and ν the kinematic viscosity. This constraint becomes instrumental in the selection of the minimum physical model size. With the smallest pump and a modeled discharge of 17,500 gpm and the selected model scale ratio of 1:7.5, the minimum model Reynolds number is about 92,000, thereby meeting this constraint.

Model Construction

The model study was conducted in the Civil Engineering Hydraulics Laboratory located in the G.G. Brown Building at the North Campus of The University of Michigan. The physical model was constructed at a scale ratio of 1:7.5. The physical model was constructed of plywood, Plexiglas and PVC piping. The drop shafts and inlet pipes to the wet wells as well as the cover to the wet well were constructed of Plexiglas in order to visualize the flow. This allowed the model to be visually inspected for the presence of subsurface vortices, air entrainment and other undesirable flow conditions. The pump suction bells were also constructed of Plexiglas for the same purpose as well as to see the rotation of the swirl meters used to determine the pre-rotation in the pump approach flow. The pump suction bells were designed with guide vanes (swirl baffles) to help eliminate any pre-rotation in the flow; these were constructed of 1/8 inch aluminum according to the detail provided in supplied drawings. The remainder of the piping in the system was constructed of PVC pipe. The five foot diameter connecting pipes from the main interceptors were reproduced in the model although the interceptors were not. The extent of the physical model is indicated on Figure 1 and the completed model can be seen in the photographs in Figure 2.

All four pump suction lines were joined into a common manifold (see Figure 2c) connected to a recirculating pump which removed the flow from the wet well and back around to the inlet conduits. The flow was regulated by adjusting butterfly valves on each of the pump suction lines and gate valves on the supply lines to obtain the desired total flow and control the flow distribution among individual lines. The flows were metered in each individual pump suction line by means of calibrated bend meters (Figure 2c). In addition, the flow on the discharge side of the recirculating pump was metered in the pipe connecting to the east inlet by means of an installed orifice meter.

Instrumentation

Flow rates were measured using a combination of calibrated bend meters on each of the four pump suction lines plus an orifice meter installed on the piping connecting to the east inlet. Pressure differences were measured with water-air differential manometers. By comparing the difference between the sum of the flows through the bend meters and the east inlet flow, the discharge to the west inlet could be computed. Preliminary tests were conducted to provide a continuity check. This involved routing all flow through the east inlet which could be metered by the main orifice meter. Flow was established through one, two, or three of the bend meters and independently metered through each of those. The sum of the flow through all the bend meters should be the same as that through the orifice meter. For the six different flow conditions established in this continuity check, continuity was satisfied to within four percent with the exception of one flow condition and half the measurements were within one percent.

The swirl angles were measured with a rotating cruciform (swirl meter), the function of which was to rotate with the component of tangential flow in the pump suction line. The swirl meter was mounted so that it rotates freely on a hub installed along the pipe centerline and consists of four vanes, each with dimensions equal to 0.8 of the relevant intake diameter. One vane was painted to orient the cruciform, especially in a rapidly rotating flow (the vanes can be seen in Figure 2a). Rotation counts were recorded to the closest rotation over 3 minute counting intervals. Counts were recorded every 30 seconds so that variations in the speed of rotation could be observed as well as any potential changes in rotational direction. Clockwise rotation (looking down into the model) was considered to be positive, and counter-clockwise rotation was considered to be negative. The swirl angle is defined by counting the rotations per unit time and computing the angle as

$$\theta = \tan^{-1}\left(\frac{\pi N D}{U}\right)$$

with θ the swirl angle, N the revolutions per unit time of the swirl meter, D the pump intake diameter and U the average axial flow velocity (the line discharge divided by the intake cross sectional area). Swirl angles of less than 5 degrees are generally considered as acceptable for axial flow pumps.

Hydraulic grade line elevations were measured at a number of locations. Within the wet well, these were measured by installation of a stand tube at locations proposed for level sensors. For measurements where the hydraulic grade line needed to be determined with accuracy, the stand tubes were connected to a larger diameter Plexiglas cylinder (stilling well) connected with small diameter tubing to damp local turbulent pressure fluctuations. Within the drop shafts, hydraulic grade lines were determined approximately visually and more precisely with stand tubes connected to pressure taps at the bottom of the drop shafts. Finally, the hydraulic grade line at the upstream end of the connecting pipes (just downstream from the inlets from the interceptors) was measured with a pressure tap/large diameter stilling well/small diameter connecting tubing configuration similar to that employed in the wet well. Point gages were installed in the stilling wells in order to measure hydraulic grade line elevations to within 0.001 ft. The reference levels for the point gages were determined by filling the model to the invert elevations of the connecting pipes (59.9 ft prototype elevation) and using the point gage readings at this condition as a reference for all other readings.

Testing Conditions

This study was conducted in distinct phases. In the first phase of the project, the specific operating rules for the pumping station were not developed and therefore the sequencing of pumps was not specified. The hydraulic grade line elevations were considered to range from a low of 58.0 ft to a high of 70.0. Maximum hydraulic grade lines during dry weather flow conditions were originally intended to prevent overtopping of the check dams in the main interceptors while higher hydraulic grade line elevations would be allowed during wet weather flow conditions. During the preliminary phases of the model testing, a number of operational problems were discovered at the lower hydraulic grade lines; these are discussed further below. At that point, further analyses were performed and a more detailed plan was developed for operation of the pump station at higher wet well hydraulic grade lines. The proposed operational rules are listed below:

Table 1. Proposed Pump Operation Rules for Phase 2 Testing.

# of Pumps Operating	Pumps in Operation	Discharge Capacity(gpm)	Pump On Elevation (ft)	Pump Off Elevation (ft)
1	# 12	17,500	62.2	61.5
2	# 12,10	51,000	63.3	62.2
3	#12,10 & 9 or 11	100,500	64.5	63.3

Note: On/Off Elevations are for operation of last pump in sequence

The second phase of the model testing was conducted for these conditions. In order to completely specify a test condition, the distribution of flows from the two wet well inlets must also be prescribed. Because the two inlets are hydraulically isolated from each other, this distribution is somewhat arbitrary although investigations indicate generally higher flows through the east inlet as compared to the west. Initial conditions for the Phase 2 testing considered an assumed equal split of inflow between the two interceptors, and after completion of those tests, a flow distribution with 75 percent of the inflow though the east inlet and 25 percent through the west inlet was established. It was found to be impossible to set the proposed wet well hydraulic grade lines with this flow split and detailed testing could not be conducted for these conditions. A discussion of this situation is provided below.

A final phase of testing was conducted to establish hydraulic relations between each inlet and the wet wells for a range of flows consistent with those listed in the table above. Investigations on the pre-rotation of the flow entering the pumps were not conducted during this phase of the investigation and measurements were limited to hydraulic grade line elevations.

Test Results

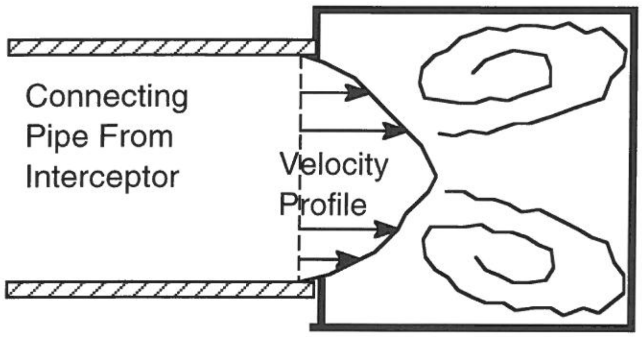
In this section, results are discussed according to the different phases of the testing as described above.

Phase 1 Results

General Flow Conditions

During the preliminary phases of the testing, a number of flow conditions were observed that would generally be regarded as undesirable with regards to pump intake conditions. These included air entrainment into the flow, the presence of submerged vortices, and considerable turbulence within the wet well. All of these factors can contribute to rough running conditions for the pump impellers and unbalanced loads on the pump shafts.

Since the pump intakes are installed in the wet well ceiling, all air entrained into the flow will exit the wet well through the pumps. The source of the air entrainment is the flow through the drop shafts. There were two mechanisms that could contribute to observed air entrainment. If the water level in the drop shaft was low enough, the plunging flow from the inlet pipes entrains air; this situation is visualized in the photograph in Figure 3. With the pipe invert elevations at 59.9 ft, this would be an approximate cutoff for this type of behavior, with lower drop shaft water levels resulting in significant air entrainment due to the plunging of the flow. However, air entrainment was still observed at drop shaft levels well above the 70 ft elevation level which is substantially above specified dry weather operating levels. This air entrainment was due to the presence of air entraining vortices in the drop shafts. These vortices were created by the inflow from the inlet conduits which created higher velocities near the center of the drop shafts as indicated in the conceptual sketch below which is of a cross section through the drop shaft near the inflow.



The swirl induced as the inflow struck the opposite wall of the drop shaft and returned along the sides was sufficient to induce considerable air entrainment, especially at higher flow rates. The vortices and air entrainment under these conditions can be seen in the photographs included as Figure 4. The volume of air entrained was a function of both flow rate and drop shaft water level; this issue was studied further in the Phase 3 investigation and is discussed in more detail below.

Submerged vortices were produced within the wet well under all flow conditions observed although the strength and persistence of these vortices appeared to depend on the particular combinations of pumps in operation. In general, the most persistent vortices were observed under Pumps 10 and 11, the two inner pumps. The videotape indicates these vortices which were visualized by the introduction of fine black sand into the wet well. The vortices were attached to the wet well bottom. When pumps 10 and/or 11 were operating in conjunction with 9 or 12, the inflow from the drop shafts washed out these large and persistent vortices at the outer pumps, presumably due to the high velocities through the inlet conduits connecting the drop shafts and the wet well. However if only Pump 12, for example, was in operation, there were more persistent submerged vortices under it. These submerged vortices could probably be significantly reduced by the placement of cones beneath each pump intake.

Some preliminary measurements of swirl angles were made during the Phase 1 investigation. These indicated very small swirl angles, generally less than one degree for the few cases studied. However, there was still a significant amount of vortex motion apparent in the pump suction lines. Since all the testing conditions involved air entrainment into the flow as discussed above, one could observe these vortices by the organization of the air bubbles. Figure 5 is a photograph of flow through one of the pump intakes. Due to the low light conditions, which necessitated longer film exposure speeds, and the high velocities through the intakes, the air bubbles tend to show up as streaks; The videotape is a better source for flow visualization. Nevertheless, organized bubble motion is clearly visible in Figure 5. The observations of significant vortex motion but measured small swirl angles can be explained by the operation of the swirl baffles. These baffles served to divide the inflow into four separate quadrants, and no organized vortex larger than roughly one-quarter the inflow area was permitted. This resulted in the formation of independent vortices in each of the four quadrants. These vortices, however, were insufficient to produce a large organized rotation that created swirl meter rotation. As discussed below in the Phase 2 results, the removal of the swirl baffle from Pump 12 increased the swirl angle in that intake by about an order of magnitude for the flow conditions studied. Thus, it is apparent that the swirl baffles are an essential component of the pump intakes in order to keep the overall swirl at acceptable levels.

The high turbulence level within the wet well was readily apparent through the flow visualization afforded by the air entrained into the flows. The major source of this turbulence was due to the expansion of the inflows into the wet well directly under the pump intakes. This turbulence along with the submerged vortices caused significant water level fluctuations in the stand tube at the location of the proposed level sensor within the wet well (this was to the side of the wet well but between Pumps 10 and 11). At the highest flow rates, the variation in water level within the stand tube was in excess of 5 ft prototype. The stand tube was of smaller diameter than the correctly scaled diameter, so it is possible that actual prototype fluctuations would be somewhat less than this. However, this would not be generally acceptable for purposes of controlling pump operation, so alternate locations were investigated in the Phase 2 study.

Observations of the flow also indicated significant head losses in the flow through the drop shafts as well as in the conduits connecting between the drop shafts and the wet well. An attempt was made to estimate the distribution of losses between the drop shaft and the connecting conduit. This was accomplished by simultaneously measuring hydraulic grade lines at the top and bottom of the drop shafts as well as within the wet well at several different flow rates. This was done for both east and west inlets. There were a number of difficulties in performing these measurements. As indicated in Figure 4a, for example, the water surface within the drop shaft is not level, even if the inlet conduit is essentially submerged. An average water surface elevation had to be estimated. In addition the other locations were subject to significant turbulent fluctuations and damping of these was necessary in order to be able to make measurements. Head losses through the east drop shaft/inlet pipe were somewhat greater than through the west connection at a given flow rate.

The drop shafts are designed with a basket strainer and other internal appurtenances to screen large solids from entering the wet well. Preliminary testing was performed with the basket as well as other internal geometry reproduced in detail. No differences in the change in head between the drop shafts and the wet well could be discerned compared to testing in which these details were omitted from the model. Consequently, all further testing was conducted without the basket strainer and other internal dropshaft elements for convenience in visualizing the flow.

The Plexiglas conduits that served as the inlet pipes connecting the drop shafts and the wet well were found to have a slightly smaller than specified internal diameter and therefore this dimension was not reproduced at the exact geometric scale in the model. This would result in larger velocities in the connecting pipe than required to produce dynamically similar flow conditions and would also result in larger head losses. Since the relation between total head loss and flow rate was nearly quadratic (head loss proportional to the discharge squared) it was assumed that the losses could be expressed as a function of the velocity squared. Therefore, the head losses between the drop shaft and the wet well were adjusted downward by the square of the ratio of the actual conduit area to the geometrically scaled area; these results are referred to as adjusted head losses. There was no need to make such a correction for the losses in the drop shafts since they were constructed on the basis of exact geometric similarity.

The results of the head loss measurements are presented in Figures 6 and 7 for the east and west inlets, respectively. The head loss presented in each figure is the elevation difference between the water level in the drop shaft and that in the stilling well connected to the wet well. As expected, both figures indicate an approximately quadratic relation between the head loss and the flow rate: $h_L \propto Q^2$. Head losses are fairly substantial; at a station capacity of approximately 150,000 gpm, the head losses through each inlet are on the order of two feet if the flow is evenly distributed and would be early six feet in the east inlet if 75 percent of the inflow entered through it.

- During the Phase 1 investigation, it became apparent that there were hydraulic limitations to the possible control of the pump sequencing during dry weather flow conditions. This is introduced by the requirement to avoid diverting flow to the storm wet well during dry weather operating conditions. Check dams in the interceptors were originally set an elevation of 62.5 ft and water levels at those points could not be exceeded without the undesirable flow diversion. The minimum wet well hydraulic grade line to avoid cavitation was initially specified at 58.0 ft so there is only a range of 4.5 ft of hydraulic grade line elevation difference between the two points in the system which can be exceeded at some flow rates according to Figures 6 and 7 which do not account for the total head change between the interceptors and the wet well. This situation is particularly exacerbated in the east entrance if a significant fraction of the inflow enters through it. Another more difficult problem is introduced when the inflow into the drop shafts is in an unsubmerged state as would typically be the case in this range of hydraulic grade lines. Under this flow state, the flow through the conduit connecting the interceptor and the drop shaft would be controlled by the interceptor water level and the occurrence of critical flow in the free surface flow at the exit from the connecting pipe at the drop shaft. Lowering the water level in the drop shaft would not increase the flow through the connecting pipe. In a condition where the flow through that pipe was nominally above the capacity of the particular combination of pumps in operation, the water level in the drop shafts (and thus the wet well) will increase until the next pump turns on. At this point, the pumping capacity is now far in excess of the inflow rate and the only storage available is in the drop shafts which have a cross-sectional area of only 49 square feet. Regardless of the pump combination, this would result in an evacuation of all water in the drop shafts, ingestion of air into the wet well and subsequent loss of pump prime in a matter of seconds. It is also likely that pump cavitation would occur during a portion of the cycle. This sort of cycle must be associated with the current operation of the pump station. It is clearly infeasible to cycle pumps on this short a time scale. Consequently, alterations in the proposed pump station operation were developed which utilized the available storage in the interceptors. This requires higher wet well hydraulic grade lines so that the flow within the drop shafts is maintained in a submerged condition.

This set of flow conditions was investigated during the Phase 2 testing as described in the next section.

Phase 2 Results

A proposed plan for sequencing the pump operations was developed with the provision of operating at higher wet well hydraulic grade lines to provide submerged inflow conditions in the dropshafts and to utilize the storage available in the interceptors to lengthen the pump cycle times. The proposed operating conditions were summarized in Table 1. The model was initially tested at these flow conditions under the assumption that the inflow into the wet well was equally contributed by the east and west inlets. The hydraulic grade line elevations listed in Table 1 were to be associated with conditions in the main interceptors. Since there are differences in head losses between the two inlets (as can be seen in Figures 6 and 7) at this flow distribution, the hydraulic grade lines in both interceptors cannot be set at a common level. The greater head loss associated with the flow in the east inlet was considered to control the pump operation and the hydraulic grade line measured in the east connecting pipe was used to set the prescribed hydraulic grade lines. Swirl angles were computed for both the on and off water levels at each combination of pump operation. The results of these measurements are included in Table 2. As can be seen, the swirl angles are well below five degrees under all operating conditions. This is in spite of the observations of submerged vortices within the wet well and is apparently related to the presence of the swirl baffles. Removal of the swirl baffles from Pump 12 resulted in significant increases in swirl angle by more than an order of magnitude in most cases as listed in Table 2.

Two new piezometer locations were suggested; these locations are indicated in Figure 8. Piezometers were installed at these two locations at the appropriately scaled diameter for the bubbler pipe proposed for the prototype. Visual observations were made of the water level fluctuations in the two piezometers. The range of fluctuations is indicated in Figure 9 and was roughly the same for both piezometer locations. The fluctuations are also seen to increase with total flow rate as expected. This range of fluctuations is substantially less than at the original location and is presumed to be suitable for the intended water level sensing application.

Following these experiments, an inflow distribution was selected in which 75 percent of the inflow entered through the east drop shaft to reflect a situation where the majority of the inflow enters through the East Jeffereson Relief Interceptor. It was not possible under this inflow distribution to set the desired hydraulic grade line elevations at the upstream end of the east connecting pipe. The inflow into the drop shafts became unsubmerged and the occurrence of critical flow at the inflow prevented lowering the hydraulic grade line to the desired level. It was therefore concluded that the pump operating conditions listed in Table 1 would only be achievable when the inflow into the wet well was approximately equally distributed between the two inlets. Although this is apparently a possible flow condition, it may not be a common one and further modifications in the pump station operation are required in order to provide feasible operating conditions over the entire range of potential inflow conditions.

Phase 3 Results

As a result of the Phase 2 findings, it was concluded that the only feasible method of operating the wet well is to pass some portion of dry weather flows to the Storm Pump Station and to utilize the third entrance into the Sanitary Pump Station. The physical model was not constructed with this prospect in mind and hydraulic testing for these conditions was not in the original scope of the model study. However, the existing model could be used to define the hydraulics of the two modeled inlets. These results can then be incorporated into an calculations of the system hydraulics with the third inlet open. This will allow the definition of feasible pump operating levels.

The third phase of model testing was intended to more carefully define the hydraulics of the east and west inlets to the wet well. Tests were performed on these individually with flow passing through only one of the inlets at a time. The purpose of this testing was to define the hydraulic grade line elevations necessary to provide submerged inlet conditions in the drop shafts and to define necessary hydraulic grade lines to minimize air entrainment insofar as possible. These experiments involved the measurement of hydraulic grade lines in both the wet well and at the upstream end of the inlet pipe into the drop shaft. This upstream hydraulic grade line elevation will basically reflect the hydraulic grade line in the interceptor except for the entrance loss in the flow from the interceptor. Examination of different pipe junction geometries listed in Idelchik (1994) indicates that this entrance loss should be on the order of about 0.4 to 0.5 of the downstream velocity head (velocity head in the connecting pipe). In addition, visual observations were made on the amount of air entrainment within the drop shafts. In this regard, it was noted that that as the wet well hydraulic grade line was gradually increased, the air entrainment decreased until a further increase in hydraulic grade line elevation resulted in little additional reduction in air entrainment.

The basic procedure involved setting an arbitrary flow rate at a relatively low wet well hydraulic grade line at which the inflow into the drop shaft was clearly at an unsubmerged condition. The hydraulic grade line elevations were measured in both the wet well and at the upstream end of the inlet pipe. Water was added to the model increasing the hydraulic grade line elevations, air entrainment was observed and hydraulic grade line elevations were again measured. This process was repeated for increasing hydraulic grade line elevations until the inlet into the drop shaft was clearly in a submerged condition. The entire process was repeated for several different flow rates. These measurements were performed for both the east and west inlets.

Measurement results for a typical flow condition are presented in Figure 10; corresponding graphs for the other flow conditions tested are presented in the Appendix as well as the basic data. At low wet well hydraulic grade lines, the flow into the drop shaft is in an unsubmerged flow state and the occurrence of critical flow at the downstream end of the connecting (entrance to the drop shaft) pipe controls the hydraulic grade line elevations further upstream. Consequently, a change in wet well hydraulic grade line does not alter the hydraulic grade line elevation in the inlet; this effect is clearly seen in Figure 10. This flow state is unacceptable with regards to pump station operation since there is no feasible way to stage the pump sequencing to match the inflows into the wet well with the limited available system storage. At higher hydraulic grade line elevations, the flow into the drop shaft is in a submerged state and there is basically a one-to-one correspondence between the change in hydraulic grade lines measured at the two locations. The transition between these two flow states is not abrupt although it does occur over a limited range of hydraulic grade lines. Two methods were selected for defining the transition state. The first (called the "average" transition point) involved extending the straight line portions of the unsubmerged and submerged stages of the curves and noting the intersection; this is indicated in Figure 10. The second approach yielded a more conservative description and was defined by the highest hydraulic grade line elevation that deviated from the straight line defined by the submerged flow state. This definition (called the "high" transition point) is also depicted in Figure 10. A final adjustment to these levels was made to account for the larger than expected head losses in the model due to the slightly undersized connecting pipe between the drop shaft and the wet well as discussed previously. The results for both definitions of the transition hydraulic grade lines for the east and west inlets, respectively, are presented in Figures 11 and 12. The Appendix also includes tables with all of these results summarized. Figures 13 and 14 present the total change in hydraulic grade line well under submerged conditions in the drop shaft between the upstream end of the connecting pipe and the wet. Figures 15 and 16 present hydraulic grade line elevations associated with changes in air entrainment as described above. Although these observations are fairly qualitative, they are also reasonable consistent and can probably be used with a fair amount of confidence. The hydraulic grade line estimates above which no significant reduction in air entrainment was observed are generally well below those in Figures 11 and 12 to maintain submerged conditions at the drop shaft inlets. Therefore, it appears that the maintenance of submerged inlet conditions will also ensure the minimum achievable air entrainment with this pump station design.

The addition of a portion of the inflow into the wet well through the third inlet will have an influence on the pressure fluctuations at the proposed level sensor locations. In general, the reduction in magnitude of inflow velocities by distributing the flow among three inlets instead of two will reduce the magnitude of the pressure fluctuations within the wet well. Neitherither of the proposed sensor locations indicated in Figure 8 appear to be in a location where they will be adversely impacted by the inflow from the third inlet. It appears that the level sensor located closest to pump 10 would be the best in this flow configuration, but both are probably still acceptable.

CONCLUSIONS AND RECOMMENDATIONS

Preliminary testing of the physical model for the proposed operation of the pump station indicated that it will not generally be possible to operate in a satisfactory fashion over the anticipated ranges of discharges. The major problems were related to the control of pump sequencing by sensing of hydraulic grade lines within the wet well. At high flow rates, the head changes in the flow through the connecting pipes, drop shafts and inlet pipes may create upstream heads greater than the elevations of the proposed crests of the check dams in the Jefferson Avenue Relief Interceptor. Hydraulic grade lines within the wet well cannot be reduced to compensate for this because of the possibility for pump cavitation and the fact that at low wet well hydraulic grade lines, the inflow into the drop shafts is not controlled by the wet well HGL but rather by the occurrence of critical flow at the inlet to the drop shafts. Raising the elevation of the check dams is not a viable option since the capability of passing storm water flows over them during wet weather conditions must be maintained. The only solution to this hydraulic problem appears to be to allow excess dry weather flows to pass into the Storm Pump Station and to allow the connection between it and the Sanitary Pump Station to provide the necessary flow capacity. A detailed hydraulic analysis will need to be performed to ensure that satisfactory hydraulic performance will occur under this flow configuration.

Investigations of the conditions at the pump intakes indicated that swirl angles were well below generally accepted limits. These small swirl angles were apparently due to the presence of the swirl baffles since the removal of the baffle under pump 12 raised the swirl angle above the recommended five degree limit for all conditions tested. Therefore, the swirl baffles are an essential part of the pump station design.

In spite of the small swirl angles, a number of poor inlet conditions were observed, including excessive turbulence, persistent submerged vortices under pumps 10 and 11 (in particular), and entrained air passing through the pump intakes. The excessive turbulence is a function of the wet well design and there is probably no feasible way to eliminate it. Air entrainment occurs in the drop shafts and also cannot be avoided with the current design but can be minimized by maintaining the water levels in the drop shafts at sufficiently high elevations. Maintaining the drop shafts to produce a submerged inlet condition (necessary for other station operation considerations) will also produce a minimum air entrainment situation. The submerged vortices can probably be drastically reduced by the installation of floor mounted cones under each pump intake. A variety of configurations have been used in other installations for these cones, but the sketch in Figure 17 indicates a potential configuration. A typical dimension of the horizontal dimension of the cone is the outside diameter of the suction bell. The height of the cone in many installations is the entire distance between the floor and the bottom of the suction bell. In this installation, the presence of the swirl baffles probably does not make this necessary, but a height on the order of the width of the cone would probably be appropriate.

The proposed water level sensor locations indicated in Figure 8 appear to be fairly adequate for purposes of sensing wet well hydraulic grade line.

Finally, it will generally be necessary to operate the pump station at a sufficiently high hydraulic grade line elevation to maintain a submerged inflow condition in at least one of the dropshafts. Figures 11 and 12 indicate the elevations estimated from the model tests for the east and west drop shafts, respectively. Two different measures of the necessary hydraulic grade line elevation are provided with the "high" one providing a more conservative estimate. These hydraulic grade line elevations were measured at the upstream end of the connecting pipes and an entrance loss will need to be added to these levels to determine elevations in the interceptors.

REFERENCES

Idelchik, I.E. (1994) "Handbook of Hydraulic Resistance," CRC Press, Boca Raton, Fla.

Padmanabhan, M. and G.E. Hecker, (1982) "Assessment of Scale Effects of Vortexing, Swirl, and Inlet Losses in Large Scale Sump Models," Alden Research Lab, Worcester Polytechnic Institute, Report to Nuclear Regulatory Commission, NUREG/CR-2760

Table 2. Swirl Angles Measured For Proposed Permutations of Pump Operation.

		SWIRL ANGLES				
		Pump				12
Pumps in Operation	East Inlet HGL (ft)	9	10	11	12	No swirl Baffle
12	61.5				1.397	5.700
12	62.2				0.761	
10, 12	62.2		0.026		0.451	9.000
10, 12	63.3		0.771		0.873	
9, 10, 12	63.3	-0.119	0.514		0.394	14.300
9, 10, 12	64.5	-0.243	0.797		0.169	
10, 11, 12	63.3		0.185	-0.863	0.789	17.200
10, 11, 12	64.5		0.257	-0.200	0.225	
9, 10, 11, 12	64.5	1.564	-0.015	1.214	0.828	13.100
9, 10, 11, 12	65.5	-0.189	0.668	-0.415	0.338	

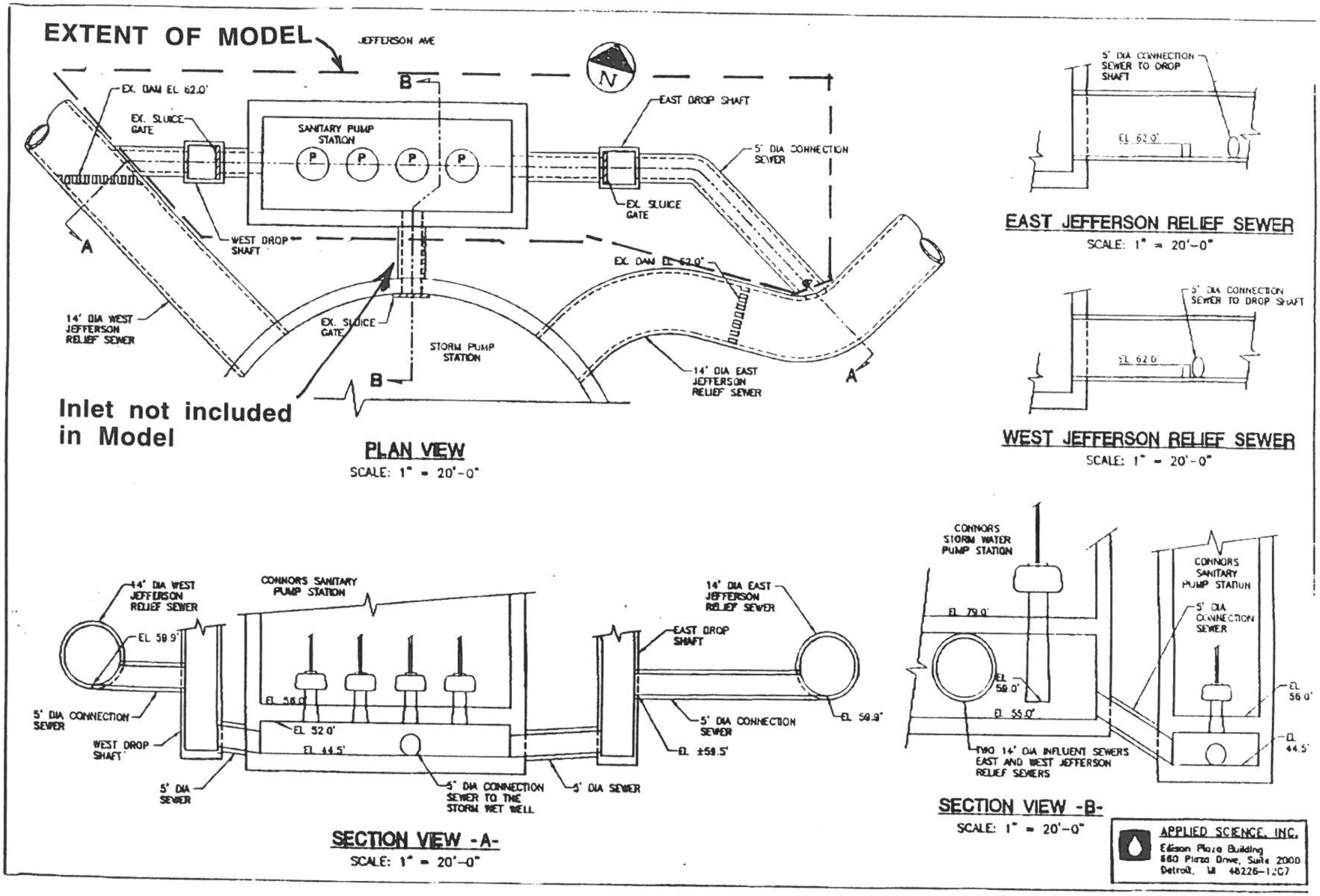


Figure 1. Layout of Conner Creek Sanitary and Storm Pump Stations.

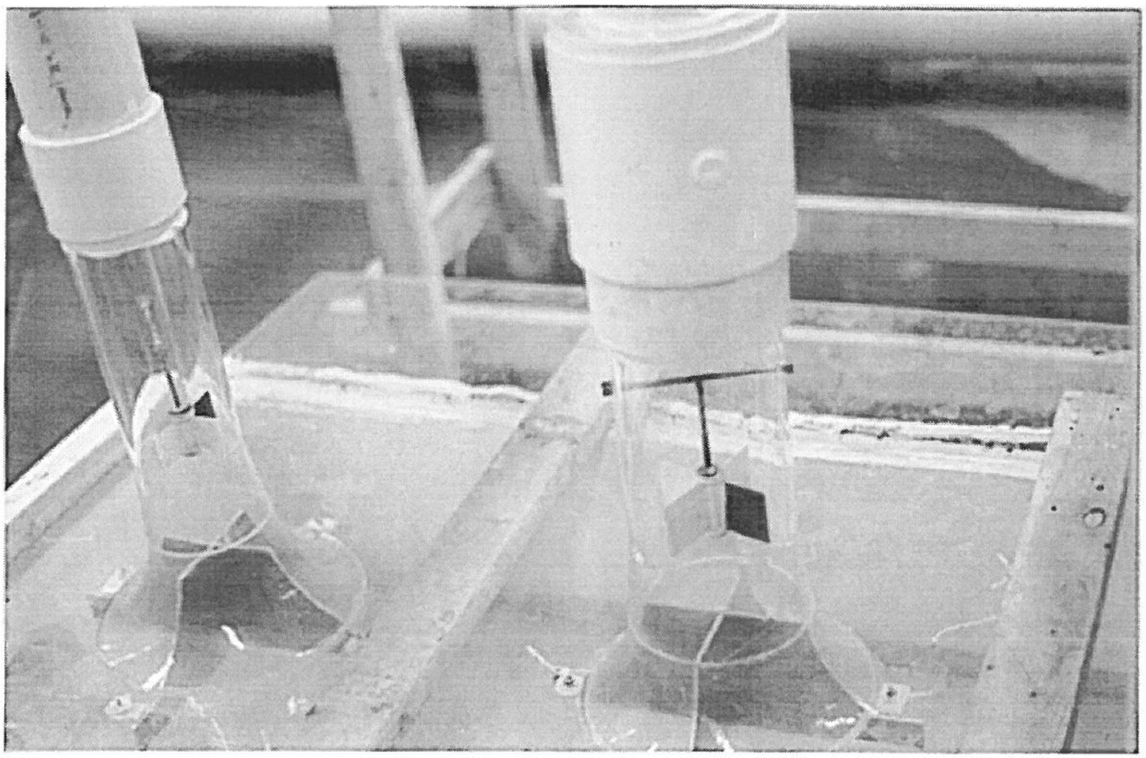


Figure 2a. Model Pump Intakes with Swirl Meters Installed.

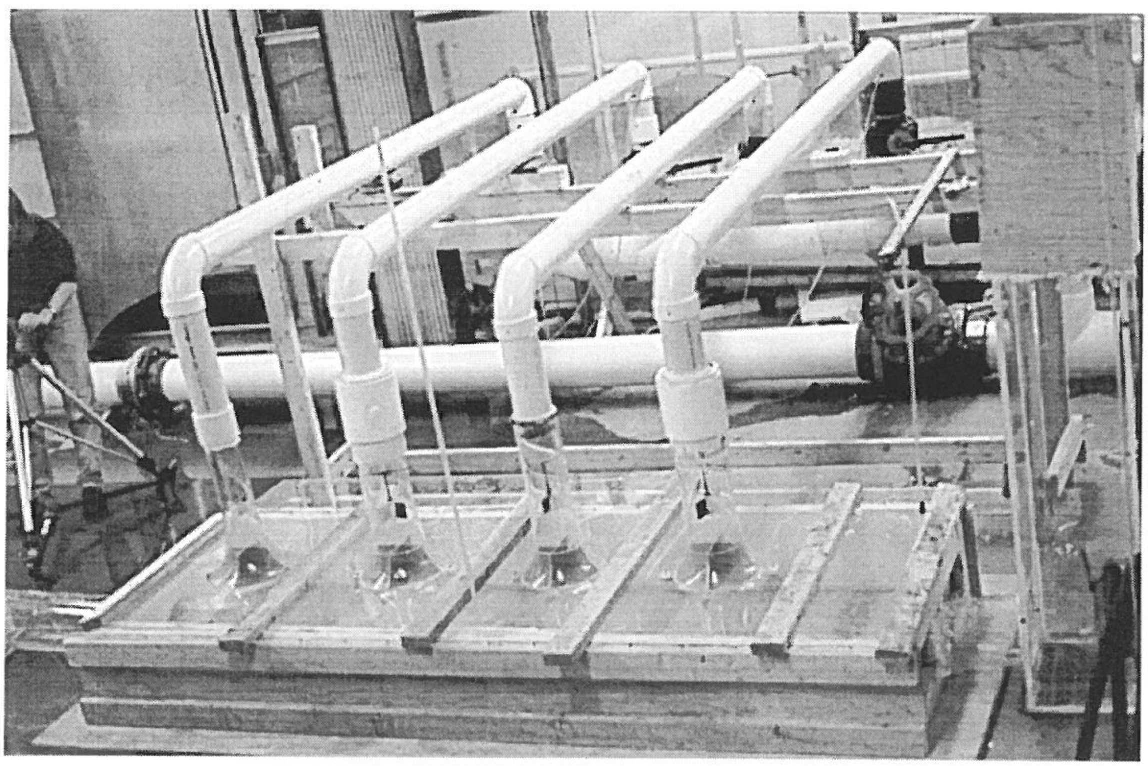


Figure 2b. Model of Wet Well and Pump Intakes. West Drop Shaft on Right.

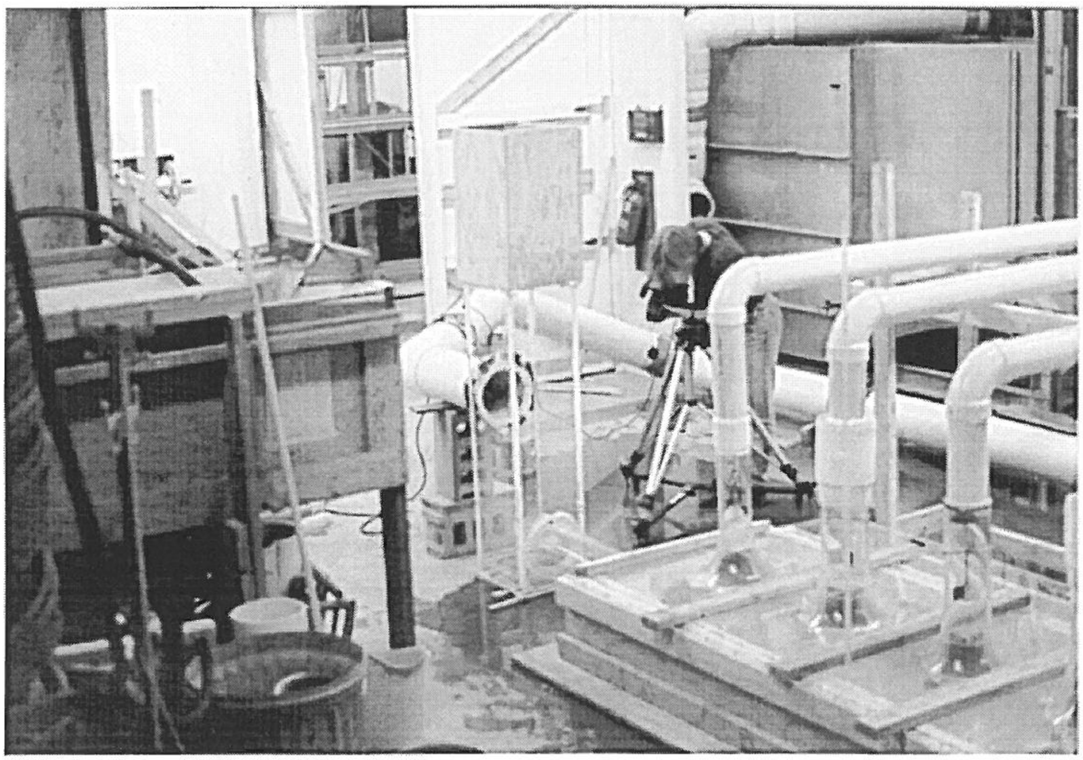


Figure 2c. East Drop Shaft with PVC Connecting Pipe and Plexiglas Inlet Pipe to Wet Well.

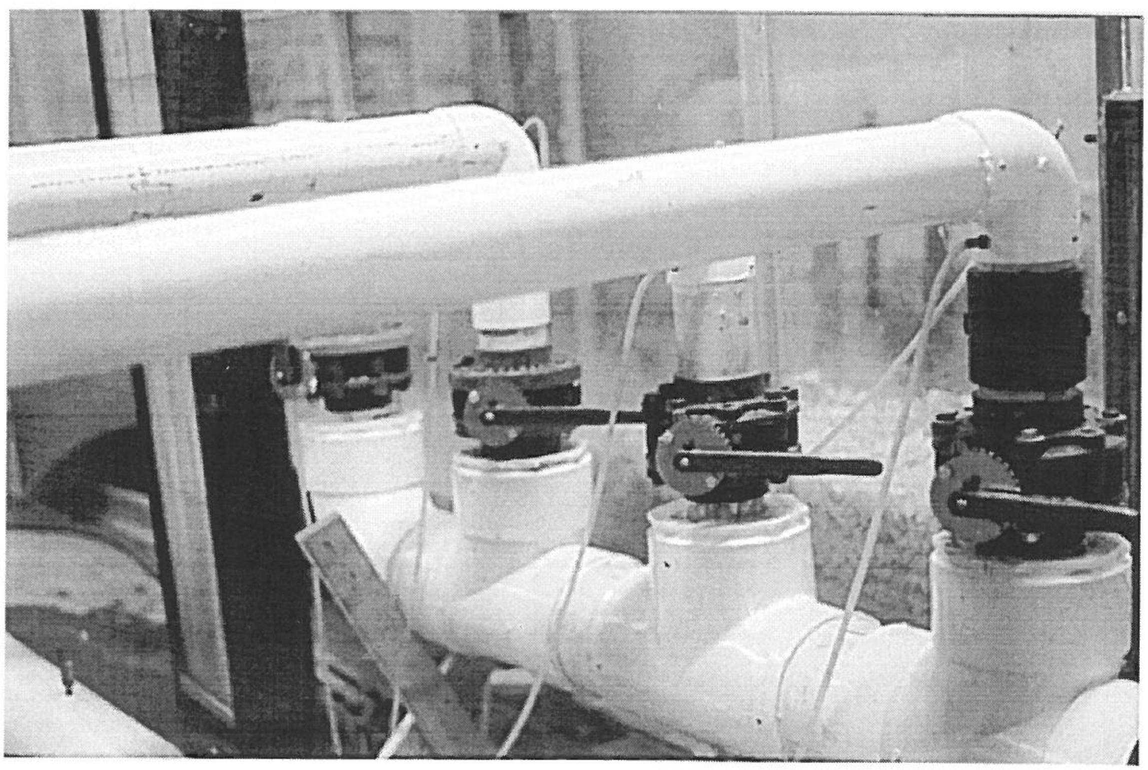


Figure 2d. Bend Elbow Meters and Manifold to Recirculating Pump.

Figure 3. Air Entrainment Due to Pumging Flow at Low Water Level in West Drop Shaft.

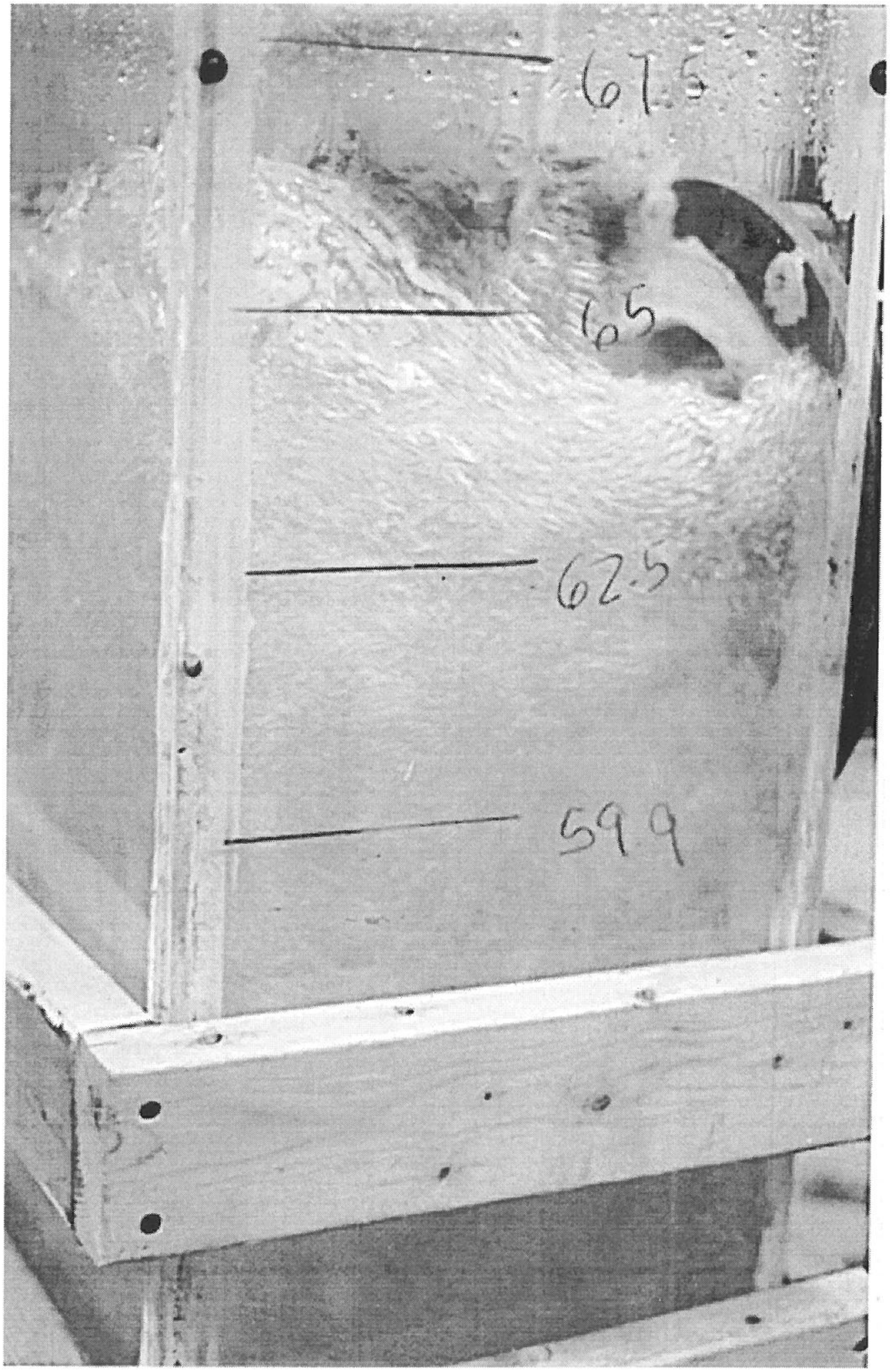


Figure 4a. Air Entrainment at Intermediate Water Level in East Drop Shaft.

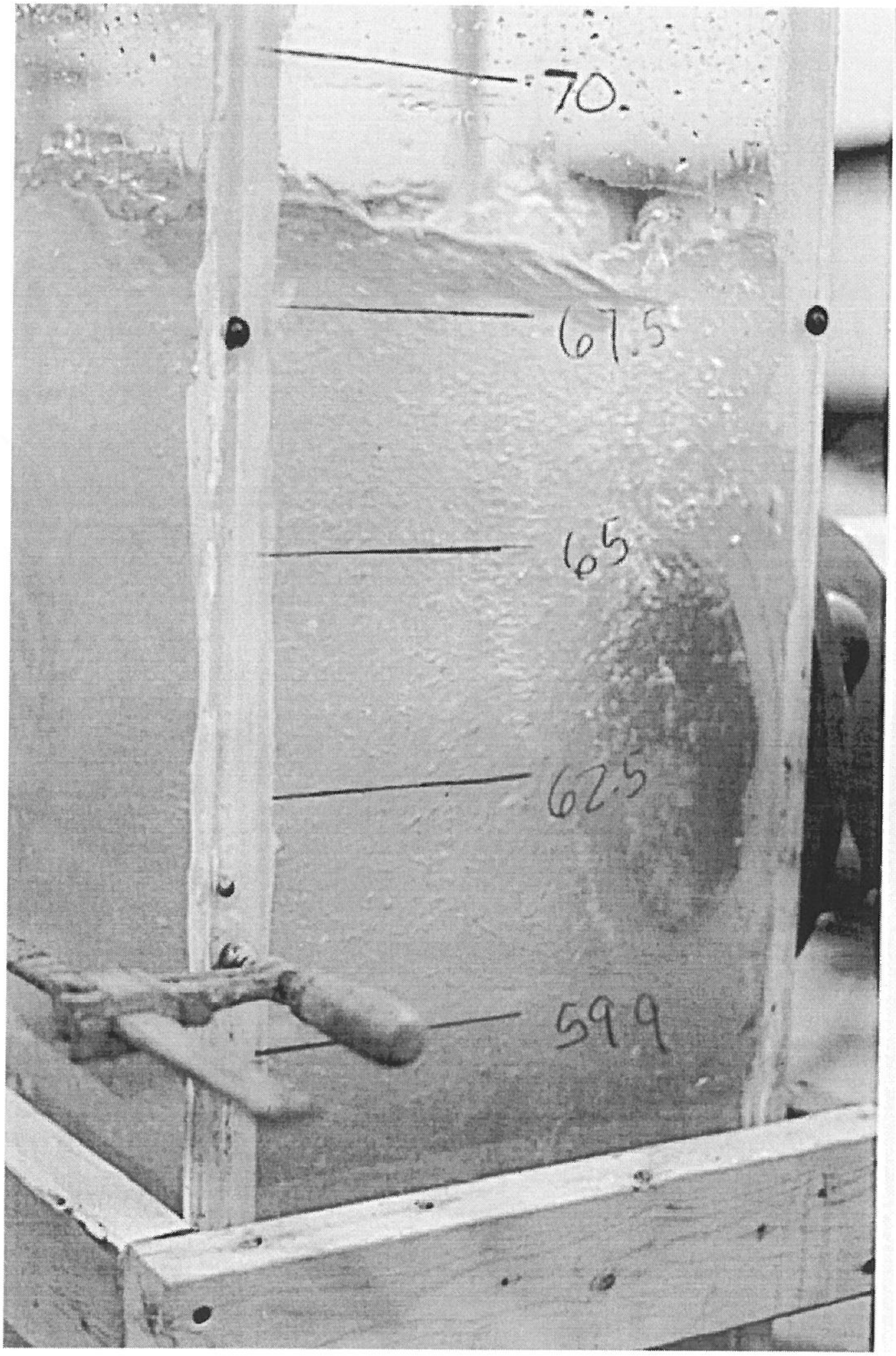


Figure 4b. Air Entrainment at High Water Level in East Drop Shaft.

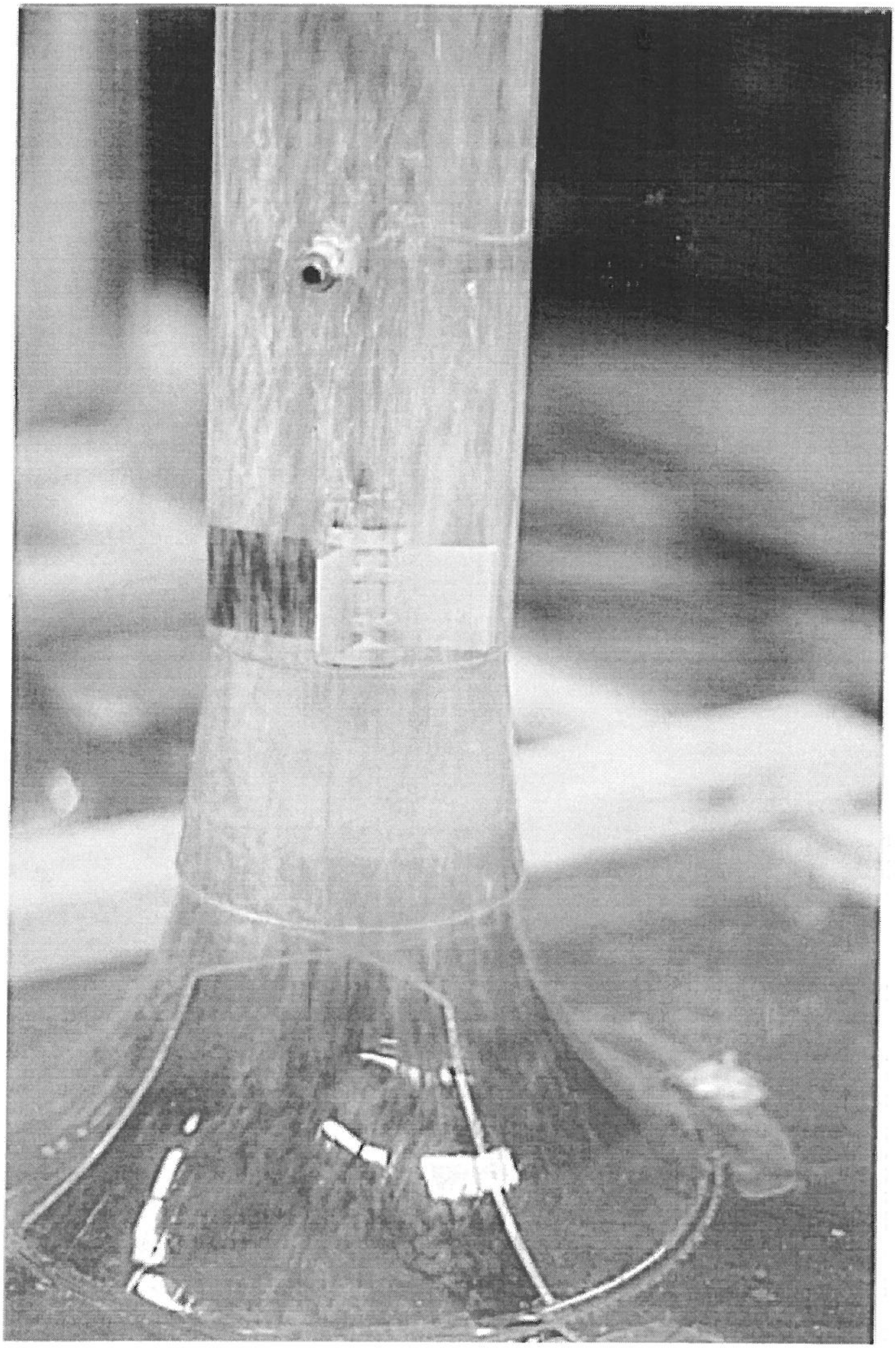


Figure 5. Small Scale Vortices in Pump Intake Visualized by Trails of Entrained Air Bubbles.

Figure 6. Adjusted Head Loss, East Drop Shaft

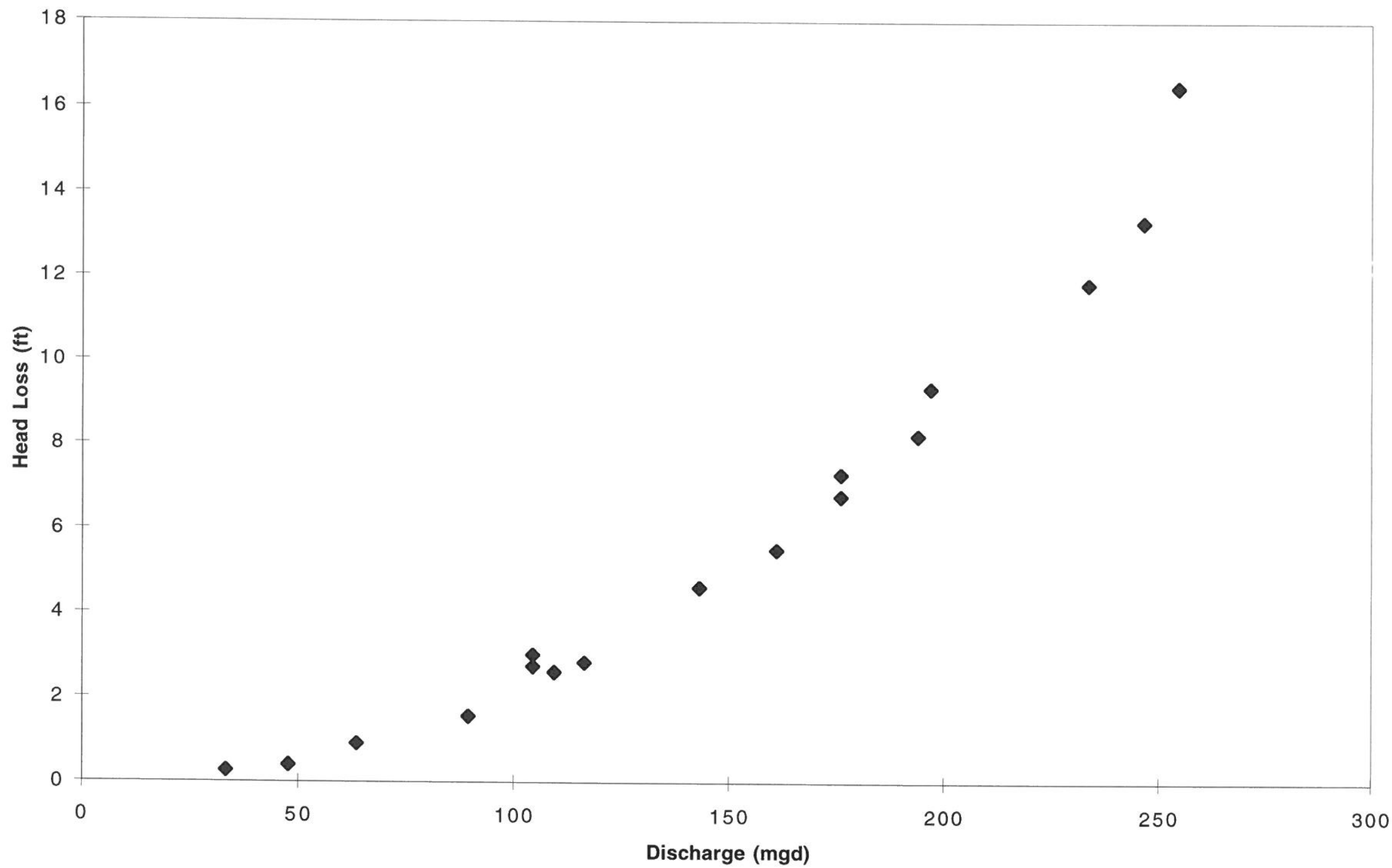
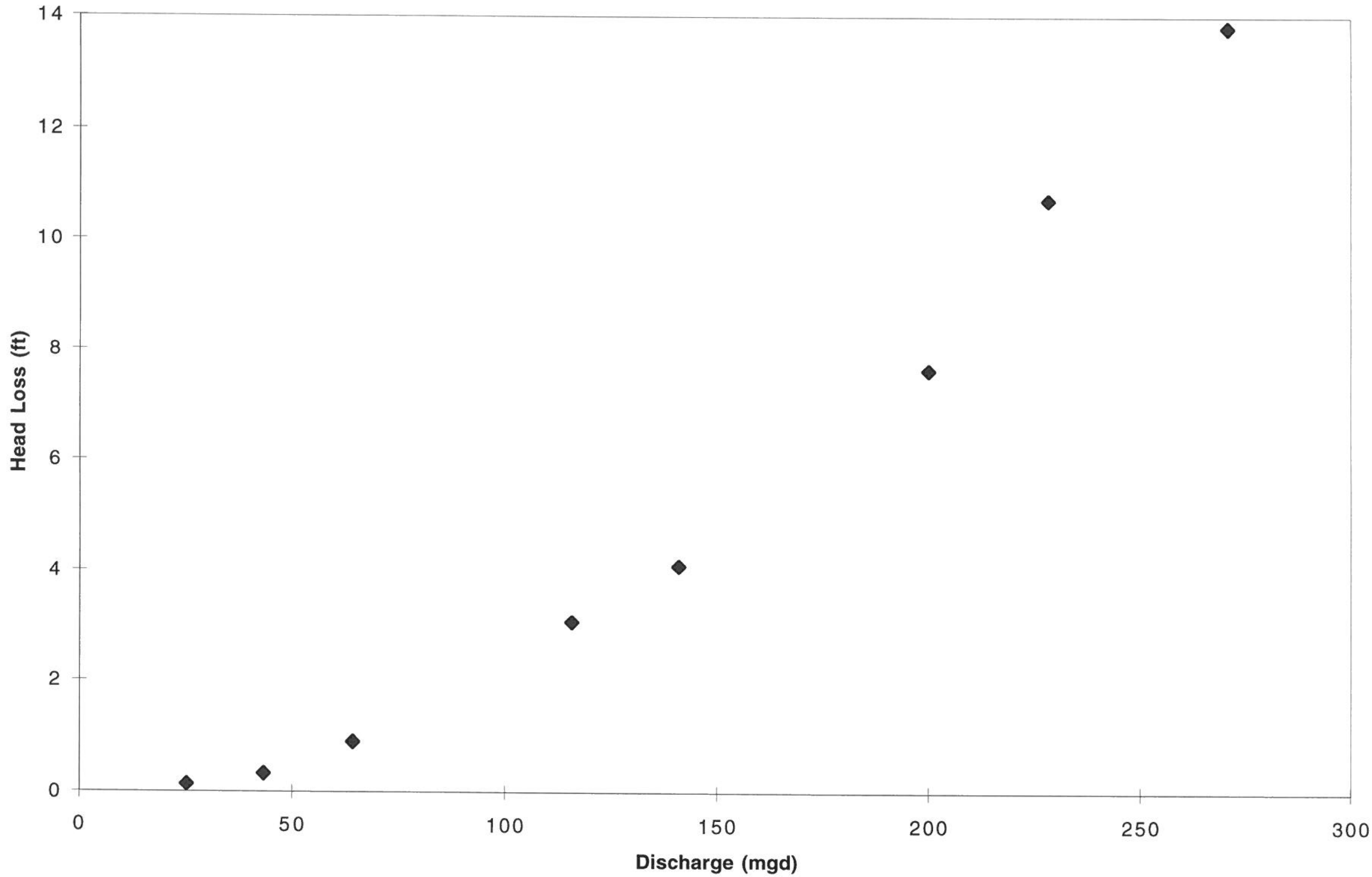


Figure 7. Adjusted Head Loss, West Drop Shaft



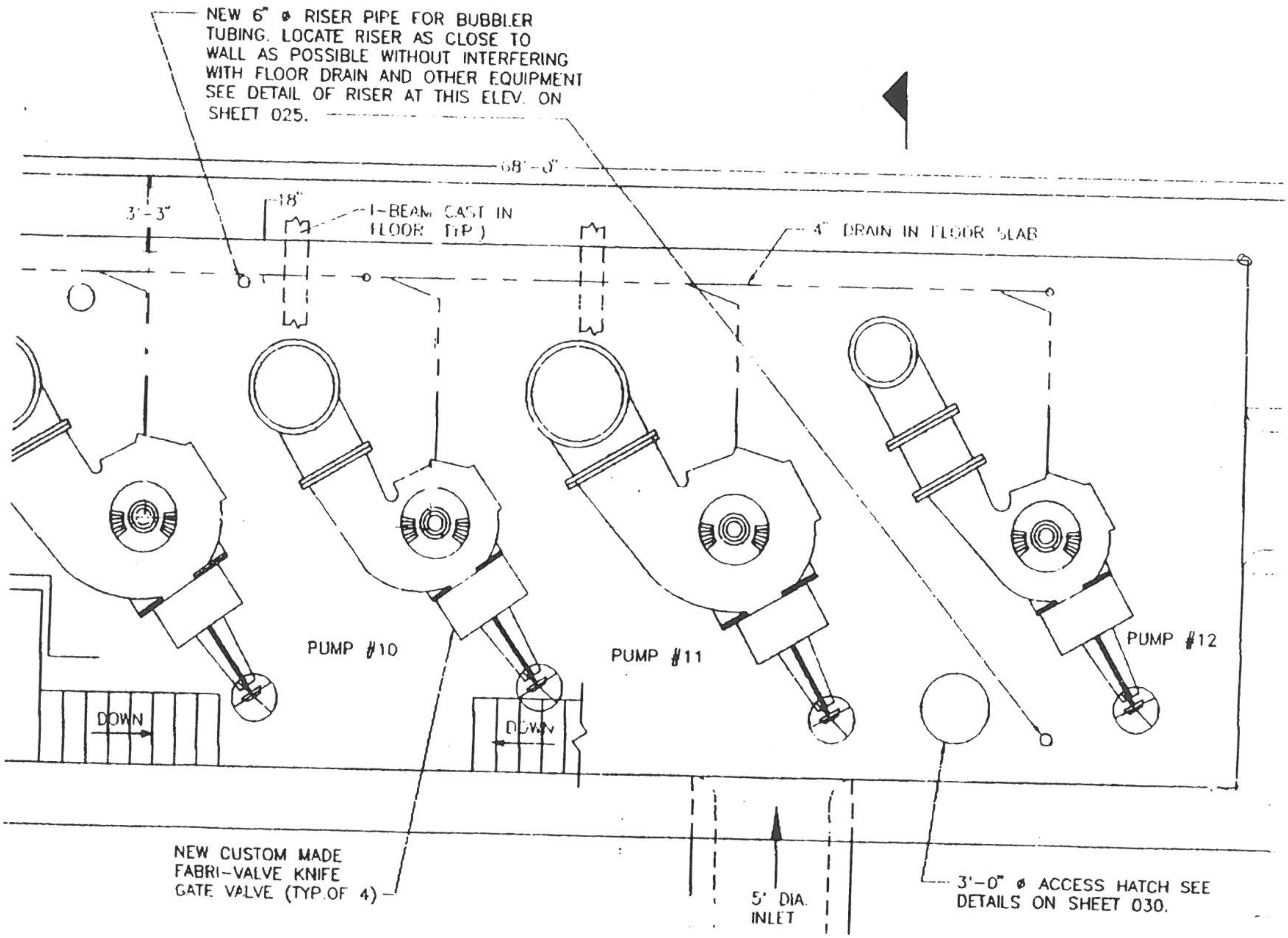


Figure 8. Proposed Locations of New Level Sensors

Figure 9. Approximate range of piezometer fluctuations (either location)

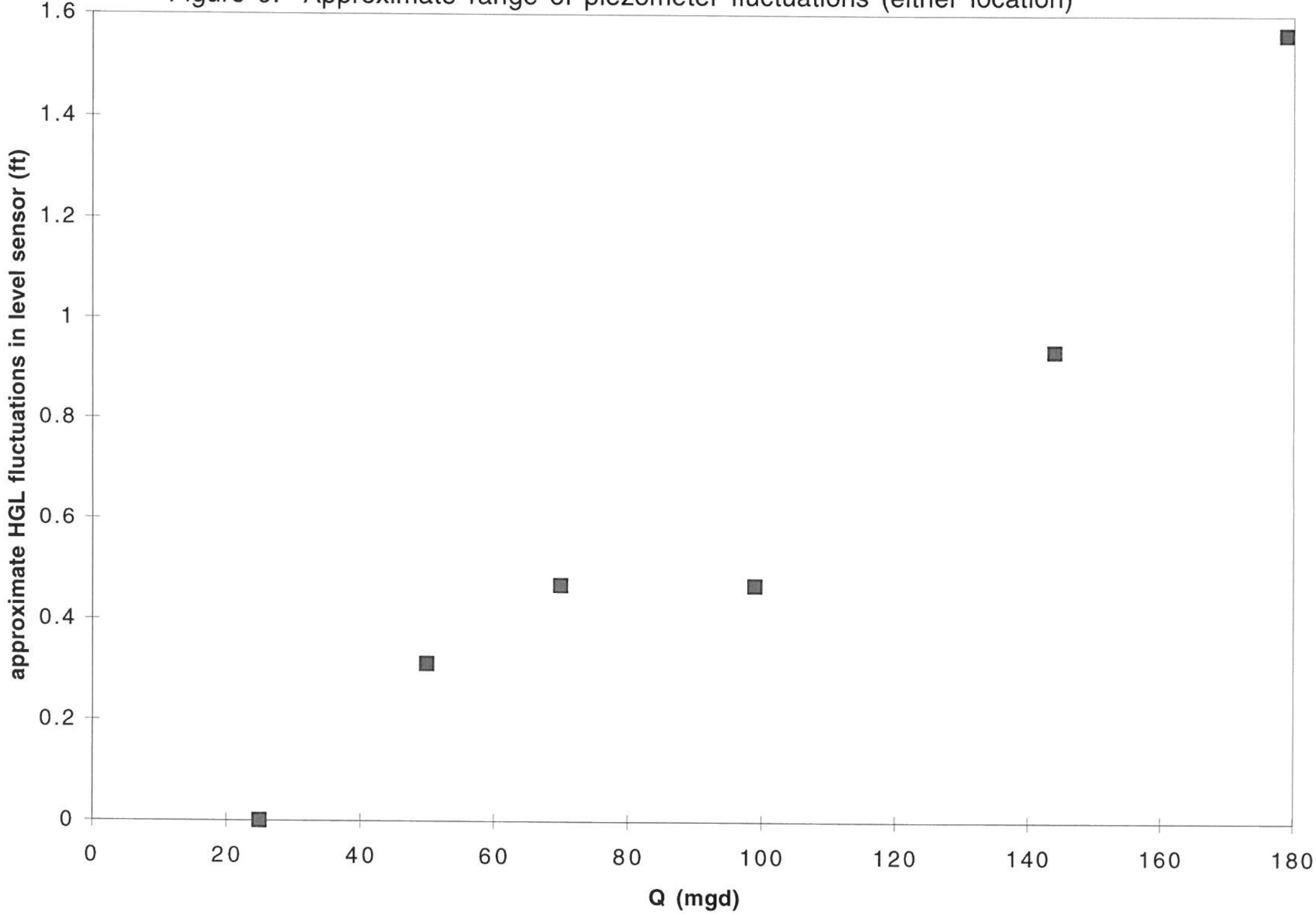


Figure 10. Definition of Transition Hydraulic Grade Lines, Q = 70 mgd

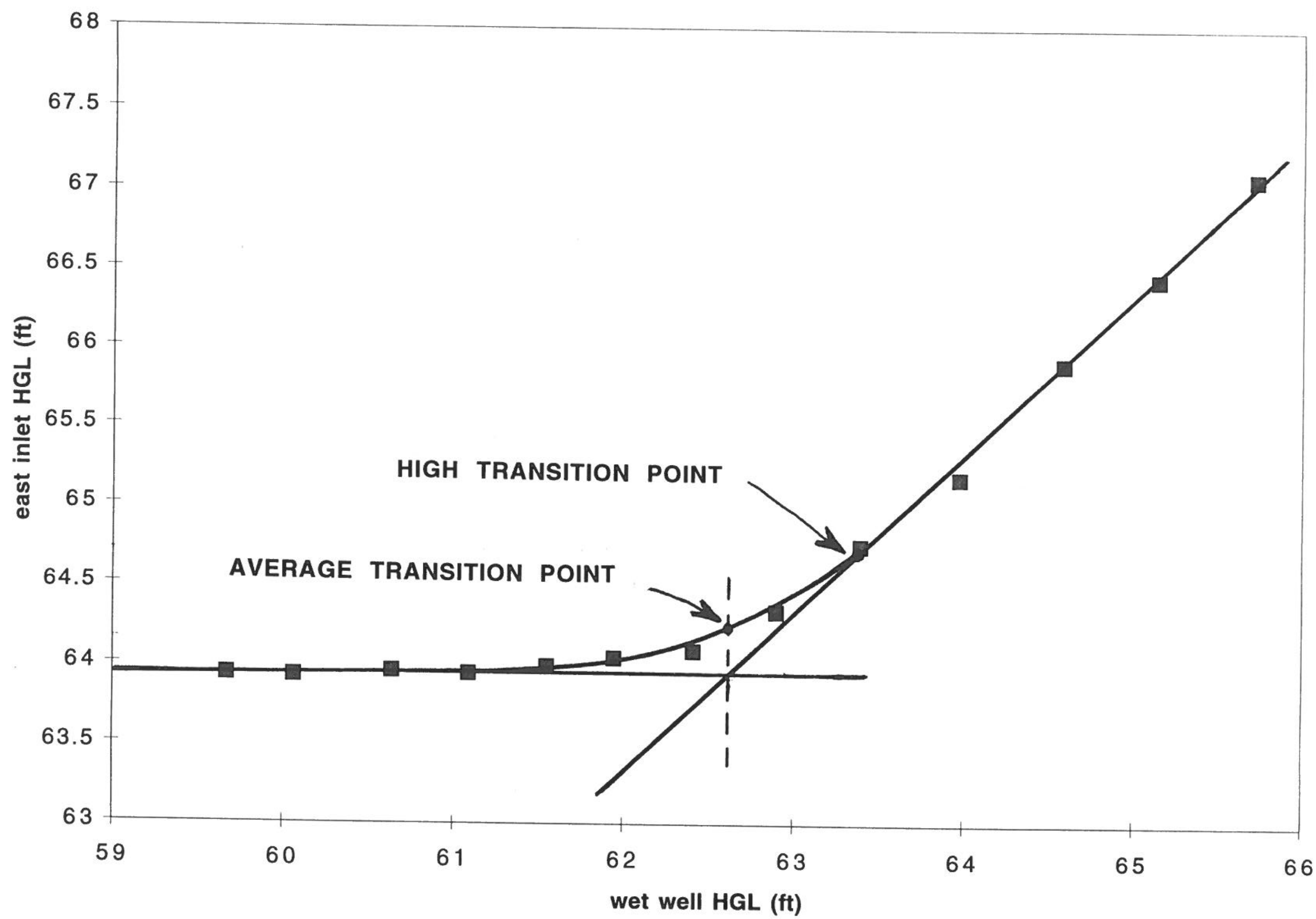


Figure 11. HGL at which wet well produces no backwater effect in east inlet

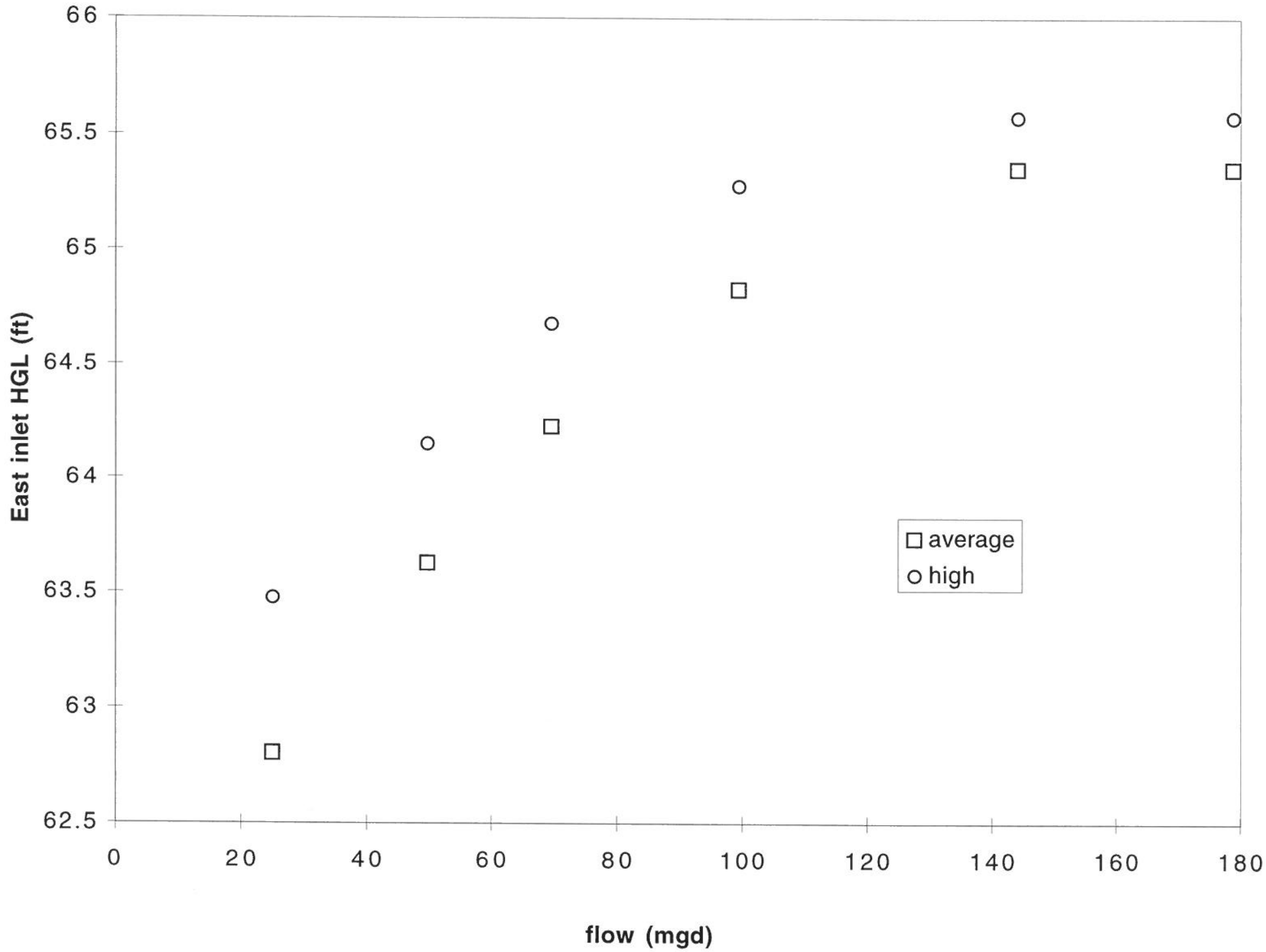


Figure 12. HGL at which wet well produces no backwater effect in west inlet

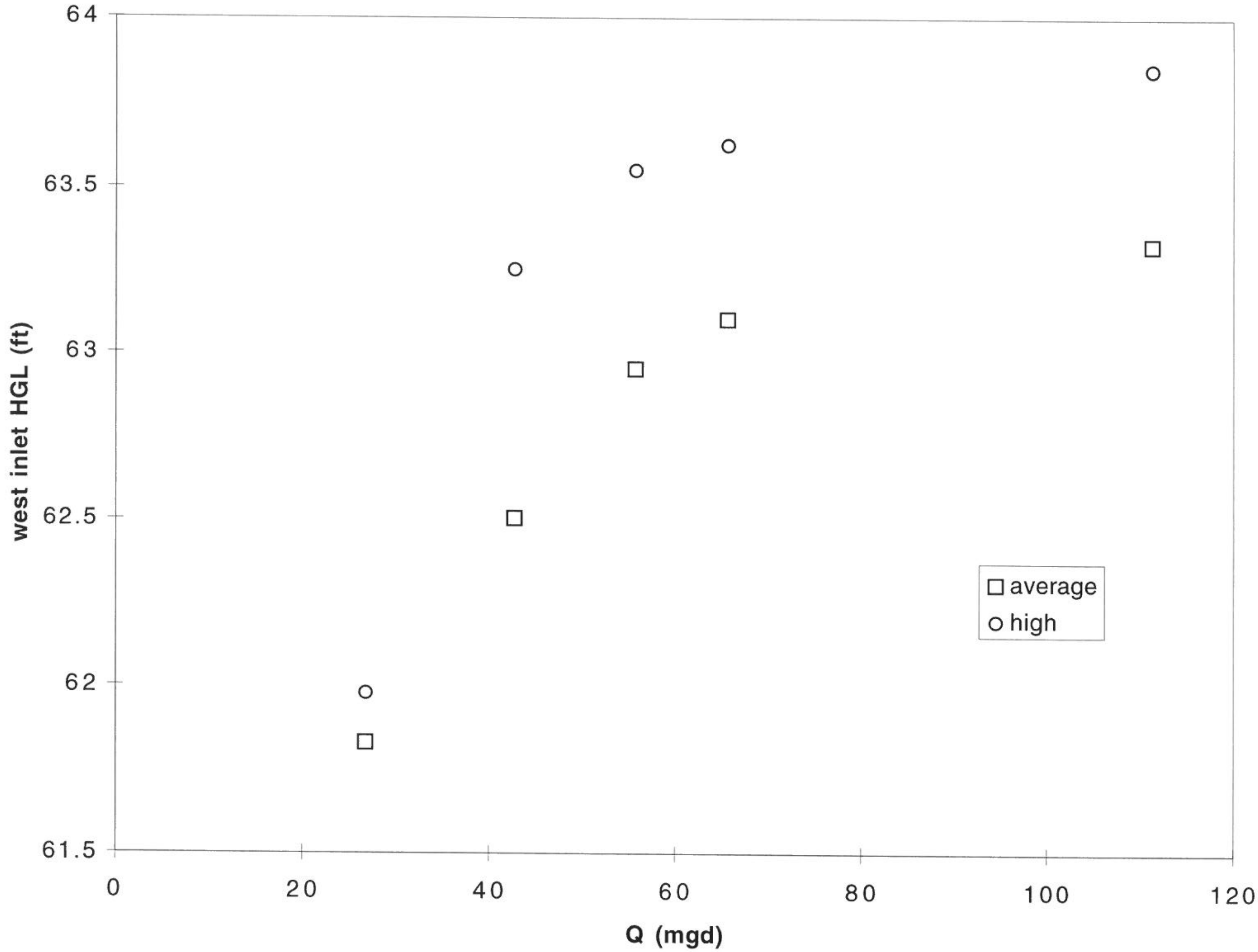


Figure 13. HGL difference between east inlet and wet well as a function of flow rate (submerged conditions within drop shaft).

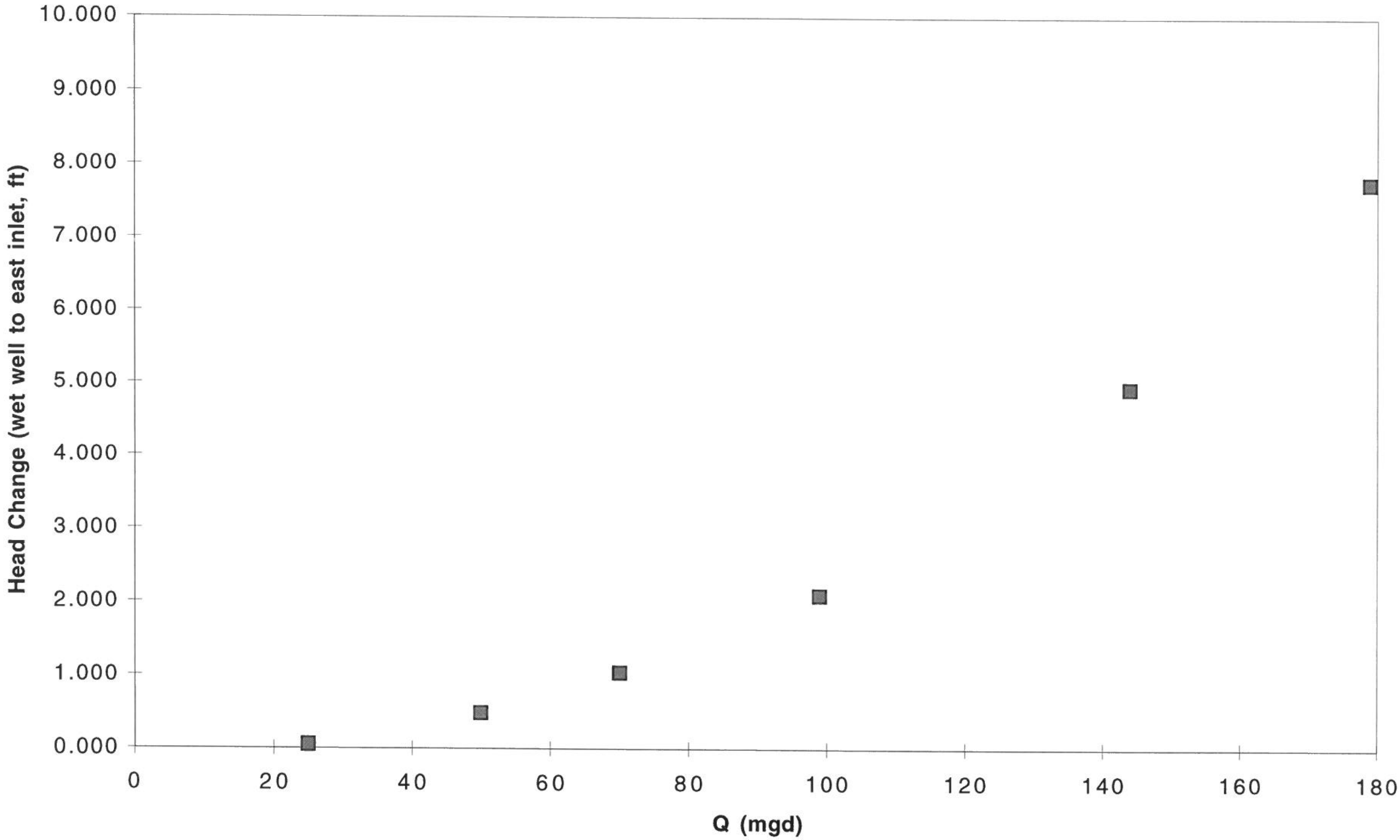


Figure 14. HGL difference between west inlet and wet well as a function of flow rate (submerged conditions within dropshaft).

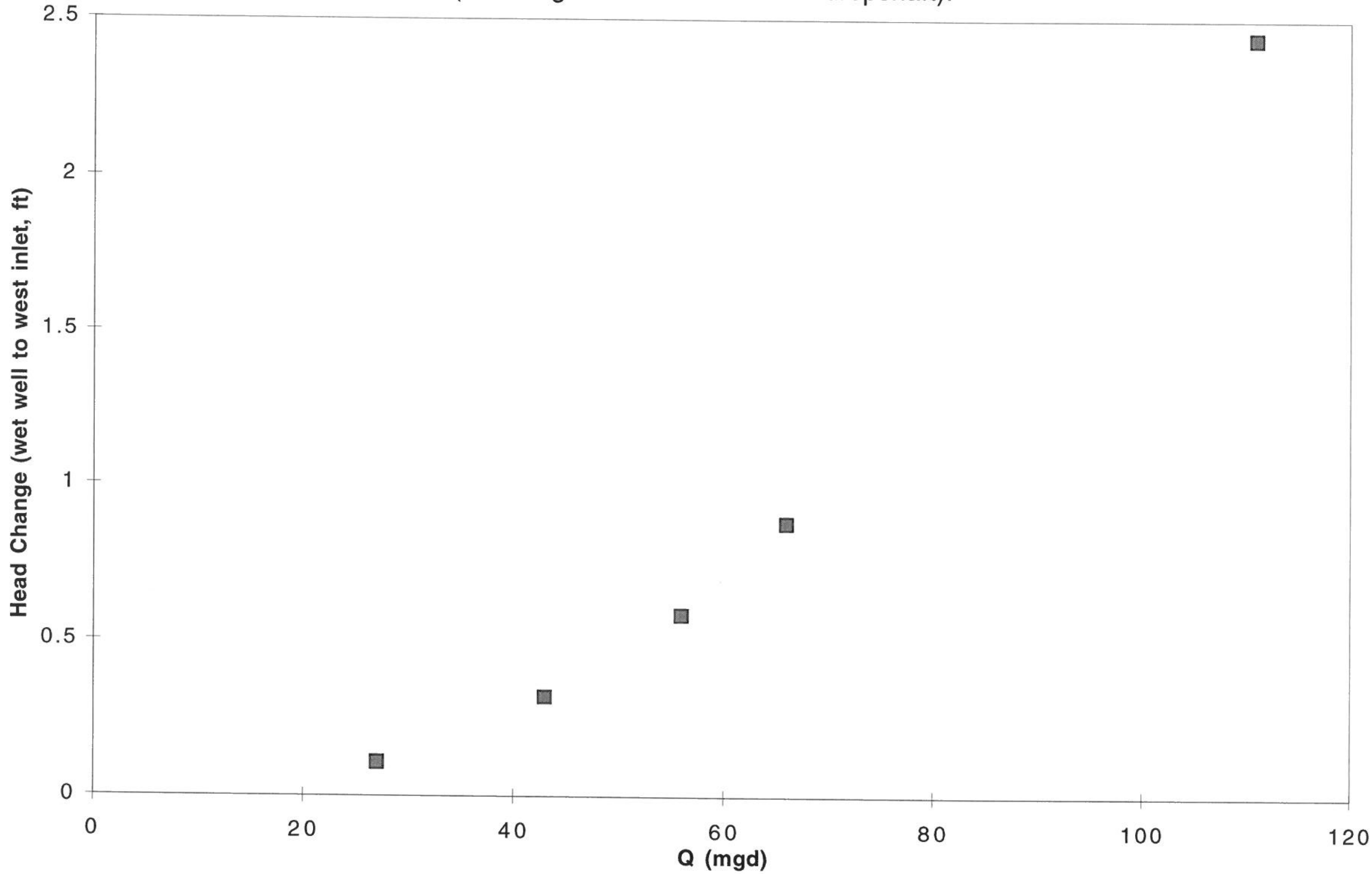


Figure 15. Wet well HGL elevations associated with air entrainment in east inlet drop shaft

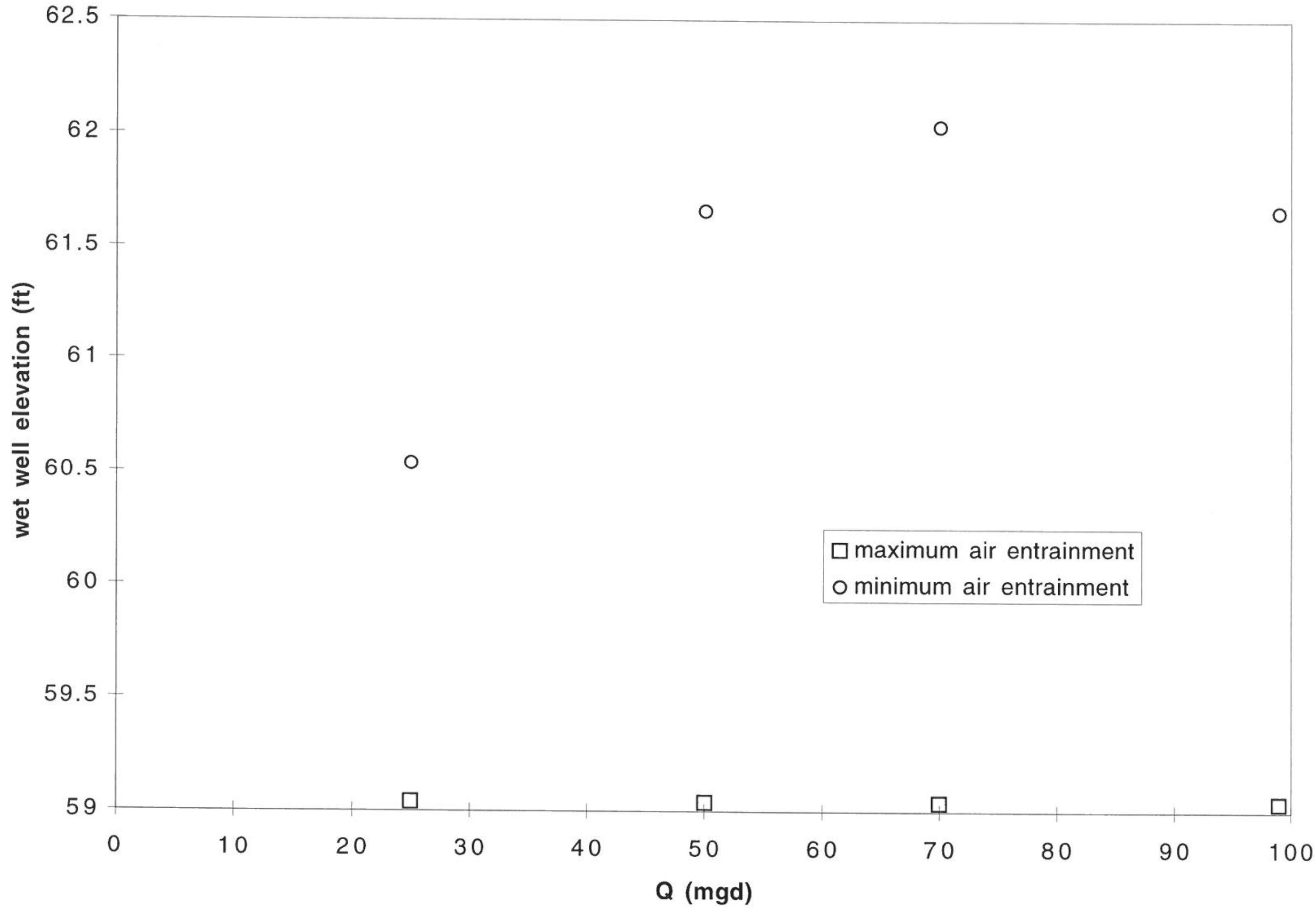
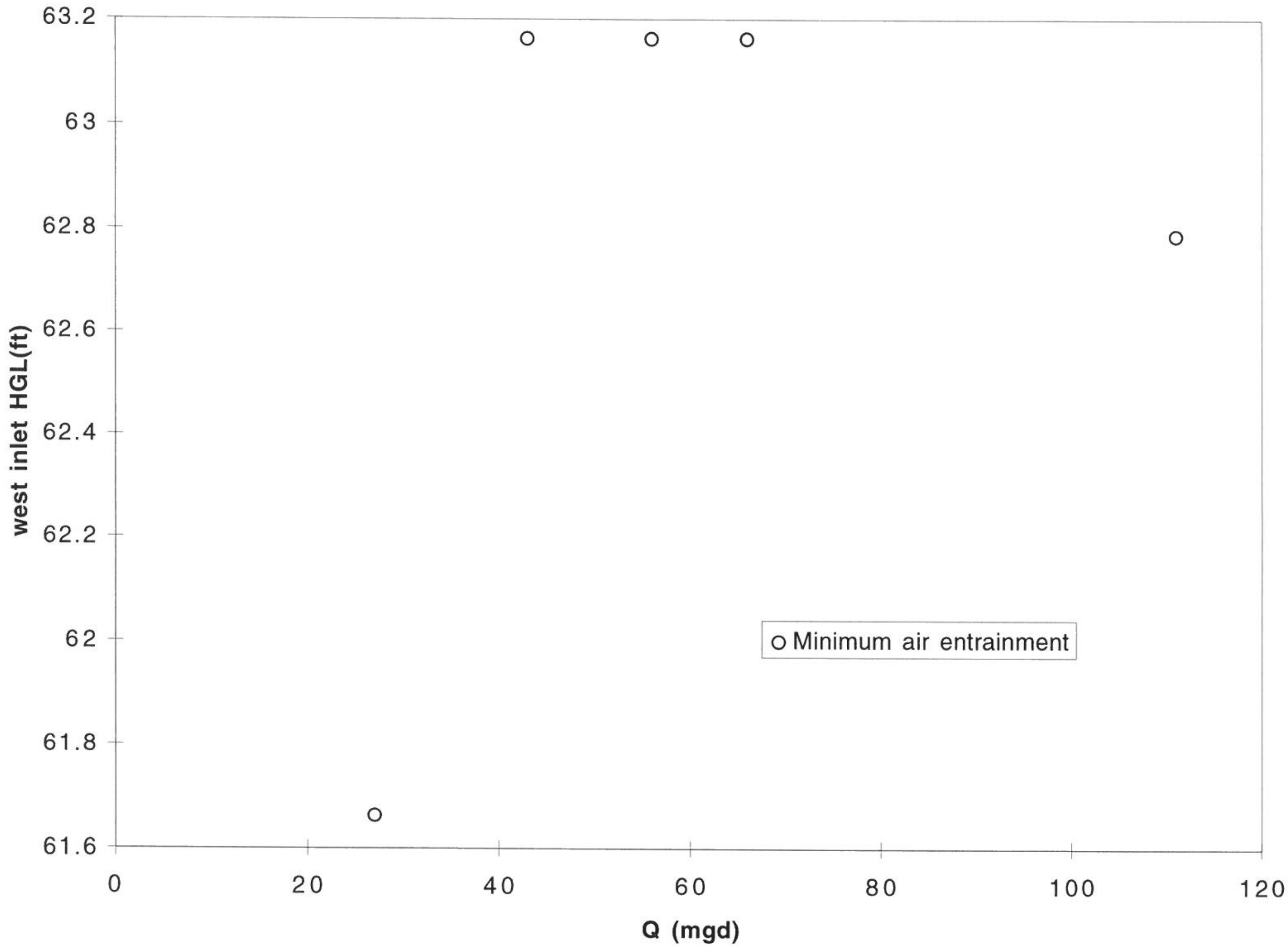


Figure 16. Wet well HGL elevations associated with air entrainment in west inlet drop shaft



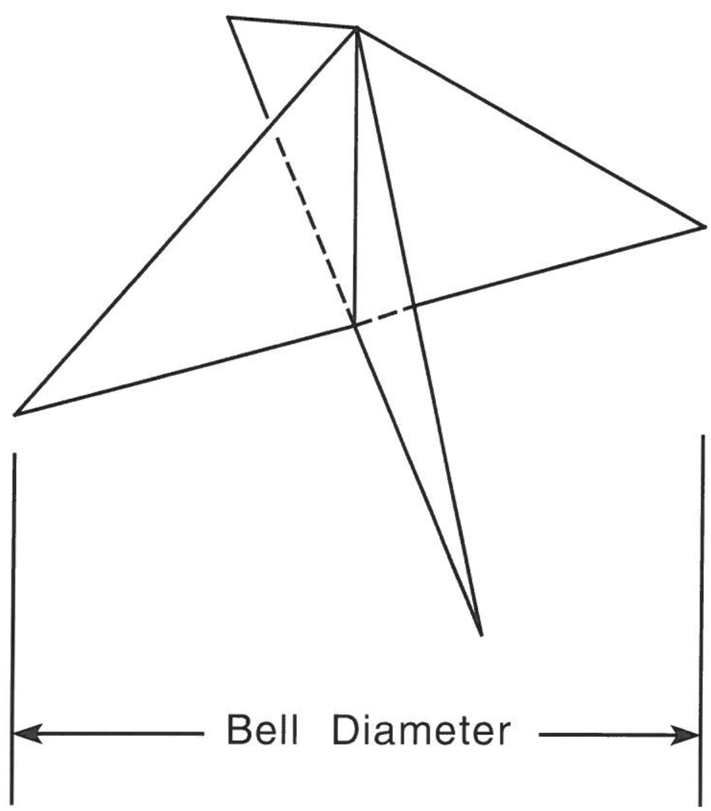


Figure 17. Typical Configuration for Cone Placed Under Pump Bell.

APPENDIX

Basic Data

Table A-1. Head Losses in East Drop Shaft and Inlet pipe.

Q (gpm)	Measured loss	Adjusted loss(ft)
176909	20.2	16.5
162397	14.5	11.8
136828	11.4	9.3
122316	8.3	6.8
122316	8.9	7.3
99511	5.6	4.6
80853	3.4	2.8
62195	1.9	1.5
44227	1.1	0.9
33170	0.5	0.4
23150	0.3	0.3
76016	3.2	2.6
72560	3.3	2.7
72560	3.7	3.0
111950	6.7	5.5
134755	10.0	8.2
171380	16.3	13.3

Table A-2. Head Losses in West Drop Shaft and Inlet pipe.

Q (gpm)	Measured loss	Adjusted loss(ft)
17490	0.2	0.1
30130	0.4	0.3
44704	1.1	0.9
80438	3.7	3.1
97991	5.0	4.1
138970	9.3	7.6
158527	13.1	10.7
188173	16.9	13.8

Table A-3. Variation of East Inlet Hydraulic Gradeline with Wet Well Hydraulic Gradeline.

Q = 25 mgd

Wet Well HGL	Inlet HGL (ft)
59.41	62.47
59.83	62.45
60.43	62.45
60.79	62.46
61.07	62.46
61.44	62.46
61.81	62.46
62.21	62.62
62.62	62.92
63.07	63.27
63.51	63.66
63.95	64.08
64.42	64.48
64.96	65.01
65.47	65.63
66.06	66.11

Q = 50 mgd

Wet Well HGL	Inlet HGL (ft)
59.50	63.41
60.59	63.41
60.88	63.40
61.25	63.40
61.63	63.40
62.07	63.40
62.43	63.46
62.83	63.64
63.19	63.91
63.61	64.24
64.06	64.63
64.57	65.14
65.35	65.89

Q = 70 mgd

Wet Well HGL	Inlet HGL (ft)
59.68	63.94
60.07	63.93
60.64	63.96
61.09	63.94
61.55	63.99
61.95	64.04
62.41	64.09
62.90	64.33
63.40	64.75
63.98	65.18
64.59	65.90
65.15	66.44
65.73	67.08

Q = 99 mgd

Wet Well HGL	Inlet HGL (ft)
59.53	64.63
60.06	64.63
60.61	64.63
60.91	64.67
61.27	64.72
61.75	64.80
62.44	65.09
63.03	65.62
63.44	66.07
63.99	66.49
64.59	67.03

Q = 144 mgd

Wet Well HGL	Inlet HGL (ft)
56.79	64.90
57.85	64.91
58.32	64.96
59.27	65.24
59.75	65.65
60.34	66.46
60.57	66.52
60.94	66.93
61.45	67.39

Q = 179 mgd

Wet Well HGL	Inlet HGL (ft)
56.69	65.81
57.12	66.34
57.58	67.26
54.60	65.14
55.31	65.14
55.64	65.22
55.92	65.33
56.24	65.45
56.49	65.50
56.99	66.09

Table A-4. Variation of West Inlet Hydraulic Gradeline with Wet Well Hydraulic Gradeline.

Q = 27 mgd

Wet Well HGL	Inlet HGL (ft)
59.36	61.73
59.81	61.73
60.13	61.73
60.43	61.73
60.84	61.73
61.18	61.73
61.76	61.94
61.98	62.14
62.24	62.39
62.54	62.69

Q = 43 mgd

Wet Well HGL	Inlet HGL (ft)
59.96	62.20
60.70	62.20
61.12	62.33
61.52	62.50
61.88	62.69
62.32	62.95
62.61	63.19
62.99	63.46
63.51	63.88
64.12	64.38

Q = 56 mgd

Wet Well HGL	Inlet HGL (ft)
59.71	62.63
60.07	62.63
60.59	62.65
61.02	62.65
61.48	62.69
61.99	63.00
62.32	63.24
62.66	63.47
63.13	63.88
63.54	64.26
64.05	64.63

Q =66 mgd

Wet Well HGL	Inlet HGL (ft)
59.40	62.92
59.87	62.92
60.60	62.95
61.21	62.98
61.58	63.05
61.99	63.26
62.38	63.52
62.80	63.88
63.22	64.17

Q = 111 mgd

Wet Well HGL	Inlet HGL (ft)
59.71	63.19
60.26	63.55
60.74	63.84
61.19	64.15
61.36	64.42
61.81	64.75
62.27	65.16
62.77	65.69
59.16	63.06
59.62	63.10
58.76	63.06

Table A-5. Hydraulic Grade Line and Other Data					
East Inlet					
	Transition HGL (ft)			Head Change, wet well to inle	
Q (mgd)	Average	High		Measured	Adjusted
25	62.8	63.5		0.101	0.051
50	63.6	64.2		0.579	0.479
70	64.2	64.7		1.288	1.038
99	63.6	64.2		2.541	2.091
144	65.4	65.6		5.981	4.931
179	65.4	65.6		9.263	7.753
West Inlet					
	Transition HGL (ft)			Head Change, wet well to inle	
Q (mgd)	Average	High		Measured	Adjusted
27	61.8	62.0		0.15	0.11
43	62.5	63.3		0.41	0.32
56	63.0	63.6		0.70	0.58
66	63.1	63.6		1.10	0.88
111	63.3	63.9		2.94	2.44

Fig. A-1 - east inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=25 mgd

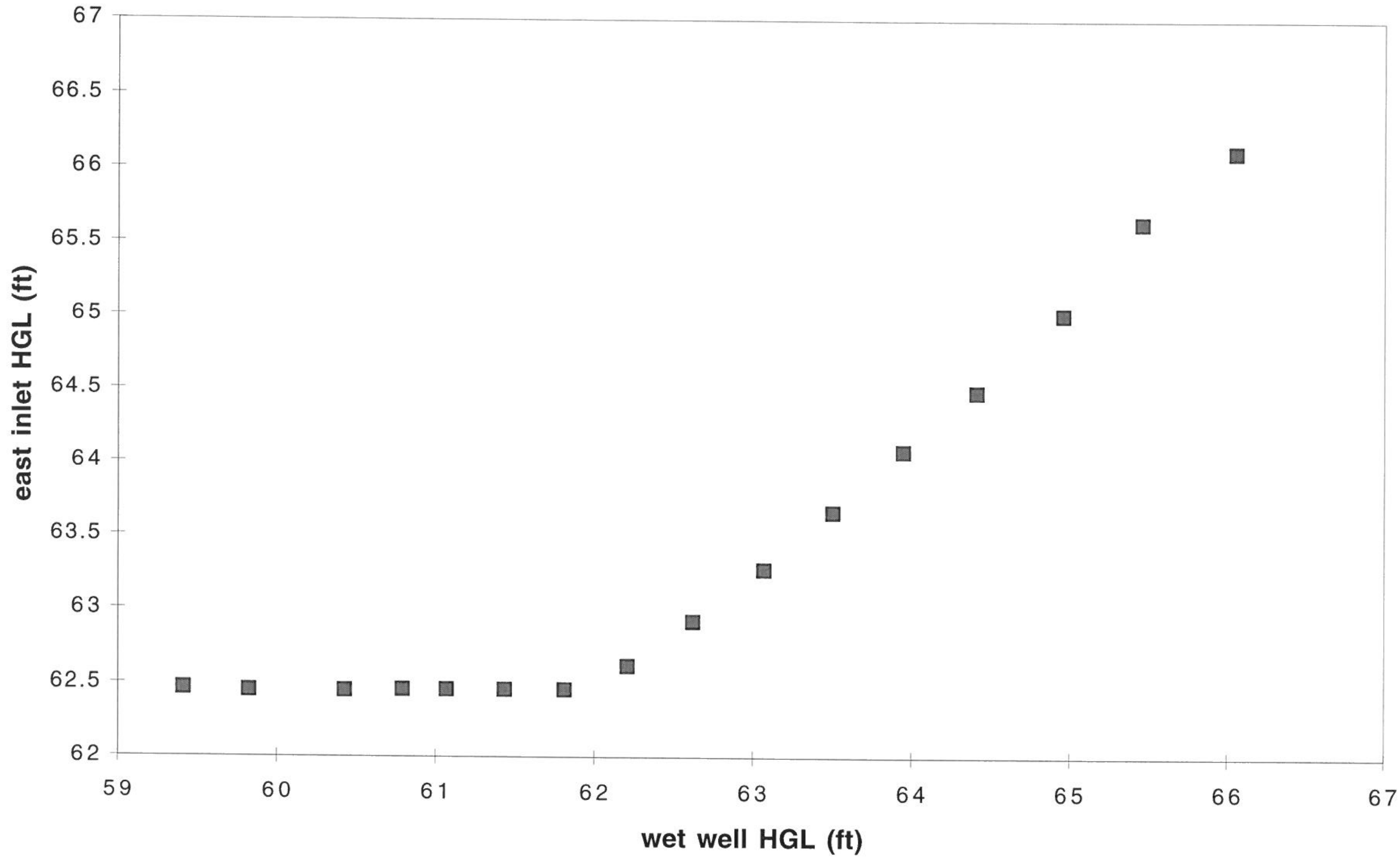


Fig. A-2 - east inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=50 mgd

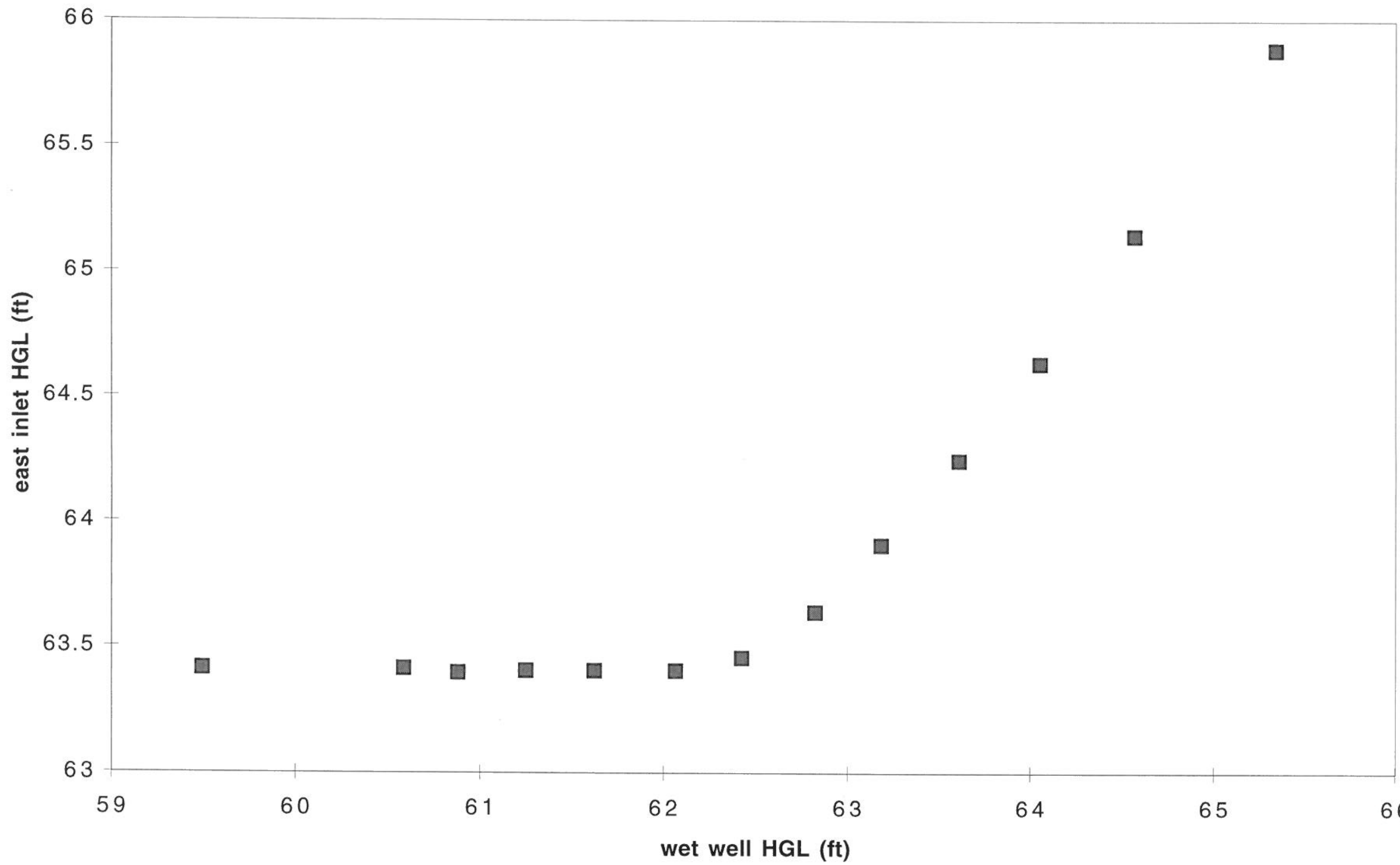


Fig. A-3 - east inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=70 mgd

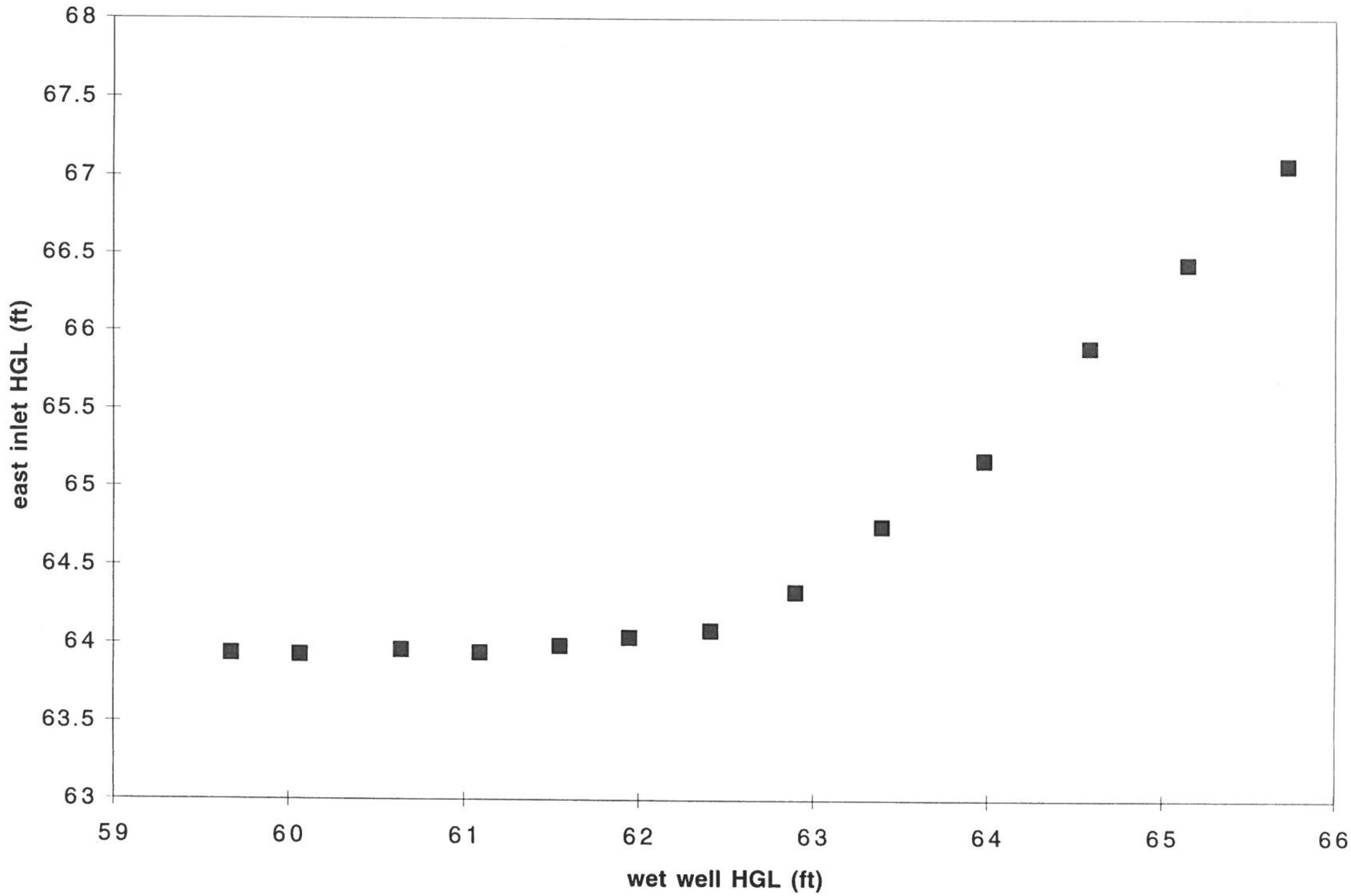


Fig. A-4 - east inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=99 mgd

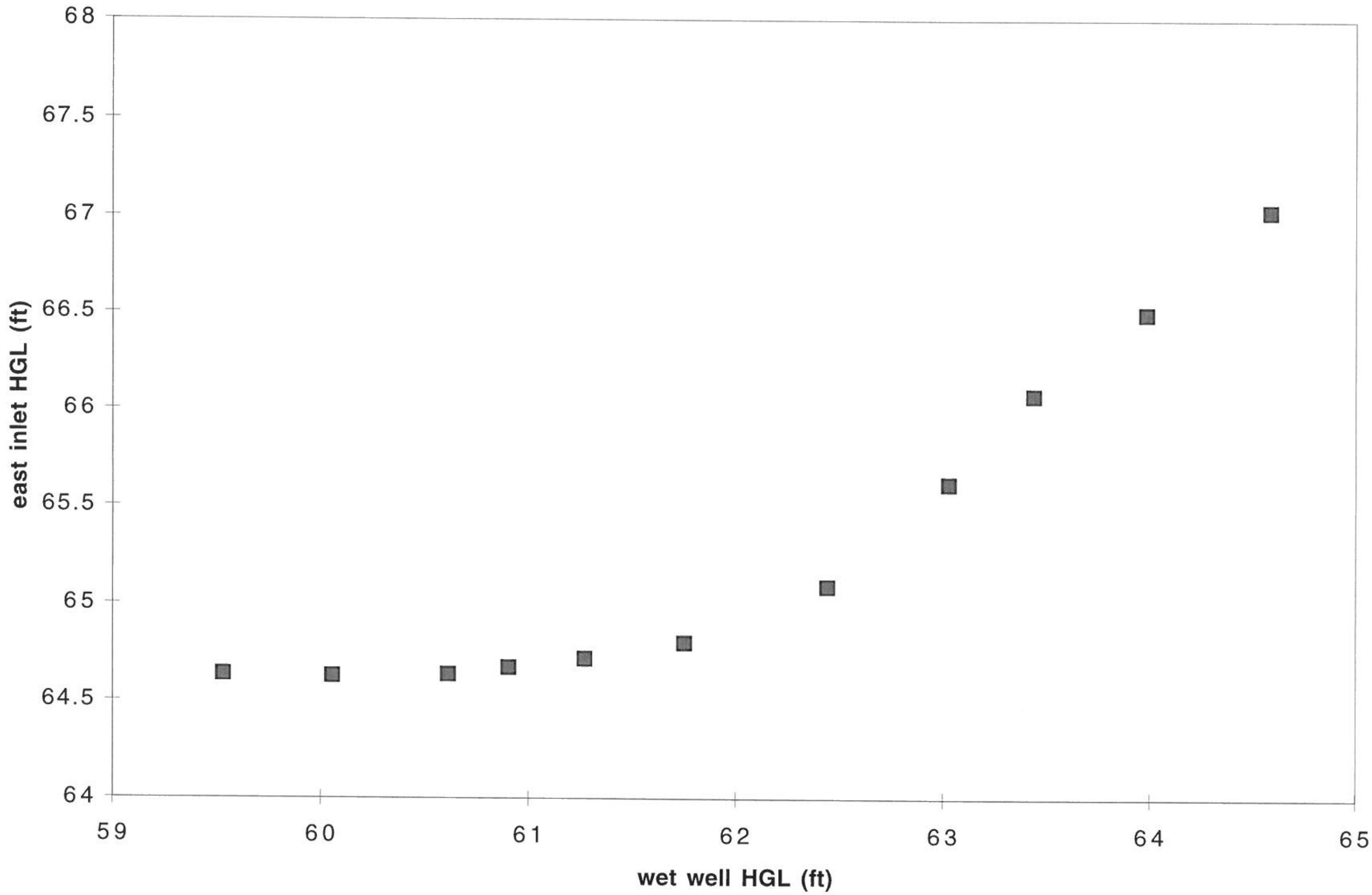


Fig. A-5 - east inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=144 mgd

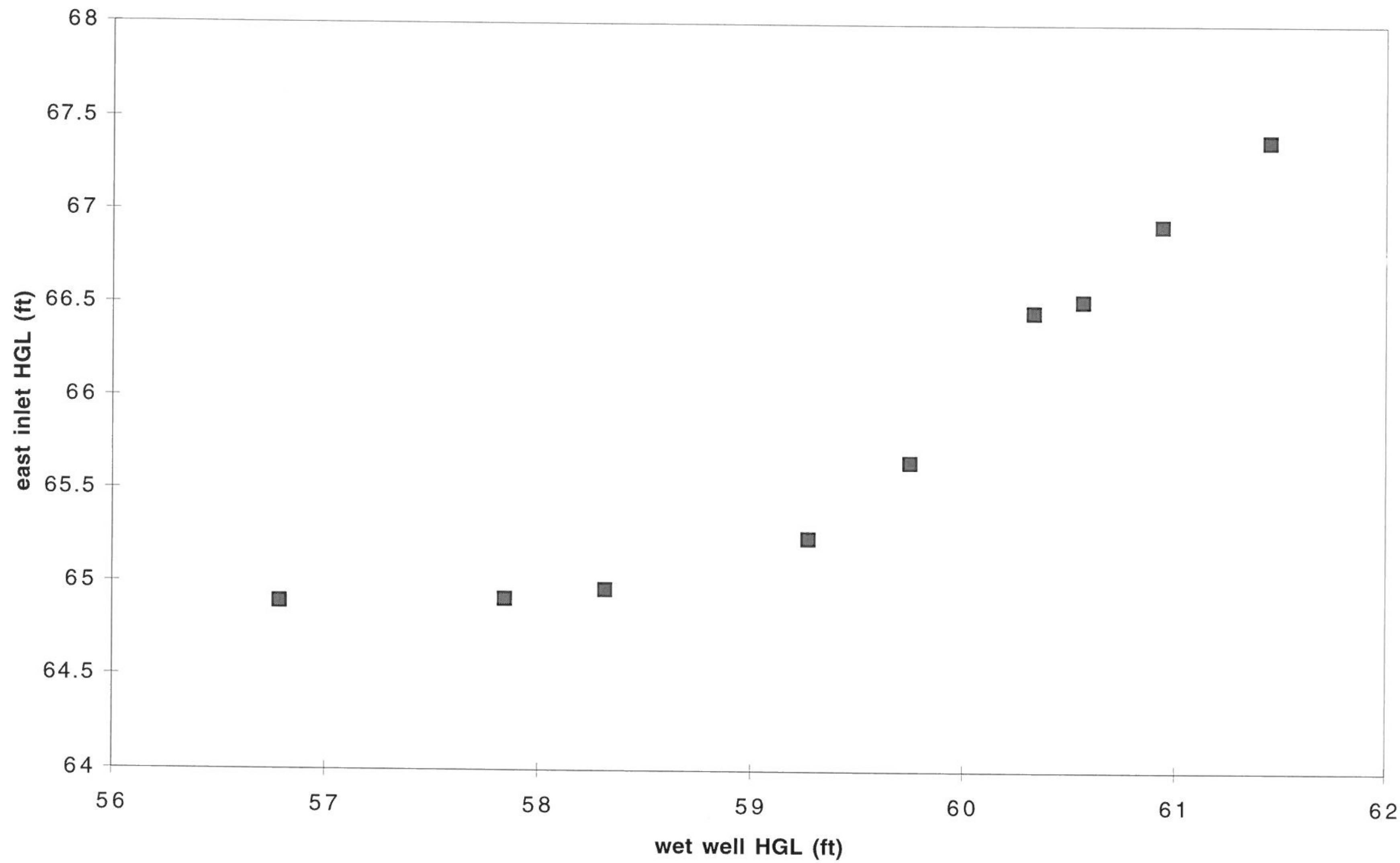


Fig. A-6 - east inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=179 mgd

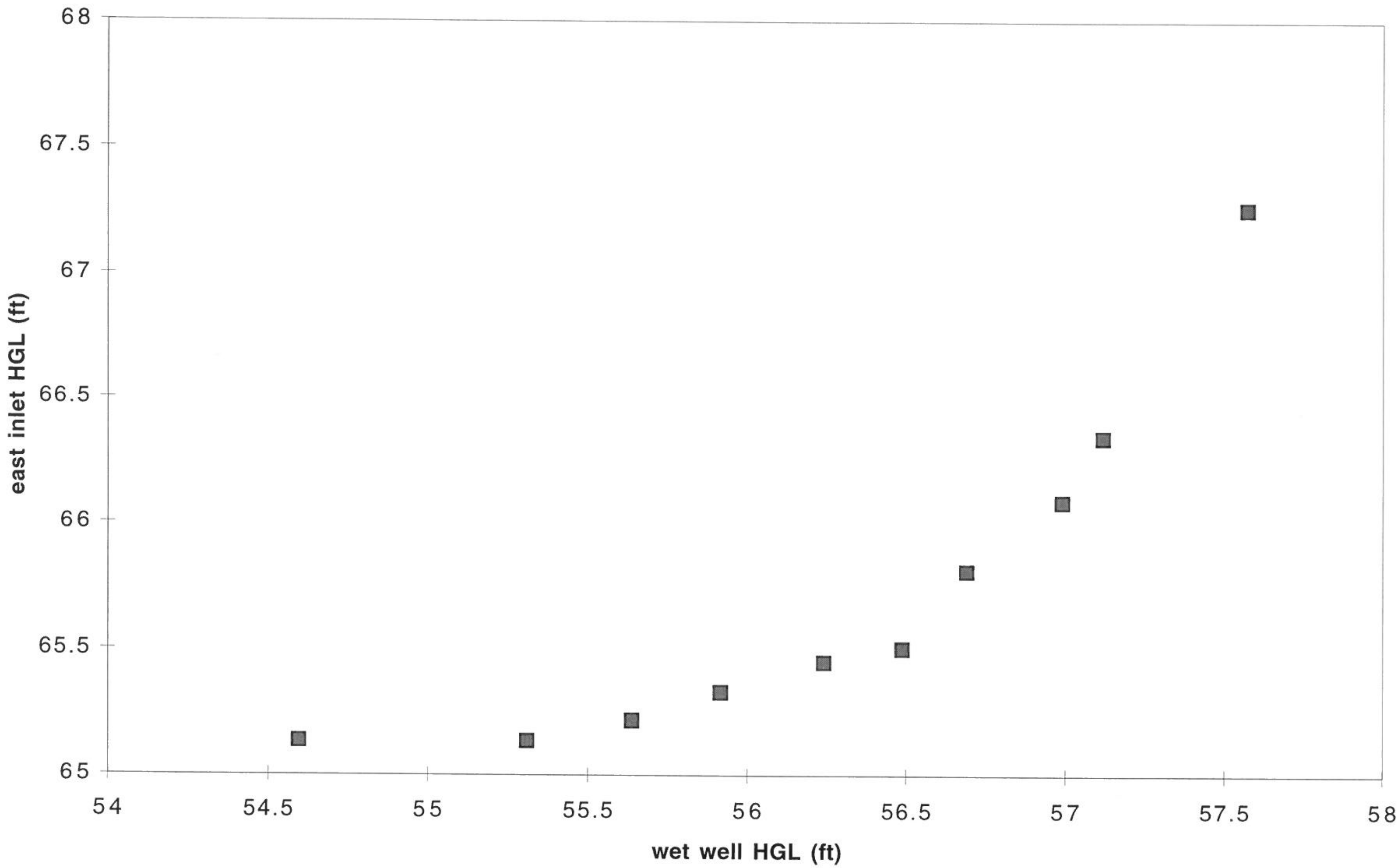


Fig. A-7 - West inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=27 mgd

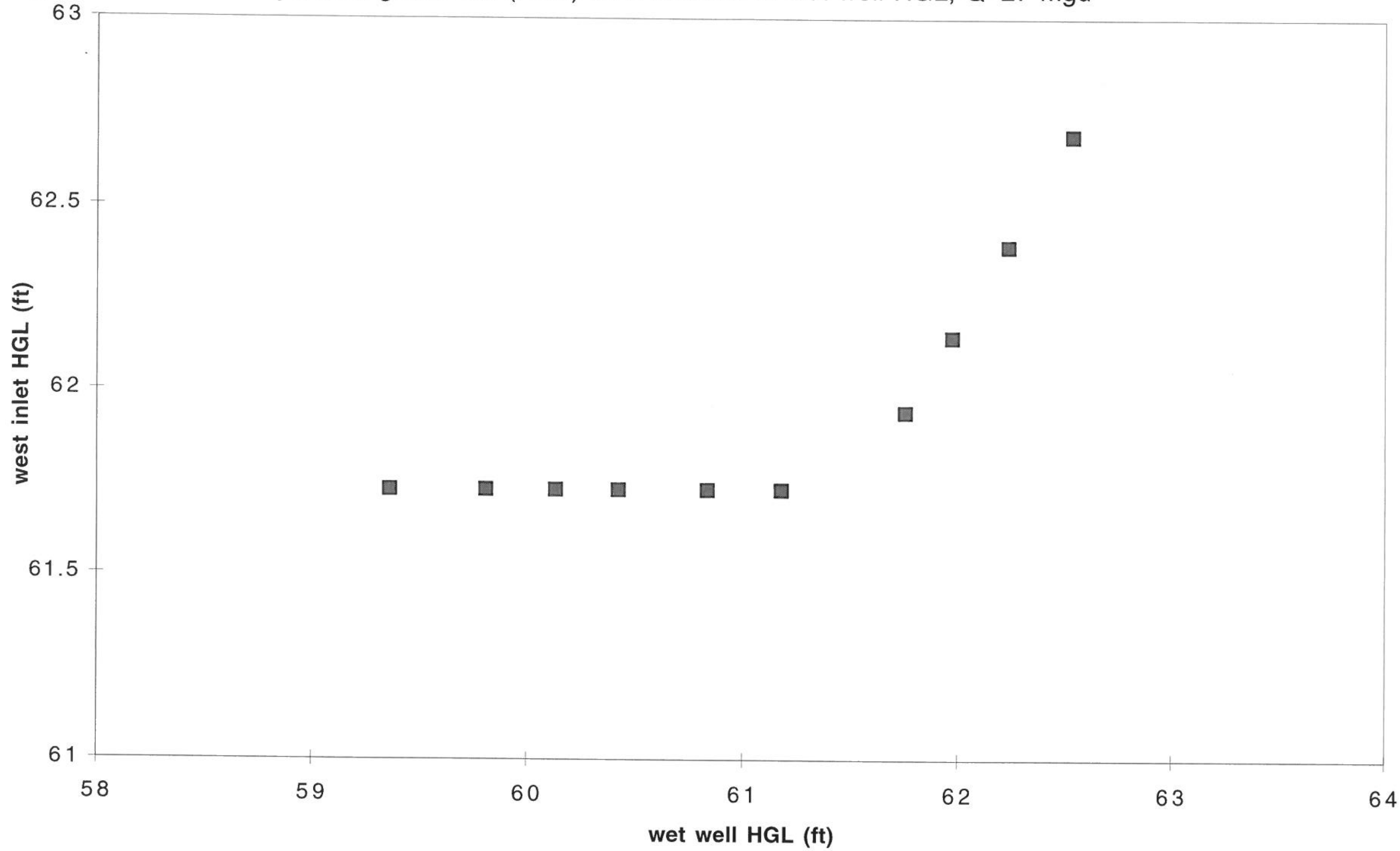


Fig. A-8 - West inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=43 mgd

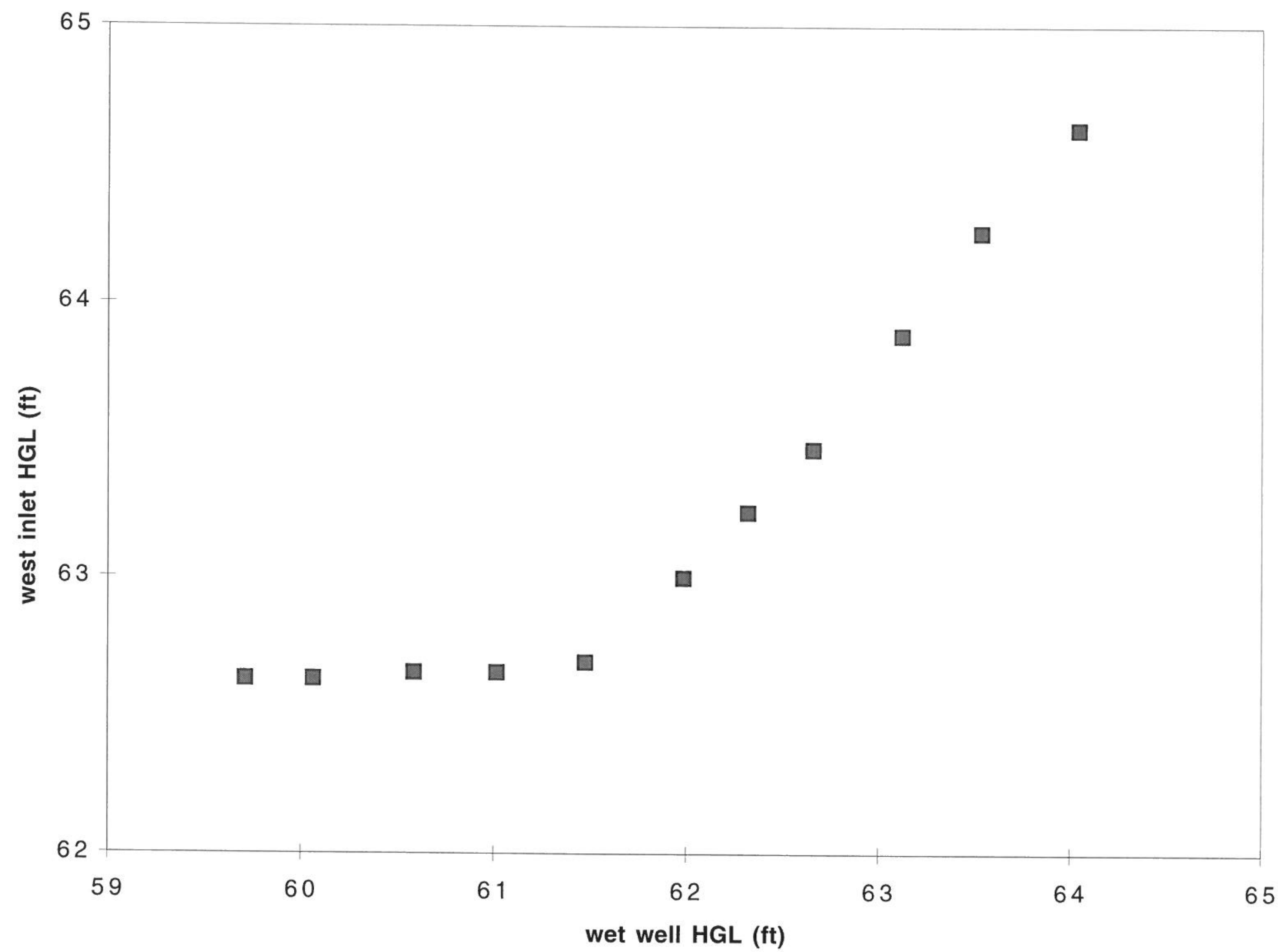


Fig. A-9 - West inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=56 mgd

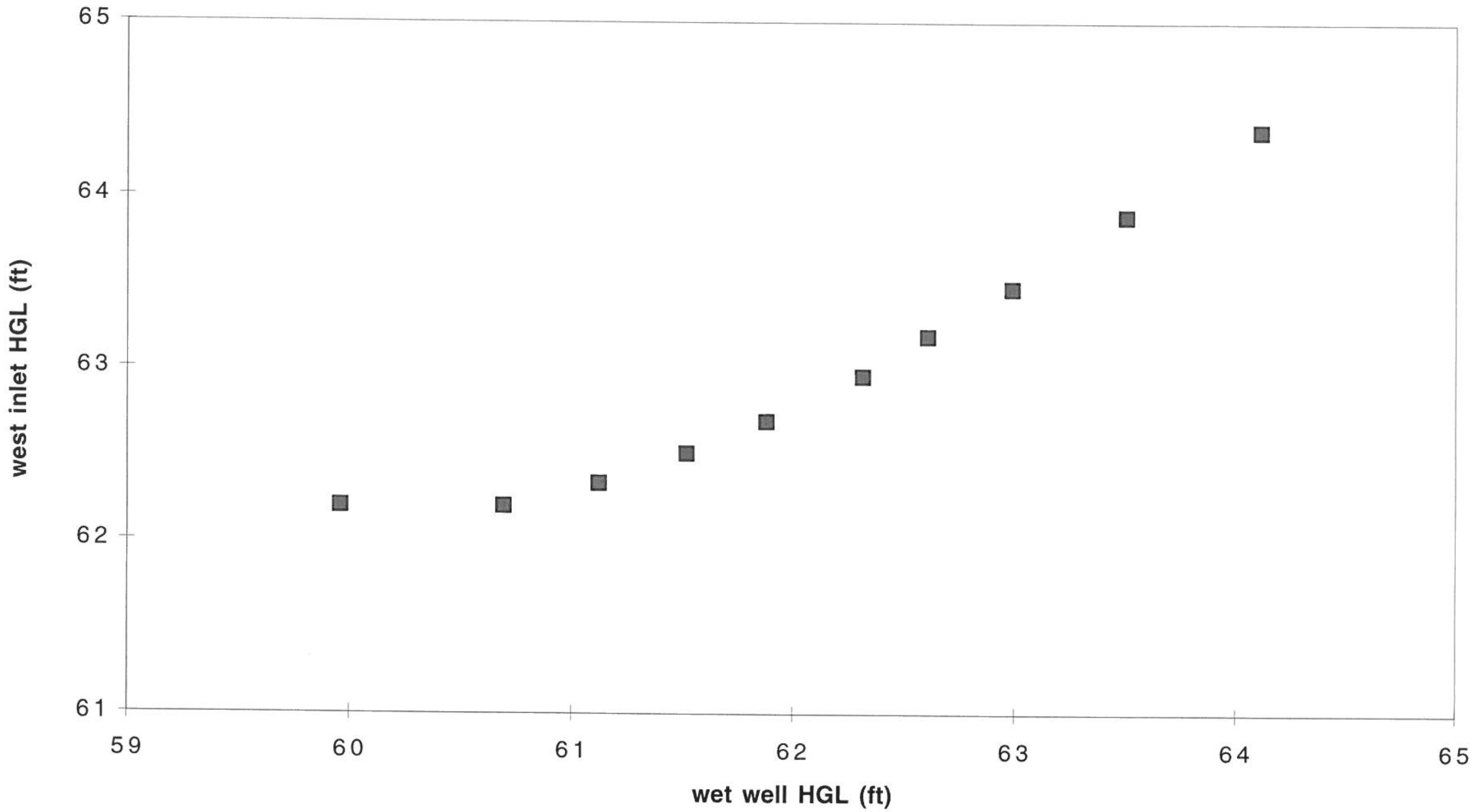


Fig. A-10 - West inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=66 mgd

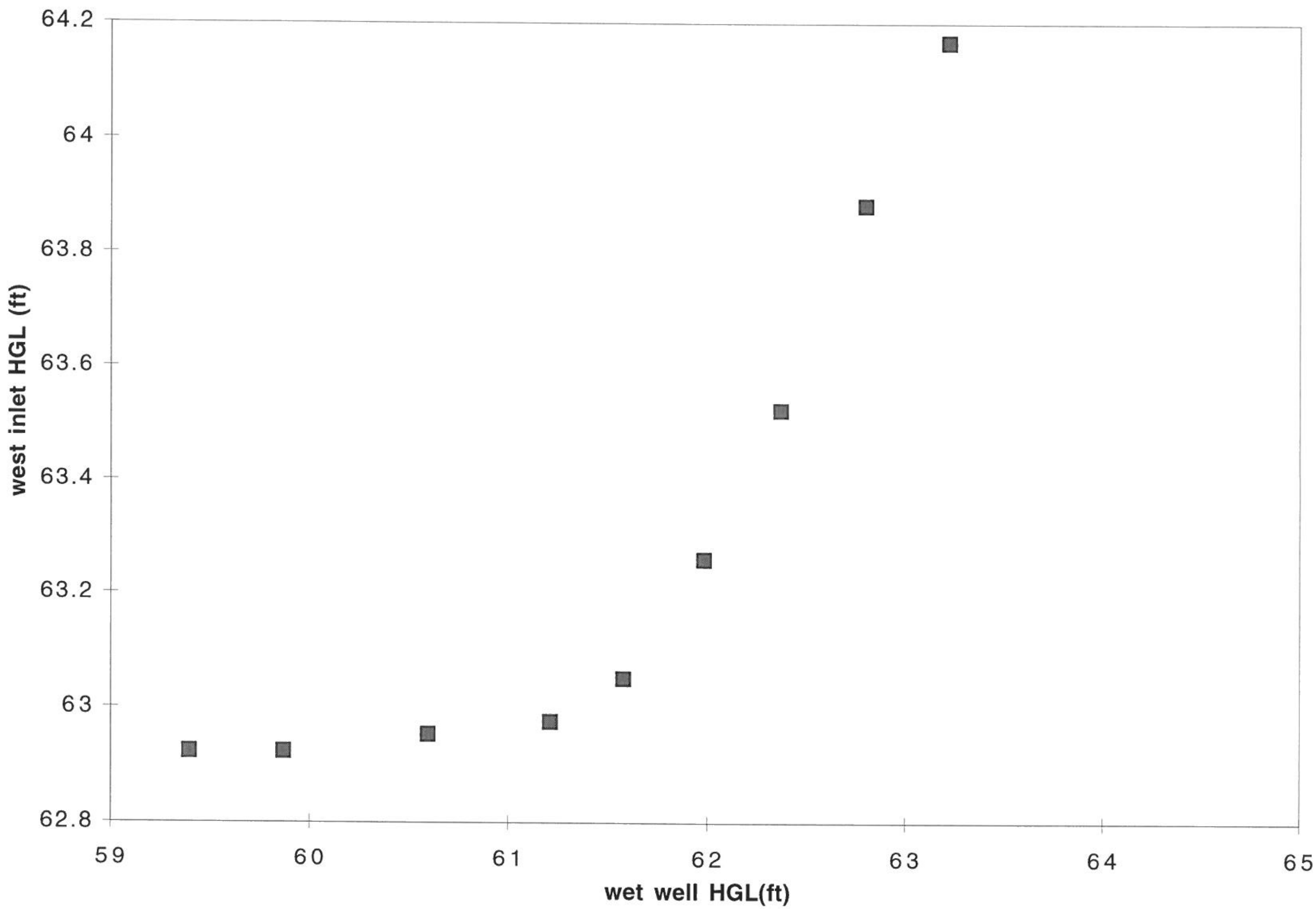
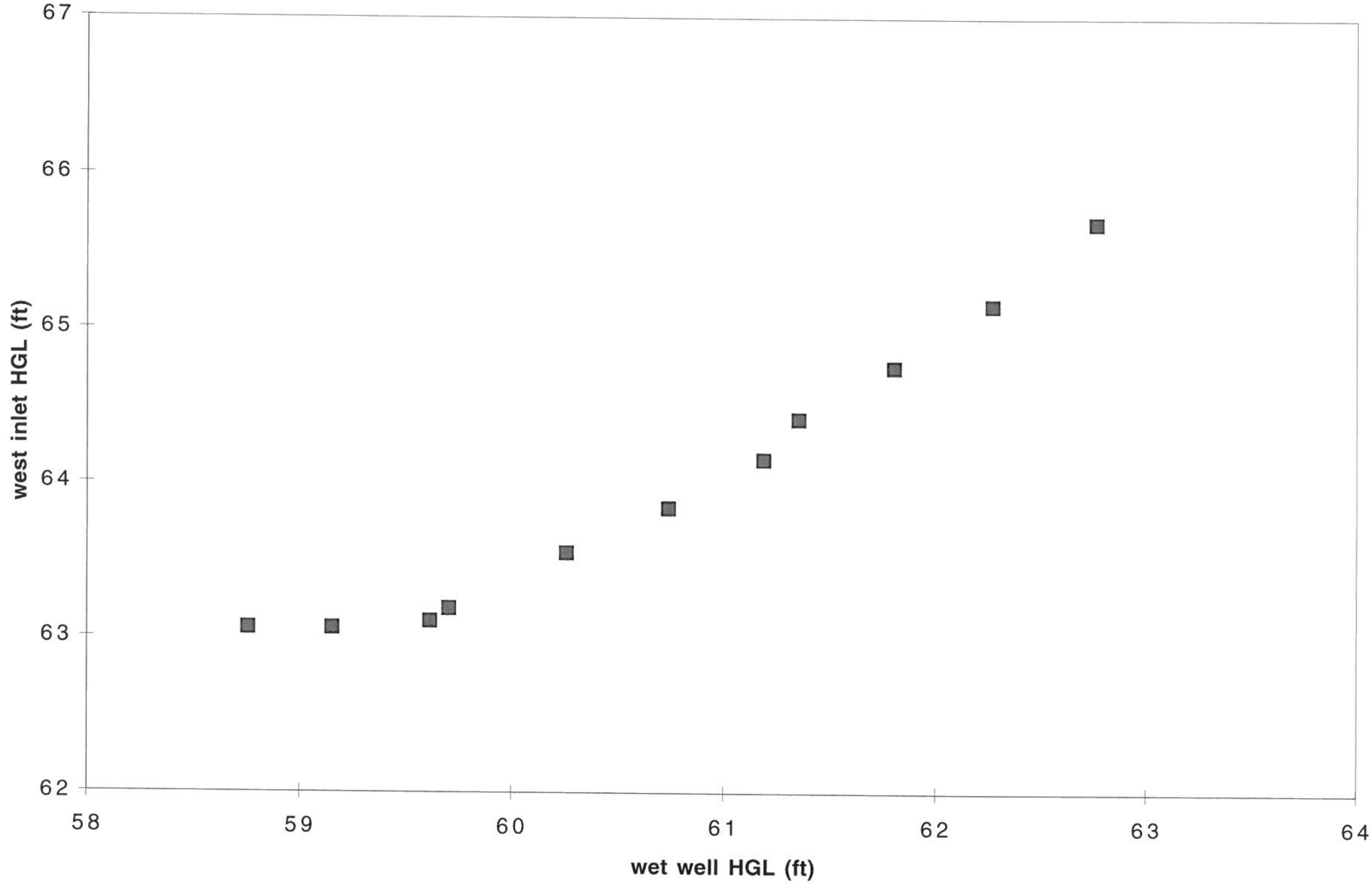


Fig. A-11 - West inlet hydraulic grade line (HGL) as a function of wet well HGL, Q=111 mgd



A9 – Summary and Review of Data Collected for the June/July 2021 Rainfall Events

The BoD selected Applied Science, Inc. (ASI) to support the AECOM team in this investigation. ASI was responsible for providing background information from GLWA and member municipalities, assembling and checking rainfall and SCADA system data and constructing the base hydraulic models to be used by the investigative team in responding to the charges in this report. The AECOM team relied on the data collection and data verification effort provided by ASI. The ASI summary report and details regarding the data collection and verification efforts of ASI are provided in Appendix A9 and should be read in conjunction with this overall report.

Summary and Review of Data Collected for the Storms of June 25-26 and July 16, 2021

For the Great Lakes Water Authority
Board of Directors Ad Hoc Committee
May 25, 2022

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Introduction

Applied Science, Inc. (ASI) was selected to assist AECOM in their study of the Great Lakes Water Authority (GLWA) wastewater collection system during two significant storms that occurred during the summer of 2021. These storms occurred on June 25-26 and July 16, 2021. Significant street and basement flooding was reported in Dearborn, Detroit, Grosse Pointe, Grosse Pointe Park and Grosse Pointe Farms, especially for the June 25-26th storm. The AECOM study focused on the East Side of the GLWA wastewater service area, but data were obtained and are presented system wide. The East Side is defined as the part of the GLWA wastewater service area that is tributary to the Fairview Pumping Station (PS).

Rainfall, wastewater level, river level, backwater gate, control/regulator gate, pumping and flow meter data were collected and are summarized in this report. Data were requested and obtained for the entire months of June and July 2021 so that antecedent and dewatering conditions could be assessed by AECOM for each storm using the SWMM model of the Regional Wastewater Collection System (RWCS).

GLWA and most East Side communities provided data obtained from their Supervisory Control and Data Acquisition (SCADA) systems. These data supported the set-up of the SWMM models completed by ASI and utilized by AECOM in their independent study. Unless stated otherwise, the elevation data in this report is presented in units of feet with respect to the Detroit datum and times are expressed in Eastern Standard Time (EST).

This report was not prepared to be a standalone document. It was prepared to provide data and analyses that will be background information for an independent study report by AECOM.

In this report, information is summarized from the DWSD Segmented Facilities Plan (1978), the O&M manuals for the GLWA operated pump stations and combined sewer overflow (CSO) control facilities (various years), the revised basis of design (BOD) report for the Conners Creek Pilot CSO Control Basin, a report prepared for Bluehill PS improvements titled "Fourth Pump Evaluation and Surge Study" (2003), the Wayne County Fox Creek District Facility Plan (1983), and the GLWA Wastewater Master Plan (WWMP).

GLWA Wastewater Collection System

The GLWA provides wastewater collection and treatment services to 79 communities in southeast Michigan. The GLWA service area is shown on Figure 1 and covers communities in Wayne, Oakland, and Macomb Counties. The areas served by sanitary sewer systems are shown in blue on Figure 1, and the areas served by combined sewers are shown in red.

Figure 2 shows the interceptor systems, some community boundaries and the sewer districts in southeast Michigan that are part of the GLWA service area. Note that Western Township Utility Authority (WTUA) is no longer part of the GLWA service area and utilizes the Ypsilanti Community Utility Authority (YCUA) for wastewater treatment services. Also, the Northeast Sewage Disposal System assets were purchased from Wayne County by the Southeast Macomb Sanitary District (SEMSD) and are now part of the SEMSD system.

The City of Detroit is served by combined sewers, as well as Hamtramck and Highland Park. Most of the Southeast Oakland Sanitary District (currently known as the GWK Drain Drainage District) is served by combined sewers. Also, parts of the Evergreen-Farmington Sanitary District (EFSD), Dearborn, Grosse Pointe, Grosse Pointe Farms, the Rouge Valley Sewage Disposal System (RVSDS) and SEMSD are served by combined sewers as shown on Figure 1. There are uncontrolled CSO outfalls in Detroit, Dearborn, Dearborn Heights, Inkster, and Redford in the GLWA service area.

There are nine (9) combined sewer overflow (CSO) control facilities in the City of Detroit that are operated by GLWA as shown on Figure 3. Six (6) are retention treatment basins (RTBs) and three (3) are screening disinfection facilities (SDFs). There are three (3) RTBs for CSO control in the EFSD, four (4) in the RVSDS, one (1) in the GWK Drain Drainage District, and three (3) in the SEMSD system. Untreated CSO outfalls exist in Detroit, Dearborn, Redford, Dearborn Heights, and Inkster.

The linear assets leased by GLWA from the City of Detroit are shown on Figure 4. These are the large sewers that serve multiple communities. A schematic of the GLWA system is shown on Figure 5. This schematic shows the locations of large sewers and interceptors, pumping stations (PS), the water resource recovery facility (WRRF), valve remote (VR) sites, CSO control facilities, in-system storage devices (ISDs), level sensors, and CSO outfalls. It does not provide detail of the suburban wastewater collection systems.

Figure 1.GLWA Wastewater Service Area

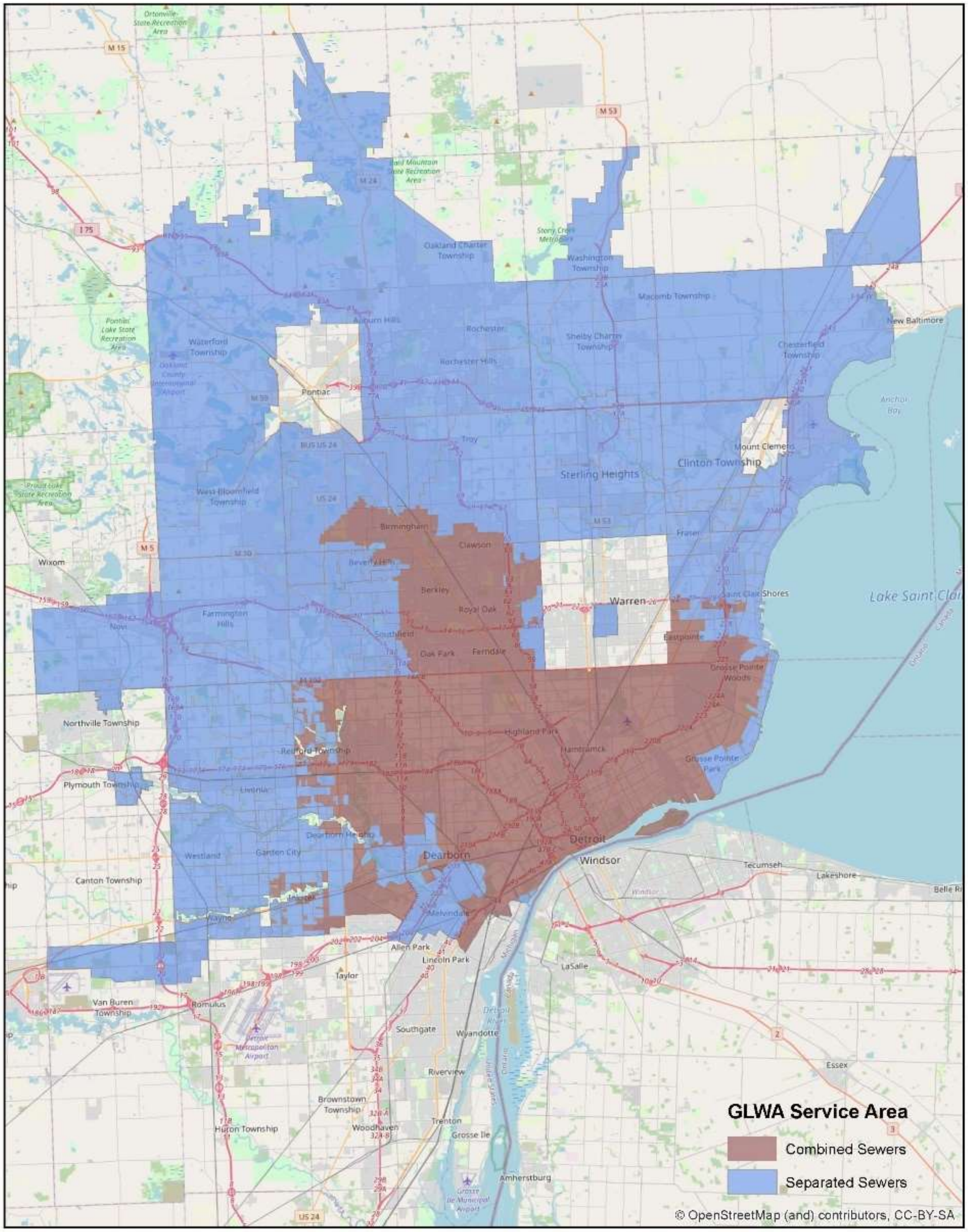


Figure 2. Regional Wastewater Collection Systems

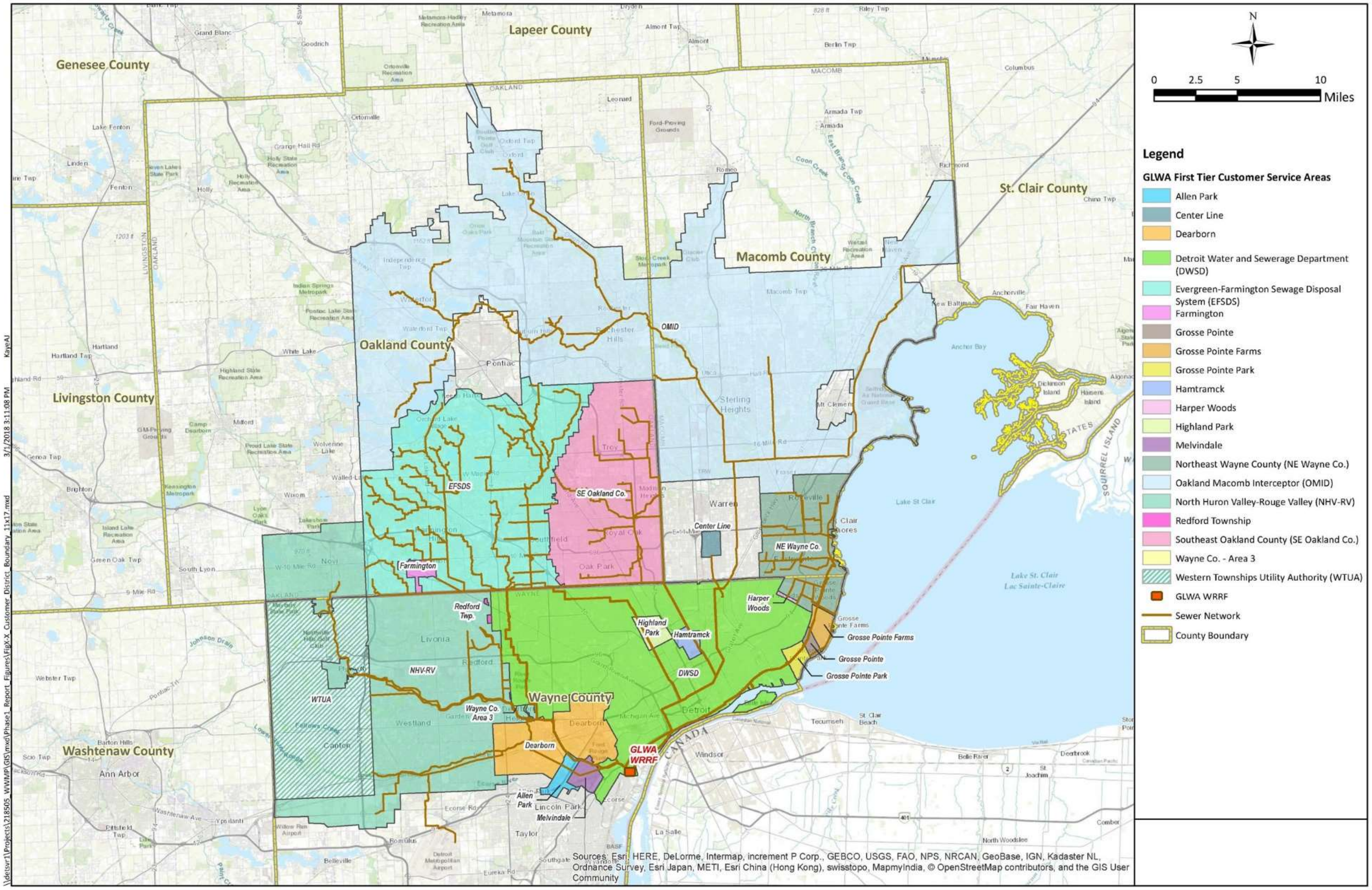


Figure 3. GLWA CSO Control Facilities

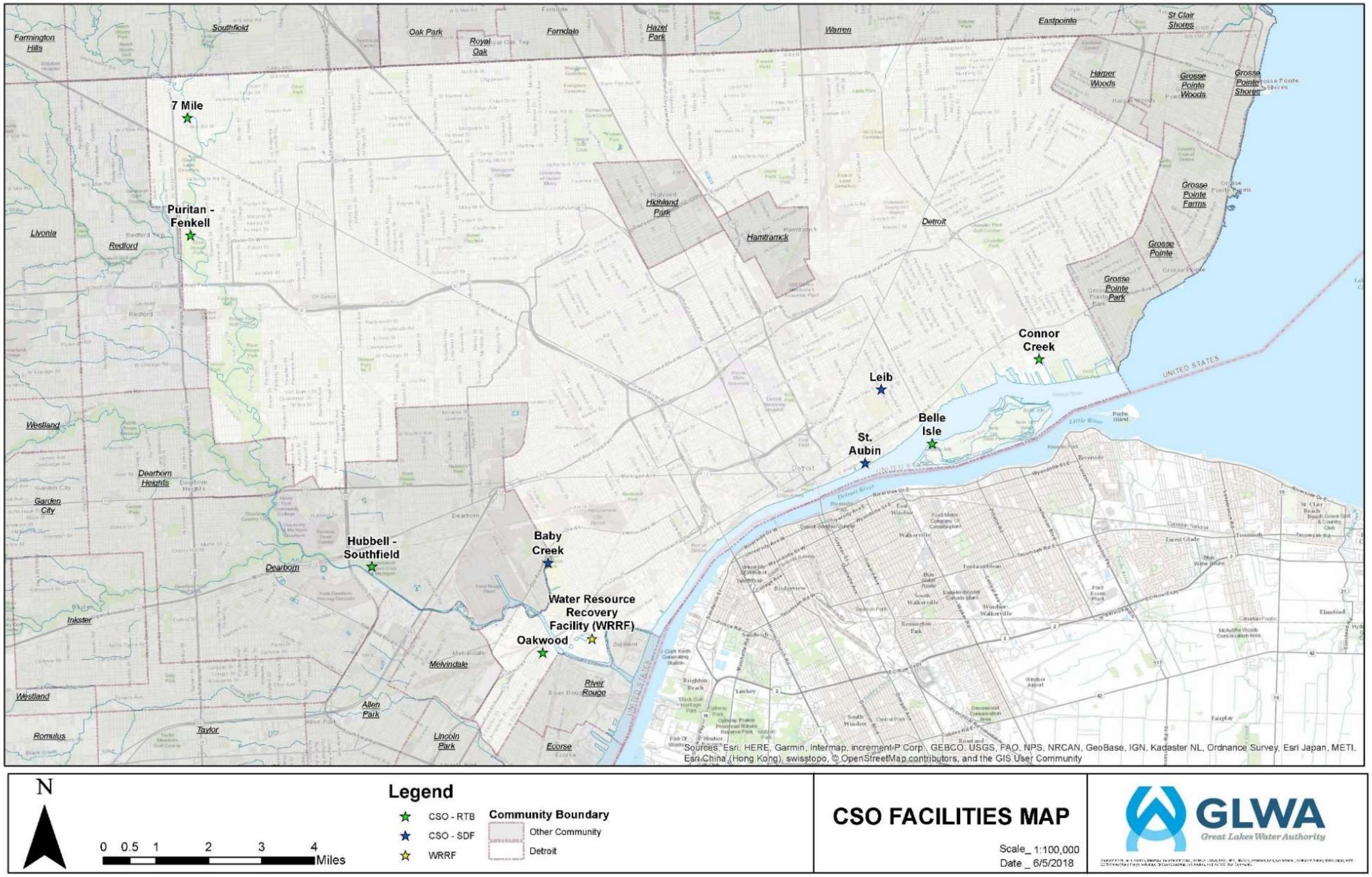


Figure 4. GLWA Linear Assets

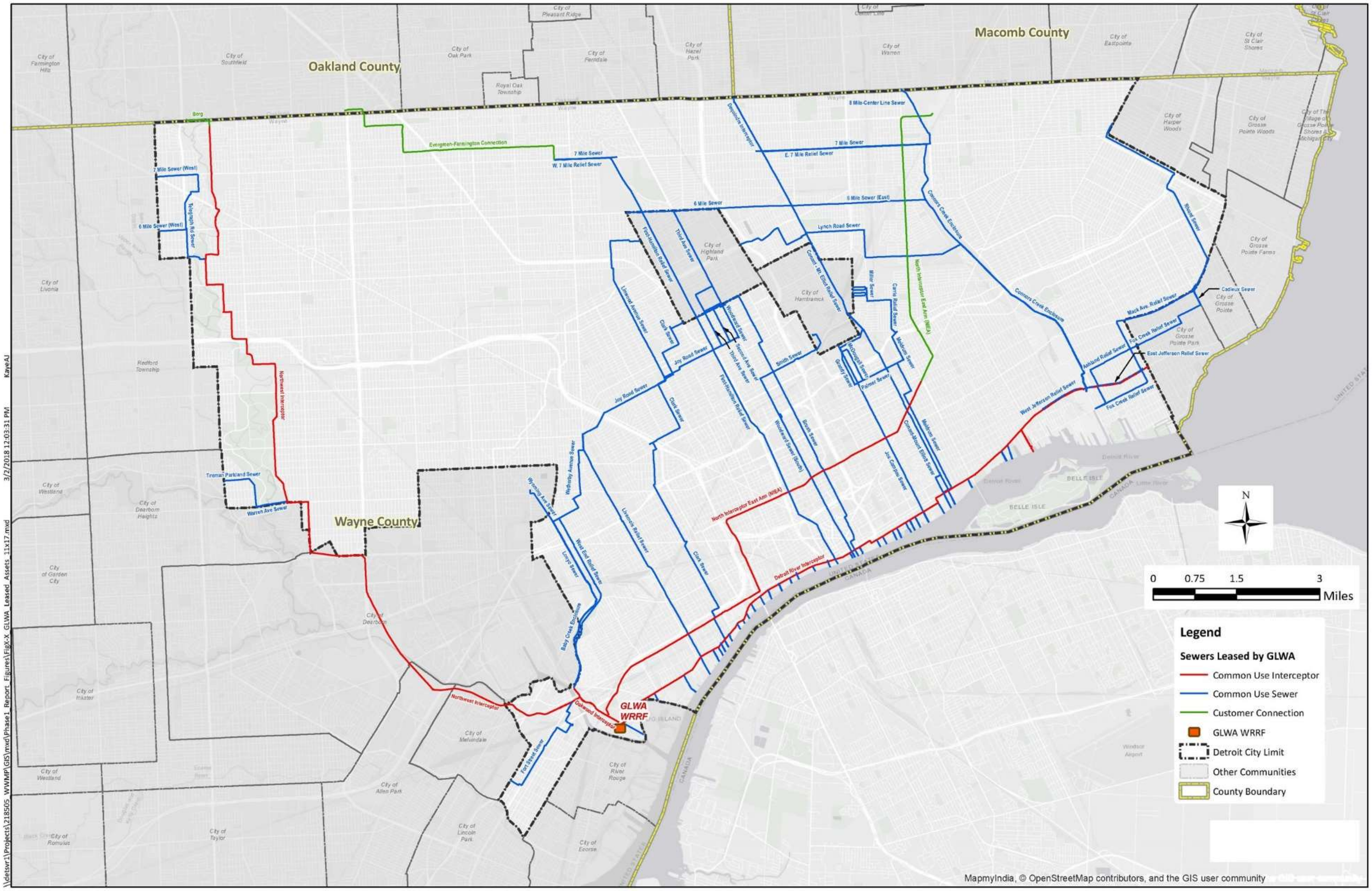


Figure 5. GLWA Wastewater Collection System Schematic

[redacted]

East Side Wastewater Collection System

The East Side includes the Fox Creek, East Jefferson, and Conner Creek Districts in Detroit, the five (5) Grosse Pointe communities, Harper Woods, Eastpointe, Roseville, and St. Clair Shores. The East Side includes lower elevation areas along the Detroit River and Lake St. Clair (LSC). Consequently, there are many pumping stations in the East Side.

The East Side includes facilities owned and/or operated by the SEMSD, the Macomb County Public Works Office (MCPWO) the Milk River Intercounty Drain Drainage District (MRIDDD), the Detroit Water and Sewerage Department (DWSD), the five Grosse Pointe communities, and GLWA. There is an extensive network of sewers, pumping stations and RTBs tributary to the Fairview PS as shown on Figure 6 and in the separately provided detailed schematic. Most of the wastewater in the East Side is pumped multiple times before reaching the WRRF.

The DRI is the outlet sewer for the East Side wastewater flow rates. The flow rates in the upstream DRI are lifted at the Fairview PS into a downstream section of DRI. The upstream DRI receives wastewater from the sanitary pumps at the Conner Creek Sanitary PS, the Conner Creek Enclosure (CCE) through the VR-2 regulator gates, the Alter sewer, and the Grosse Pointe Park PS.

The Conner Creek Sanitary and Storm PS receives wastewater from the East Jefferson Relief sewer. The East Jefferson Relief sewer receives wastewater from the Fox Creek Enclosure, the Ashland sewer, the dewatering pumps at the Conner Creek RTB through the Lycaste sewer, the Bluehill PS through the Fox Creek Relief sewer system, the sanitary pumps at the Freud PS through the Tennessee sewer, and other DWSD sewers in the East Jefferson District.

The Fox Creek Enclosure conveys wastewater from three (3) pumping stations: the SEMSD owned and operated Kerby Road PS, the Grosse Pointe Farms PS also at Kerby Road, and the Neff PS owned and operated by the City of Grosse Pointe. The Martin, Chapaton, and Milk River RTBs exist upstream of the SEMSD Kerby Road PS and are dewatered through this pumping station.

GLWA operates and maintains the Conner Creek Sanitary and Storm PS, and the Freud PS. GLWA operates the Bluehill Sanitary and Storm PS. The sanitary pumps convey dry weather and dewatering flow rates, and the storm pumps convey wet weather flow rates as shown on the separately provided detailed schematic. The Conner Creek RTB receives combined wastewater from the CCE, the Conner Creek Storm PS, and the storm pumps at the Freud PS.

The pumping station capacities, the number of sanitary/storm pumps, and the normal range of wet well levels for the GLWA operated pumping stations in the East Side are summarized on Table 1. Firm capacity is the pumping station capacity with one of the largest pumps out-of-service.

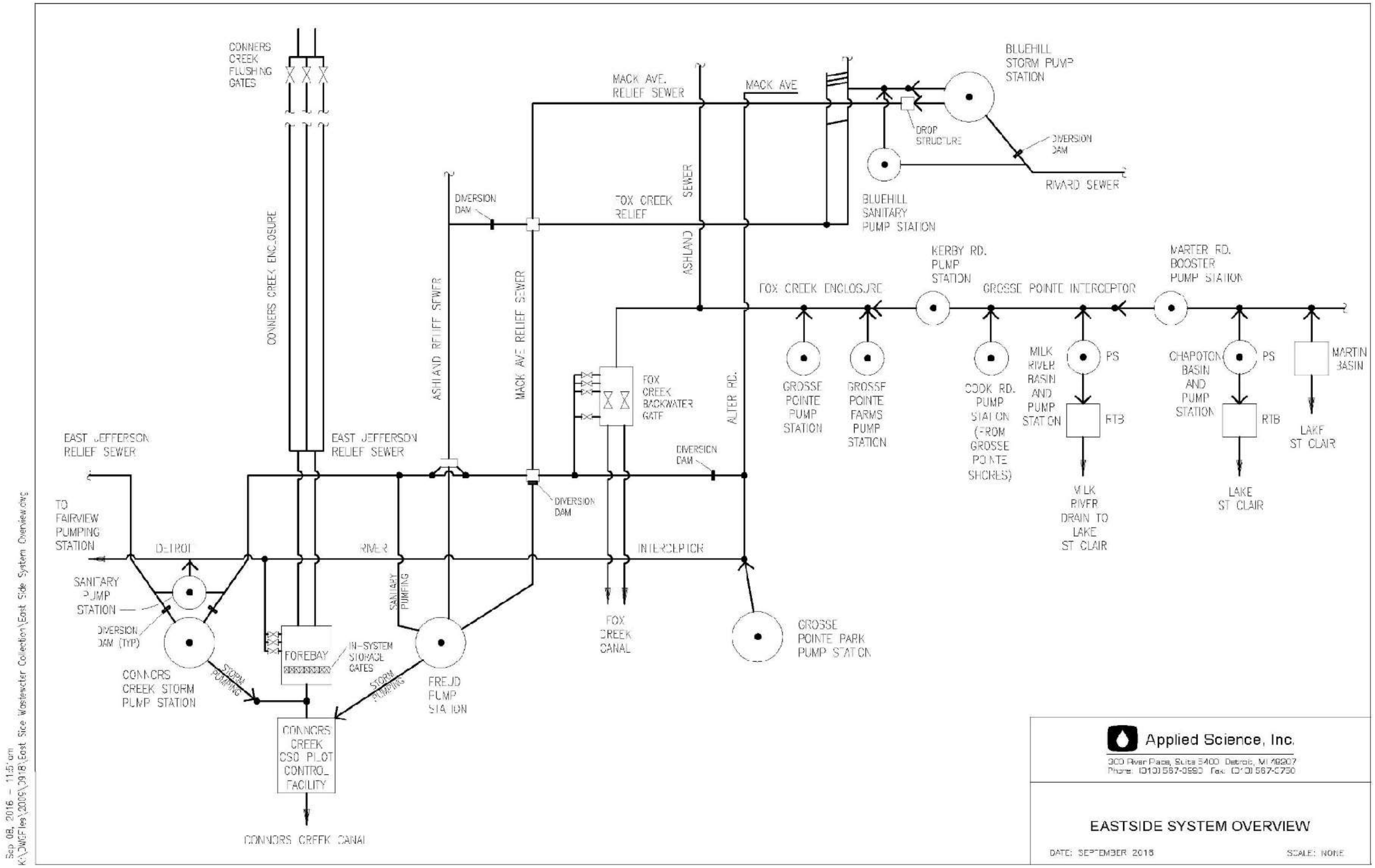
Table 1. East Side GLWA Pumping Station Summary

Pumping Station	Number of Sanitary or Storm Pumps	Rated Firm Capacity (cfs)	Rated Total Capacity (cfs)	Normal Range of Wet Well Levels (feet-Detroit datum)
Temporary Fairview[1]	7	310	372	74.25 to 81
Fairview after Rehabilitation	7	371	433	67 to 77
Conner Creek Sanitary	4	224	333	59 to 65
Conner Creek Storm	8	3,500	4,000	65 to 79
Freud Sanitary	2	20	55	25 to 65
Freud Storm	8	3,150	3,600	45 to 75
Bluehill Sanitary	2	10	20	68 to 72.5
Bluehill Storm	4	961	1,338	67 to 82

Note:

1. Fairview PS was being rehabilitated during the 2020-2021. Temporary bypass pumps were in-place from the spring of 2020 through the fall of 2021.

Figure 6. East Side Sewer System Schematic



Rainfall Data

Rainfall data were collected for the months of June and July 2021 for rain gauges throughout southeast Michigan. Rainfall data were collected for gauges operated by GLWA, Dearborn, Wayne County, Oakland County, Macomb County, Grosse Pointe, Grosse Pointe Farms, and the SEMSD. Also, some rainfall data were obtained from private rain gauges that reported data to the Wundergound network to provide additional resolution.

The rainfall data were collected for about 75 rain gages. Rain gauges were eliminated from further review and set aside if the rain gauge location was outside of the area being modeled, if there were missing/questionable data, if the location was close to another rain gauge, or if the data were not available at 5-minute intervals. The data for thirty-eight (38) rain gauges were compiled, QA/QC reviewed, and processed to provide a complete data set with rainfall estimated at 5-minute intervals for the entire months of June and July 2021.

The rainfall data was processed as input data to the SWMM model of the GLWA regional wastewater collection system (RWCS). The storm/combined sewer subcatchments, and subareas in the SWMM model were assigned to the nearest rainfall gauge. Rainfall intensity-duration-frequency analyses also were performed separately by AECOM.

The rainfall data provides a detailed picture of the storms that occurred in June and July 2021. For both the storms of June 25-26th and July 16th, the highest rainfall occurred in an east-west band from Dearborn, across downtown Detroit and through the Grosse Pointes. Figure 7 shows the total rainfall amounts for the selected rain gauges for the storm of June 25-26th. The highest amounts of rainfall over the two-day period were recorded in Dearborn (7.50-inches), in midtown Detroit (7.54-inches) and in Grosse Pointe Park (8.14-inches). The most intense rainfall occurred from about 11 PM on June 25 to 1 AM on June 26, 2021.

Figure 8 shows the total rainfall amounts for the selected rain gauges for the storm of July 16, 2021. The highest amounts of rainfall were recorded in Dearborn (4.20-inches), and in Grosse Pointe Park (4.71-inches). The most intense rainfall occurred from about 9 to 11 AM on July 16th.

Figure 7. Total Rainfall for the Storm of June 25-26, 2021

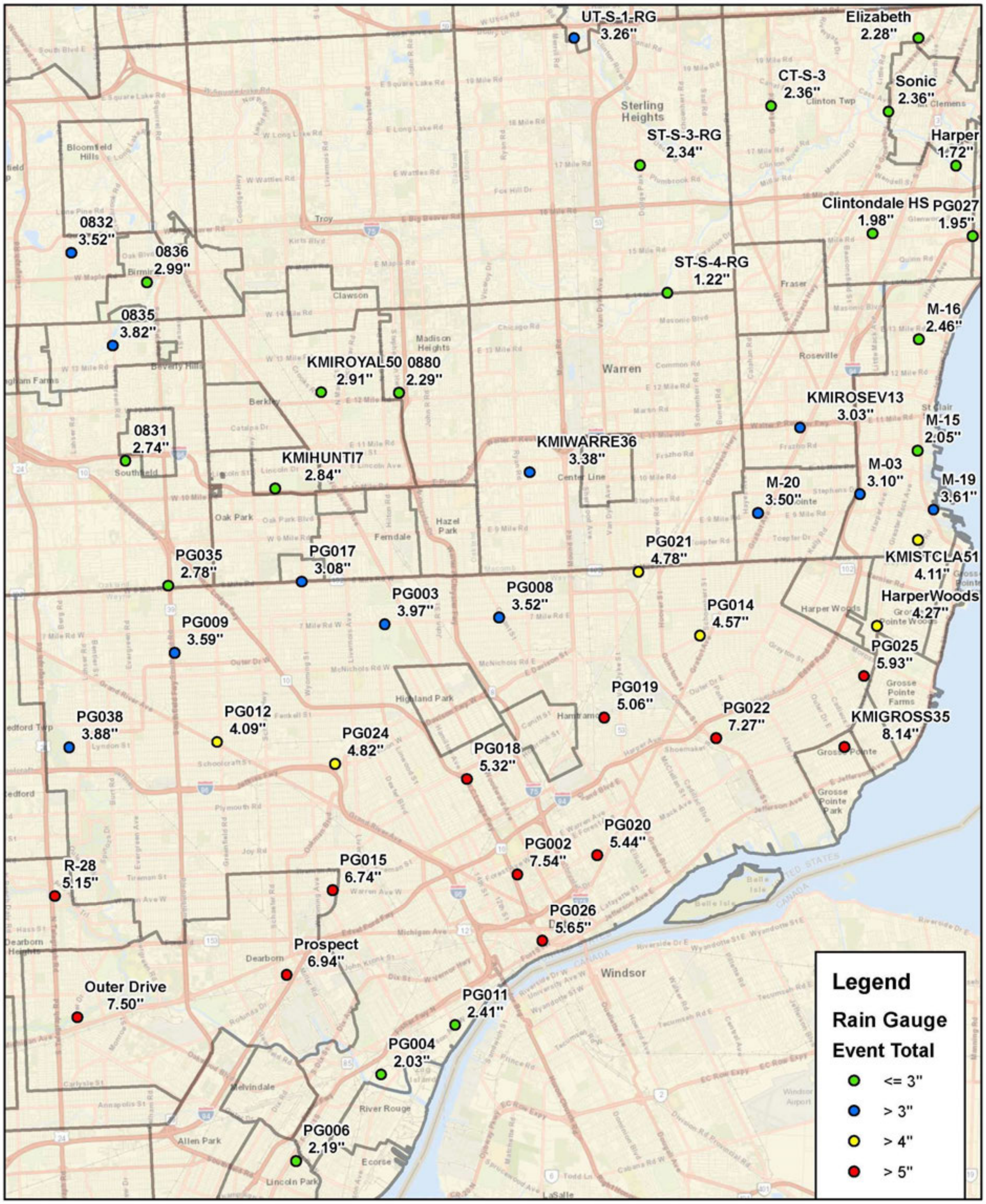
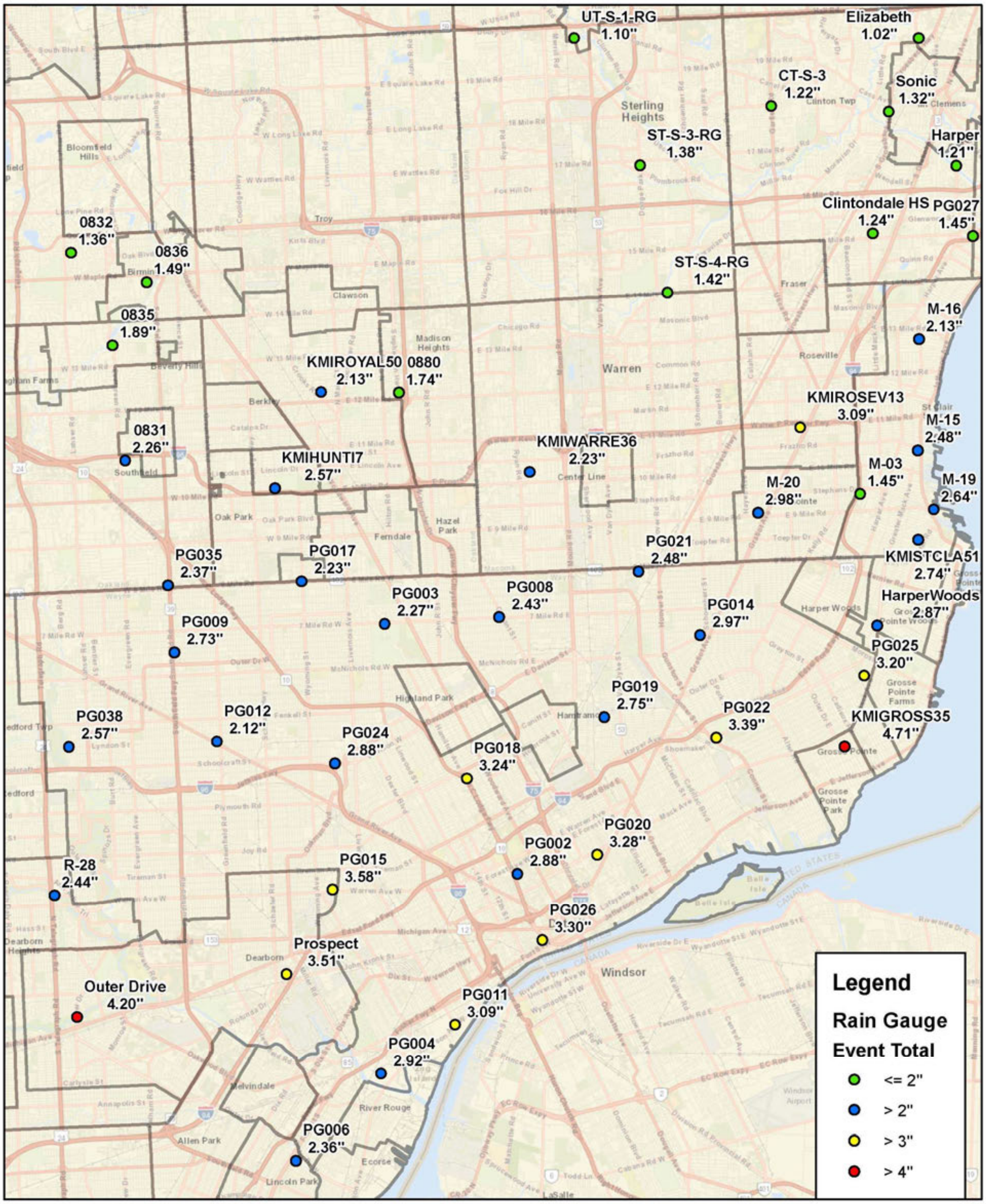


Figure 8. Total Rainfall for the Storm of July 16, 2021



GDRSS Flow Meter Data

The SWMM model of the RWCS used in the AECOM study was truncated at the suburban flow meter locations with two exceptions. First, the SWMM model included the east and west wastewater districts in the City of Dearborn. Second, the SWMM model included the SEMSD wastewater collection system upstream of the SEMSD Kerby Road PS. These areas were not represented with billing flow meter hydrographs because detail of the community sewer systems is available in the SWMM model of the RWCS, and the performance of these suburban systems was of interest. For all other suburban systems, the GDRSS billing flow meter data for June and July 2021 was input to the SWMM model.

The GDRSS flow meter data for the billing meters were obtained at 5-minute intervals and processed to be SWMM model input data for the entire months of June and July 2021. These data were previously QA/QC reviewed by GLWA and accepted as-is. Data from Wayne County's RVSDS flow meters were obtained, QA/QC reviewed and used in-place of the GDRSS flow meters for the RVSDS since these GDRSS billing meters were not in-service during the summer of 2021.

The peak hour flow rates for each billing meter were calculated using the GDRSS and RVSDS flow meter data. These flow rates are given for calendar hours, summarized on Table 2, and are compared to the respective community/district contract limit flow rates.

The peak wastewater flow rate for Allen Park exceeded the contract limit flow rate for only the storm of July 16, 2021.

The peak wastewater flow rates for Centerline and the SEMSD at the Kerby Road PS slightly exceeded the contract limit flow rate for both storms. However, the SEMSD flow meter, Meter WM-S-1, is a relatively new flow meter that is still being calibrated.

The peak wastewater flow rate for Dearborn slightly exceeded the contract limit flow rate for the storm of June 25-26th. However, Meter DN-S-2 in Dearborn is upstream of a sanitary sewer overflow (SSO) point that overflowed for both storms. Therefore, the GDRSS meter flow rates for both storms include the SSO flow rates and overestimate the peak flow rates discharged to GLWA.

The peak wastewater flow rates for the City of Farmington were below the contract limit flow rates for both storms.

The peak wastewater flow rates for the Cities of Grosse Pointe and Grosse Pointe Park significantly exceeded the contract limit flow rates for both storms.

For both storms, the peak flow rates from the remaining larger sewer districts in the GLWA wastewater collection system (EFSD, GWKDDD, OMIDDD, and RVSDS) were well below their contract limit flow rates as shown on Table 2.

Table 2. Peak Hourly Community/District Flow Rates

Community/Sewer District	Flow Meter(s)	Peak Average Hourly Flow Rate (cfs)		Existing Contract Limit Flow Rate (cfs)
		June 25-26, 2021	July 16, 2021	
Allen Park	AP-S-1	3.24	13.22	--
	AP-S-2	0.74	0.65	--
	AP-S-1 + 2	3.69	13.84	10.6
Centerline	CL-S-1	13.27	13.28	13
Dearborn	DN-S-2	50.90	51.90	--
	DN-S-4	5.63	3.28	--
	DN-S-5	2.02	0.75	--
	DN-S-6	0.03	0.05	--
	DN-S-7	0.03	0.42	--
	DN-S-8	71.39	65.43	--
	DN-S-2, 3, 4, 5, 6, 7 + 8	122.09	118.36	120
GWK Drain Drainage District	SE-S-1	250.79	245.49	260
Farmington, City of	FA-S-1	5.75	5.69	7.9
Grosse Pointe, City of	GP-S-1	346.10	305.79	192
Grosse Pointe Farms, City of	GPF-S-1	552.41	385.33	554
Grosse Pointe Park, City of	GK-S-1 + 2	113.76	113.76	84
Melvindale	ME-S-1	13.13	13.07	15
Oakland County Evergreen-Farmington Sanitary District	OC-S-1	156.80	159.08	170
Oakland-Macomb Interceptor Drain Drainage District	NES-S-T	322.95	241.99	423
Southeast Macomb Sanitary District	WM-S-1	133.09	134.20	127
Wayne County Rouge Valley Sewage Disposal System	WC-S-1	1.00	1.00	230
	WC-S-2 + 3	151.30	148.21	159.5
	WC-S-1, 2 + 3	307.20	318.13	389.5

Reported CSO/SSO

The reported CSO and SSO data for the facilities and communities in the GLWA service area were obtained and reviewed from the Michigan Department of Environment, Great Lakes and Energy (EGLE) for the storms of June 25-26th and July 16th.

For the storm of June 25-26th, nearly *all* the RTBs in the GLWA service area reported discharges of treated CSO. GLWA did not report overflow from only the Seven Mile and Puritan-Fenkell RTBs. Also, SSO was reported in the EFSD, RVSDS, GWKDD, Dearborn, Farmington, Grosse Pointe Shores and Troy wastewater collection systems. Untreated CSO was reported from outfalls in the GLWA/DWSD, RVSDS, Inkster, Dearborn Heights, and Dearborn wastewater collection systems. This storm was a major storm across southeast Michigan and produced the largest volumes of SSO and CSO for the year 2021.

For the storm of July 16, 2021, many of the RTBs in the GLWA wastewater service area discharged treated CSO including those in the GLWA, EFSD, GWKDD, Dearborn, SEMSD, and RVSDS. Also, SSO was reported in the EFSDS, RVSDS, Dearborn, Melvindale, and Grosse Pointe Shores wastewater collection systems. Untreated CSO was reported in the GLWA/DWSD, RVSDS, Inkster, Dearborn Heights, and Dearborn wastewater collection systems. This storm was also a major storm but produced the smaller volumes of SSO and CSO than the storm of June 25-26th.

River Level Data

The SWMM model requires a river/lake level versus time boundary condition at each CSO outfall and facility. River/lake level data for June and July 2021 were obtained from the USGS, NOAA and GLWA for use in developing these boundary conditions. The USGS operates two relevant gauges on the Rouge River. One is on Main Branch of Rouge River in Detroit at Plymouth Road and the other is on the Lower Rouge River at Military Road in Dearborn. NOAA operates river level gauges along the Detroit River at Windmill Pointe, Fort Wayne, and Wyandotte. And GLWA operates river level gauges at numerous CSO outfalls along both the Rouge and Detroit Rivers.

The river level data obtained from GLWA were QA/QC reviewed and processed. For the GLWA outfalls along the Rouge River upstream of Warren Avenue, the GLWA and USGS gauge data at Plymouth Road were used to develop river level versus time boundary conditions at each CSO outfall for June and July 2021. For CSO outfalls without a river level gauge or with missing or erroneous data, river levels were estimated using previously determined correlations to other nearby GLWA or USGS river gauges.

For CSO outfalls to Lake St. Clair, the NOAA river level at Windmill Pointe was used. For CSO outfalls along the Detroit River, the NOAA river levels at Windmill Pointe, Fort Wayne and Wyandotte were interpolated to the outfall locations and used as boundary conditions in the SWMM modeling. For the WRRF outfalls and CSO outfalls on the lower Main Rouge River, a Detroit River level was interpolated from the NOAA data to near Zug Island.

The NOAA data for the Detroit River is presented on Figure 9 for June and July 2021. The Detroit River is a strait between LSC and Lake Erie. Therefore, Detroit River levels do not respond to rainfall and storms in the same way as most rivers. The Detroit River levels are slightly influenced by rainfall, barometric pressures, and winds.

Figure 9 shows that the Detroit River level varied during June and July 2021 by about 0.75-feet. The data also shows that the Detroit River levels were above average values of about 95-feet at Fort Wayne for the entire months of June and July 2021. A 25-year river level for the Detroit River at Fort Wayne is estimated to be about elevation 96.25-feet.

The USGS river level data on the Lower Rouge River at Military Road were used as the boundary conditions for the nearby Dearborn CSO outfalls. For the storm of June 25-26th, the Lower Rouge River flow rate and levels were the highest ever recorded along the Lower Rouge River in over the past 73-years of record (since 1948).

The Rouge River level data provided by GLWA at the Hubbell-Southfield RTB was utilized as the boundary condition for the Hubbell-Southfield RTB and other nearby CSO outfalls. The GLWA data for the Rouge River at the Hubbell-Southfield RTB reached a top of range value during the peak of the storm of June 25-26th. A high-water mark reported by Dearborn was used to estimate the Rouge River level during the top of range period. The Rouge River level rose over 6-feet at the Hubbell-Southfield RTB during the storm of June 25-26th to about elevation 102.7-feet. This river level is above the Hubbell-Southfield RTB effluent weir crest level of 99.5-feet.

The Rouge River level data for the USGS and the Hubbell-Southfield RTB gauges for June and July 2021 are given on Figure 10. The rises in level for the storm of July 16th were less than that of the storm of June 25-26th.

Figure 9. Detroit River Levels

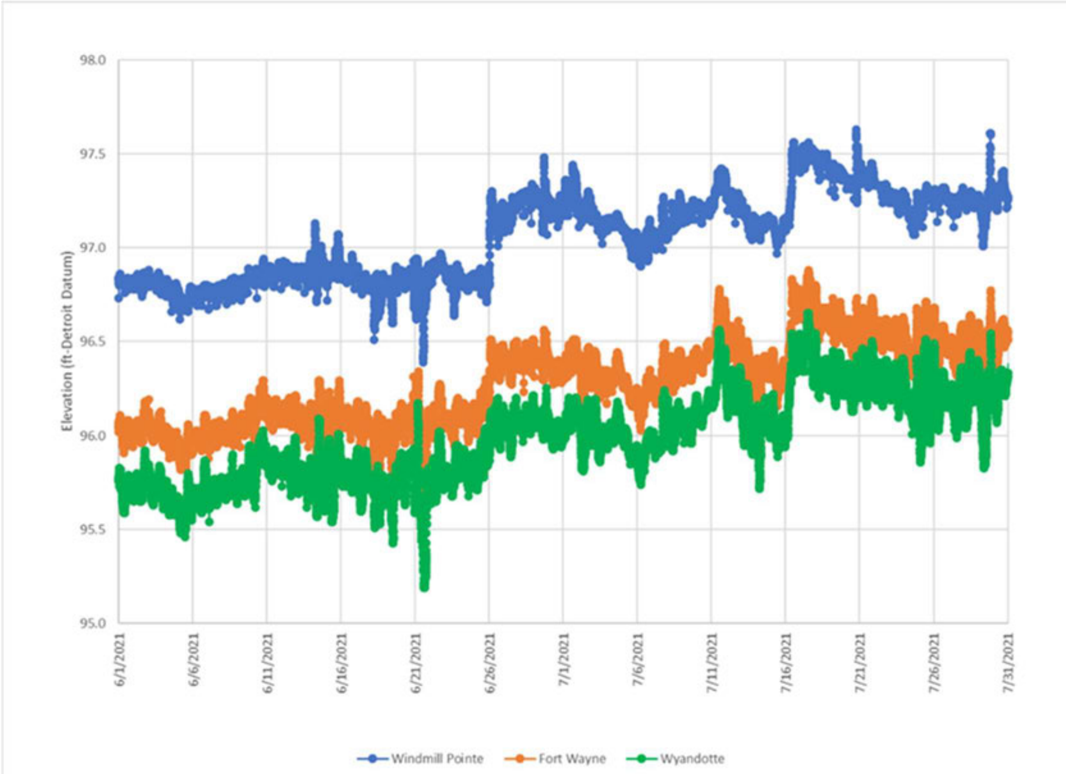
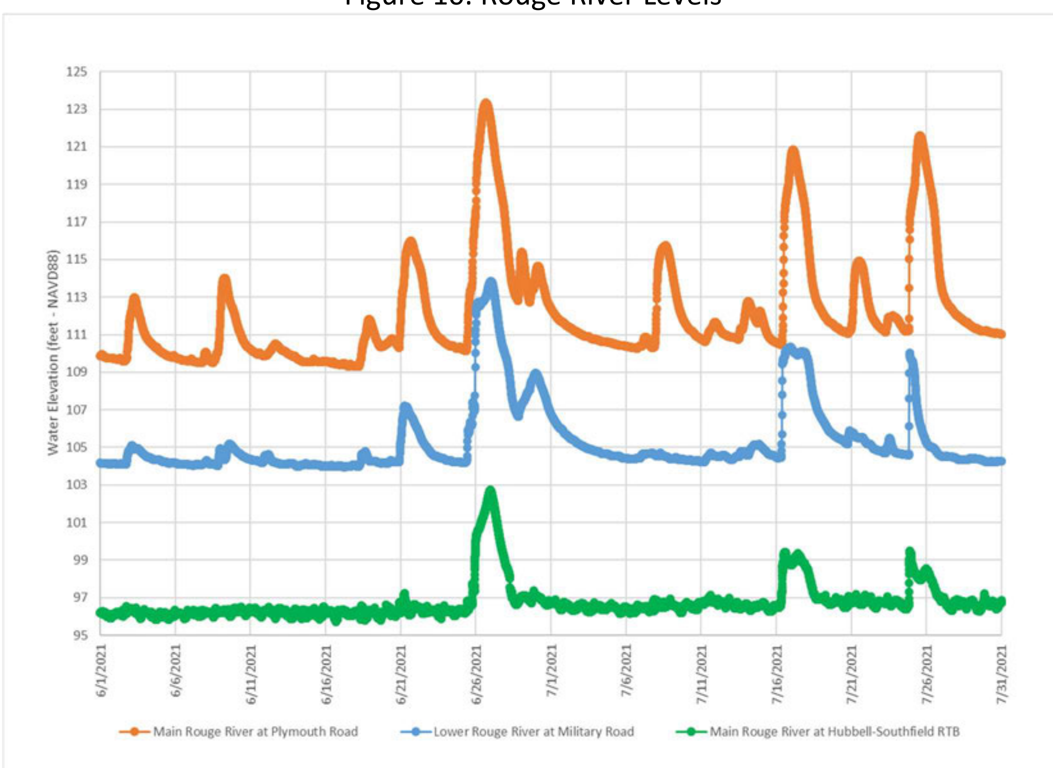


Figure 10. Rouge River Levels



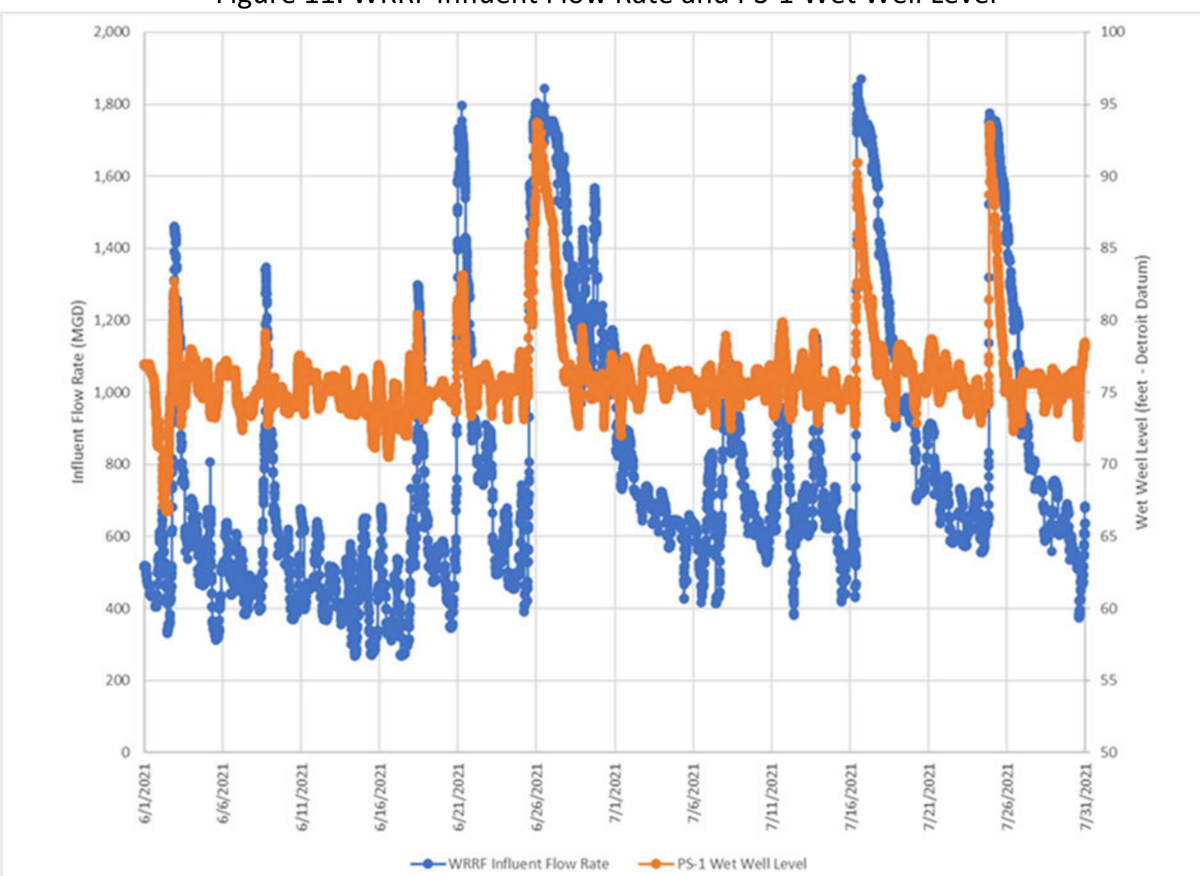
WRRF Wet Well Levels

The wet well levels in raw wastewater pumping stations No. 1 and 2 (PS-1 and PS-2) at the Water Resource Recovery Facility (WRRF) were provided by GLWA and used as boundary conditions in the SWMM modeling work performed by AECOM. The influent flow rate and PS-1 wet well level versus time are presented on Figure 11 for the months of June and July of 2021.

In dry weather, the wet well levels generally vary about elevation 76-feet. In wet weather, the wet well levels rise significantly. The maximum raw influent treatment capacity of the WRRF is about 1,800-MGD. This flow rate was reached for both the storms of June 25-26th and July 16th. The combined capacity of the three interceptors that convey wastewater to the WRRF is greater than the treatment capacity of the WRRF. Therefore, the wet well levels rise in wet weather, backwater in the interceptors is created, the interceptor flow rates are reduced, and excess wastewater flow rates become SSO or CSO.

For the June 25-26th storm, the peak wet well level was about 93.7-feet. This level was only about 2.7-feet below the Detroit River level at Fort Wayne. For the July 16th storm, the peak wet well level was about 91.0-feet and about 6.7-feet below the Detroit River level at Fort Wayne.

Figure 11. WRRF Influent Flow Rate and PS-1 Wet Well Level



Temporary Fairview PS

A site plan of the Fairview PS is shown on Figure 12. From the spring of 2020 through the fall of 2021, the Fairview PS was shut down, a bulkhead was installed that isolated the Fairview PS wet well from the upstream DRI, and temporary bypass pumps were installed in the existing gate shaft on the upstream DRI. The temporary bypass pumps discharged into the north stop log chamber on the DRI downstream of Fairview PS shown on Figure 12. During this timeframe, significant rehabilitation was completed at the pumping station.

Figure 12. Fairview PS Site Plan

[redacted]

The temporary bypass pumps were vertical turbine pumps with variable frequency drives. This type of pump requires significant submergence to operate. The operating wet well levels for the temporary pumping station were higher than those that would occur with the pre- and post-2021 Fairview PS as given on Table 2.

A maximum wet well level was set at elevation 81-feet for the temporary Fairview PS. Whenever the wet well level exceeded about elevation 81-feet, overflow occurred along the upstream DRI at weirs and stop log chambers into the lower elevation East Jefferson Relief sewer (and back to the Conner Creek PS). Wet well levels generally exceeded elevation 81-feet briefly during wet weather and system dewatering.

In accordance with GLWA's Interim Wet Weather Operating Plan (IWOP), the pumping is reduced during wet weather at the Fairview PS, sometimes to zero, whenever the wastewater depth exceeds the 8/10th depth points in the DRI at downstream Meters DT-S-8 and/or DT-S-12. This procedure avoids overloading the downstream DRI and allows combined wastewater flow rates into the DRI from downstream trunk sewer regulators under peak wet weather conditions. This procedure is implemented to reduce downstream untreated CSO to the Detroit River.

Figures 13 and 14 show the wastewater flow rates and depths versus time at Meter DT-S-8 for the two storms. Meter DT-S-8 is on the DRI downstream of Fairview PS and is located along Jefferson Avenue near Holcomb Street (outside the Jeffersonian apartment building). The DRI at this location is an 11-feet diameter conduit and there is only one sewer connection at McClellan Street between Fairview PS and Meter DT-S-8. Therefore, most of the flow rate at Meter DT-S-8 is discharge from the Fairview PS.

For the storm of June 25-26th, the peak depth reached at Meter DT-S-8 was about 16-feet. Even though DRI depths were significantly greater than the 8/10ths point, a decision was made to continue pumping, except for two short duration shutdowns. The pumping records provided by the temporary bypass pumping contractor, Mersino Dewatering, Inc. (MDI), showed the following pumping operations on June 25-26th.

- At about 9 PM on June 25th, all pumps were briefly turned off.
- From about 9 PM on June 25th through 1 AM on July 26th, two pumps were operating.
- At about 1 AM on June 26th, all pumps were briefly turned off.
- From about 1 AM through about 7:25 AM on June 26th, three pumps were operating.
- From about 7:25 AM through about 9:30 AM on June 26th, two pumps were operating.
- From about 9:30 AM through about 3:30 PM on June 26th, only one pump was operating.
- From about 3:30 AM through about 5:30 PM on June 26th, two pumps were operating.
- Full pumping resumed at about 5:30 PM on June 26th.

For the storm of July 16, 2021, the peak depth reached at Meter DT-S-8 was about 13.5-feet. Even though DRI depths were greater than the 8/10ths point, a decision was made to continue pumping through the peak of the storm. The pumping records provided by MDI showed the following temporary bypass pumping operations on July 16th.

- From about 9:40 AM to about 11:20 AM, three pumps were operating.
- From about 11:20 AM to about 12:15 AM, only one pump was operating.
- At about 12:15 PM, all pumps were briefly turned off.
- From about 12:15 AM to about 4:45 PM, only one pump was operating.
- From about 4:45 PM to about 7:15 PM, no pumps were operating.
- From about 7:15 PM to about 8:45 PM, only one pump was operating.
- From about 8:45 PM on July 16th to about 12:00 PM on July 17th, two pumps were operating.

- Full pumping resumed at about 12:00 PM on July 17th.

The wet well depth at the temporary Fairview PS was measured with three (3) level sensors by MDI. For the storm of June 25-26th, the wet well level rose above the estimated Detroit River level for about 45-minutes during the peak of the storm as shown on Figure 15. During this timeframe, the peak wastewater elevation was only about 2 to 3-feet below ground levels at the Fairview PS. This suggests that the backwater gates opened on the surge overflow along the boat canal and CSO occurred during the 45-minute timeframe. There are no proximity switches on these backwater gates that would confirm this CSO discharge.

Also, the Fairview PS wet well level increased and the bulkhead(s) that were isolating the Fairview PS from the DRI were reported to have failed and flooding of the wet and dry wells occurred.

For the storm of July 16th, the wet well level rose to about elevation 88-feet as shown on Figure 16. No CSO occurred from the backwater gates on the surge overflow on the DRI upstream of Fairview PS for the storm of July 16th since the Detroit River levels were above 97-feet during this storm.

Figure 13. Meter DT-S-8 for the June 25-26th Storm

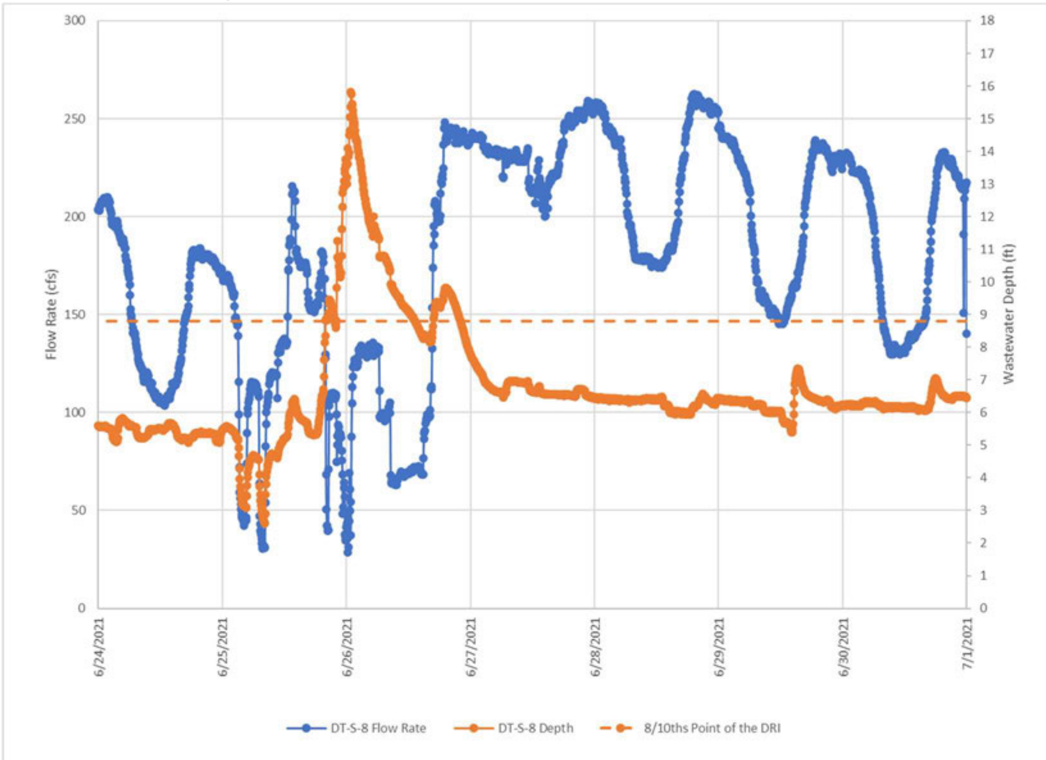


Figure 14. Meter DT-S-8 for the July 16th Storm

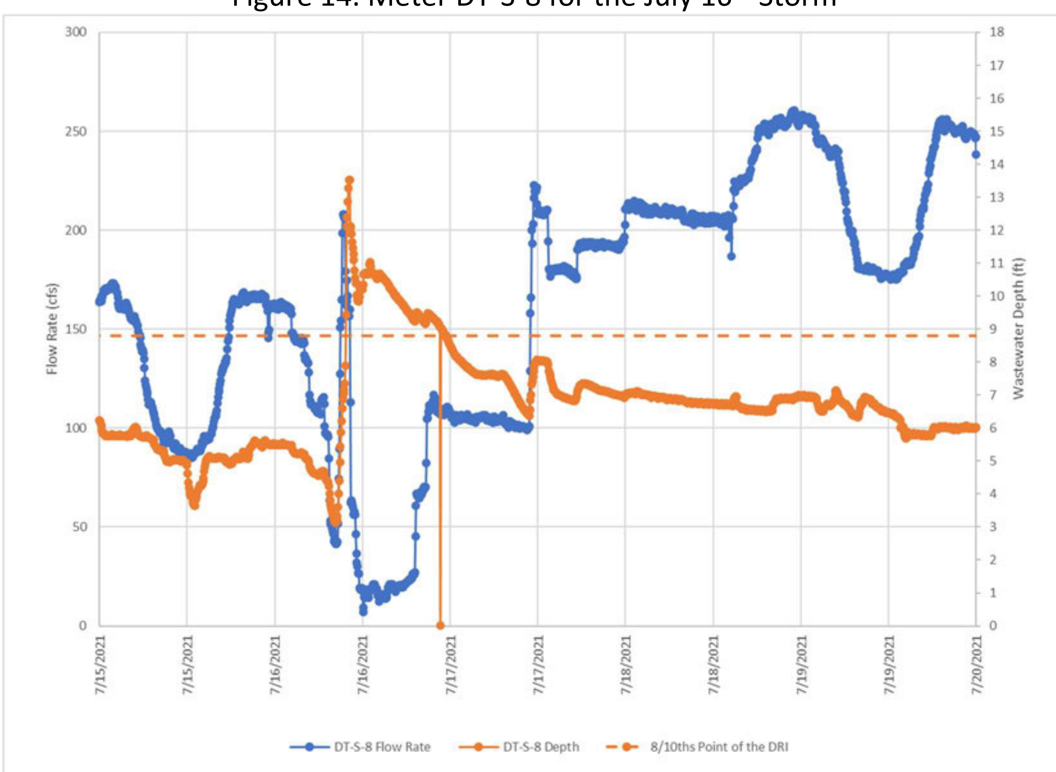


Figure 15. Temporary Fairview PS Wet Well Level for the June 25-26th Storm

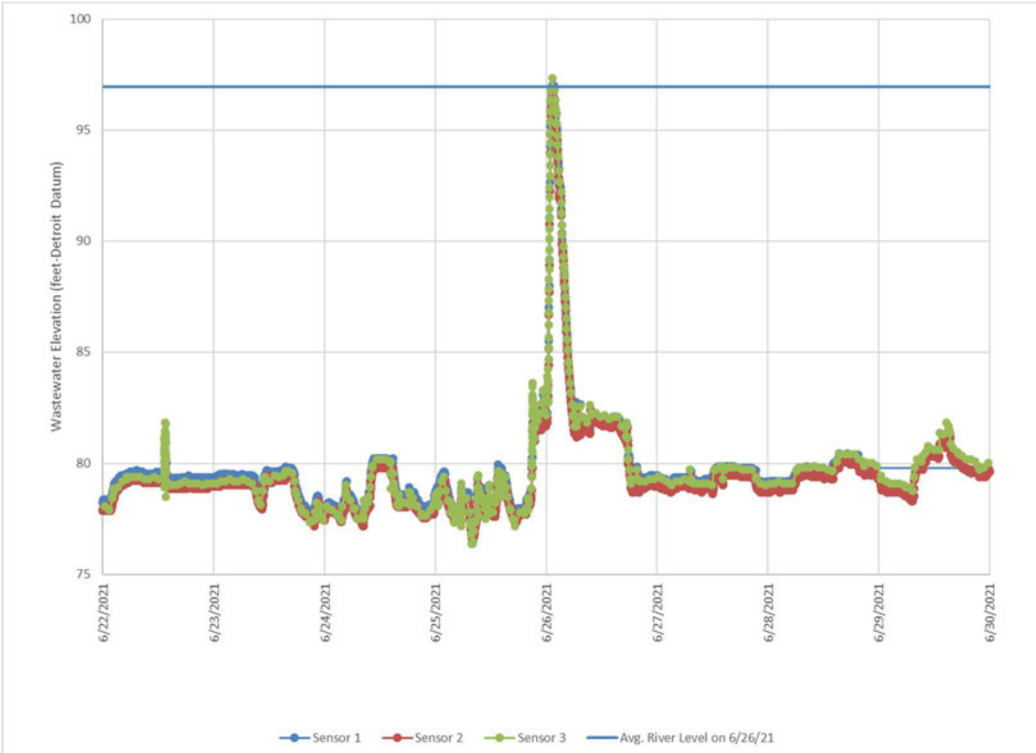
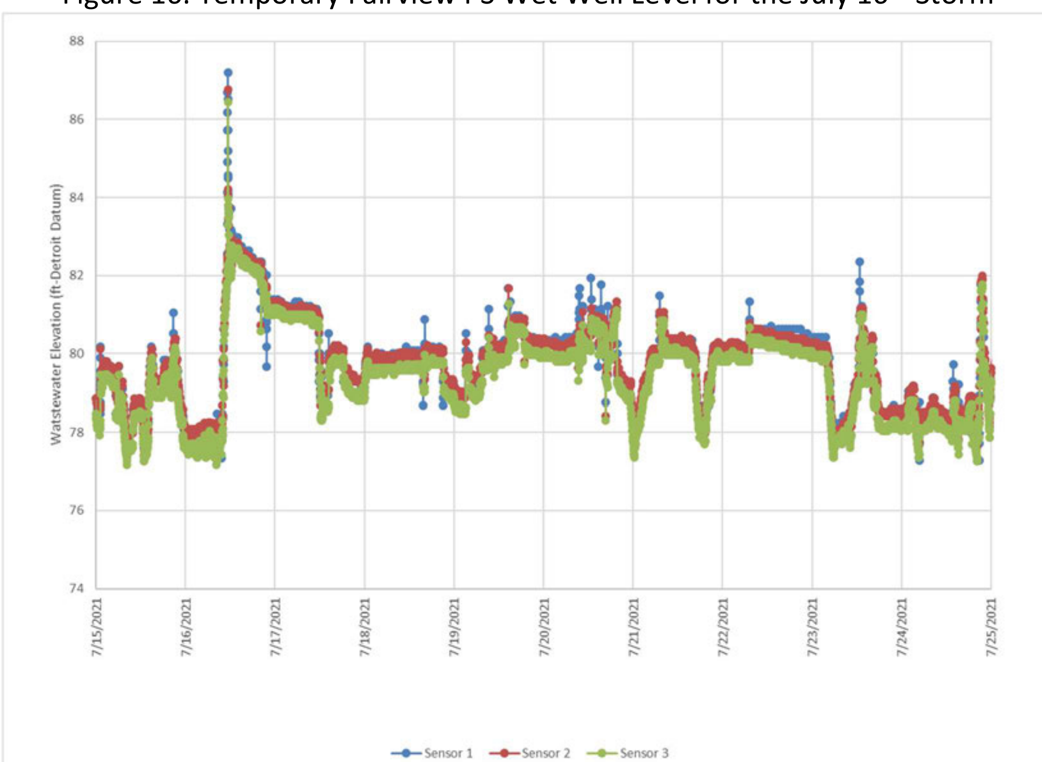


Figure 16. Temporary Fairview PS Wet Well Level for the July 16th Storm



Conner Creek Forebay and RTB

The Conner Creek regulator gates (VR-2a, b and c), and the Conner Storage Gates (CSGs) are located at the Forebay on the CCE. For both storms, the VR-2a was opened prior to the storms, all VR-2 gates were closed during the peak of the storms, and VR-2a was gradually opened to dewater the CCE and the Conner Creek RTB in-system storage volume after the storms. VR-2b and 2c were closed preceding, during and following the storms. The CSGs were closed prior to the storms and were opened when the wastewater level in either the CCE or the Conner Creek RTB levels rose to about elevation 95-feet. The CSGs were closed after dewatering was completed.

For the storm of June 25-26th, six of nine CSGs, twelve of sixteen effluent launder gates (ELGs), and fifteen of sixteen effluent relief gates (ERGs) were opened during the storm. For the storm of July 16th, six of nine of the CSGs, sixteen of sixteen ELGs, and sixteen of sixteen ERGs were opened during the storm. This suggests that some of the non-working gates were repaired between the storms.

It is important to note that the ERGs at the Conner Creek RTB are located on the canal-side of the end wall of the Conner Creek RTB and are always completely underwater. Consequently, the ERGs cannot be opened and tested in dry weather because opening one or more of these gates would allow an inrush river water into the RTB that would fill and damage equipment in the RTB.

The Forebay and Conner Creek RTB wastewater levels for the storms are plotted on Figures 17 and 18, respectively. As expected, the Forebay levels are slightly higher than the RTB levels. The launder weir in the RTB has a crest elevation of 98-feet and the maximum design wastewater elevation in the RTB is about 99-feet. The top elevation of the Forebay hatches is at 101-feet.

The Forebay and RTB levels were generally maintained between elevations 99 to 100-feet during both storms. This indicates that even with some CSGs, ELGs and ERGs out-of-service, there was sufficient capacity through the CCE and Conner Creek RTB for the peak flow rates for both storms. Also, it is concluded that any sludge deposits in the CCE between the Forebay and RTB had no significant effect on the wastewater levels and capacity.

The CCE and the Conner Creek RTB are dewatered by gravity through the VR-2 gates into the DRI to about elevation 83-feet. The dewatering pumps at the Conner Creek RTB finish the dewatering of the CCE and the Conner Creek RTB below elevation 83-feet. The CCE and the Conner Creek RTB were not emptied until about July 5th after the storm of June 25-26th. Additional rainfall occurred on June 28-29th to keep the CCE and Conner Creek RTB full. The CCE and Conner Creek RTB were not emptied until about July 24th after the storm of July 16th. Additional rainfall occurred on July 19-20th to keep the CCE and Conner Creek RTB full.

It is important to note that the CCE and Conner Creek RTB dewatering period is an ideal time to test and repair the vacuum priming systems on the storm pumps at the Conner Creek PS. The wastewater level in the CCE and Conner Creek RTB needs to be greater than 79-feet to prime the storm pumps and the wastewater levels in the CCE and Conner Creek RTB were greater than elevation 79-feet for several days after each storm. This prolonged dewatering is typical for most significant storms.

Figure 17. Conner Creek Forebay and RTB Levels for the June 25-26th Storm

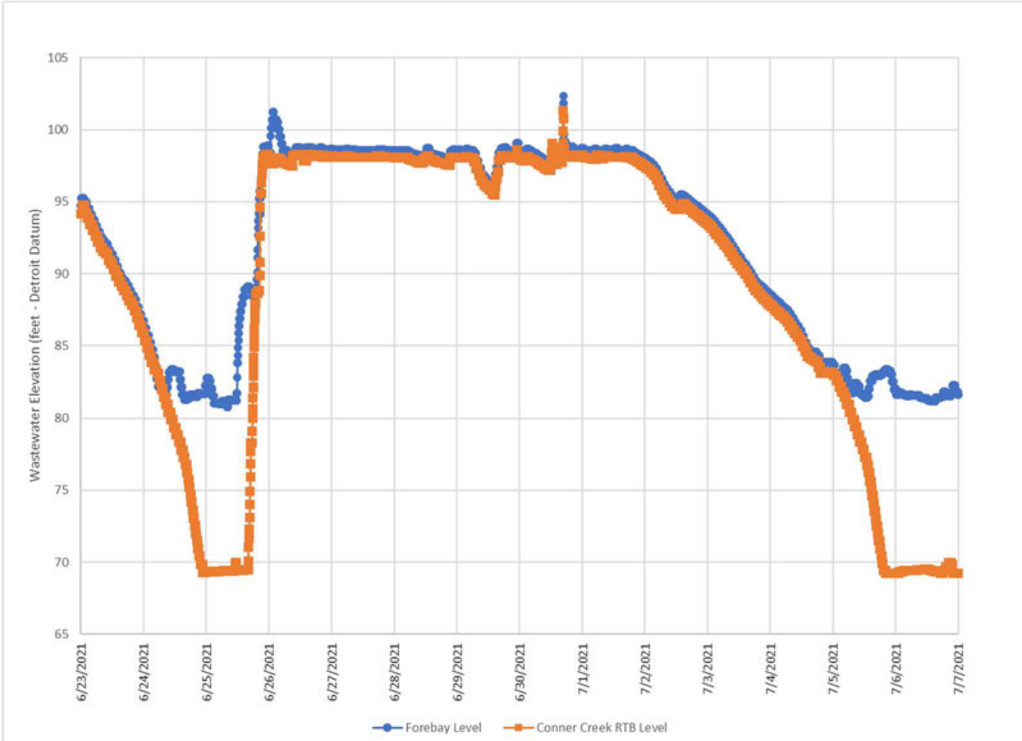
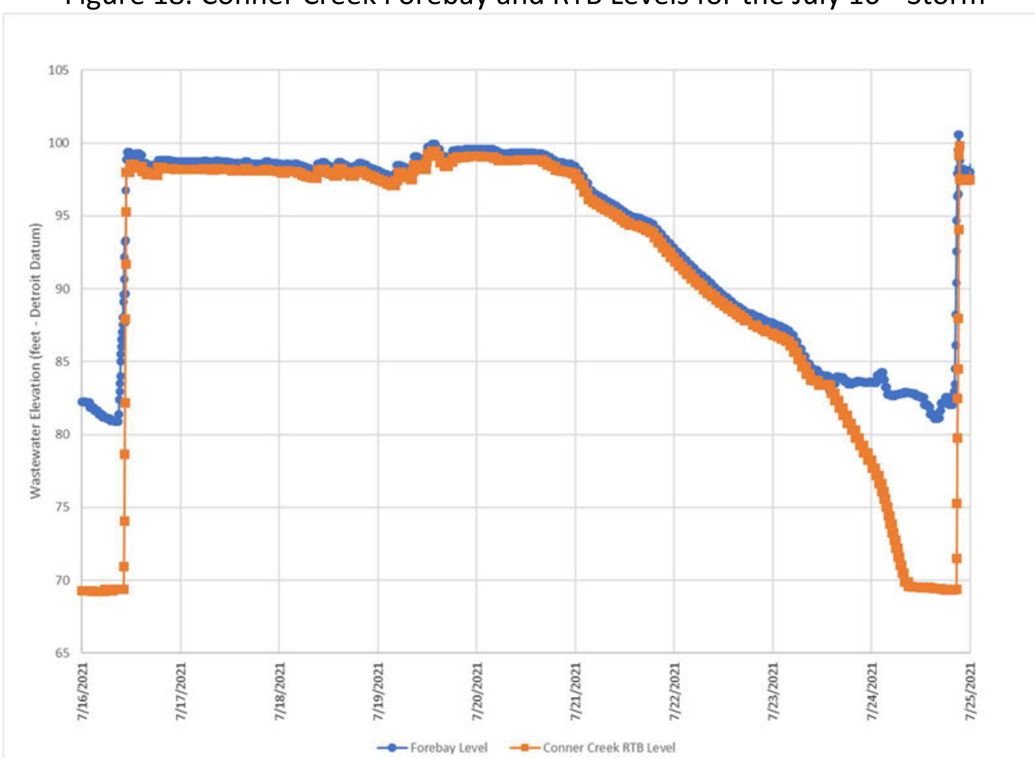


Figure 18. Conner Creek Forebay and RTB Levels for the July 16th Storm



Conner Creek, Freud, and Bluehill PS Operations

See the Figures 19 through 24 for plots of storm pumping versus time at the Conner Creek Storm, Freud, and Bluehill PS for the storms of June 25-26th and July 16th. The respective pumping station wet well levels versus time and the high normal wet well level also are shown on the plots.

During the storm of June 25-26th, a maximum of five (5) storm pumps were running at the Conner Creek Storm PS and three (3) storm pumps ran at the Freud PS. The Conner Creek PS wet well exceeded the level sensor top of range at about elevation 86-feet for about 2.5-hours. The Freud PS wet well is hydraulically interconnected with the Conner Creek Storm PS wet well above elevation 68-feet and it reached a maximum level of about 100-feet. At the Bluehill PS, two (2) storm pumps operated during the peak of the storm and the wet well level exceeded the level sensor top of range at about 86-feet for about 5-hours during the peak.

During the peak of the storm of July 16th, six (6) storm pumps were running at the Conner Creek Storm PS and four (4) storm pumps ran at the Freud PS. The Conner Creek Storm PS maximum wet well was about elevation 73-feet and the Freud PS maximum wet well was about 78-feet. At the Bluehill PS, one storm pump operated during the peak of the storm and the wet well level exceeded the level sensor top of range at about 86-feet for about 3.5-hours during the peak.

The Bluehill PS has 3 large storm pumps and one smaller storm pump. In the plots, the smaller pump has about ½ of the capacity of the large storm pumps. This can be seen for the July 16th storm when the number of pumps equaled ½, 1-½, 2-½ and 3-½.

Sanitary pumps at Conner Creek Sanitary, Freud and Bluehill PS are generally turned off when storm pumping is occurring in wet weather. This is a standard operating procedure that is followed because the capacities of the storm pumps greatly exceed that of the sanitary pumps. Also, for the sanitary pumps at Conner Creek Sanitary PS, downstream capacity at Fairview PS is limited during wet weather based on the downstream DRI levels. The periods when the sanitary pumps were turned off at the Conner Creek Sanitary, Freud and Bluehill PS are given on Table 3 for the storms of June 25-26 and July 16, 2021, respectively. It is important to note that the sanitary pumps at the Bluehill PS were operated during most of the peak of the storms to provide relief to the upstream service area.

Figure 19. Storm Pump Operations at the Conner Creek Storm PS for the June 25-26th Storm

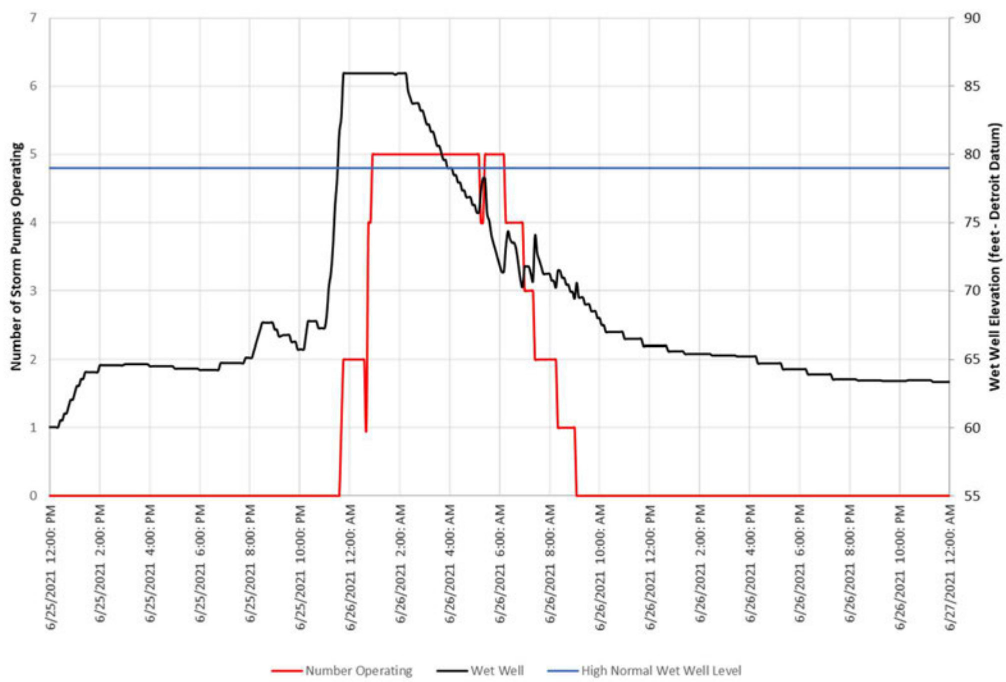


Figure 20. Storm Pump Operations at the Conner Creek Storm PS for the July 16th Storm

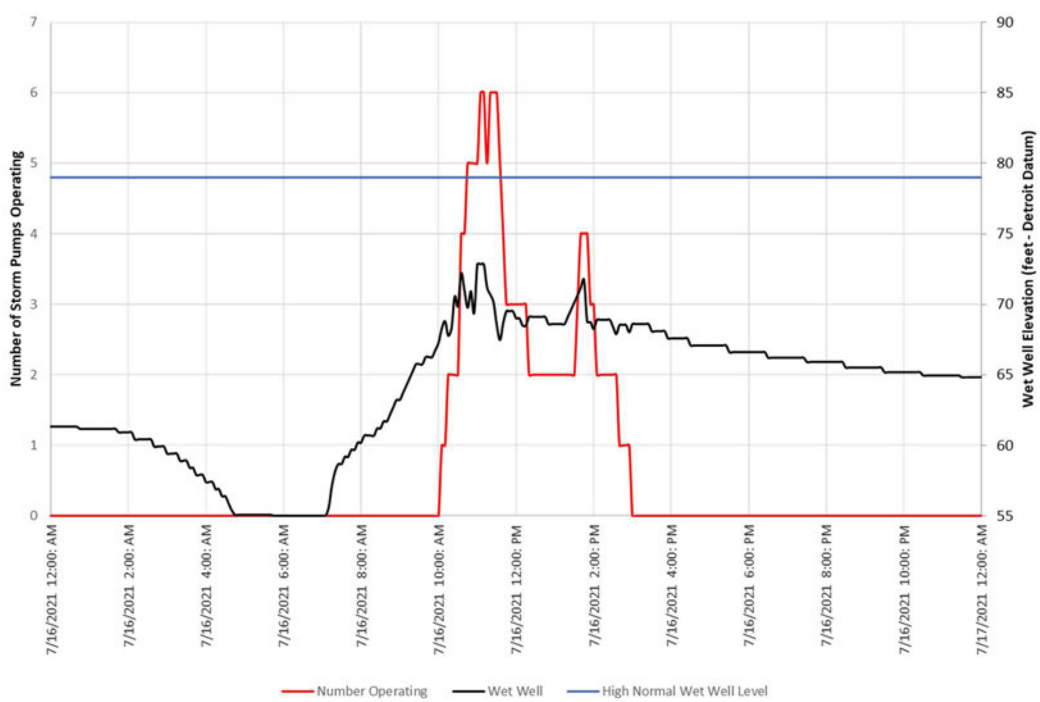


Figure 21. Storm Pump Operations at the Freud PS for the June 25-26th Storm

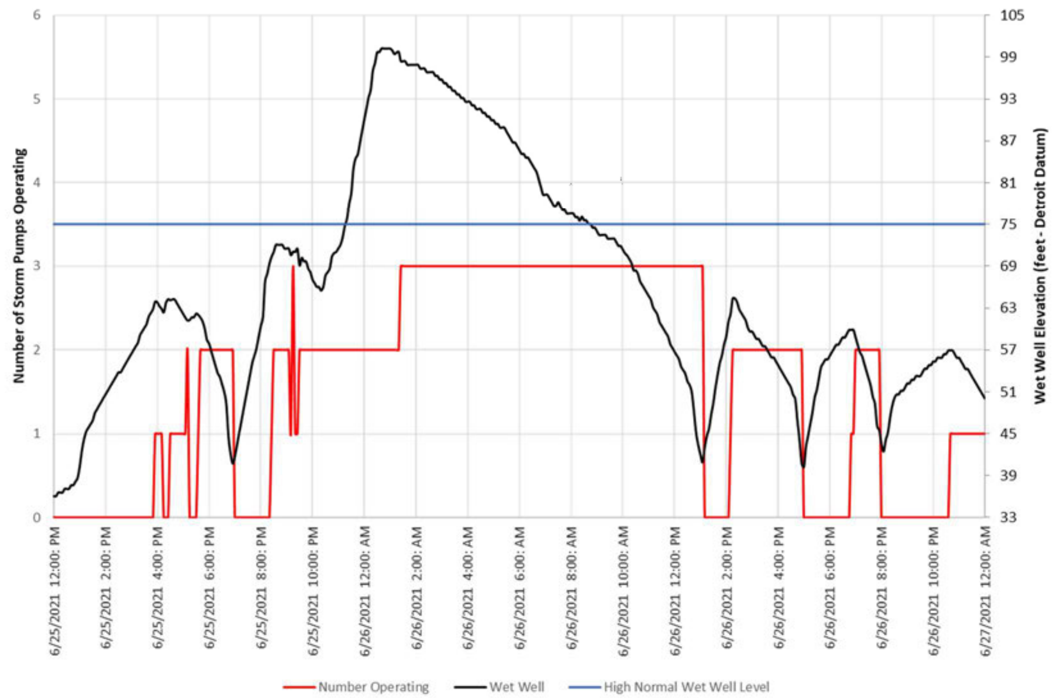


Figure 22. Storm Pump Operations at the Freud PS for the July 16th Storm

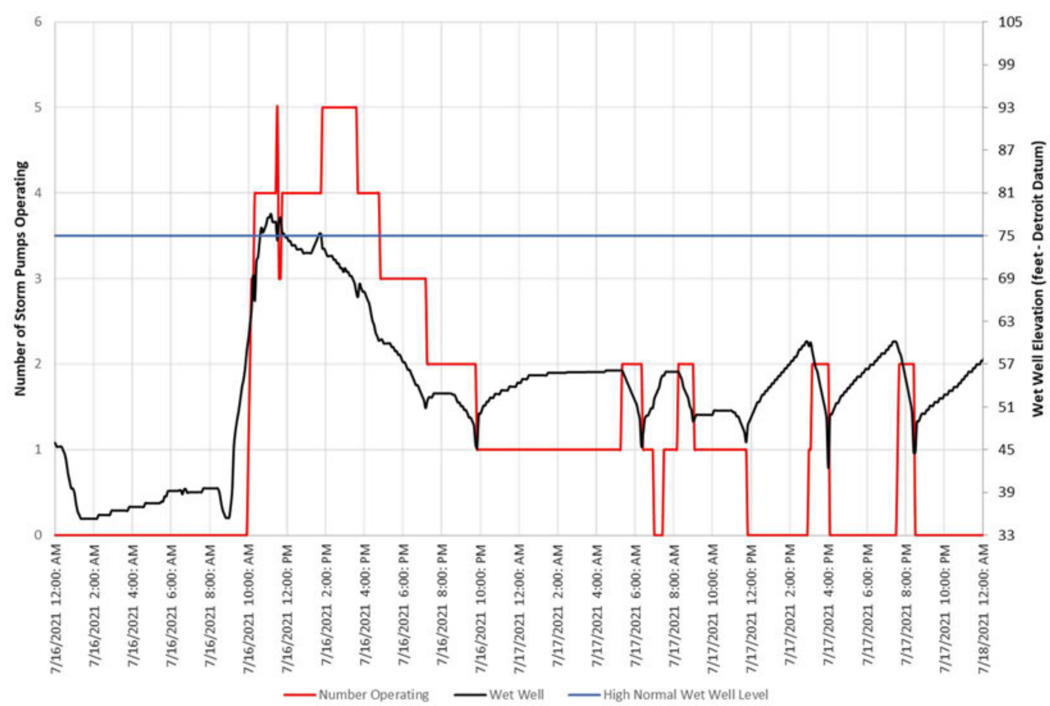


Figure 23. Storm Pump Operations at the Bluehill PS for the June 25-26th Storm

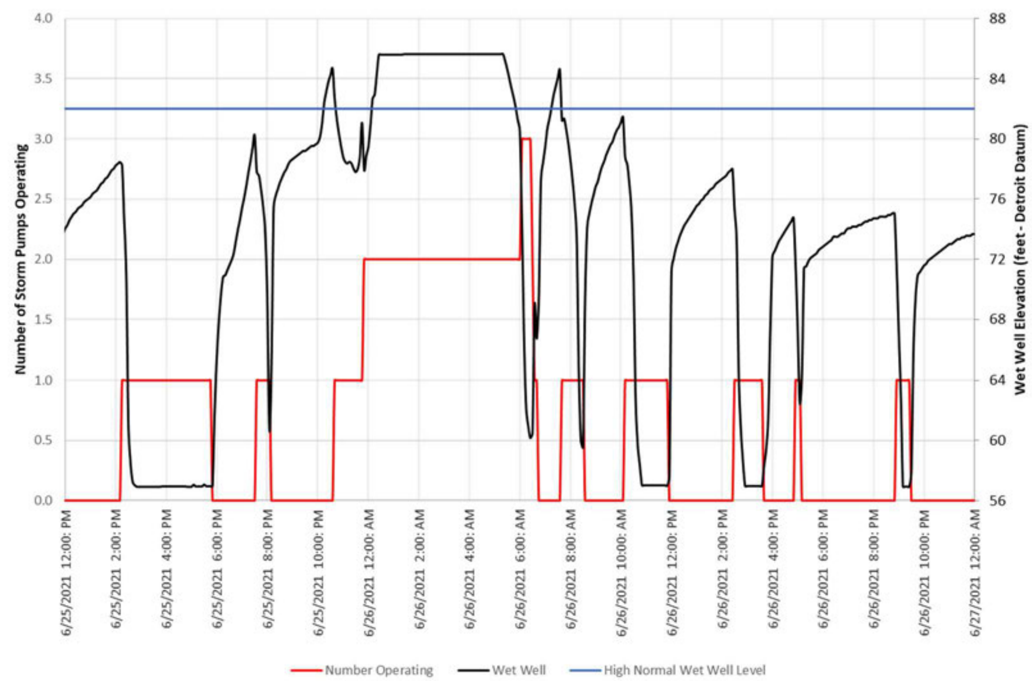


Figure 24. Storm Pump Operations at the Bluehill PS for the July 16th Storm

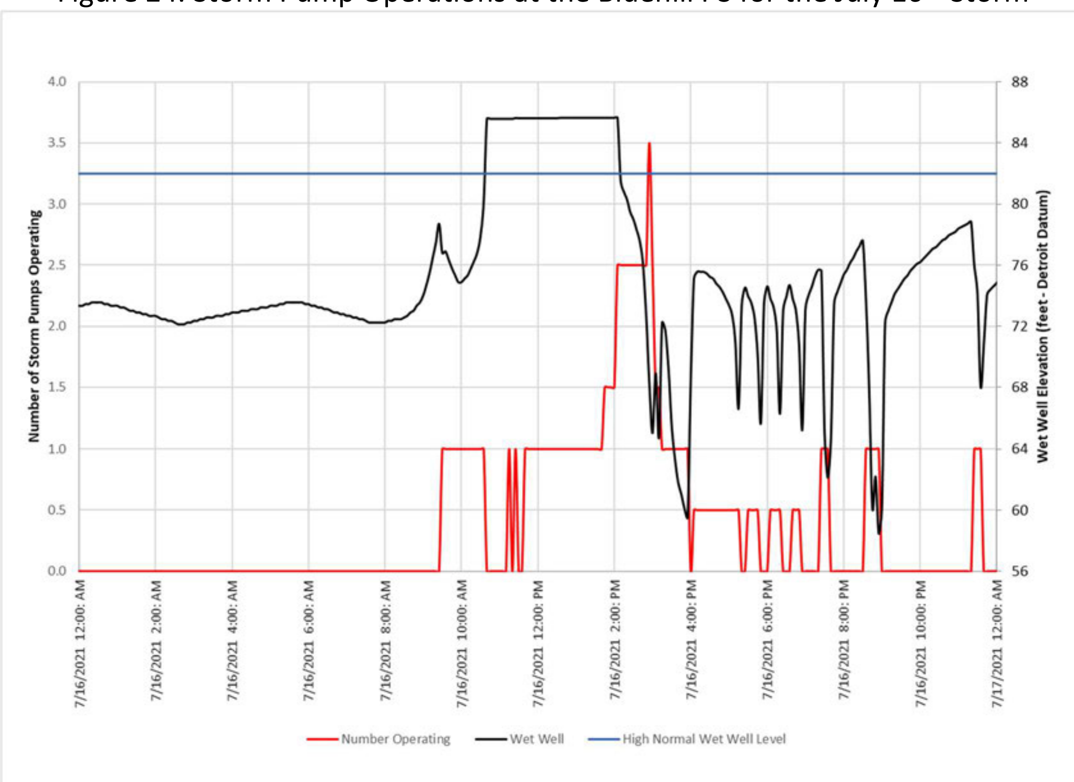


Table 3. Periods of No Sanitary Pumping

Pumping Station	Storm of June 25-26, 2021	Storm of July 16, 2021
Conner Creek Sanitary PS Sanitary Pumps #9 through #12	6/25/21 at 2:00 PM to 6/26/21 at 1:15 PM	7/16/21 at 10:45 AM to 7/16/21 at 7:00 PM
Freud PS Sanitary Pumps #9 and #10	6/25/21 at 1:40 PM through 6/27/21 at 6:40 AM	7/16/21 at 10:05 AM through 7/17/21 at 7:05 AM
Bluehill PS Sanitary Pumps #5 and #6	6/25/21 at 2:15 PM through 6/25/21 at 6:50 PM	7/16/21 at 10:45 AM through 7/16/21 at 11:15 PM and 7/16/21 at 11:30 AM through 7/16/21 at 12:10 PM

Fox Creek Outfall

There is a CSO outfall, B001, at the Fox Creek regulator chamber at downstream end of the Fox Creek Enclosure (FCE) and the Ashland sewer. The outfall leads to the Fox Creek canal as shown on Figure 5. The canal runs for over 6,800-feet to the Detroit River near Windmill Pointe. At the regulator chamber, there are two parallel backwater gates that will swing open if the upstream wastewater level is greater than the water level in the canal. GLWA has proximity switches installed on the backwater gates and a level sensor in the regulator chamber.

For the storm of June 25-26th, the west backwater gate was open continuously for about 4 hours from about 12:00 AM through 4:05 AM on June 26th. In addition, the east backwater gate was reported to be intermittently open from about 12:30 AM through about 4:35 AM. The Fox Creek regulator chamber level sensor data is not reasonable as it remained significantly below the Detroit River level at Windmill Pointe during the time that the backwater gates were reported to be open by the proximity switches.

For the storm of July 16th, the west backwater gate was reported to remain closed. The east backwater gate was reported to be continuously open from July 2 through July 31, 2021 (the end of the data period). The east backwater gate proximity switch data is obviously erroneous for the July 16th storm.

The Fox Creek outfall was visited at about 6:20 AM on June 26, 2021. A photo of the canal was taken and is shown on Figure 25. There was a strong sewage smell detected, the canal water was very turbid, and few floatables were observed on the water surface. It was apparent that a CSO recently occurred.

In the SWMM model of the RWCS obtained from GLWA, the Fox Creek outfall, B001, was mathematically represented with a rating curve that relates flow rate through the outfall and canal to the difference in the hydraulic grade lines (HGLs) in the Fox Creek regulator chamber and the Detroit River at Windmill Pointe. This relationship did not account for the significant head losses through the approximately 30-feet wide, 6,800-feet long canal. An updated rating curve was developed and used in the SWMM modeling work by AECOM.

A high-water mark (a debris line including some sanitary trash) can be seen on another photo taken on June 26, 2021 along the fence and presented on Figure 26. This high-water mark is about 3 to 4-feet above the water surface in the photo. The orange “Tiger” dam can be seen along the canal. Tiger dams were installed along the canal in the spring of 2020 to protect the neighborhood from flooding due the extremely high Detroit River levels being experienced.

It is important to note that GLWA flushes the Fox Creek canal after storms by opening a gate at the Fox Creek regulator chamber. When the flushing gate is opened, canal and Detroit River water are drawn back into the GLWA wastewater collection system.

The canal was visited at about 2 PM on July 16, 2021 and a photo of the canal is included from this visit on Figure 27. A slight sewage smell was evident, but the canal water was clearer. The sewage smell could have been from the nearby Fox Creek regulator chamber. Branches, leaves and trash can be seen floating in the canal in the photo taken on July 16, 2021. This evidence, combined with the proximity switch data, confirms that no CSO occurred on July 16, 2021 from Outfall B001.

Figure 25. Fox Creek Canal at Jefferson Avenue on June 26, 2021

Figure 26. Fox Creek Outfall at Jefferson Avenue on June 26, 2021

Figure 27. Fox Creek Canal at Jefferson Avenue on July 16, 2021

Fox Creek Enclosure

The FCE begins at Chalfonte and Kerby Roads in Grosse Pointe Farms and runs to Ashland Street near Jefferson Avenue in Detroit. The Grosse Pointe Farms PS discharges into the FCE at Kerby and Chalfonte Roads. Also, the SEMSD Kerby Road PS discharges into the FCE at Kerby and Chalfonte Roads. The Neff PS discharges sanitary and combined wastewater from the City of Grosse Pointe into the FCE at Neff and Charlevoix Roads.

The FCE is a concrete arch from Kerby Road to Cadieux Road with an open channel capacity of about 530-cfs. The FCE is a 14-feet diameter concrete pipe from Cadieux to Bedford Roads in Grosse Pointe Park. From Bedford Road in Grosse Pointe Park to Ashland Street in Detroit, the FCE is a 15-feet diameter concrete pipe. The 14 and 15-feet diameter segments of the FCE have an open channel capacity of 772-cfs.

A hydraulic profile of the FCE from the 1983 Fox Creek Facility Plan is shown on Figure 28. The flow rates assumed for the hydraulic profiles are given in Table 4. The elevations shown on the profile are with respect to the NGVD29, and these elevations can be converted to the Detroit datum by subtracting 479.766-feet (or about 480-feet).

Table 4. Assumed Flow Rates in the Fox Creek Enclosure

Item	Profile Flow Rates (cfs)		
	A	B and C	D and E
SEMSD Kerby Road PS	127	152	188
Grosse Pointe Farms PS at Kerby Road	420	450	554
Subtotal	547	602	742
Neff PS in Grosse Pointe	170	170	204
Total	717	772	946

The current community/district contract limit flow rates are given on Table 1. SEMSD is allocated a contract limit flow rate of 127-cfs and Grosse Pointe Farms is allocated 554-cfs in the FCE. The sum of these contract limits is 681-cfs, and this flow rate exceeds the open channel design capacity of about 530-cfs in the arch section of the FCE from Kerby to Cadieux Roads.

The City of Grosse Pointe is allocated a contract limit flow rate of 192-cfs in the FCE. Therefore, the total peak flow rate in the FCE from about Neff Road to Ashland Street is 681 + 192 = 873-cfs. This flow rate exceeds the open channel design capacity in the FCE of 772-cfs between Cadieux Road and Ashland Street.

The starting wastewater levels in the FCE at the downstream end at the Fox Creek regulator chamber are about elevation 91-feet (571-feet NGVD29) for Profile A, the crown elevation of the FCE at Ashland Street of about 94-feet (574-feet NGVD29) for Profiles B and D, and the crown elevation of the box sewer section in Ashland Street of about 97-feet (577-feet NGVD29) for Profiles C and E.

The Detroit River level at Windmill Pointe was above elevation 97-feet during the June 25-26th storm as shown on Figure 9 and the peak canal level at Jefferson Avenue was about 3 to 4-feet above the Detroit River level. Therefore, the peak wastewater level at the Fox Creek regulator chamber was higher than those shown on the profiles on Figure 28.

The profiles on Figure 28 show that the FCE will surcharge and overflow to ground from low elevation manholes under peak flow rate conditions and with a high wastewater level at the Fox Creek regulator chamber.

Some manholes along the FCE were checked in the days after the June 25-26th storm for evidence that overflow to ground occurred. For the June 25-26th storm, it appears that overflow occurred from FCE manholes at Balfour, Kensington, Cloverly, and Kerby Roads. Not every manhole was located and checked, so other manholes may have overflowed as well. Manhole covers in the roadways that were dislodged by overflow could have been immediately reset by residents, public safety or DPW personnel.

The manhole cover at Balfour Road in Grosse Pointe Park was found on June 29th to be completely off the frame and flipped over on the lawn as shown on Figure 29. The cover was reset after the photograph was taken. The manhole and surrounding pavement in Chalfonte Road at Cloverly Road in Grosse Pointe Farms were damaged and washed away from the overflow during the June 25-26th storm. The manhole was patched as shown on Figure 30 and subsequently repaired. And overflowing manholes at Kerby Road on the FCE were photographed by Grosse Pointe Farms DPW personnel during the June 25-26th storm as shown on Figure 31.

For the July 16th storm, the FCE manholes were checked during the storm. No evidence of overflow was found except at Kerby Road. Some minor flooding along Chalfonte Road near Kerby and Hillcrest Roads occurred due to this overflow.

The flow rates in the FCE are measured by Meter WM-S-2 at Bishop Road Grosse Pointe Park. The flow meter is a Laser Flow type meter and is setup to measure depths and flow rates when depths are below about 11-feet in the 14-feet diameter pipe. The flow rate and depth data for Meter WM-S-2 are plotted on Figures 32 and 33 for the storms of June 25-26th and July 16th, respectively. Also, the sum of the SEMSD Kerby Road PS (SEMSD), the Grosse Pointe Farms PS (GPF) and the Grosse Pointe Neff PS (GPC) is shown on the figures.

Figure 32 shows that the FCE depth at Meter WM-S-2 exceeded the top of range value of about 11-feet from about midnight on June 26th to past 6 AM. The level sensor depth data dropped to about 9-feet during the top of range period and is erroneous. The Meter WM-S-2 flow rates calculated for this period also are erroneous because the flow rate calculation for the meter requires an accurate depth measurement. For about 4-hours during this drop out period, the SEMSD, Grosse Pointe Farms and Grosse Pointe are thought to have been discharging over 900-cfs into the FCE.

Figure 33 shows that the FCE depth at Meter WM-S-2 exceeded the top of range value for only about 30-minutes during the peak of the storm. This result confirms that little overflow to ground occurred from the FCE for this storm.

Figure 33 shows large discrepancies between the total pumping by SEMSD, Grosse Pointe Farms and Grosse Pointe and the meter flow rates during the storm. There is good agreement during low flow periods and Meter WM-S-2 was calibrated for these lower flow rates. Therefore, it is likely that Meter WM-S-2 was underreporting the higher flow rates that occur in wet weather. Also, the flow rates from the "storm" pumps at the Grosse Pointe Farms PS and the Neff PS are estimated using runtimes and capacity curves that are likely overestimating the flow rates being pumped.

Figure 28. Hydraulic Profiles for the Fox Creek Enclosure

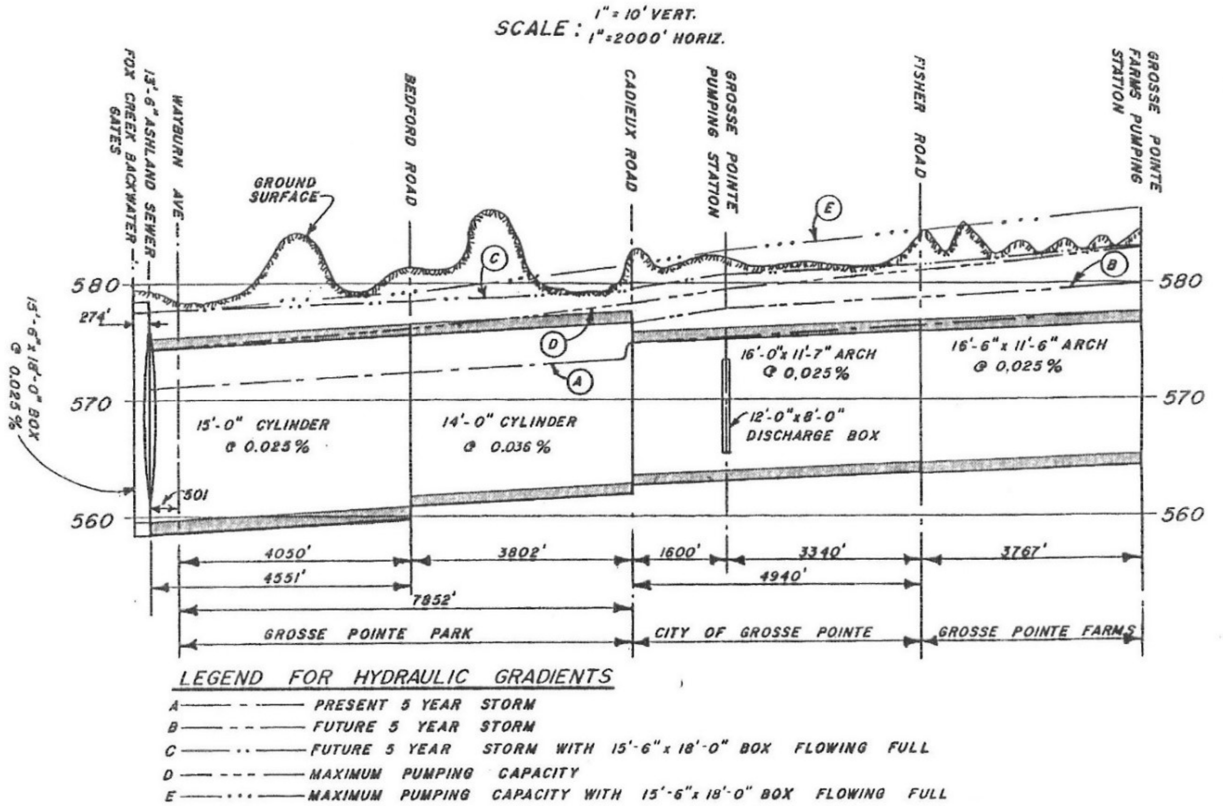


Figure 29. Fox Creek Enclosure Manhole at Balfour Road on June 29, 2021

Figure 30. Fox Creek Enclosure Manhole at Chalfonte and Cloverly Roads on July 16, 2021

Figure 31. Fox Creek Enclosure Manholes at Chalfonte and Kerby Roads on June 26, 2021

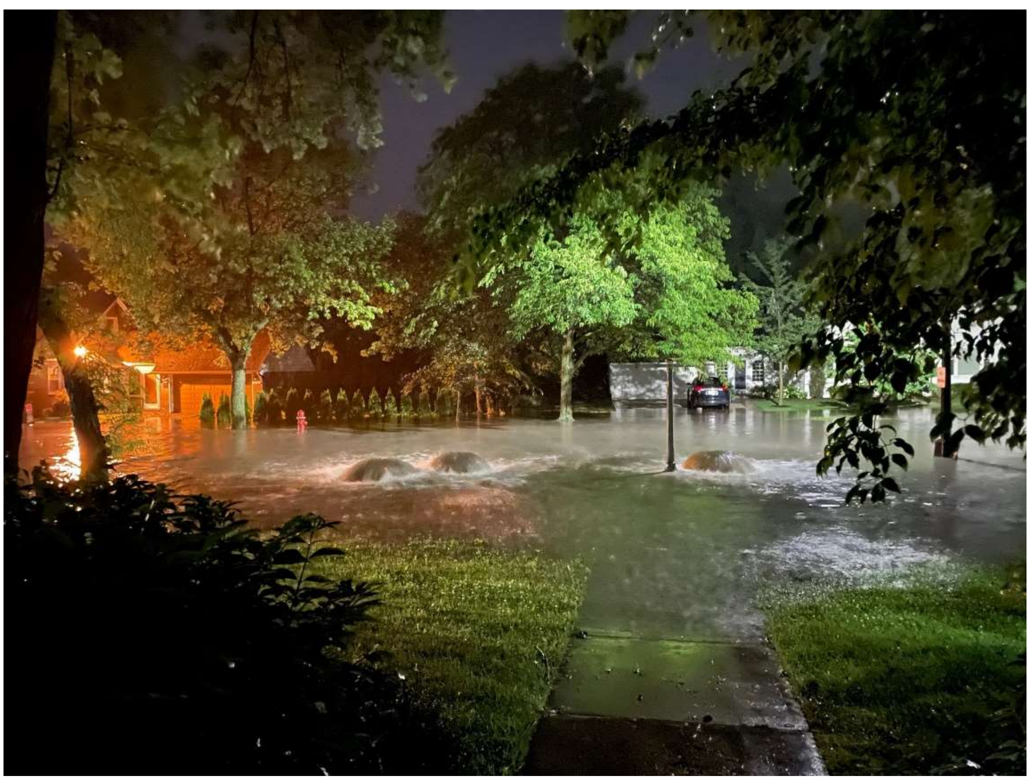


Figure 32. Meter WM-S-2 Flow Rates and Depths for June 25-26, 2021

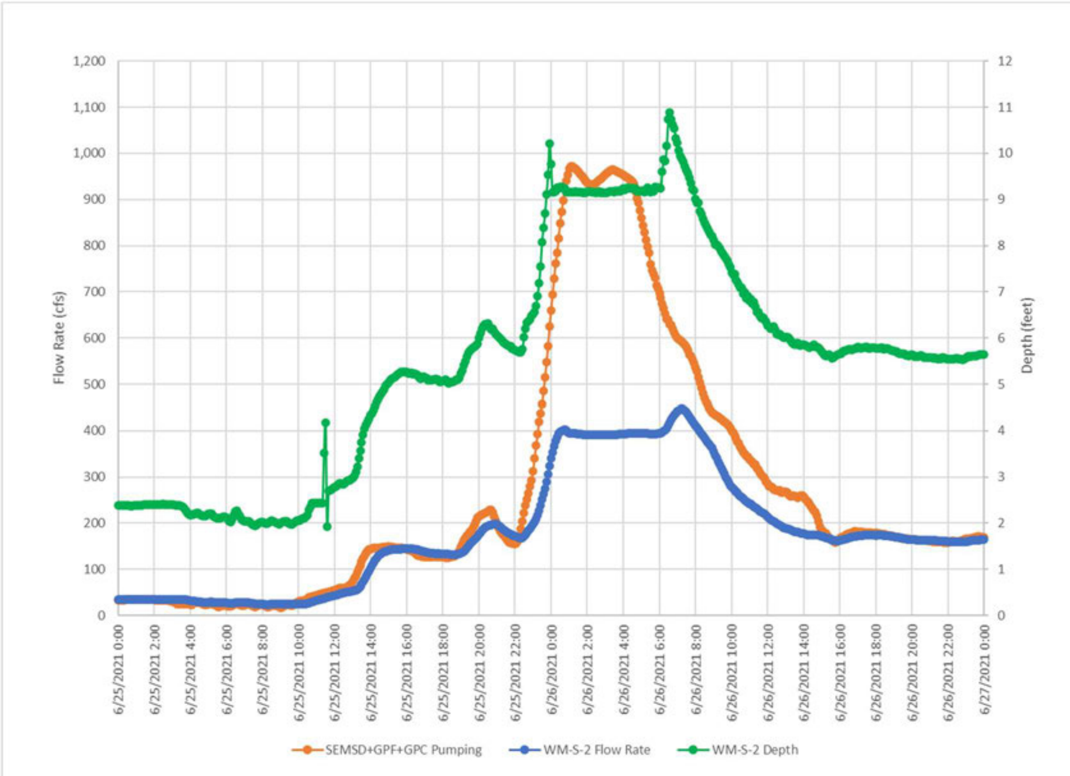
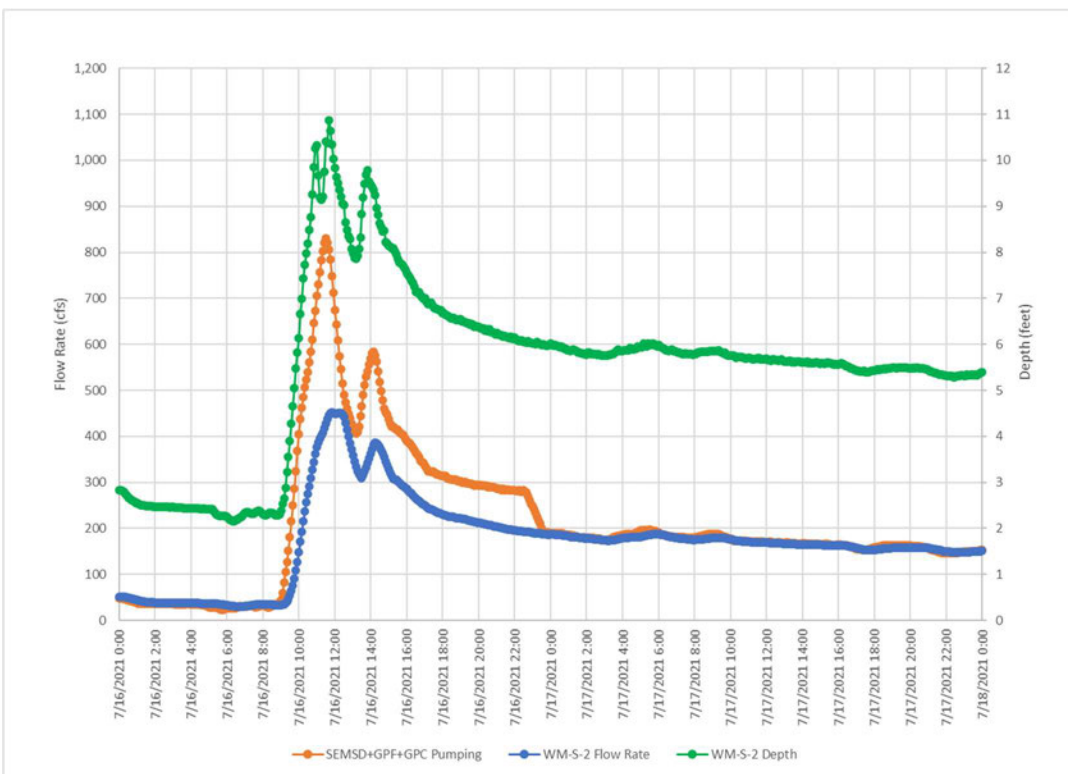


Figure 33. Meter WM-S-2 Flow Rates and Depths for July 16-17, 2021



East Side Sewer Levels

Sewer level data were provided by GLWA for all level sensors that were shown to be active on Figure 5. Also, level data for the GDRSS billing flow meters were obtained. The level sensor data in the East Side were QA/QC reviewed, and data that were considered reasonable were grouped together and plotted based on hydraulic connectivity. Data for only the storm of June 25-26th were plotted. For the storm of July 16th, the Conner Creek and Freud PS wet wells were about their respective high normal wet well levels.

Figure 34 shows the Freud PS wet well level plotted for the June 25-26th storm along with the data for two sensors on the Fox Creek Relief sewer, one sensor on the FCE, and a sensor at the Bluehill PS on the discharge channel. This plot shows that the high wastewater level at the Freud PS created backwater in the Fox Creek Relief sewer system back to the Bluehill PS and into the FCE. The peak wet well level occurred about 1 AM at both the Freud PS and in the Bluehill PS discharge channel. The backwater reached elevation about 100-feet (about elevation 580-feet NAVD88) and contributed to the flooded ground in the Fox Creek District of Detroit downstream of the Bluehill PS, in the East Jefferson District of Detroit, and in low elevation areas of Grosse Pointe Park, Grosse Pointe and Grosse Pointe Farms. Wastewater levels began to drop about 7 AM once the Freud PS level receded to about elevation 82-feet. His plot shows that the DRI level at Ashland Street was backwater affected by the wastewater level at the Freud PS.

The wastewater levels along the DRI are plotted on Figure 35 for the storm of June 25-26, 2021. These levels include the wastewater level at the Fairview PS recorded by MDI, the wastewater level at Meter DT-S-7, a wastewater level on the East Jefferson Relief sewer at Lemay Street, and the wastewater level near the upstream end of the DRI at Ashland Street. This plot shows that the East Jefferson Relief sewer and the DRI were surcharged to about the same levels during the peak of the storm of June 25-26th.

There are two major flow inputs to the DRI at the upstream end – one from the Grosse Pointe Park PS and another from the Alter sewer. There is an overflow chamber on the Alter sewer at Jefferson Avenue that connects to the East Jefferson Relief sewer. The East Jefferson Relief sewer has a chamber at Jefferson Avenue and Manistique Street with an overflow weir that leads to the Freud PS. Therefore, under peak wet well conditions at the Freud PS, the upstream end of the DRI at Ashland Street was hydraulically connected to the Freud PS wet well level when the Freud PS wet well is greater than the Alter Road overflow level of 85.1-feet.

The level at the upstream end of the DRI at Ashland Street/Alter Road would have reached at least the peak wet well level at the Freud PS of 100-feet. The DRI level began receding at about 6 AM when the Freud PS wet well receded below elevation 85-feet.

Figure 34. Freud PS Wet Well Level and Other Nearby Level Sensor Data

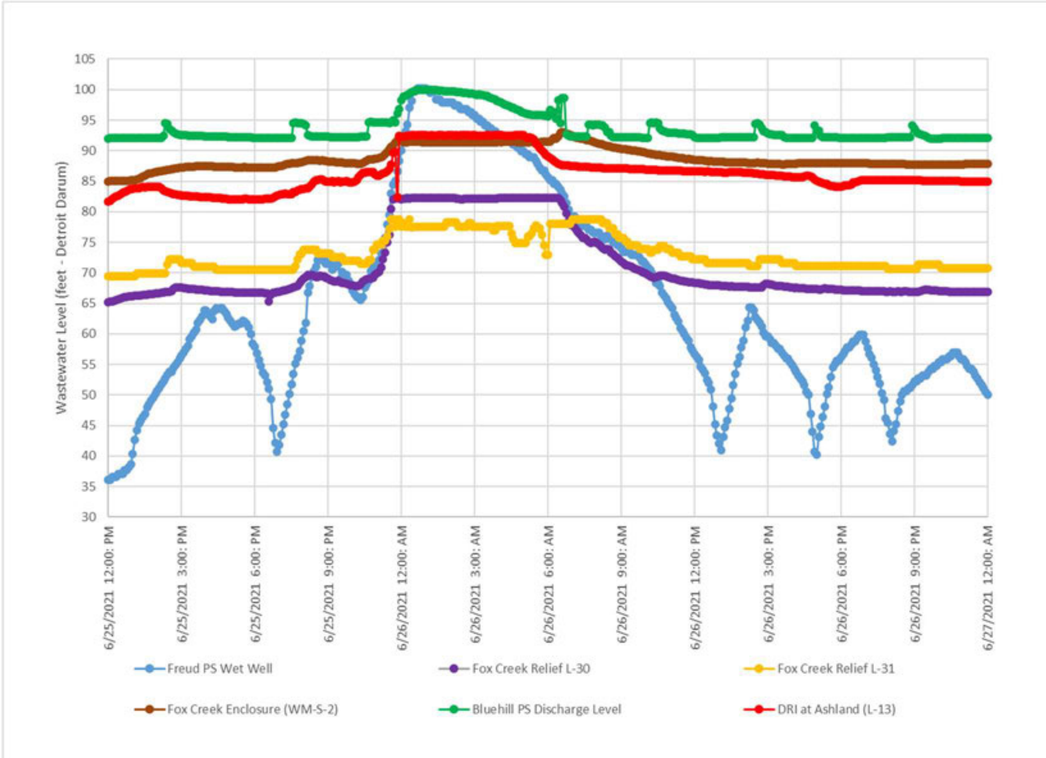
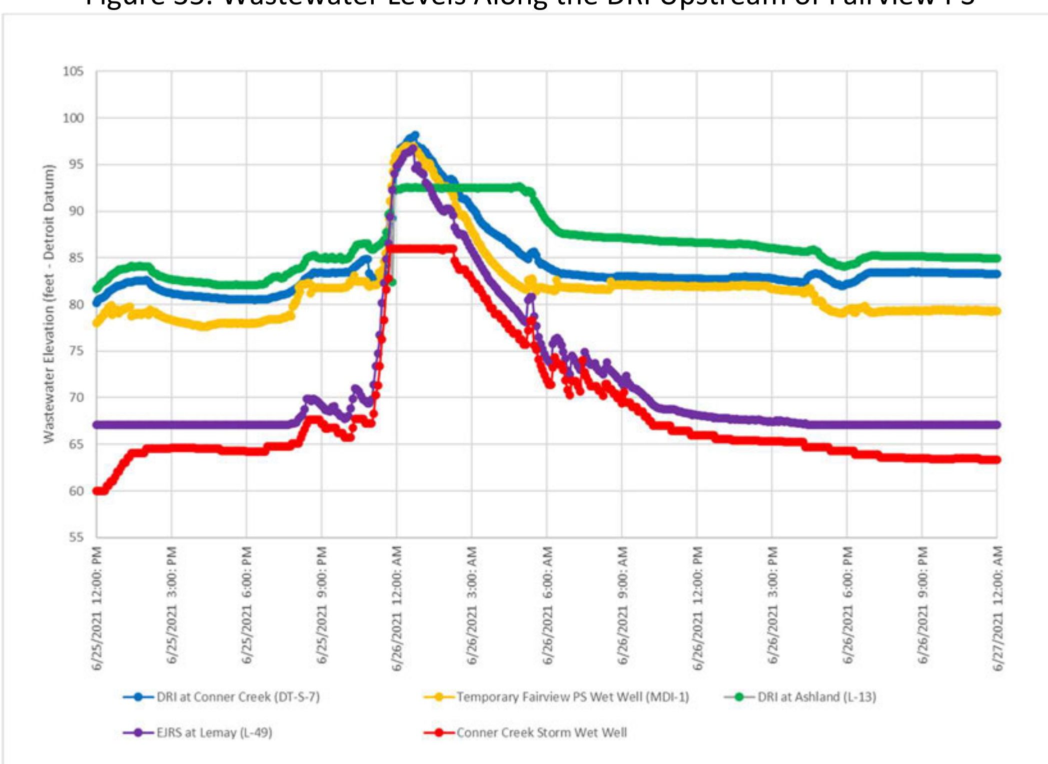


Figure 35. Wastewater Levels Along the DRI Upstream of Fairview PS



City of Detroit Storm/Combined Sewer Design Standards

The City of Detroit has storm, combined and relief sewers that were built to convey the peak flow rates from the 10-year design storm. This statement is supported by the City's Department of Public Works (DPW) street drainage design standards and relief sewer calculations prepared by DWSD.

The Rational Method was used to design the storm, combined, and relief sewers in Detroit using a 10-year frequency rainfall intensity-duration-frequency (IDF) curve. For each pipe, the upstream drainage area, percent impervious, and the time of concentration, Tc, were estimated. The Tc is the time for the peak runoff rate from the most remote part of the drainage area to reach the pipe being designed. The Tc includes the time for runoff to flow over the land surface, in the gutters of the streets and in any upstream storm or combined sewer. Larger drainage areas will have larger Tc values. The storm and combined sewer drainage areas in Detroit generally have Tc values between 15-minutes and 3-hours.

The peak runoff flow rate is then estimated with an equation:

$Q = C \times I \times A$, where,

C = the runoff coefficient (based on the percent imperviousness of the drainage area),
I = the rainfall intensity in inches/hour for the Tc, and
A = the drainage area in acres.

The rainfall IDF curve is used to obtain the value of rainfall intensity, I for the given Tc. Since nearly all the storm, combined and relief sewers were designed prior to 1960, the relationships from Technical Paper No. 25 (TP-25) were likely used for Detroit, Michigan.

The rainfall intensity decreases with increasing Tc. For a 15-minute Tc, the rainfall intensity, I, equaled about 4.5-inches/hour. For a 1-hour Tc, the rainfall intensity, I, equaled about 2.0-inches/hour. For a 3-hour Tc, the rainfall intensity, I, equaled about 0.85-inches/hour.

In summary, the rainfall used to design the storm, combined and relief sewers in Detroit typically varied from:

1.1-inches in 15-minutes for small drainage areas,
2.0-inches in 1-hour for larger drainage areas, and
2.6-inches in 3-hours for the largest relief sewers.

The storm, combined and relief sewer systems in Detroit were designed with rectangular 30-hole catch basin covers assumed to be in a clean condition. If the catch basins are clogged, then street flooding may result and flow rates into the combined sewer system would be reduced.

City of Detroit Flooding Observations for the Storm of June 25-25, 2021

The information presented in this section is not intended to be comprehensive. There may be many more locations of street and property flooding in Detroit that that occurred for the storms of June 25-26th and July 16th that are not discussed or documented in this study.

Flooding occurred and has been documented in news along the freeways in Detroit (I-94, I-96, I-375, I-75 and M-10). This flooding is understandable because these freeways are built, in large part, in corridors that are below the surrounding ground elevations. In Detroit, the freeways are generally lower in elevation and are drained by gravity and pumping at low points into DWSD combined sewers.

Flooding of a shipping yard and damage to vehicles on the Jefferson North Assembly Plant (JNAP) property was documented in an article the Free Press. The shipping yard is along the CCE near Mack Avenue and an unknown number of vehicles were damaged. The flooding in the shipping yard on June 26th is shown on Figure 36.

Flooding along Scripps Street near Marlborough Street on June 26th is shown in a photograph on Figure 37. This location is in the East Jefferson District of Detroit and is in the Jefferson-Chalmers neighborhood. The flooding damaged the bottom garage door panels as seen in the photograph taken later June 26th and shown on Figure 38.

About 6:30 AM on June 26, 2021, streets were still flooded and impassable by passenger vehicle in the Jefferson-Chalmers neighborhood as shown on Figure 39. A resident at 720 Manistique Street reported that the surface flooding reached the top of his first step on his front porch as shown on Figure 40.

Also, a manhole on one of the influent relief sewers to the Freud PS was reported by GLWA personnel to have overflowed during the June 25-26th storm. The Freud PS is within the Jefferson-Chalmers neighborhood and the East Jefferson District of Detroit. A photograph from September 9, 2021 is presented on Figure 41 showing the repaired manhole surrounded by straw outside the Freud PS near the intersection of Clairpointe and Freud Streets.

For the storm of July 16th, some freeway flooding was reported but no significant street or property flooding was reported in the Jefferson-Chalmers or other neighborhoods. However, significant basement flooding was reported for this storm in Detroit.

Figure 36. Flooding at the JNAP on June, 26, 2021

Figure 37. Scripps Street near Marlborough Street on June 26, 2021

Figure 38. Scripps Street near Marlborough, the Morning of June 26, 2021

Figure 39. Manistique Street (700 Block) Looking South on June 26, 2021

Figure 40. Residence at 720 Manistique Street

Figure 41. Damaged Manhole Outside of Freud PS

Grosse Pointe Park

The City of Grosse Pointe Park declined to provide rainfall or sewer system data to the GLWA for this study. However, some GDRSS billing flow meter data was available from GLWA, and Grosse Pointe Park provided useful information in a public town hall meeting on July 8th, in a public statement posted on the City's website on July 16th, and in a newspaper article published on July 27th in the Grosse Pointe Times.

The total rainfall was reported by Grosse Pointe Park to be 8.19-inches for the storm of June 25-26, 2021, and 3.79-inches for the storm of July 16, 2021. These rainfall totals are in-line with the rainfall data for the surrounding gauges.

For both storms, Grosse Pointe Park indicated that all pumps at the sanitary pumping station at Jefferson Avenue and Maryland Street and the storm water pumping station in Patterson Park operated without interruption. At the sanitary pumping station, there are three (3) smaller dry weather pumps and three (3) larger wet weather pumps. At the storm water pumping station, there are six (6) pumps designed to convey flow rates from a 10-year storm without any surface flooding and from a 100-year storm with minor surface flooding.

The GDRSS billing flow meter data for the storms of June 25-26th and July 16th are presented on Figures 42 and 43, respectively. The Grosse Pointe Park flow rates are measured with a combination of a magmeter on a forcemain and a flume on a 48-inch diameter discharge pipe. The flume was submerged by backwater for the June 25-26th storm but operated without submergence for the entire July 16th storm. The flow rates were estimated for the period of submergence based on the uninterrupted pumping reported by the City of Grosse Pointe Park.

In the town hall presentation, a photo of an overflowing manhole was included and is shown on Figure 44. This manhole is located along Jefferson Avenue near the bus stop shelter on Maryland Street. The manhole is likely on the discharge pipe from the Grosse Pointe Park PS that connects to the DRI further downstream. The photo shows that some of flow rate being pumped at the Grosse Pointe Park PS was not conveyed to the DRI for the June 25-26th storm. The overflow reduced the peak flow rates delivered to GLWA below the reported values for the June 25-26th storm by an unknown amount. Also, the photo shows flooding in Maryland Street beyond the bus stop shelter.

Figure 42. Grosse Pointe Park Flow Rates for the June 25-26th Storm

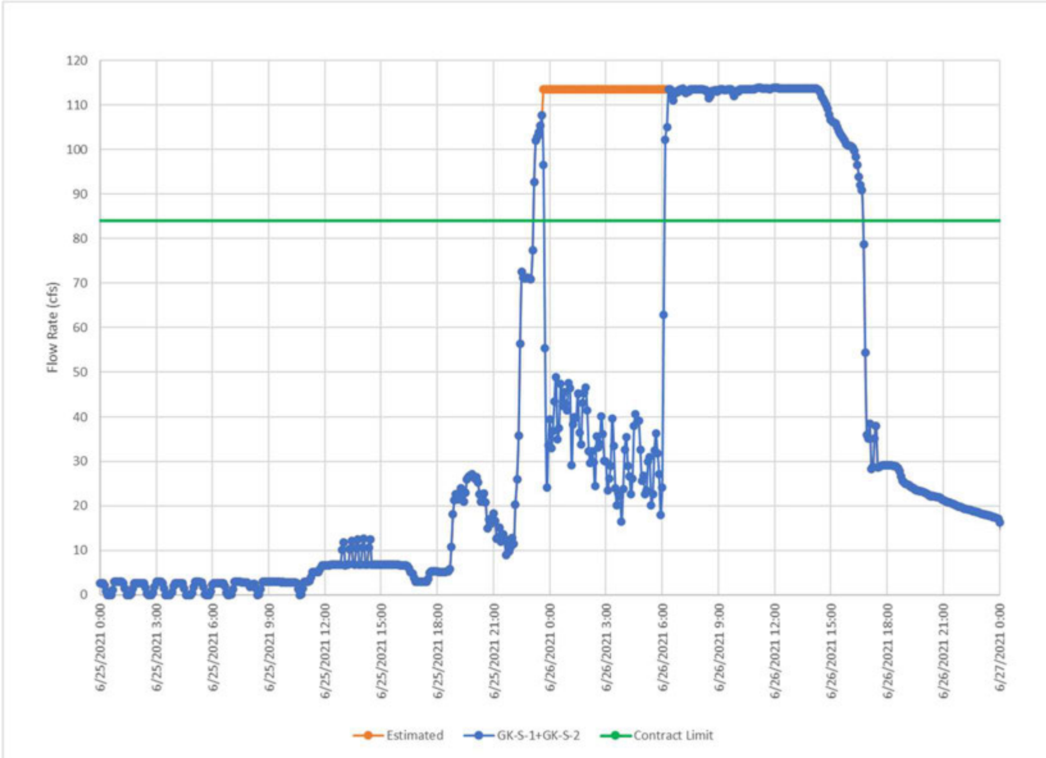


Figure 43. Grosse Pointe Park Flow Rates for the July 16th Storm

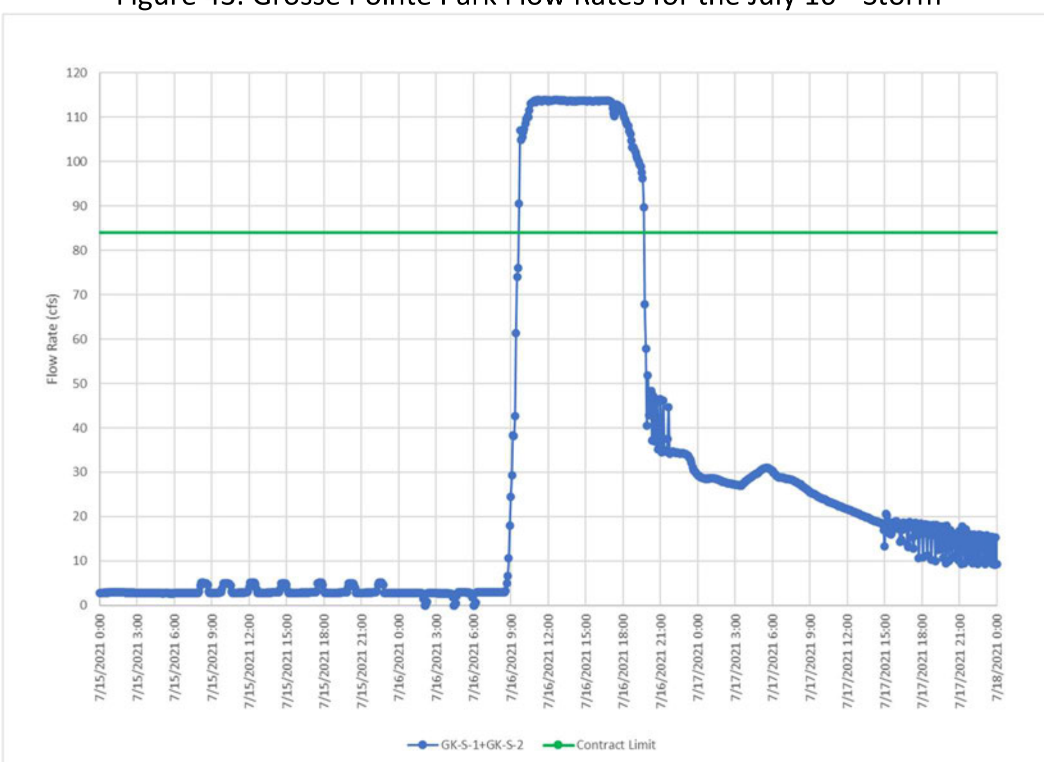


Figure 44. Overflowing Manhole at Grosse Pointe PS for the Storm of June 25-26, 2021

The intersection of Jefferson Avenue and Alter Road was still flooded on the morning of June 26th at about 6 AM. Also, the low elevation areas along streets in Grosse Pointe Park were flooded and impassable. Many automobiles (including SUVs and pickup trucks) were observed to be askew in the roadways and likely floated into those positions and were abandoned.

The intersection of Hampton and Maryland Streets is a low-lying area of Grosse Pointe Park near the Grosse Pointe Park PS. St. Ambrose Church is located along Hampton Street and experienced basement flooding at the church and rectory as well as basement and surface flooding that damaged the adjacent underground event space, the Ark, for the storm of June 25-26th.

Figure 45 shows the skylights, the plaza above, and the emergency exit doors of the Ark to the sidewalk level. The surface flooding reached the second step below the plaza level, covered the lower part of the skylight windows, forced open the emergency exit doors and flooded the underground Ark.

Figure 46 shows a manhole on the Fox Creek Relief sewer in the sidewalk on the north side of Vernor Road near Kensington Road. The manhole cover has a spot of green paint on it. Overflow from this manhole was reported by nearby residents for the storm of June 25-26th. Overflow occurred through voids under the sidewalk into the street. Gravel and sand bedding was washed out and can be seen between the sidewalk and curb.

For the storm of July 16th, significant street flooding was observed in low elevation areas in Grosse Pointe Park. Some roads were impassable with a passenger vehicle during the peak of the storm. Also, a geyser was documented from a storm sewer manhole at Fairfax and Pemberton Street as shown on Figure 47. Geysers occur during fast-filling conditions, and this is additional evidence that the July 16th storm had large and intense rainfall in Grosse Pointe Park.

For the storm of June 25-26th, about 3,000 homes reported basement flooding. This amounts to about 75% of the homes in the City of Grosse Pointe Park. The highest concentration of basement flooding was reported to be experienced in the lower lying areas of Grosse Pointe Park south of Jefferson Avenue.

For the storm of July 16th, about 200 homes reported basement flooding. Again, the highest concentration of basement flooding was reported to be experienced in the lower lying areas south of Jefferson Avenue.

Figure 45. The Ark at St. Ambrose Church

Figure 46. Fox Creek Relief Sewer Manhole along Vernor Road near Kensington Road

Figure 47. Geyser in Grosse Pointe Park on July 16, 2021

City of Grosse Pointe

The City of Grosse Pointe provided rainfall data, pump operating data, wet well levels, and flooding observations for this study. Also, some information was obtained from a presentation made to the public, from newspaper articles and from GDRSS billing flow meter data.

The rainfall data recorded by the City of Grosse Pointe at the Neff PS for the storms of June 25-26th and July 16th were reviewed and found to be lower than surrounding rainfall gauge data and unreasonable. Therefore, these data were not used in this study.

Grosse Pointe has an "inland" combined sewer district and a "lake" district that is served by sanitary sewers. The sanitary and combined wastewater from Grosse Pointe is pumped into the FCE at the Neff PS near Neff and Charlevoix Roads. The Neff PS includes three (3) dry weather pumps that discharge wastewater through a magmeter, Meter GP-S-1. Also, there are four (4) wet weather (storm) pumps, and these flow rates are estimated based on pump runtimes and capacity curves. The estimated storm pump flow rates are reported as Meter GP-S-STORM to GLWA. The flow rates for the storm pumps may be overestimated as suggested by the analysis of Meter WM-S-2 flow rates presented in the Fox Creek Enclosure section of this report.

For both the storms of June 25-26th and July 16th, Grosse Pointe utilized all available pumps at the Neff PS to minimize the basement and street flooding that occurred in the community. The GDRSS billing flow meter data for the storms of June 25-26th and July 16th are presented on Figures 48 and 49, respectively. These data include the estimated flow rates from the wet weather (storm) pumps plus the metered flow rates from the dry weather pumps.

For the storm of June 25-26th, significant street and basement flooding occurred throughout lower elevation areas of the City of Grosse Pointe. Many roadways were impassable. The DPW Director had to wade through floodwaters on Neff Road to get to the Neff PS from Mack Avenue during the June 25-26th storm. The DPW Director's truck was engulfed by flood waters and damaged on Neff Road between Mack Avenue and Charlevoix Road as shown on Figure 50. While all pumps were operating at the Neff PS during the peak of the storm, the Neff PS wet well level exceeded its top of range value for nearly 5-hours.

For the June 25-26th storm, surface flooding occurred in a commercial area along Kercheval Avenue in Grosse Pointe and entered the first floors and basements of numerous businesses. At about 6 AM on June 26th, the intersection of Cadieux Road and Kercheval Avenue was still flooded. Stalled cars can be seen in the intersection as viewed from Cadieux Road looking north as shown on Figure 51. By 6 AM, the flooding had receded, but many streets were still impassable to passenger vehicles in Grosse Pointe.

For the storm of June 25-26th, about 900 homes reported basement flooding. This amounts to about 50% of the homes in the City of Grosse Pointe. The highest concentration of basement flooding was reported in the combined sewer area north of Waterloo.

For the storm of July 16th, about 50 homes reported basement flooding. Surface flooding occurred in lower elevation areas including the commercial area along Kercheval Avenue as shown on Figure 52.

Figure 48. Grosse Pointe Flow Rates for the June 25-26th Storm

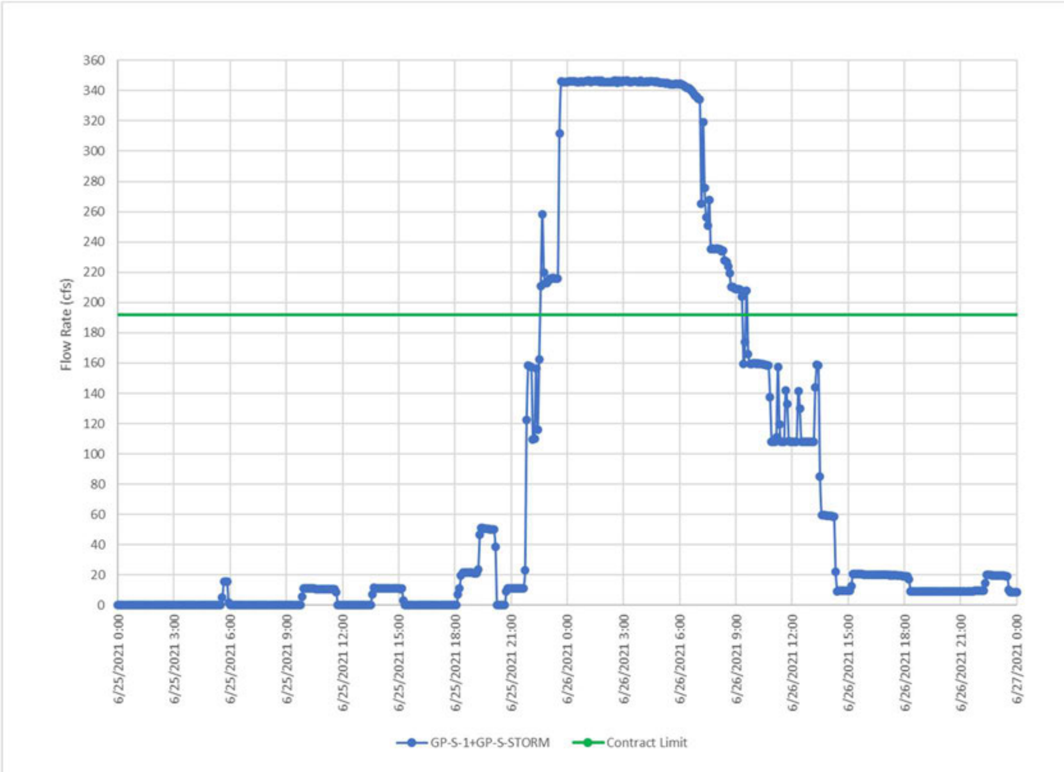


Figure 49. Grosse Pointe Flow Rates for the July 16th Storm

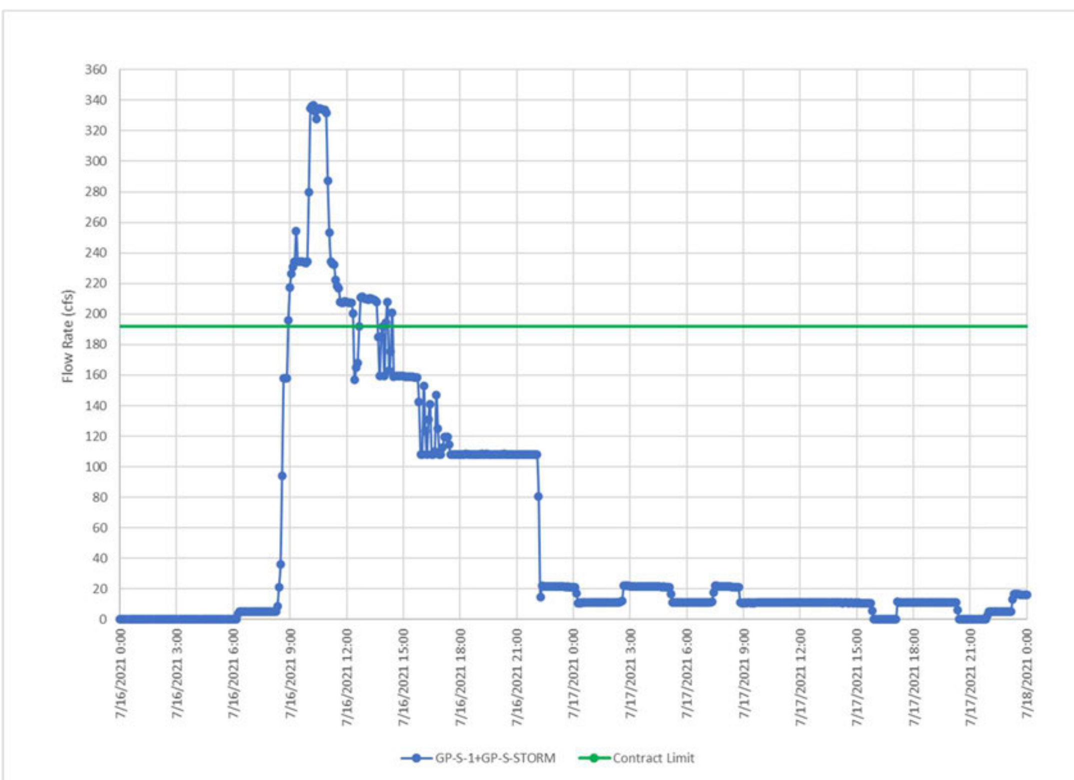


Figure 50. Grosse Pointe DPW Directors Truck in Floodwaters on June 26, 2021

Figure 51. Cadieux Road Looking Toward Kercheval Avenue at about 6 AM on June 26, 2021

Figure 52. Kercheval Avenue at Cadieux Road Looking East on July 16, 2021

Grosse Pointe Farms

The City of Grosse Pointe Farms provided rainfall data, pump operating data, wet well levels, and flooding observations for this study. Also, some information was obtained from a presentation made to the public, from newspaper articles and from GDRSS billing flow meter data.

Grosse Pointe Farms operates two rain gauges, one at the wastewater pumping station at Kerby and Chalfonte Roads and another at water treatment plant at Moross Road and Grosse Pointe Boulevard. Data were provided in 5-minute increments at the pumping station. Only total daily rainfall depth is available for the rain gauge at the water treatment plant.

For the storm of June 25-26th, about 5.55 and 6.5-inches of rainfall were recorded at the pumping station and water treatment plant, respectively. For the storm of July 16th, about 2.89 and 3.94-inches of rainfall were recorded at the pumping station and water treatment plant, respectively. These data are reasonable when compared to the data for surrounding rain gauges.

The rainfall data at the pumping station was not used in the SWMM modeling because it was received too late and is redundant to another nearby rain gauge. The rainfall data at the water treatment plant could not be used in the modeling because only daily totals are available and finer detail is needed for the SWMM modeling.

Grosse Pointe Farms has an “inland” combined sewer district and a “lake” district that is served by sanitary sewers. The sanitary and combined wastewater from Grosse Pointe Farms is pumped into the FCE at the Kerby and Chalfonte Roads.

The Grosse Pointe Farms PS includes three (3) dry weather pumps that discharge wastewater through a magmeter, Meter GPF-MAG. Also, there are five (5) wet weather (storm) pumps, and these flow rates are estimated based on pump runtimes and capacity curves. The estimated sanitary plus the storm pump flow rates are reported as Meter GPF-S-1 to GLWA. The flow rates for the storm pumps may be overestimated as suggested by the analysis of Meter WM-S-2 flow rates presented in the Fox Creek Enclosure section of this report.

The operational data for the largest storm pumps (#7 and #8) were not provided. It is not clear whether these pumps were operated and, if operated, whether their estimated flow rates are included in the Meter GPF-S-1 data.

For both the storms of June 25-26th and July 16th, Grosse Pointe Farms appears to have operated their pumps to maximize their contract limit flow rate and minimize the basement and street flooding that occurred in the community. The GDRSS billing flow meter data for the storms of June 25-26th and July 16th are presented on Figures 53 and 54 respectively. These data include the estimated flow rates from the wet weather (storm) pumps plus the metered flow rates from the dry weather pumps.

For the storm of June 25-26th, significant street and basement flooding occurred throughout lower elevation areas of the City of Grosse Pointe Farms (primarily in the “inland” district). From about 1:15 AM to about 4:30 AM, the wet well depth at the pumping station exceeded the top of range value of 15-feet. From about 0:55 AM to about 5:55 AM, the depth of wastewater in the FCE at Kerby Road exceeded the top of range value of 12-feet. Figure 31 shows three manholes on the FCE at Kerby Road overflowing during the storm of June 25-25th.

For the storm of July 16th, some street and basement flooding occurred throughout lower elevation areas and primarily in the “inland” district of the City of Grosse Pointe Farms. The maximum wet well depth at the pumping station was about 11-feet. The maximum depth of wastewater in the FCE depth at Kerby Road was about 11-feet. The wastewater depth in the FCE slightly exceeded 11-feet from about 11:50 AM to 12:30 PM on July 16th.

For the storm of June 25-26th, about 1,300 homes reported basement flooding. This amounts to about 37% of the homes in the City of Grosse Pointe Farms. For the storm of July 16th, only about 12 homes reported basement flooding.

Figure 53. Grosse Pointe Farms Flow Rates for the June 25-26th Storm

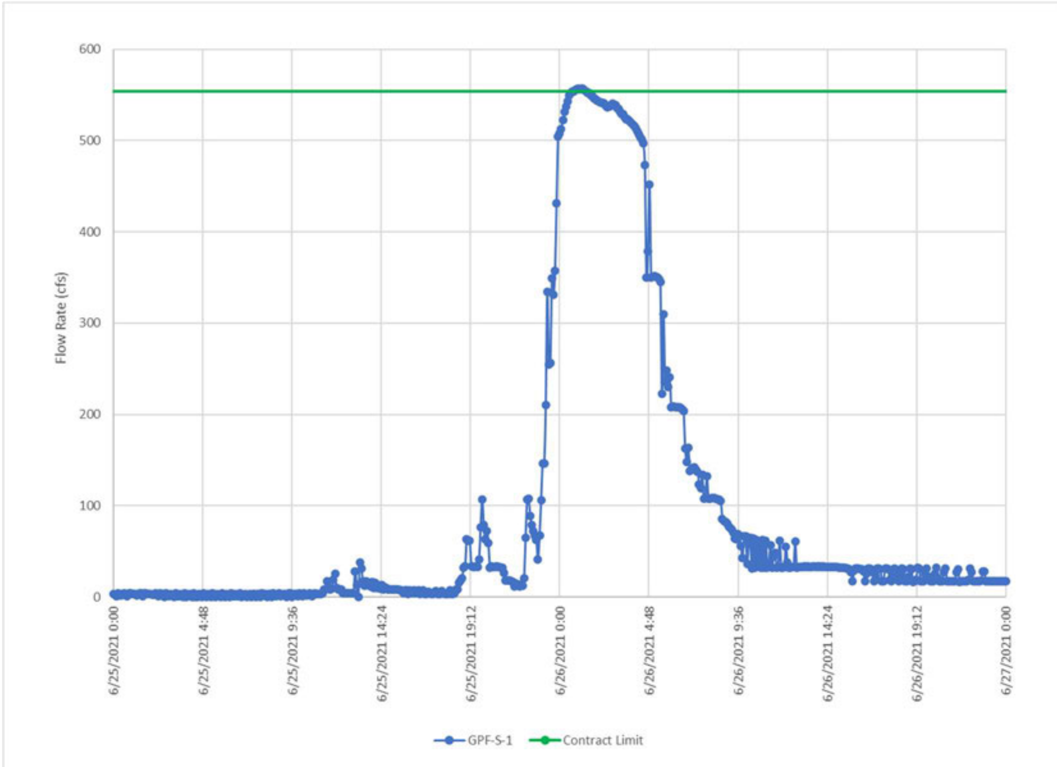
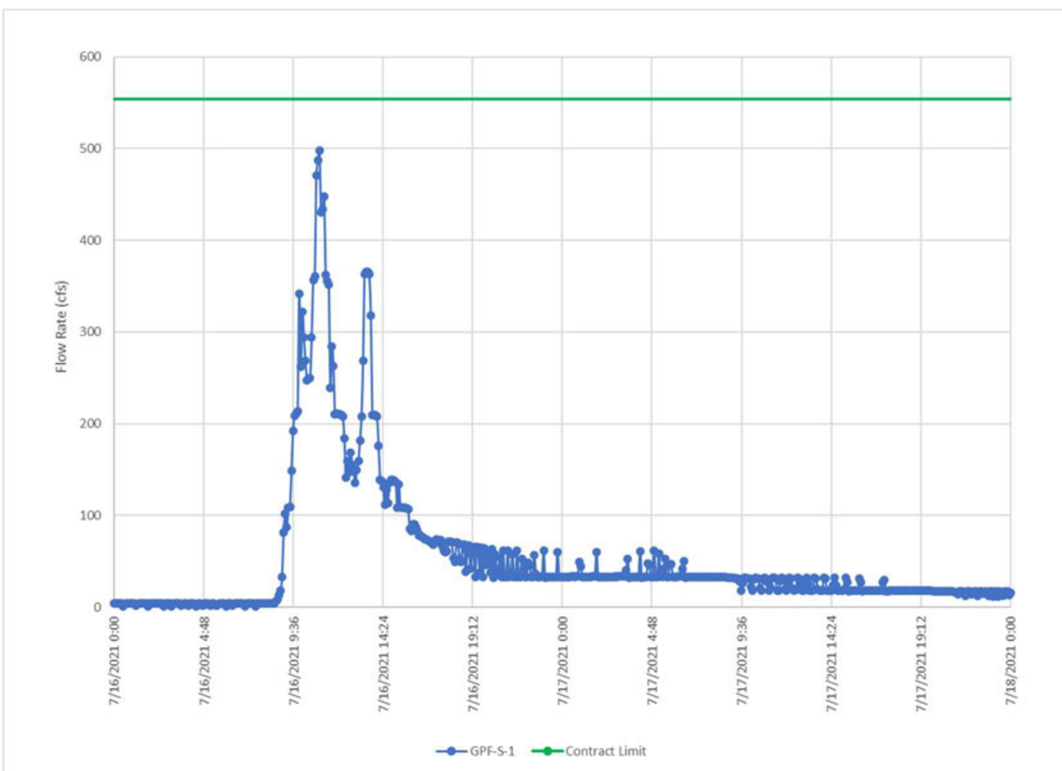


Figure 54. Grosse Pointe Farms Flow Rates for the July 16th Storm



SEMSD

The SEMSD provided rainfall data, flow meter data, control/regulator gate operating data, pump operating data, and wet well levels for this study. The rainfall data were QA/QC reviewed and data for two (2) SEMSD rain gauges were used in the SWMM modeling.

SEMSD pumps wastewater from the downstream end of the Grosse Pointe Interceptor (GPI) into the upstream end of the FCE at the Kerby Road. The GPI receives wastewater flow rates from a Grosse Pointe Shores connection at Cook Road, a Harper Woods connection through a control gate at Cook Road, the Milk River PS and RTB at Parkway Drive, and the Marter Road Booster PS along Marter Road near St. Joan Street. All these connections are in Grosse Pointe Woods.

The Marter Road Booster PS is also operated by the SEMSD and is at the upstream end of the GPI. The Marter Road Booster PS is the outlet from the SEMSD wastewater collection system. The SEMSD collects wastewater from Eastpointe, St. Clair Shores and Roseville. Parts of these communities are served by combined sewers as shown on Figure 1.

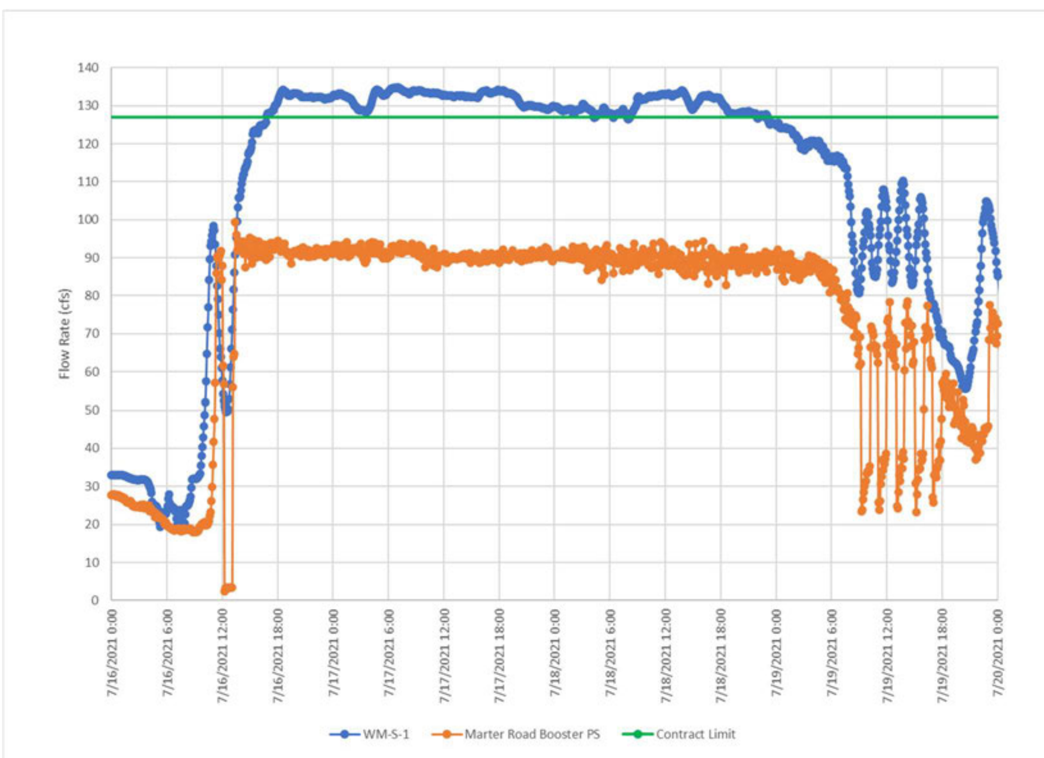
The SEMSD flow rates pumped at Kerby Road are measured by GDRSS Meter WM-S-1. The Meter WM-S-1 data for the storms of June 25-26th and July 16th are presented on Figures 55 and 56, respectively. The data were processed to provide a rolling hourly average because there is a high degree of pump cycling at the SEMSD Kerby Road PS. Also, the flow rates for the magmeter at the Marter Road Booster PS are shown (with no averaging). Meter WM-S-1 is a relatively new flow meter and its accuracy and adjustment factor is still being determined.

During the peak of both storms and at the request of Grosse Pointe Farms DPW personnel, SEMSD reduced its pumping into the FCE at the Kerby Road PS. Therefore, the peak flow rates for SEMSD did not occur simultaneously with other the peak flow rates in the GLWA wastewater collection system. When this reduction occurred, the SEMSD closed the Harper Woods control gate, turned off the pumps at the Marter Road Booster PS, turned off the sanitary pumps at the Milk River PS, and closed the dewatering gates at the Milk River RTB. These actions forced additional wastewater flow rates to and through the Milk River and Chapaton RTBs.

Also, note the long dewatering time for the in-system storage and the Martin, Chapaton and Milk River RTBs on Figures 55 and 56. It takes about 3 days to dewater the stored wastewater volume when the upstream RTBs are completely filled in wet weather.

Figure 55. SEMSD Flow Rates for the June 25-26th Storm

Figure 56. SEMSD Flow Rates for the June 25-26th Storm



Milk River Intercounty Drain Drainage District

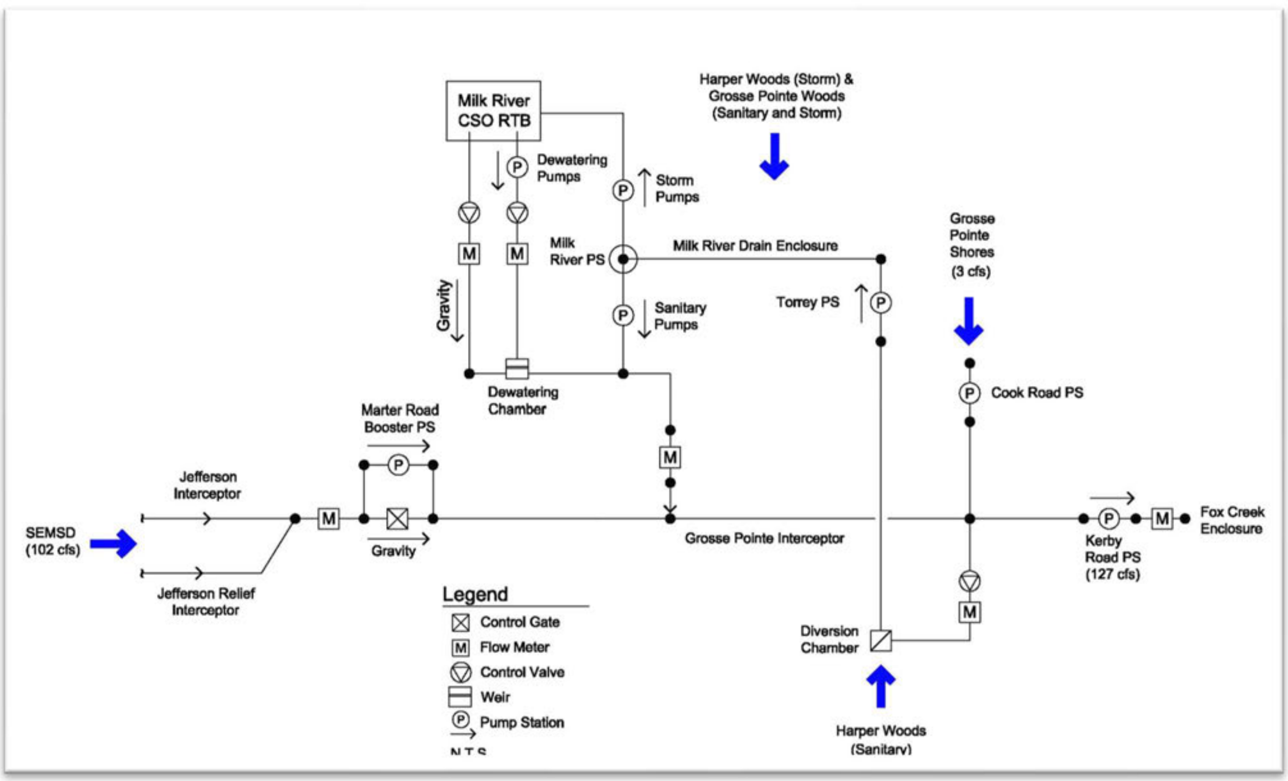
The MRIDDD also provided rainfall data, pump operating data, and wet well levels for this study. The Harper Woods control gate, the Milk River PS and RTB, and the drains in Harper Woods and Grosse Pointe Woods are owned by the MRIDDD. The SEMSD operates these facilities for the MRIDDD.

The MRIDDD provided rainfall data for two gauges. One is at the Harper Woods control gate near the intersection of Mack Avenue and Cook Road. The rainfall for this gauge was used in the SWMM modeling. The other rain gauge is at the Milk River PS and RTB near the intersection of Parkway and Marter Roads. The Milk River PS and RTB gauge was reasonable, but redundant to other gauges and not used in the SWMM modeling.

About 4.33 and 4.08-inches of rainfall were measured in the MRIDDD at the Harper Woods control gate and at the Milk River PS and RTB for the storm of June 25-26th, respectively. About 2.87 and 2.84-inches of rainfall were measured in the MRIDDD at the Harper Woods control gate and at the Milk River PS for the storm of July 16th, respectively.

A schematic of the MRIDDD and GPI is shown on Figure 57 for reference.

Figure 57. Milk River Intercounty Drain System Schematic



The Harper Woods control gate is on a Harper Woods sewer connection to the GPI at Cook Road. The control gate is open in dry weather and closed in wet weather. When closed, the Harper Woods flow rates are conveyed to the Torrey Road PS for pumping into the Black Marsh Drain (not shown on the schematic). The Black Marsh Drain discharges into the Milk River Drain, which in turn discharges to the Milk River PS and RTB.

The Harper Woods control gate was completely closed from hour 20:05 to hour 21:15 on June 25th, hour 0:40 to hour 7:55 on June 26th, and hour 11:55 to hour 14:45 on July 16th.

The outbound flow rate from the Milk River PS and RTB includes the flow rates from the sanitary pumps and the dewatering flow rates from the RTB. The outbound flow rate is plotted on Figures 58 and 59 for the storms of June 25-26th and July 16th, respectively. The flow rates from the MRIDDD to the GPI and GLWA were reduced below the contract limit of 22-cfs during both storms. However, during subsequent dewatering, the contract limit flow rate of 22-cfs was exceeded to hasten dewatering of the in-system storage and RTB.

At the Milk River PS, six (6) of seven (7) large wet weather (storm) pumps were in-service and were operated during the storms of June 25-26th and July 16th. Run hours were given at 10-minute intervals rounded to a whole hour. Therefore, it was not possible to plot the number of storm pumps that were operated versus time with any detail. One storm pump (#5) was out-of-service because it was being rehabilitated.

The wet well depth versus time is plotted on Figures 60 and 61 for the storms of June 25-26th and July 16th, respectively. The wet well depth that equals the crown of the upstream 16-feet diameter Milk River Drain is also plotted. It is apparent that the storm pumps are generally operated to maintain the storm wet well depth between 15 and 25-feet in wet weather.

The maximum wet well depth was about 35-feet for the storm of June 25-26th. This depth is about 9-feet above the crown elevation of the 16-feet diameter Milk River Drain at the Milk River PS. The maximum wet well depth was about 29-feet for the storm of July 16th. This depth is about three (3) feet above the crown elevation of the Milk River Drain at the Milk River PS.

Grosse Pointe Woods is a large part of the MRIDDD. For the storm of June 25-26th, about 395 homes reported basement flooding in Grosse Pointe Woods. There was a concentration of basement flooding reports in the area served by the Torrey Road PS. For the storm of July 16th, only about 8 homes reported basement flooding in Grosse Pointe Woods.

Harper Woods is also part of the MRIDDD. Basement flooding reports in Harper Woods were not available, but it was reported that the Harper Woods library experienced basement flooding and damage from the storm of June 25-26th.

Grosse Pointe Woods had extensive street flooding due to catch basin restrictions on residential streets. The 4 and 6-hole catch basin restrictions that are installed on residential streets were considered successful in attenuating the flow rates to the Milk River PS and minimizing basement flooding in the Grosse Pointe Woods.

Figure 58. Milk River PS and RTB Flow Rates to the GPI for the June 25-26th Storm

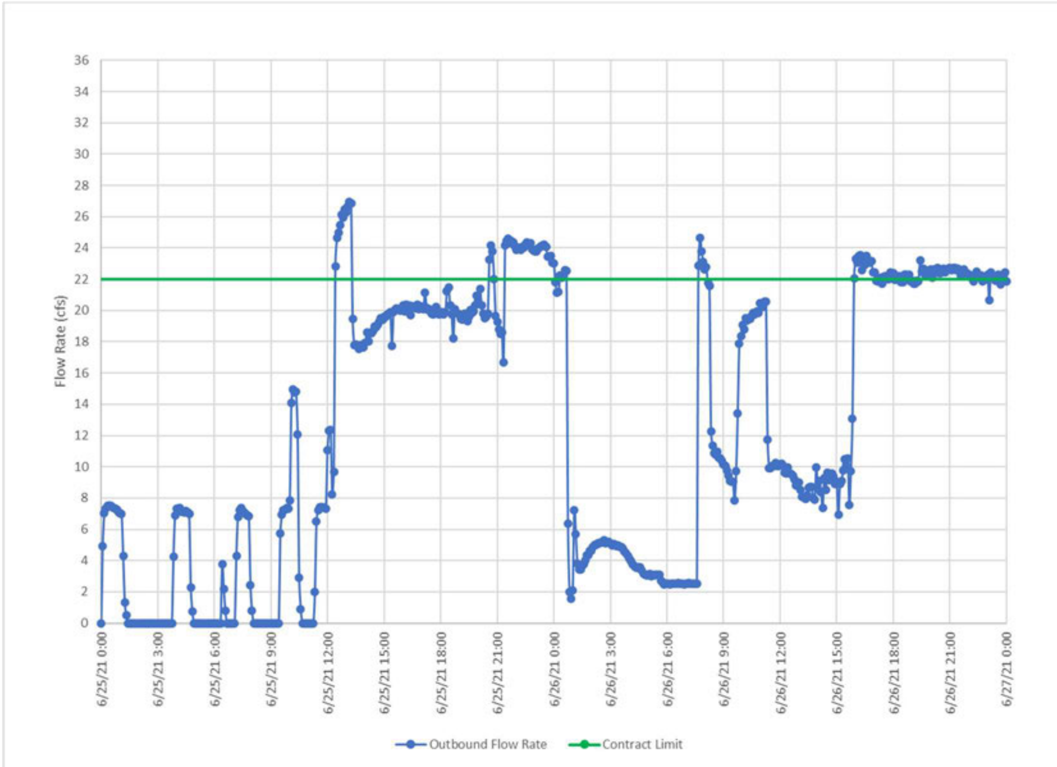


Figure 59. Milk River PS and RTB Flow Rates to the GPI for the July 16th Storm

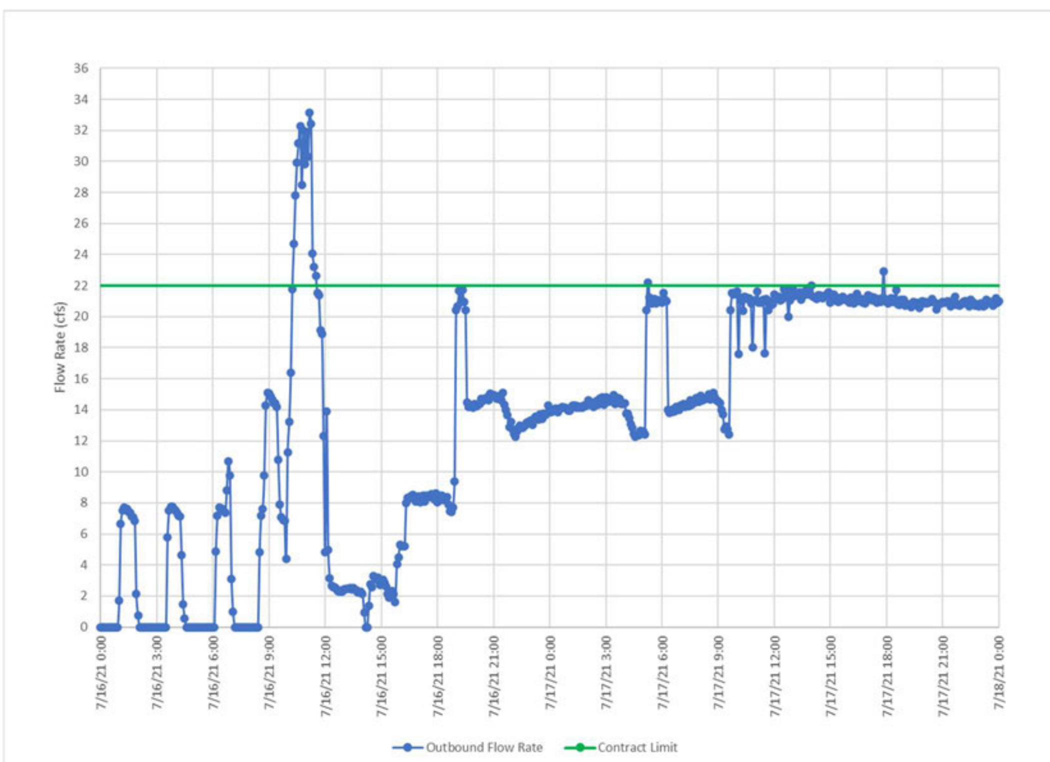


Figure 60. Milk River PS Wet Well Depth for the June 25-26th Storm

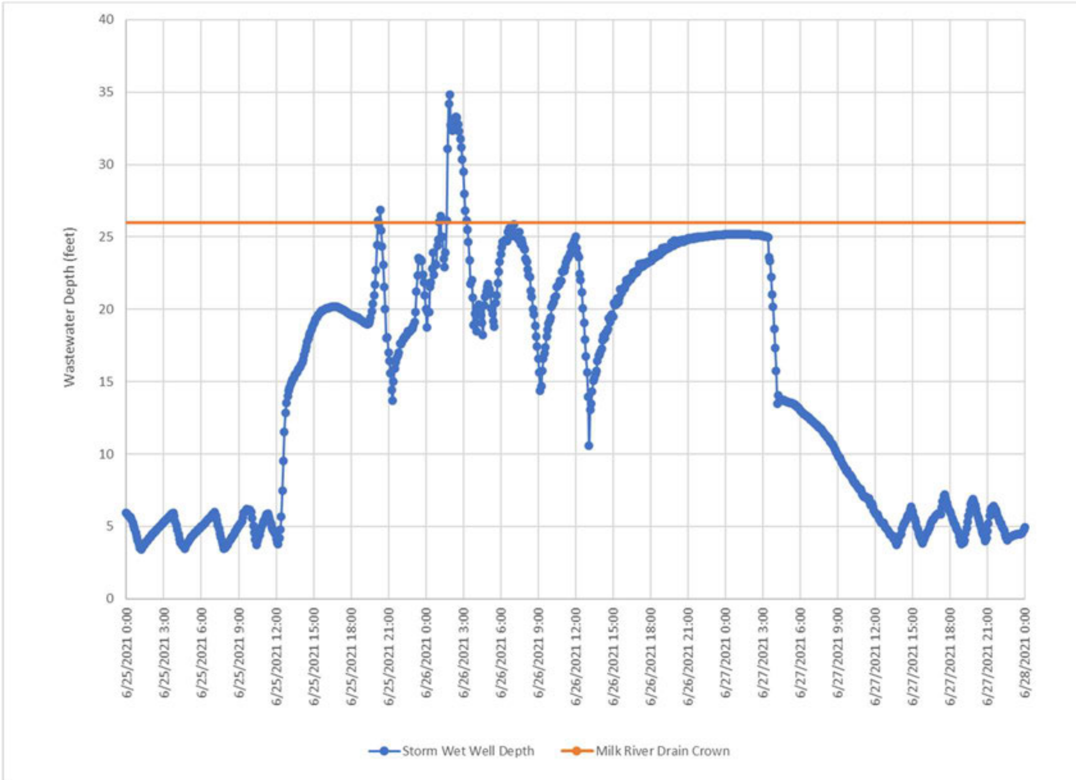
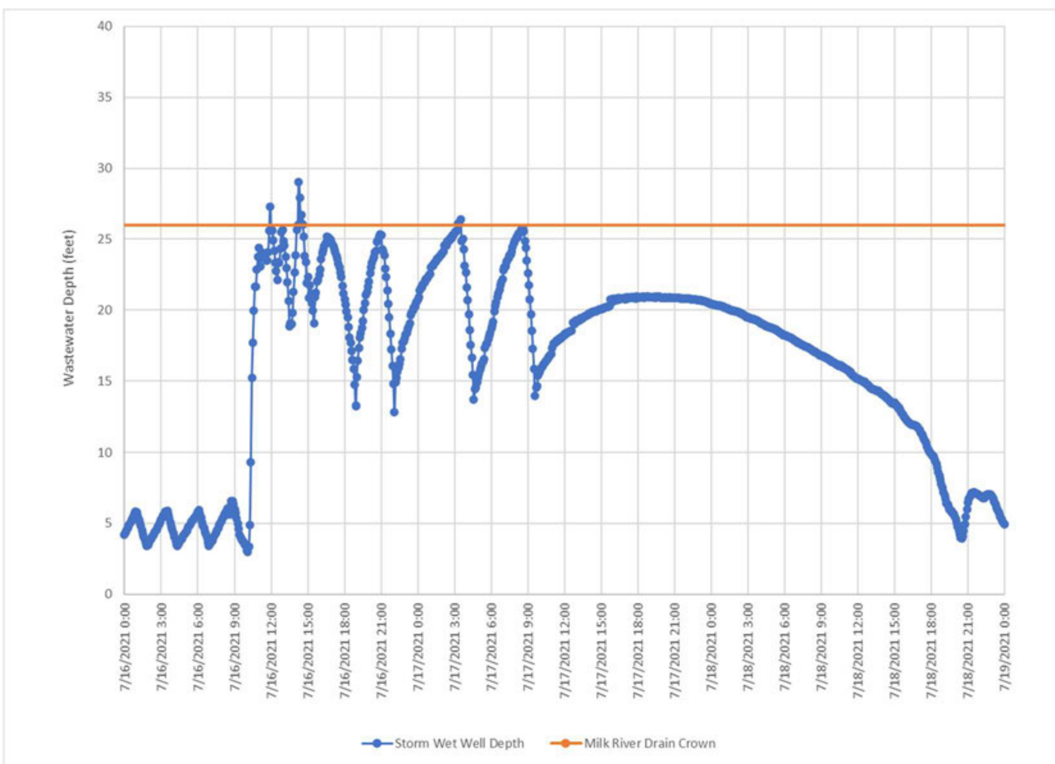


Figure 61. Milk River PS Wet Well Depth for the July 16th Storm



Macomb County Public Works Office

The MCPWO provided rainfall, pumping, gate and RTB operating data for the storms of June 25-26, 2021. Rainfall data were QA/QC reviewed, and data for ten (10) of the MCPWO rain gauges were used in the SWMM modeling.

The MCPWO operates two RTBs for the SEMSD communities upstream of the Marter Road Booster PS. The Chapaton RTB is located along 9 Mile Road near Jefferson in St. Clair Shores. The Martin RTB is located along Bon Brae Street near Jefferson Avenue in St. Clair Shores.

All three (3) of the three (3) large storm pumps (514-cfs) at the Chapaton PS operated throughout the peak of both storms. Also, the 9 Mile Drain gravity bypass to LSC was opened and discharged during the peak of the June 25-26th storm. Consequently, basement flooding was minimal in the combined and sanitary sewer areas of the 8-½ and 9 Mile Drain drainage areas in St. Clair Shores for both storms.

The number of storm pumps operating and the wet well depth at the Chapaton PS during the June 25-26th and July 16th storms are shown on Figures 62 and 63, respectively. The storm pumps are large, variable pitch pumps, the pumping rate varies significantly with the blade pitch, and the blade pitch of the impeller is not reflected on the figures. During the peaks of the storms, the blade pitch was at 90% of the maximum value to prevent overheating, excessive vibration, and tripping of the storm pumps. A high normal wet well depth of 30-feet is plot on the figures. This wet well depth was exceeded for both storms.

Shutting off Marter Road Booster PS during the peak of the storms caused the MCPWO to open a gate to allow flow rates from the SEMSD owned and operated Jefferson Interceptor into the wet well of the Chapaton PS. The additional flow rates from the Jefferson Interceptor were pumped, treated with chlorine, conveyed through the Chapaton RTB, and discharged to LSC.

The pumping was reduced by SEMSD at the Marter Road Booster PS for about 10-hours from hour 0:05 to hour 10:05 on June 26th. The pumps were turned off by SEMSD for about 40-minutes from about hour 1:20 to hour 2:00 on June 26th.

The pumping was reduced by SEMSD at the Marter Road Booster PS for about 85-minutes from hour 11:55 to hour 13:20 on July 16th. The pumps were turned off by SEMSD for about 45-minutes from about hour 12:15 to hour 13:00 on July 16th.

The additional wastewater volumes that were treated and discharged were estimated to be about 8.4 and 2.5-MG, respectively, for the June 25-26th and July 16th storms using the Marter Road Booster PS magmeter flow rate data shown on Figures 55 and 56.

Figure 62. Storm Pump Operations at the Chapaton PS for the June 25-26th Storm

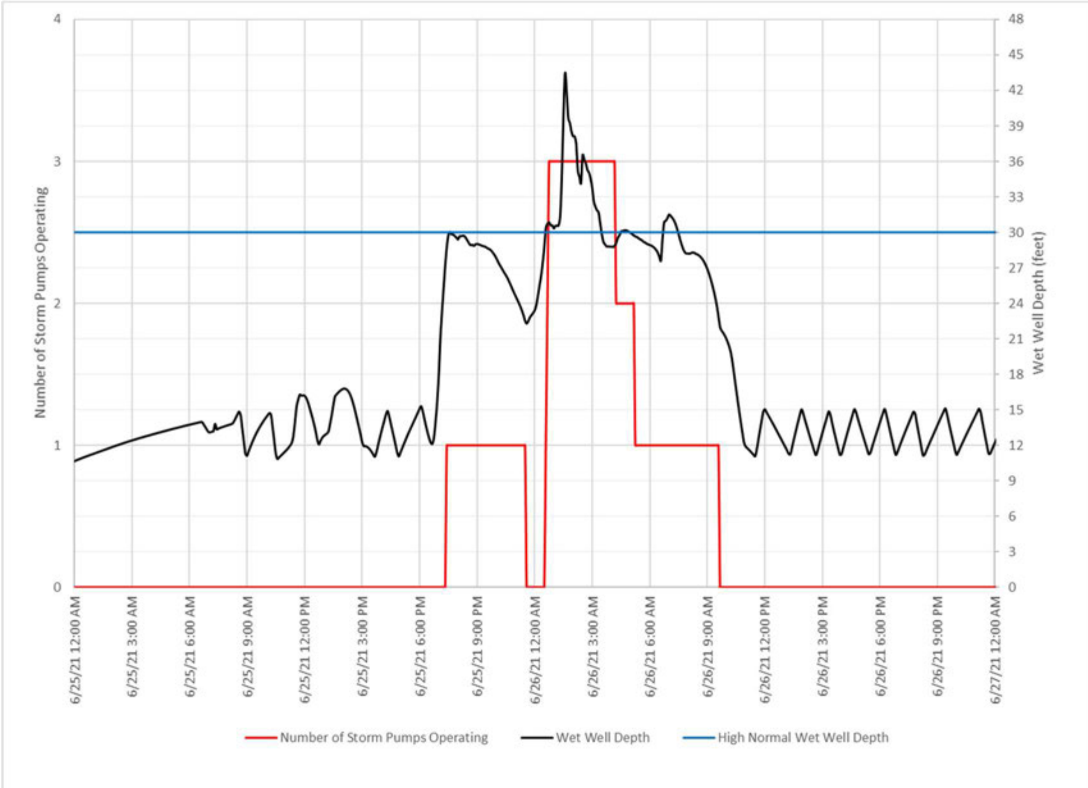
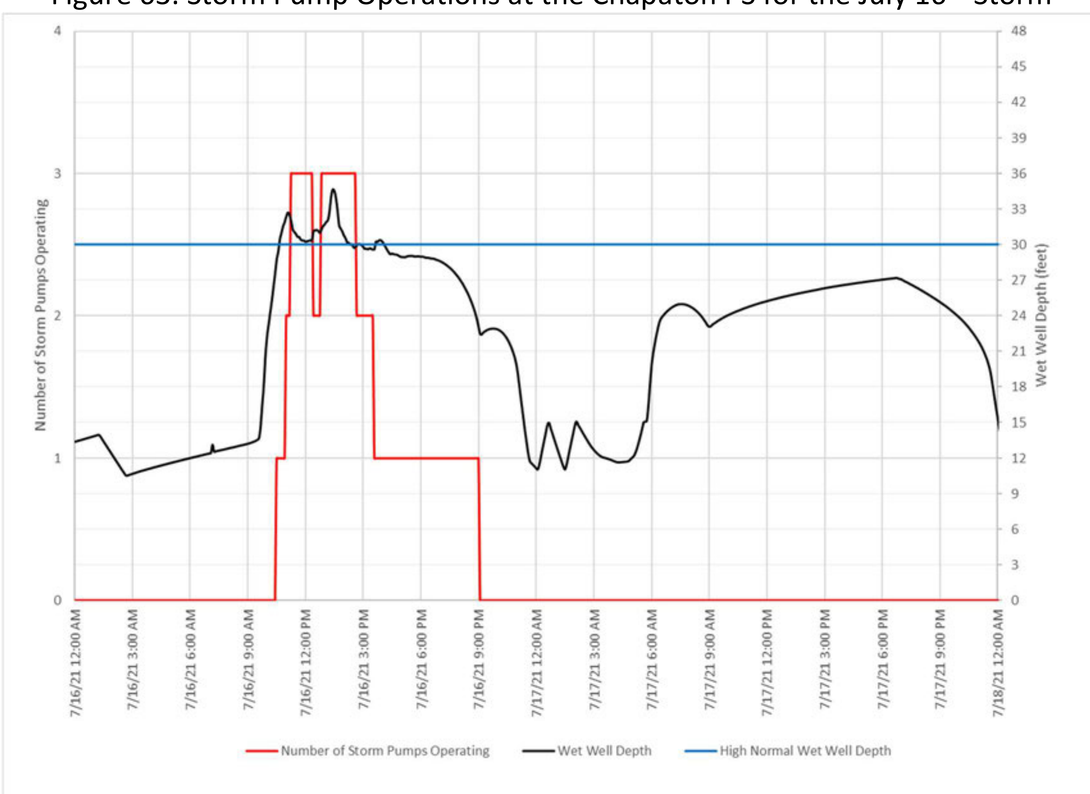


Figure 63. Storm Pump Operations at the Chapaton PS for the July 16th Storm



Baby Creek CSO Facility

SCADA data for the Baby Creek CSO Facility was provided by GLWA, reviewed, and summarized. These data included level sensor, flow meter and gate operating data. Screen operating data and data indicating opening/closing of emergency relief gates were not provided. Wastewater is screened and disinfected at the Baby Creek CSO Facility in wet weather.

The Baby Creek CSO Facility was built about 5,300-feet from the river between the Baby Creek double box sewer and the Elmer Ternes box sewer. Downstream of the facility, the Baby Creek Enclosure is a triple box sewer that runs along the Dearborn-Detroit border in southwest Detroit.

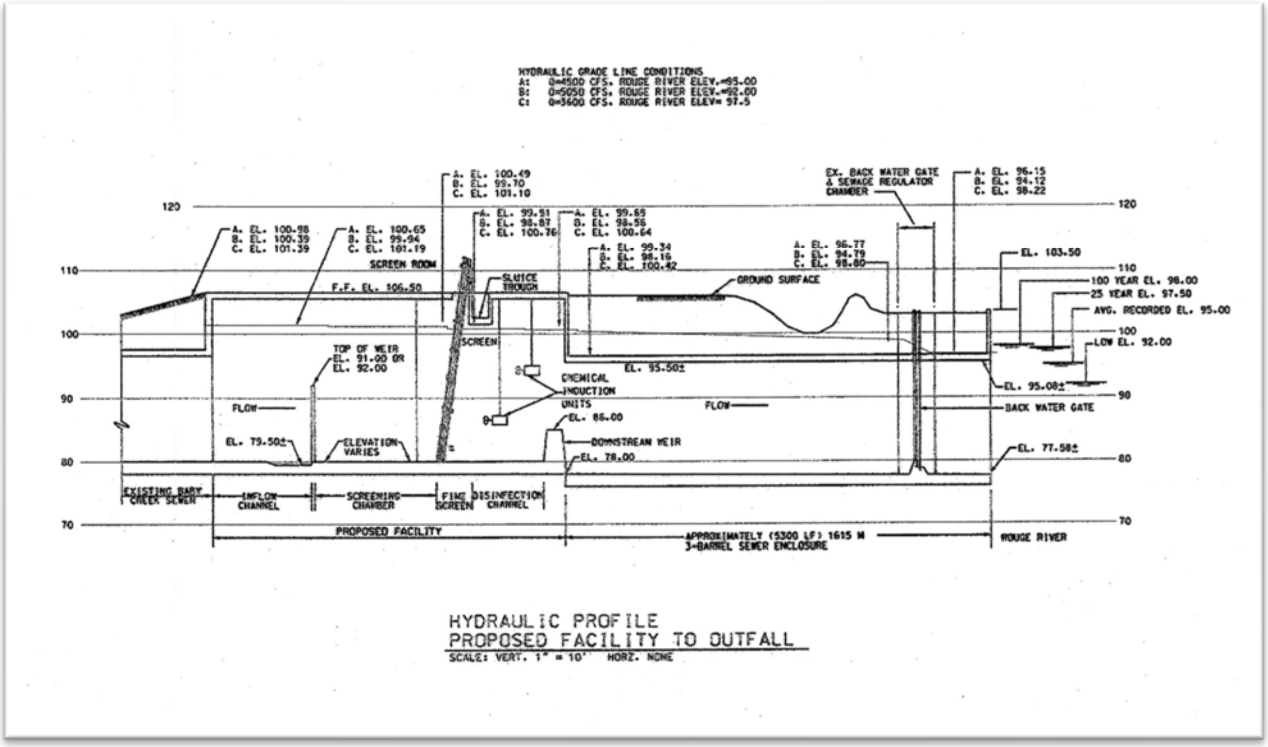
A schematic of the screening/disinfection facility is presented on Figure 64. There are four (4) flow meters on the influent conduits to the facility as shown on the schematic. A hydraulic profile from the facility to the Rouge River is shown on Figure 65.

The Baby Creek CSO Facility was designed with a 10-year, 1-hour design storm peak flow rate of 5,100-cfs. Other design criteria include Rouge River levels that ranged from 92 to 97.5-feet, screening losses less than 1-foot. On Figure 65, three hydraulic profiles are shown with flow rates of 4,500, 5,050 and 3,600-cfs. The expected head loss from the facility to the river are 5.49, 7.7, and 4.25-feet for these flow rates, respectively.

Figure 64. Baby Creek CSO Facility Schematic

[redacted]

Figure 65. Baby Creek CSO Facility Hydraulic Profile



The level sensor, gate operating data, and flow rate data for the storm of June 25-26th are presented on Figures 66 and 67. The level sensor, gate operating data, and flow rate data for the storm of June 25-26th are presented on Figures 68 and 69.

For both storms, the head losses across the screens were less than 1-foot throughout the storms. This indicates that sufficient screens were in operation and/or the emergency relief gates were properly opened to bypass the screens to maintain low and acceptable head losses across the screening/disinfection facility.

For the June 25-26th storm, the wastewater level upstream of the screens remained at a top of range value of about 103-feet for about 3-hours during the peak of the storm. The Rouge River level was about elevation 96-feet and within the range of design river levels. The head loss from the Baby Creek CSO Facility to the river was over 7-feet with a peak flow rate measurement of about 2,800-cfs.

For the July 16th storm, the peak wastewater level upstream of the screens was 101.7-feet. The Rouge River level was about elevation 96.7-feet and within the range of design river levels. The head loss from the Baby Creek CSO Facility to the river was about 5-feet with a peak flow rate measurement of about 1,600-cfs.

For both storms, the peak flow rate measurements do not align with the measured head loss from the screening/disinfection facility to the river. Either the Baby Creek Enclosure has more head loss than expected due to blockages or sediment depths, or the peak flow rates through the screening/disinfection facility are being significantly underestimated.

A report prepared by AECOM in February 2022 was reviewed to resolve this issue. AECOM recently inspected the three parallel box sewers that run from the Baby Creek CSO Facility to the river and measured the sediment (sludge) depths along each box sewer. No blockages were found. The sediment depths varied along the length and cross-sections of each box sewer and were generally between 0 and 3-feet. The total sediment volume in the three (3) parallel outfall sewers was estimated to be about 6,070-cubic yards (or 1.2-MG), and the total storage volume in the three parallel box sewers is about 30-MG. The sediment volume is only about 4% of the total sewer volume and is not causing significant additional head loss. Therefore, it is concluded that the flow rate measurements on the influent conduits to the Baby Creek CSO Facility are significantly underreporting the flow rates.

For the June 25-26th storm, the two parallel VR-7 gates (each gate is 6-feet wide by 4-feet high) were closed for about 3.33-hours at the beginning of the storm. The VR-7 gates were open during the peak of the storm and throttled after the storm to dewater the Baby Creek Enclosure. Keeping these gates open allowed as much flow as possible to the WRRF and the wet well level at PS-1 increased significantly after the VR-7 gates were opened during the peak of the storm.

For both storms, the four backwater gates opened and discharged treated CSO to the Rouge River during the peak of the storms. For the June 25-26th storm, Backwater Gate #1 “chattered” during the peak and Backwater Gate #3 remained open even after the wastewater levels in the Baby Creek Enclosure receded. These issues commonly occur at backwater gates and could be instrumentation issues or caused by debris caught in the backwater gate.

Figure 66. Baby Creek CSO Facility Levels and Gate Operations for the June 25-26th Storm

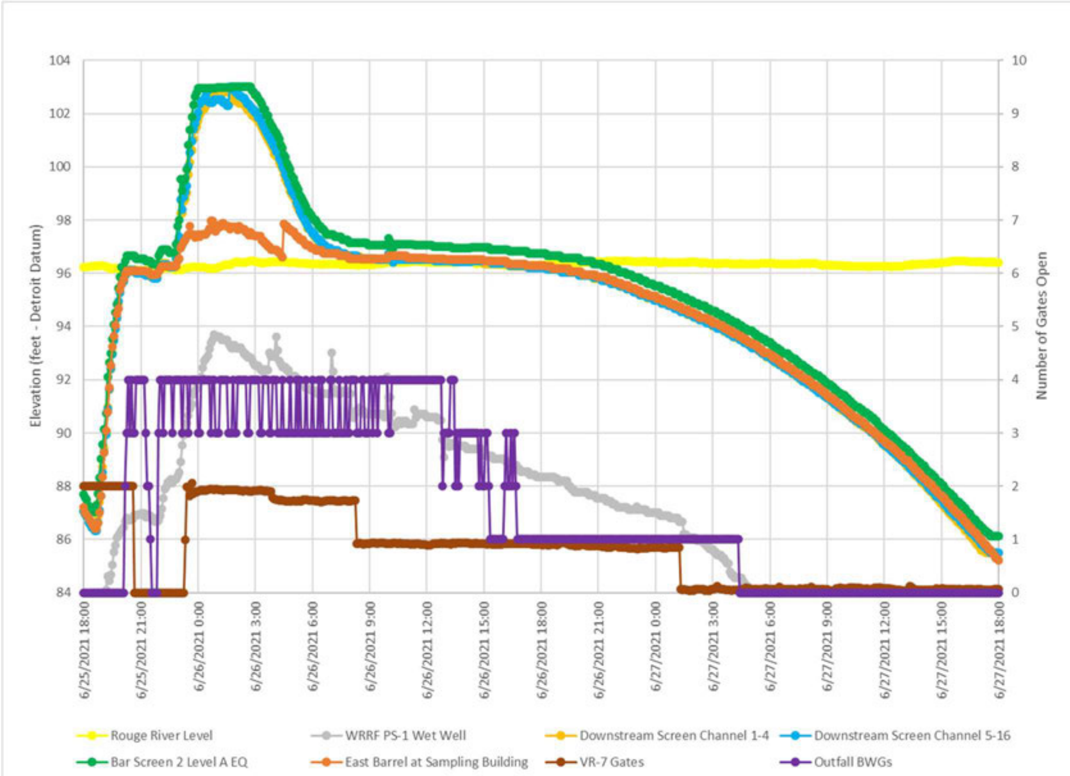


Figure 67. Baby Creek CSO Facility Levels and Flow Rate for the June 25-26th Storm

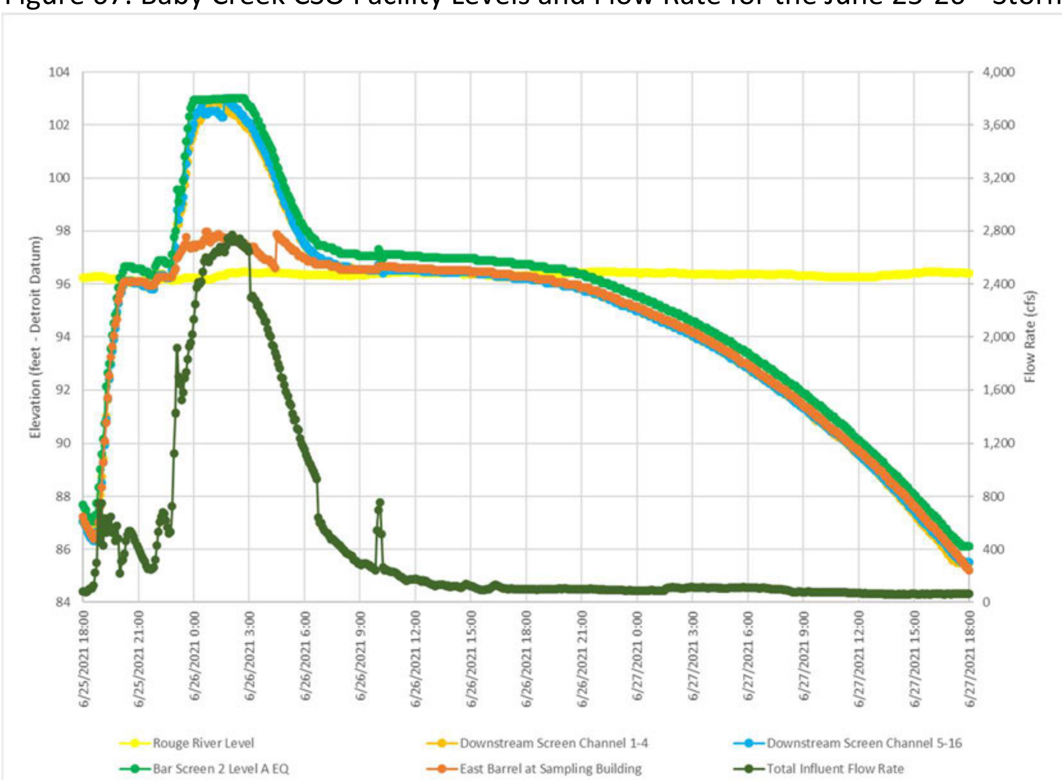


Figure 68. Baby Creek CSO Facility Levels and Gate Operations for the July 16th Storm

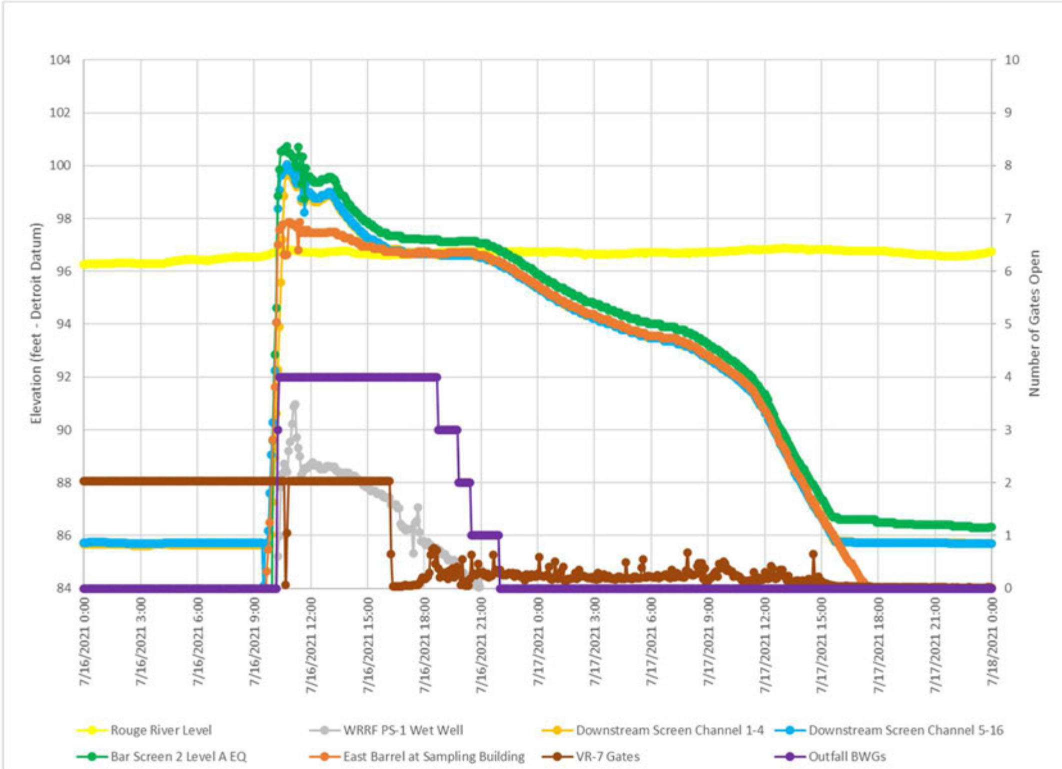
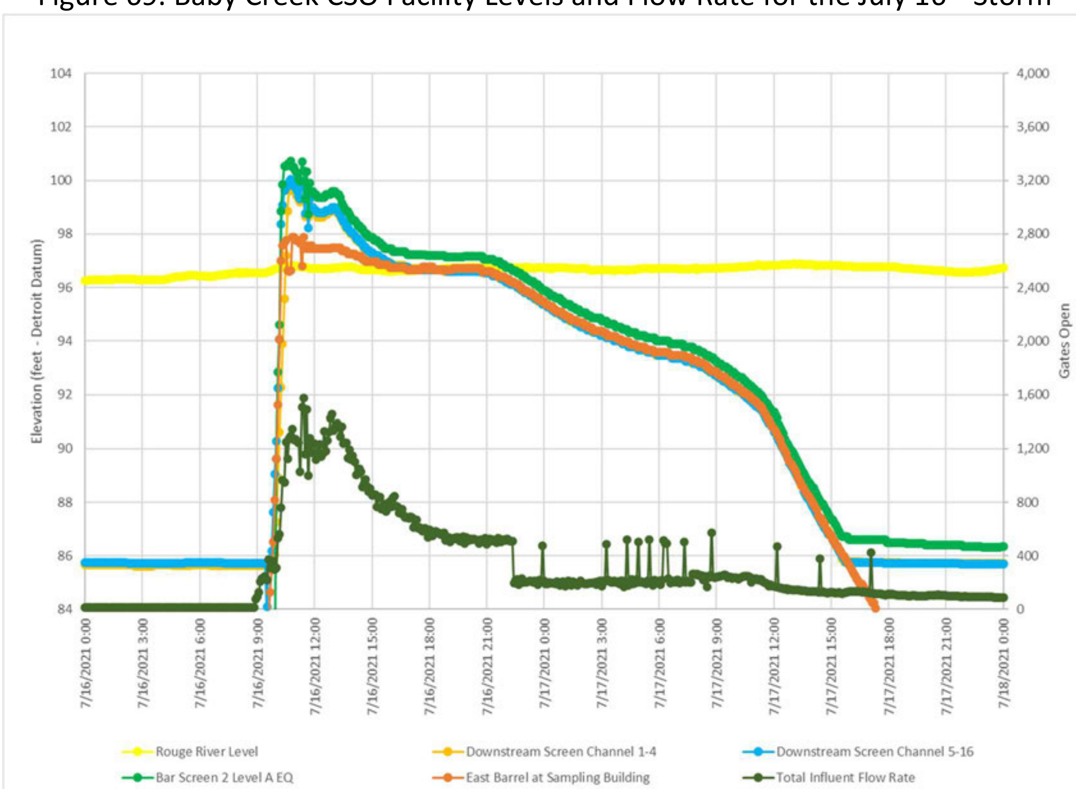


Figure 69. Baby Creek CSO Facility Levels and Flow Rate for the July 16th Storm



Hubbell-Southfield RTB

Figure 70 presents a schematic of the Hubbell-Southfield RTB. The gates at the RTB are described on Table 5. It is important to note that the large roller gates at the RTB require 20 to 30 minutes to completely open or close.

Figure 70. Hubbell-Southfield RTB Schematic

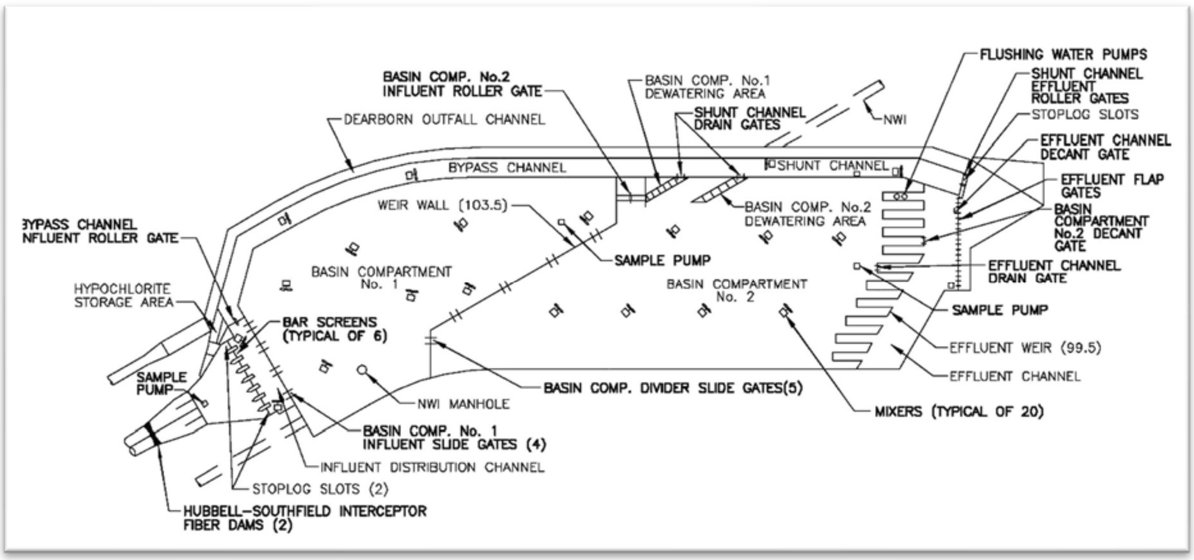


Table 5. Hubbell-Southfield RTB Gate Descriptions

Name	Number & Type	When Open Allows Flow	
		From	To
ISGs	4 slide gates	Influent Distribution Channel	Basin #1
BSGs	5 slide gates	Basin #1	Basin #2
IRGs	2 roller gates	Influent Distribution Channel	Bypass Channel
BRGs	2 roller gates	Bypass Channel	Basin #2
ERGs	2 roller gates	Bypass Channel	Rouge River

There are six (6) mechanically cleaned bar screens at the RTB that discharge to an influent distribution channel. Compartment #1 (Basin #1) is a first flush capture tank. Compartment #2 (Basin #2) is a flow-through compartment with an effluent weir with a capacity of about 2,200-cfs and a crest elevation of 99.5-feet. The effluent weir crest is normally above the water level in the Rouge River. For flow rates greater than 2,200-cfs, the ERGs are to be opened/throttled to discharge wastewater to the Rouge River through the Bypass and Shunt Channels. The maximum design wastewater elevation upstream of the screens is 106-feet with a peak flow rate of 5,100-cfs and a Rouge River of elevation 102-feet.

There are inflatable dams in the Hubbell-Southfield double box sewer just upstream of the RTB. No data was provided for these inflatable dams. These dams are intended to inflate to fill the in-system storage in the upstream double box sewer before flow rates occur into the RTB. The dams are intended to minimize CSO discharges to the Rouge River.

The SCADA data for the Hubbell-Southfield RTB for the storms of June 25-26th and July 16th are presented on Figures 71 and 72, respectively. These data include gate position and wastewater levels at the RTB and a wastewater level upstream in the Hubbell-Southfield double box sewer at Meter DT-S-3. Meter DT-S-3 is located along Mercury Drive south of Ford Road. Ground elevation at Meter DT-S-3 is about elevation 117-feet.

For both storms, the data shows minimal head losses across the screens. This indicates that the screens were properly operated during the storms and not restrictive.

The following observations are made for the June 25-26th storm.

- The river level sensor at the RTB was at the top of range during the peak of the storm. A Rouge River high-water mark of about 102.7-feet was measured by the City of Dearborn at the Hubbell-Southfield RTB. Prior to the storm, the river level was about 96.1-feet. The river level increased by about 6.6-feet during the storm. A significant flood occurred on the Rouge River for this storm as previously discussed.

- Basin #1 was filled by about hour 12:30 on June 25th. The BSGs between Basin #1 and Basin #2 were closed throughout the storm and the BRGs were open at the start of the storm.

- The IRGs started to open at about hour 12:35 on June 25th while the ISGs were completely closed by hour 12:40. The IRGs were not completely open until about hour 13:00. There was a small surge in the wastewater level upstream of the screens caused by the IRGs not being sufficiently open before the ISGs were fully closed.

- From about hour 12:40 on June 25th to about hour 2:05 on June 26th, all RTB flow rates were flowing through Basin #2 to the Rouge River.

- From about hour 0:00 to 2:05 on June 26th, the wastewater levels upstream of the screens reached a top of range value of about 105-feet. The top of range period is during the time of the peak rainfall of the June 25-26th storm.

- The ERGs started opening at about hour 2:05 on June 25-26th while the BRGs were simultaneously closing. The wastewater levels upstream of the screens dropped below elevation 105-feet immediately after the ERGs were opened.

- From about hour 2:30 to hour 23:20 on June 26th, all RTB flow rates to the Rouge River were occurring through the RTB Bypass and Shunt Channels.

- The wastewater level at Meter DT-S-3 increased quickly at about hour 23:35 on June 25th and was about ground level from about hour 23:50 on June 25th to hour 5:20 on June 26th.

The following observations are made for the July 16th storm.

- The peak Rouge River level measured at the RTB was about elevation 99.4-feet. This level is just below the Basin #2 effluent weir crest elevation of 99.5-feet.

- Basin #1 was filled by about hour 10:25 on July 16th. The BSGs between Basin #1 and Basin #2 were closed throughout the storm and the BRGs were open at the start of the storm.

- The IRGs were completely open before the ISGs were closed. The IRGs started to open at about hour 10:40 on July 16th while the ISGs were completely closed by hour 10:40.

- From about hour 11:00 to about hour 12:55 on July 16th, the RTB flow rates were flowing through both Basin #2 and the Bypass and Shunt Channel to the Rouge River. The BRGs were closed, opened, and closed in this period. The ERGs were opened, closed then opened during this period.

- The ERGs were open and the BRGs were closed from about hour 12:55 to hour 22:00 on July 16th. During this timeframe, all RTB flow rates to the Rouge River were occurring through the RTB Bypass and Shunt Channels.

- At hour 22:00, the BRGs started opening and the ERGs started closing. After this time, all RTB flow rates to the Rouge River were occurring through Basin #2.

- There was a 20-minute spike in wastewater level at Meter DT-S-3 between hour 10:30 to hour 10:50 on July 16th. This spike coincides with the peak rainfall and is likely caused by a backwater wave from the downstream Hubbell-Southfield RTB, and air movement and pressures in the Hubbell-Southfield double box sewer during peak flow conditions.

Figure 71. Hubbell-Southfield RTB Levels and Gate Operations for the June 25-26th Storm

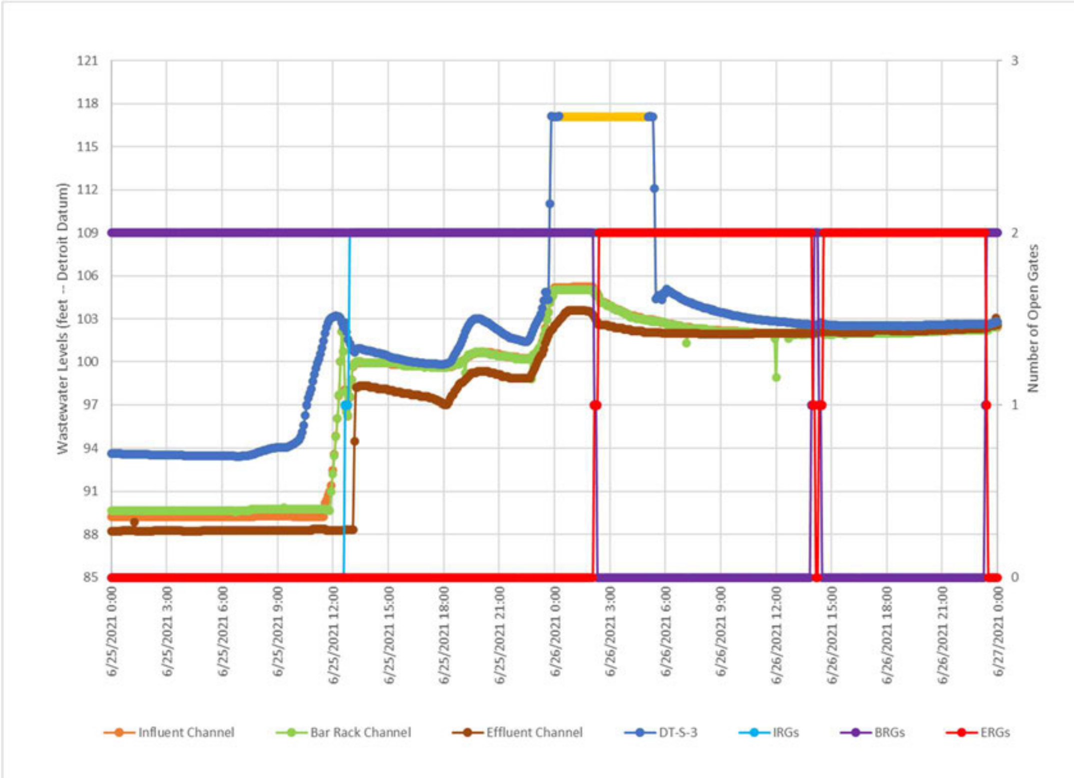
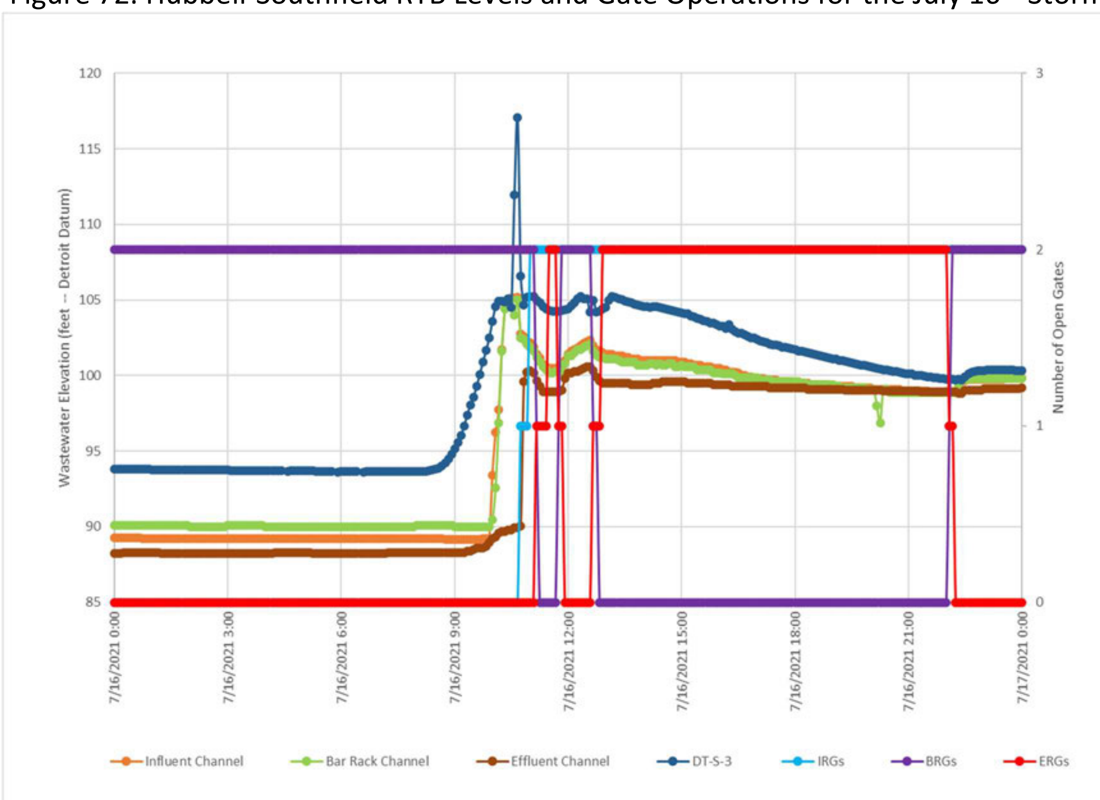


Figure 72. Hubbell-Southfield RTB Levels and Gate Operations for the July 16th Storm



APPENDIX B – RAINFALL ANALYSIS

B1 – Summary of Available Data

There are multiple precipitation gages in the Detroit metropolitan area, most of which are operated by local governments; however, there are also a few precipitation gages operated by federal agencies as well as private individuals. A total of 108 precipitation gages that provide 5-minute interval observations were identified in the affected area. The local agencies that operate 5-minute interval precipitation gages and the number of gages operated by the respective agency are:

Great Lakes Water Authority (GLWA) – 36 gages

Oakland County Water Resources Commissioner's office – 27 gages

SEMSD / Macomb County Public Works Office – 24 gages

Wayne County – 6 gages

City of Dearborn – 2 gages

NOAA operates a rain gage (KDET) at the Coleman A. Young Municipal Airport that provided 5-minute interval data that were converted from hourly observations. In addition, 12 precipitation gages that are operated by private individuals as part of the Weather Underground WUNDERMAP meteorological network (https://www.wunderground.com/wundermap) were identified and evaluated for analysis.

A review of the data obtained from the 108 identified precipitation gages was performed to identify missing data or other anomalies that result from gage malfunctions or data processing errors. This review identified 24 of the 108 identified gages (approximately 22 percent) as having potential issues with the observed data; the remaining 84 gages were deemed to have recorded sufficiently reliable data to be included in the general review to characterize the intensity, duration, and frequency of the June/July 2021 Rainfall Events. A smaller subset of the precipitation gages (i.e., 38) was deemed to provide sufficient reliability and spatial coverage to be used as inputs for hydrologic and hydraulic modeling that is being performed as part of the analysis of the extent, severity, and causes of the flooding that resulted from the June/July Rainfall Events. A list of the precipitation gages in the Detroit metropolitan area along with their use in this analysis are provided in Table 35.

The 5-minute precipitation data for each of the 84 precipitation gages used was accumulated into daily precipitation totals for the months of June and July. In addition, the daily precipitation totals for each gage were accumulated into monthly totals for June and July and event totals for the 2-day periods of June 25 and 26 and July 16 and 17. It is important to note that the accumulated daily, monthly, and event totals are based on daily precipitation totals defined as midnight to midnight for the given day. The tabulated daily precipitation totals can be provided on request. The monthly and 2-day event precipitation totals are provided in Table 36.

Table 35: Precipitation Gages Identified in the Detroit Vicinity

Rain Gage Identifier	Agency/Source	Used to Characterize Storms	Used for Hydraulic Model Input
Outer Drive	City of Dearborn	Yes	Yes
Prospect	City of Dearborn	Yes	Yes
PG002	Great Lakes Water Authority	Yes	Yes
PG003	Great Lakes Water Authority	Yes	Yes
PG004WS	Great Lakes Water Authority	Yes	Yes
PG006	Great Lakes Water Authority	Yes	Yes

Rain Gage Identifier	Agency/Source	Used to Characterize Storms	Used for Hydraulic Model Input
PG008	Great Lakes Water Authority	Yes	Yes
PG009	Great Lakes Water Authority	Yes	Yes
PG011	Great Lakes Water Authority	Yes	Yes
PG012	Great Lakes Water Authority	Yes	Yes
PG014	Great Lakes Water Authority	Yes	Yes
PG015	Great Lakes Water Authority	Yes	Yes
PG017	Great Lakes Water Authority	Yes	Yes
PG018	Great Lakes Water Authority	Yes	Yes
PG019	Great Lakes Water Authority	Yes	Yes
PG020	Great Lakes Water Authority	Yes	Yes
PG021	Great Lakes Water Authority	Yes	Yes
PG022	Great Lakes Water Authority	Yes	Yes
PG024	Great Lakes Water Authority	Yes	Yes
PG025	Great Lakes Water Authority	Yes	Yes
PG026	Great Lakes Water Authority	Yes	Yes
PG027	Great Lakes Water Authority	Yes	Yes
PG035	Great Lakes Water Authority	Yes	Yes
PG038	Great Lakes Water Authority	Yes	Yes
HarperWoods	Macomb County Public Works Office	Yes	Yes
M-03	Macomb County Public Works Office	Yes	Yes
M-15	Macomb County Public Works Office	Yes	Yes
M-16	Macomb County Public Works Office	Yes	Yes
M-19	Macomb County Public Works Office	Yes	Yes
M-20	Macomb County Public Works Office	Yes	Yes
STS4	Macomb County Public Works Office	Yes	Yes
R-27	Wayne County	Yes	Yes
R-28	Wayne County	Yes	Yes
R-29	Wayne County	Yes	Yes
KMIGROSS35	Weather Underground	Yes	Yes
KMILIVON57	Weather Underground	Yes	Yes
KMIROSEV13	Weather Underground	Yes	Yes
KMISTCLA51	Weather Underground	Yes	Yes
PG007	Great Lakes Water Authority	Yes	No
PG013	Great Lakes Water Authority	Yes	No
PG028	Great Lakes Water Authority	Yes	No

Rain Gage Identifier	Agency/Source	Used to Characterize Storms	Used for Hydraulic Model Input
PG029	Great Lakes Water Authority	Yes	No
PG033 Modified	Great Lakes Water Authority	Yes	No
PG036	Great Lakes Water Authority	Yes	No
Clintondale HS	Macomb County Public Works Office	Yes	No
CTS3	Macomb County Public Works Office	Yes	No
ELIZABETH_RG2	Macomb County Public Works Office	Yes	No
HARPER_RG3	Macomb County Public Works Office	Yes	No
NGI	Macomb County Public Works Office	Yes	No
NorthAve_23	Macomb County Public Works Office	Yes	No
SONIC	Macomb County Public Works Office	Yes	No
STS3	Macomb County Public Works Office	Yes	No
UTS1	Macomb County Public Works Office	Yes	No
0802	Oakland County Water Resources Commissioner	Yes	No
0803	Oakland County Water Resources Commissioner	Yes	No
0804	Oakland County Water Resources Commissioner	Yes	No
0807	Oakland County Water Resources Commissioner	Yes	No
0808	Oakland County Water Resources Commissioner	Yes	No
0812	Oakland County Water Resources Commissioner	Yes	No
0813	Oakland County Water Resources Commissioner	Yes	No
0814	Oakland County Water Resources Commissioner	Yes	No
0815	Oakland County Water Resources Commissioner	Yes	No
0816	Oakland County Water Resources Commissioner	Yes	No
0821	Oakland County Water Resources Commissioner	Yes	No
0831	Oakland County Water Resources Commissioner	Yes	No
0832	Oakland County Water Resources Commissioner	Yes	No
0833	Oakland County Water Resources Commissioner	Yes	No
0835	Oakland County Water Resources Commissioner	Yes	No
0836	Oakland County Water Resources Commissioner	Yes	No
0837	Oakland County Water Resources Commissioner	Yes	No
0841	Oakland County Water Resources Commissioner	Yes	No
0843	Oakland County Water Resources Commissioner	Yes	No
0848	Oakland County Water Resources Commissioner	Yes	No
0880	Oakland County Water Resources Commissioner	Yes	No
R-11	Wayne County	Yes	No
R-12	Wayne County	Yes	No

Rain Gage Identifier	Agency/Source	Used to Characterize Storms	Used for Hydraulic Model Input
KMICANTO56	Weather Underground	Yes	No
KMICANTO61	Weather Underground	Yes	No
KMICANTO89	Weather Underground	Yes	No
KMIHUNTI7	Weather Underground	Yes	No
KMILIVON109	Weather Underground	Yes	No
KMILIVON122	Weather Underground	Yes	No
KMIROYAL50	Weather Underground	Yes	No
KMIWARRE36	Weather Underground	Yes	No
PG005	Great Lakes Water Authority	No	No
PG010	Great Lakes Water Authority	No	No
PG030	Great Lakes Water Authority	No	No
PG031	Great Lakes Water Authority	No	No
PG032	Great Lakes Water Authority	No	No
PG034	Great Lakes Water Authority	No	No
PG037	Great Lakes Water Authority	No	No
PG039	Great Lakes Water Authority	No	No
CH-S-1-RG	Macomb County Public Works Office	No	No
CT-S-4	Macomb County Public Works Office	No	No
M-21	Macomb County Public Works Office	No	No
M-22	Macomb County Public Works Office	No	No
SY-S-1	Macomb County Public Works Office	No	No
WA-S-1	Macomb County Public Works Office	No	No
Clintondale PS	Macomb County Public Works Office	No	No
KerbyRd PS	Macomb County Public Works Office	No	No
KDET, converted from hourly	National Oceanic and Atmospheric Administration	No	No
0810	Oakland County Water Resources Commissioner	No	No
0811	Oakland County Water Resources Commissioner	No	No
0820	Oakland County Water Resources Commissioner	No	No
0827	Oakland County Water Resources Commissioner	No	No
0834	Oakland County Water Resources Commissioner	No	No
0850	Oakland County Water Resources Commissioner	No	No
R-13	Wayne County	No	No

Table 36: Monthly and Event Rainfall Summary

		June 1 to June 30		June 25 and 26		July 1 to July 31		July 16 and 17	
Precipitation Gage	Hydraulic Model Input	Total Period Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation
PG002	Yes	12.13	4.69	7.54	4.69	6.60	2.88	3.11	2.88
PG003	Yes	7.57	2.10	3.97	2.10	6.63	2.27	2.42	2.27
PG004WS	Yes	6.03	1.63	2.03	1.63	6.53	2.92	3.02	2.92
PG006	Yes	5.70	1.65	2.19	1.65	6.47	2.36	2.60	2.36
PG008	Yes	6.81	1.90	3.52	1.90	6.34	2.43	2.57	2.43
PG009	Yes	7.38	2.34	3.59	2.34	6.57	2.73	2.85	2.73
PG011	Yes	5.90	1.88	2.41	1.88	6.51	3.09	3.35	3.09
PG012	Yes	8.05	2.09	4.09	2.09	6.00	2.12	2.24	2.12
PG014	Yes	7.55	2.70	4.57	2.70	6.20	2.97	3.16	2.97
PG015	Yes	9.48	4.28	6.74	4.28	7.20	3.58	3.77	3.58
PG017	Yes	6.23	1.94	3.08	1.94	6.59	2.23	2.34	2.23
PG018	Yes	8.06	2.85	5.32	2.85	6.87	3.24	3.42	3.24
PG019	Yes	9.01	2.59	5.06	2.59	7.38	2.75	2.96	2.75
PG020	Yes	8.66	3.30	5.44	3.30	6.57	3.28	3.52	3.28
PG021	Yes	10.45	3.43	4.78	3.43	6.86	2.48	2.70	2.48
PG022	Yes	12.44	3.89	7.27	3.89	8.10	3.39	3.61	3.39
PG024	Yes	7.94	2.48	4.82	2.48	6.47	2.88	3.05	2.88
PG025	Yes	9.86	3.21	5.93	3.21	8.34	3.20	3.39	3.20
PG026	Yes	9.26	3.82	5.65	3.82	9.90	3.30	5.25	3.30
PG027	Yes	5.50	1.18	1.95	1.18	6.94	1.54	1.61	1.45
PG035	Yes	7.08	1.99	2.78	1.99	6.94	2.37	2.46	2.37
PG038	Yes	7.19	2.38	3.88	2.38	6.75	2.57	2.67	2.57

Precipitation Gage	Hydraulic Model Input	June 1 to June 30		June 25 and 26		July 1 to July 31		July 16 and 17	
		Total Period Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation
Prospect	Yes	10.86	4.19	6.94	4.19	6.83	3.51	3.95	3.51
HarperWoods	Yes	7.89	2.48	4.27	2.48	7.33	2.87	3.07	2.87
STS4	Yes	4.42	0.81	1.22	0.81	5.50	1.42	1.57	1.42
R-27	Yes	9.58	4.69	5.92	4.69	6.78	3.12	3.29	3.12
R-28	Yes	7.97	3.14	5.15	3.14	6.86	2.44	2.58	2.44
R-29	Yes	7.12	1.79	2.59	1.79	6.16	2.58	2.70	2.58
KMIGROSS35	Yes	12.47	4.31	8.14	4.31	8.90	4.71	5.02	4.71
KMILIVON57	Yes	7.30	2.07	2.89	2.07	6.58	3.00	3.13	3.00
KMIROSEV13	Yes	6.48	1.63	3.03	1.63	7.37	3.09	3.34	3.09
KMISTCLA51	Yes	8.26	2.89	4.11	2.89	6.85	2.74	2.97	2.74
PG007	No	9.10	3.69	4.37	3.69	8.75	2.36	2.08	1.62
PG013	No	10.88	2.00	3.94	2.00	12.64	2.32	3.44	2.32
PG028	No	6.19	2.93	3.42	2.93	8.33	1.86	0.97	0.92
PG029	No	8.56	1.55	2.14	1.55	7.47	2.08	0.75	0.72
PG033 Modified	No	6.49	1.91	2.84	1.91	3.07	2.83	2.91	2.83
PG036	No	7.97	3.76	5.68	3.76	9.02	3.96	4.04	3.96
OC0802	No	6.81	2.18	2.50	2.18	5.50	1.88	0.83	0.76
OC0803	No	5.93	1.27	1.47	1.03	5.52	2.04	1.04	0.88
OC0804	No	8.25	2.88	2.23	2.22	5.90	2.07	1.28	1.03
OC0807	No	10.86	3.32	2.21	1.62	6.66	2.91	0.89	0.85
OC0808	No	8.65	2.09	2.50	2.09	6.05	2.30	0.80	0.71
OC0812	No	6.47	0.93	0.90	0.90	5.05	1.85	0.72	0.68

Precipitation Gage	Hydraulic Model Input	June 1 to June 30		June 25 and 26		July 1 to July 31		July 16 and 17	
		Total Period Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation
OC0813	No	5.03	0.91	1.62	0.91	4.49	2.01	0.77	0.75
OC0814	No	6.12	0.90	1.78	0.90	4.56	2.01	0.76	0.73
OC0815	No	4.93	0.99	1.46	0.99	4.46	1.63	0.66	0.63
OC0816	No	5.44	0.85	0.70	0.57	6.91	2.73	1.01	0.98
OC0821	No	4.48	1.12	0.80	0.58	4.26	2.11	0.54	0.51
OC0831	No	7.20	1.88	2.74	1.88	7.40	2.26	2.36	2.26
OC0832	No	7.00	2.85	3.52	2.85	6.16	2.09	1.78	1.36
OC0833	No	6.65	2.29	2.88	2.29	6.06	1.79	1.88	1.79
OC0835	No	7.51	3.26	3.82	3.26	7.10	1.95	1.99	1.89
OC0836	No	5.77	2.55	2.99	2.55	6.62	1.65	1.58	1.49
OC0837	No	6.83	2.63	3.27	2.63	4.82	1.79	0.03	0.02
OC0841	No	6.14	1.84	2.13	1.84	5.35	2.00	1.28	1.19
OC0843	No	8.10	3.14	3.95	3.14	7.42	1.78	1.88	1.67
OC0848	No	9.45	3.58	4.28	3.58	8.70	2.67	2.11	1.65
OC0880	No	5.70	1.64	2.29	1.64	5.10	1.97	1.85	1.74
Outer Drive	Yes	11.09	4.20	7.50	4.20	8.67	4.20	4.41	4.20
Clintondale HS	No	5.59	1.17	1.98	1.17	6.20	1.76	1.56	1.24
CTS3	No	6.65	1.80	2.36	1.80	4.85	1.42	1.34	1.22
ELIZABETH_RG2	No	6.51	1.83	2.28	1.77	5.37	1.32	1.15	1.02
HARPER_RG3	No	4.67	1.04	1.72	1.04	5.50	1.54	1.45	1.21
M-03	Yes	6.17	1.96	3.10	1.96	4.04	1.45	1.45	1.45
M-15	Yes	5.38	1.35	2.05	1.35	5.07	2.48	2.68	2.48

Precipitation Gage	Hydraulic Model Input	June 1 to June 30		June 25 and 26		July 1 to July 31		July 16 and 17	
		Total Period Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation	Period Total Precipitation	Maximum Daily Precipitation
M-16	Yes	6.36	1.44	2.46	1.44	6.94	2.13	2.33	2.13
M-19	Yes	7.40	2.44	3.61	2.44	5.64	2.64	2.85	2.64
M-20	Yes	7.03	2.09	3.50	2.09	6.76	2.98	3.23	2.98
NGI	No	4.69	1.85	2.12	1.85	3.13	0.75	0.73	0.61
NorthAve_23	No	5.22	1.92	2.21	1.92	3.73	1.07	0.83	0.72
SONIC	No	6.70	1.64	2.36	1.64	5.45	1.39	1.47	1.32
STS3	No	5.48	1.74	2.34	1.74	5.31	1.59	1.49	1.38
UTS1	No	6.85	2.86	3.26	2.86	5.26	1.84	1.17	1.10
R-11	No	5.52	1.88	2.55	1.88	4.84	1.92	2.02	1.92
R-12	No	8.89	2.68	4.43	2.68	5.64	2.45	2.58	2.45
KMICANTO56	No	9.25	2.55	4.31	2.55	4.86	2.15	2.29	2.15
KMICANTO61	No	8.55	3.08	5.05	3.08	6.78	3.71	3.82	3.71
KMICANTO89	No	11.09	3.59	6.25	3.59	5.23	2.82	3.05	2.82
KMIHUNTI7	No	7.31	2.14	2.84	2.14	7.73	2.57	2.67	2.57
KMILIVON109	No	8.51	2.25	3.80	2.25	6.63	2.86	2.99	2.86
KMILIVON122	No	5.69	1.89	2.63	1.89	8.21	3.62	3.78	3.62
KMIROYAL50	No	7.27	2.13	2.91	2.13	7.36	2.13	2.26	2.13
KMIWARRE36	No	6.60	2.19	3.38	2.19	6.54	2.23	2.41	2.23

The 5-minute interval observations from each of the 84 precipitation gages identified in the previous section as having reliable data were accumulated into the following 11 standard durations: 5-minute, 10-minute, 15-minute, 30-minute, 60-minute, 2-hour, 3-hour, 6-hour, 12-hour, 24-hour, and 48-hour. The maximum precipitation depths for each of these 11 durations were selected for each gage and are summarized and compared to the annual chance of exceedance, or return period, of each duration, as presented in "NOAA Atlas 14 Precipitation-Frequency Atlas of the United States Volume 8 Version 2.0: Midwestern States (Colorado, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota, Wisconsin)" (NOAA 2013).

The return period/duration data from Atlas 14, Volume 8 were obtained from NWS Office of Water Prediction, Hydrometeorological Design Studies Center, Precipitation Frequency Data Server (https://hdsc.nws.noaa.gov/hdsc/pfds/index.html). The Precipitation Frequency Data Server allows user to download a raster image of the study area for the individual combination of return period and duration. The 5-, 10-, 25-, 50-, 100-, 200-, 500-, and 1,000-year return period raster data for the 5-minute, 10-minute, 15-minute, 30-minute, 60-minute, 2-hour, 3-hour, 6-hour, 12-hour, 24-hour, and 48-hour durations were downloaded, projected to the North American Datum of 1983 High Accuracy Reference Network, State Plane Michigan South, International Feet coordinates and then clipped to an area that encompassed the Detroit metropolitan area. The return period/duration raster data was then used to determine the Atlas 14 precipitation depth for the 10-, 25-, 50-, 100-, 200-, 500-, and 1,000-year return periods for each of the 11 durations at each precipitation gage location, creating a frequency curve for each of the 11 durations at each of the 84 precipitation gages.

The maximum observed precipitation depths for each of 11 standard durations at each gage were compared to the Atlas 14 computed return periods for the specified durations to determine: 1) the range of return period for the maximum observed precipitation depth; and 2) the estimated return period. The tabulated range of return period and estimated return period for the maximum observed precipitation depth for each duration can be provided upon request.

The maximum observed precipitation depth and the associated estimated return periods for the 84 precipitation gages for the 5-minute,15-minute, 60-minute, 3-hour, 12-hour, 24-hour, and 48-hour durations were selected as representative of the intensity, duration, and frequency of precipitation of the June 25/26 Rainfall Event are displayed in a set of maps (Figure 46 through Figure 52) to illustrate the spatial distribution of the precipitation depths that occurred during each event, as well as the associated return periods for the representative duration. Similar maps for the July 16 Rainfall Event are shown in Figure 54 through Figure 60.

As shown on these maps, the precipitation depths were not uniform across the impacted area for either precipitation event.

The intensity, duration, and frequency of precipitation events can be characterized by plotting precipitation depth versus duration for a given return period, creating what are known as Intensity, Duration, and Frequency (IDF) curves. These IDF curves are used to illustrate the variation of precipitation depth for a specified return period over the range of the standard durations. As part of this review of the severity of the June 25/26 and July 16 rainfall events a set of IDF curves for the impacted area were constructed by averaging the Atlas 14 return period precipitation depths for each gage for each of the standard durations. The observed maximum precipitation depths for each of the durations that were selected as representative of the intensity, duration, and frequency of precipitation durations are shown in Figure 46 through Figure 52. Six precipitation gages were chosen as representing the most severe (or largest) precipitation depths across the representative durations; the six greatest depths for each duration were not plotted in order to simplify these plots because doing so could result in plotting the depths for as many as 42 gages for each event, creating a data plot that would be difficult to interpret. The comparative IDF curves are shown in Figure 53 and Figure 61.

B2 – June 25/26 Rainfall Event

The June 25/26 Rainfall Event began in the early morning hours of June 25, at approximately 3:00 a.m. The majority of the total precipitation occurred during an approximately 24-hour period, throughout the day on the 25 and ending at approximately 03:00 on the 26. The observed maximum 48-hour total depth exceeded the maximum 24-hour total depth by, on average, less than 0.1 inch over all gage locations. There was no difference between the observed maximum 48-hour and 24-hour total depths at 30 percent of the precipitation gages and the largest difference between the 48-hour and 24-hour depths was 0.6 inches, at 2 locations (Macomb County Harper gage and Oakland County 0814 gage) in the more lightly impacted northern part of the Detroit metropolitan area.

The most intense periods of precipitation during the June 25/26 Rainfall Event were the 5-minute and 10-minute durations and the 3-hour through 24-hour durations. Return periods for observed precipitation exceeded 1,000 years for the 5-minute duration at the PG021 gage location and were greater than 500 years for the 5- and 10-minute durations at the PG021 and KMICANTO61 gage locations in central Oakland County, northeast Wayne County, and northwest Wayne County (Figure 46 through Figure 52). Return periods for observed precipitation exceeded 1,000 years for the 2-hour through the 24-hour duration at the multiple gage locations, including KMIGROSS35, PG021, PG002, PG022, Outer Drive, and Prospect gage locations in areas located along I-94 near the south-central Detroit and the Grosse Pointe area, along or near the northern shores of the Detroit River and Lake St. Clair.

Comparisons of the average IDF curves for the Detroit area to the observed precipitation depths at the selected gage locations indicate the severity of the June 25/26 Rainfall Event across all durations, as well as the variation in severity at different durations (Figure 53). The precipitation at the 0804 gage exceeded the 1,000-year return period at the 5-minute duration and was greater than a 500-year event at the 15-minute duration; however, the return period of the June 25/26 Rainfall Event at the 0804 gage location decreased with increasing storm duration, so that at the 12- and 24-hour durations the return period of the observed precipitation at 0804 was at 5 years or less. In contrast, the return period of observed precipitation at the other gage locations (KMIGROSS35, Outer Drive, PG002, PG022, and Prospect) plotted for the duration less than 1 hour ranged from 5 to 50 years; the return period for durations of 1 hour or greater increased consistently until from 50 to 100 years at 1 hour, to more than 500 or 1,000 years at the 12- and 24-hour durations.

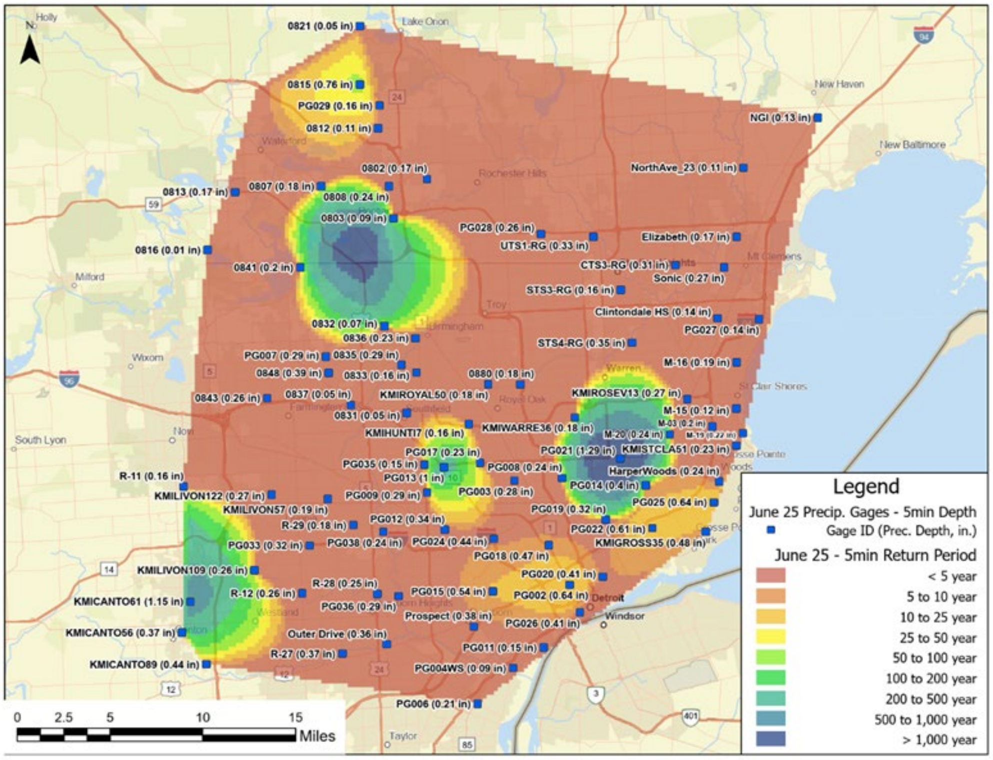


Figure 46: 5-minute Precipitation Depth and Return Period for June 25/26 Rainfall Event

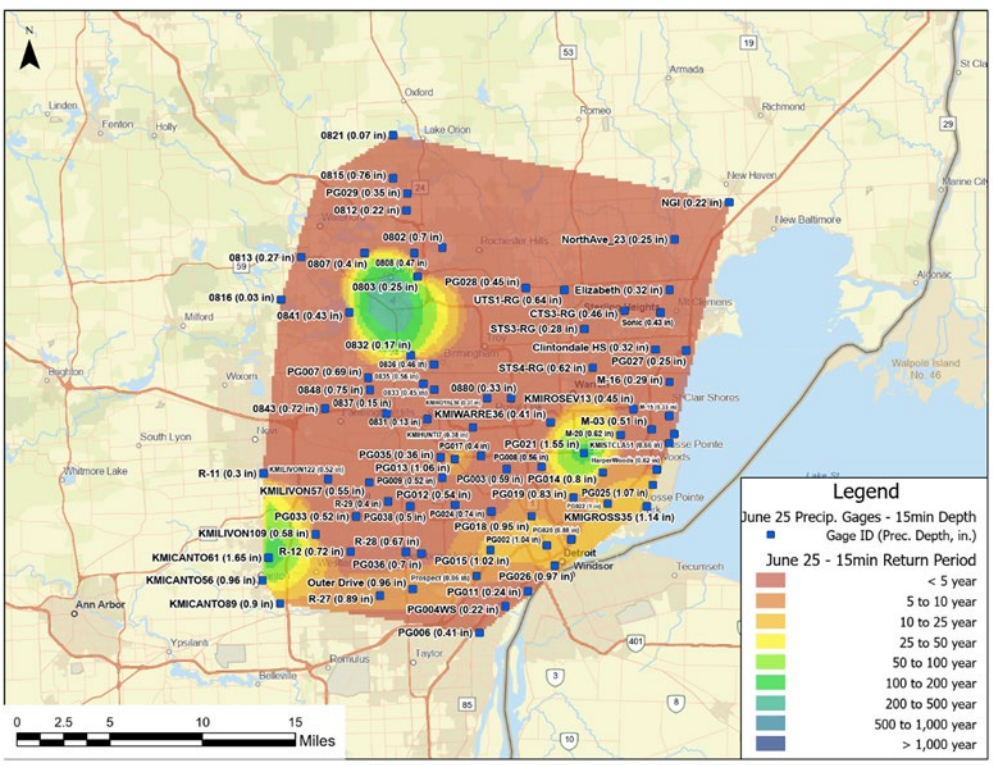


Figure 47: 15-minute Precipitation Depth and Return Period for June 25/26 Rainfall Event

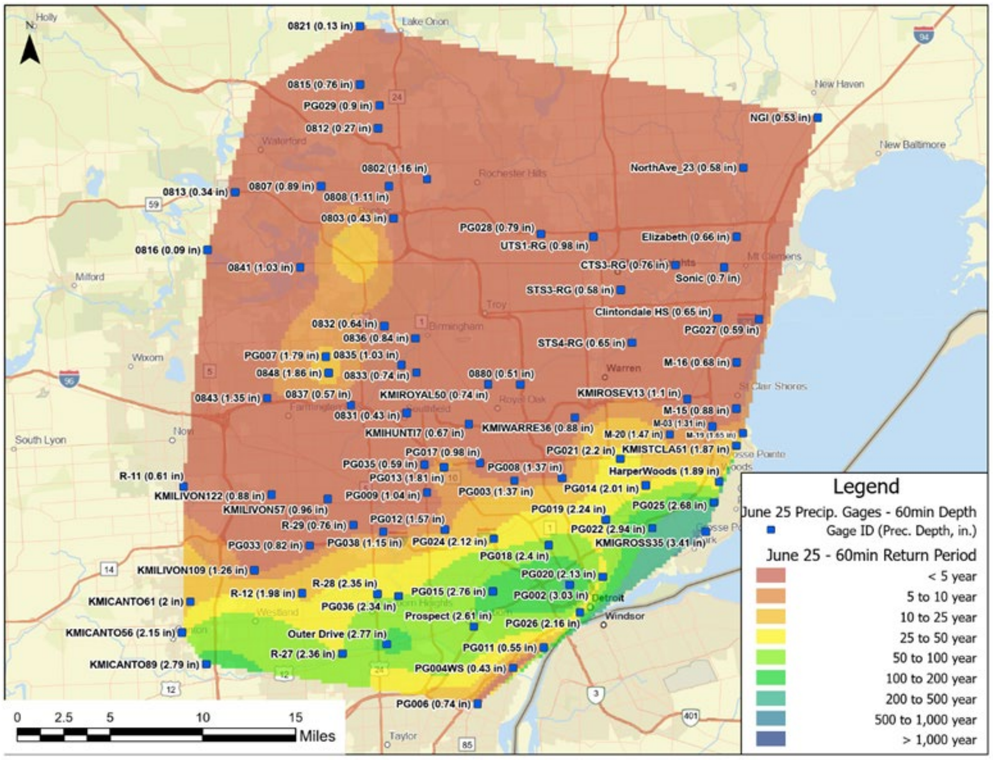


Figure 48: 60-minute Precipitation Depth and Return Period for June 25/26 Rainfall Event

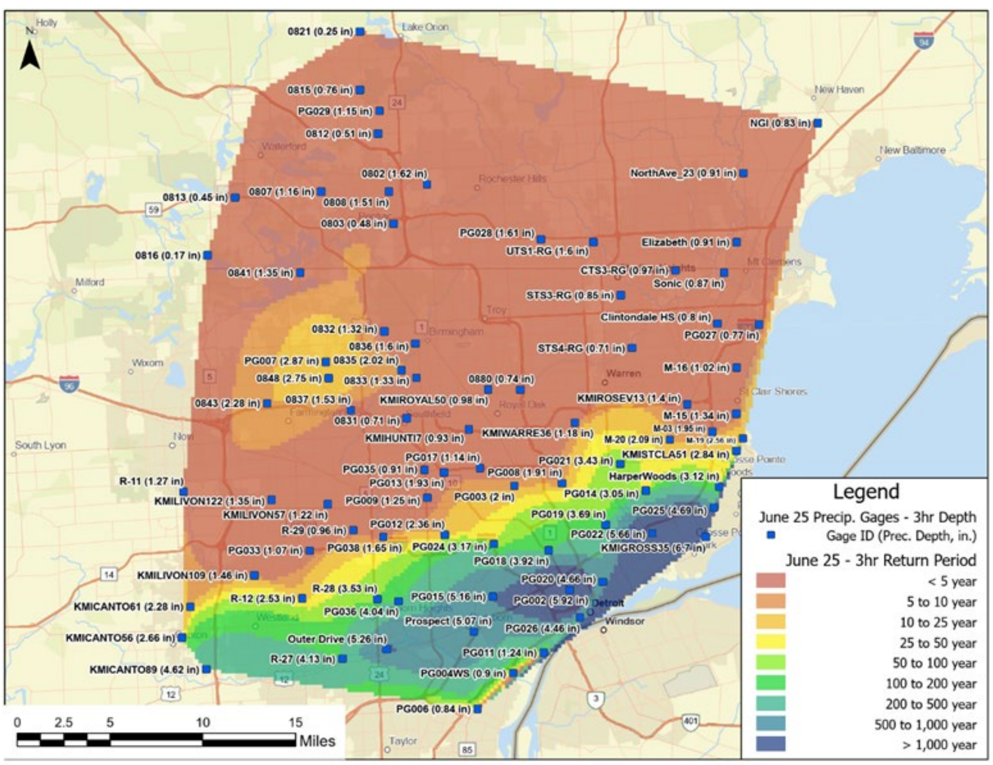


Figure 49: 3-hour Precipitation Depth and Return Period for June 25/26 Rainfall Event

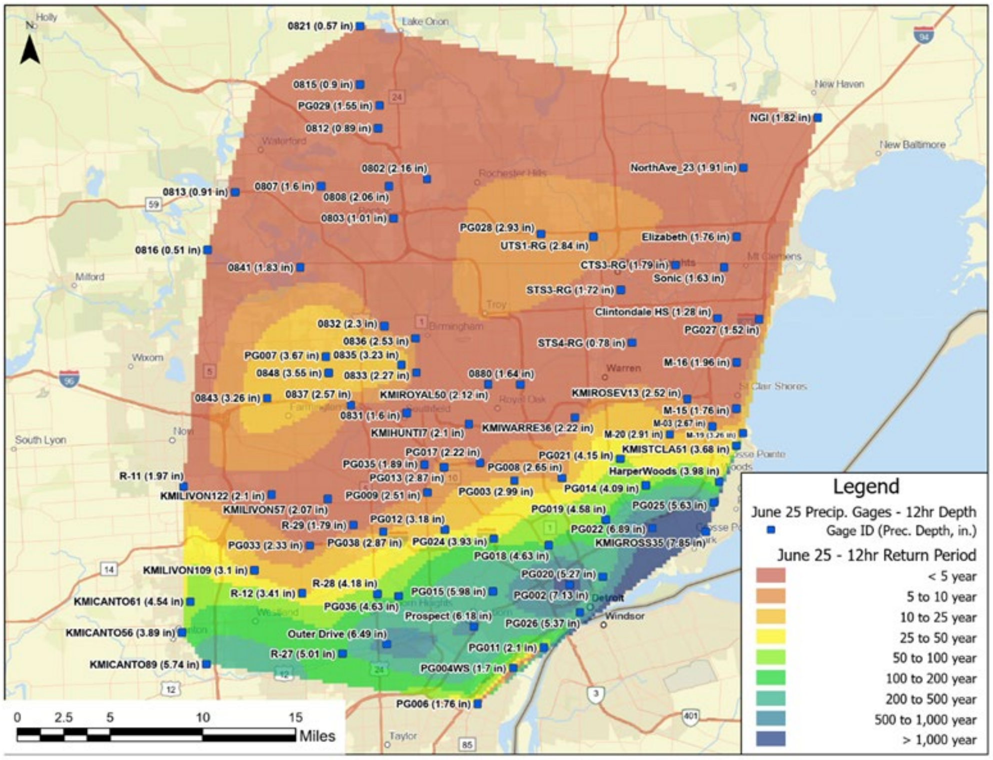


Figure 50: 12-hour Precipitation Depth and Return Period for June 25/26 Rainfall Event

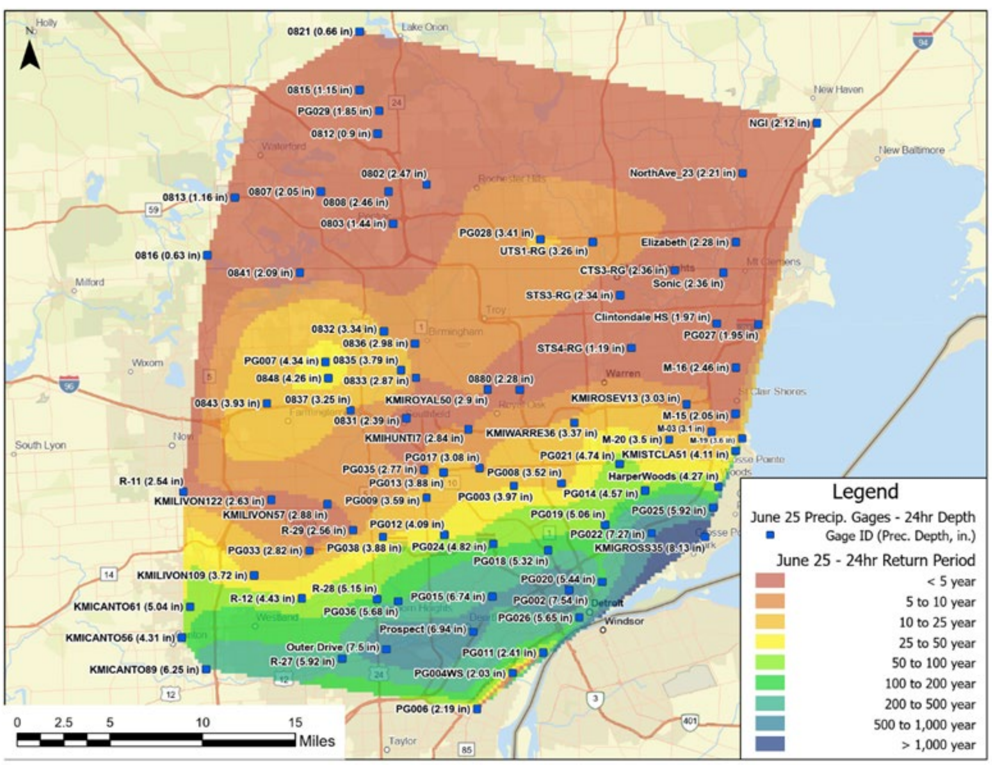


Figure 51: 24-hour Precipitation Depth and Return Period for June 25/26 Rainfall Event

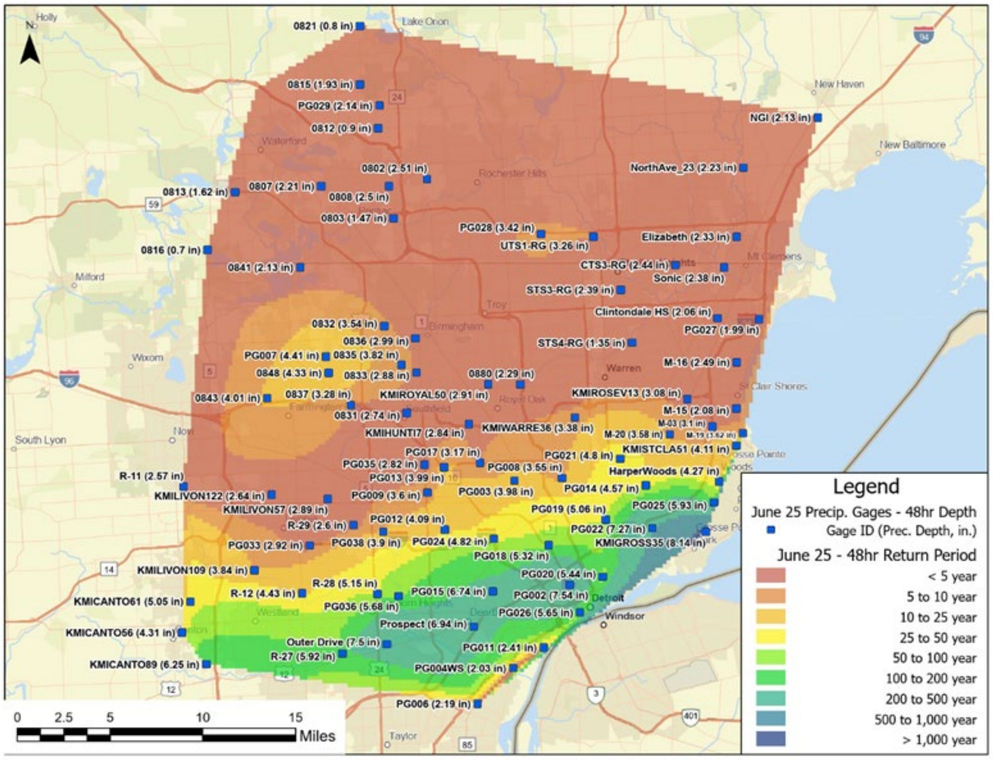


Figure 52: 48-hour Precipitation Depth and Return Period for June 25/26 Rainfall Event

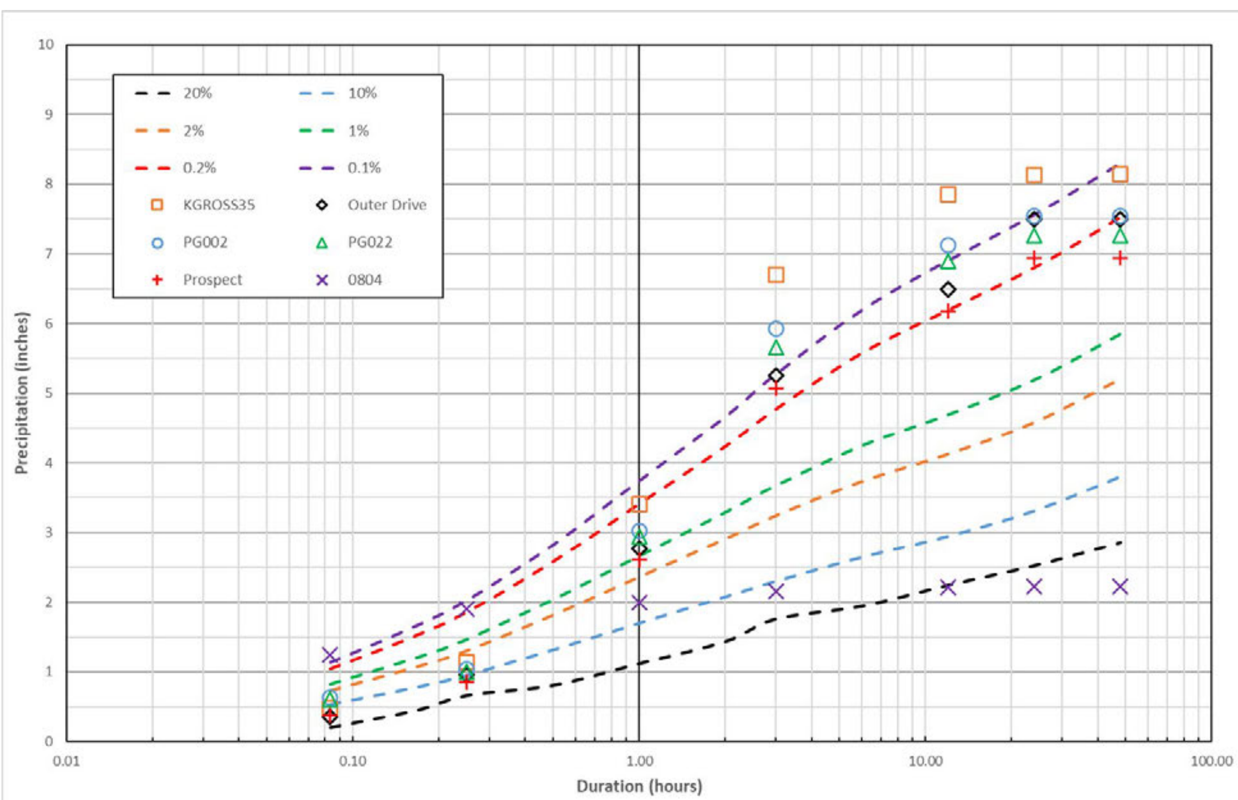


Figure 53: Intensity, Duration, and Frequency for Detroit Area Compared to Observed Precipitations Depths for June 25/26 Rainfall Event

B3 – July 16 Rainfall Event

The precipitation event of July 16, 2021 began between 6:00 a.m. and noon on the morning of July 16. The majority of the total precipitation occurred during an approximately 12-hour period, throughout the day on July 16 and ending at approximately 6:00 p.m. in the early evening of the 16. The observed maximum 24-hour total depth exceeded the maximum 12-hour total depth by 0.2 inches over all gage locations on average. The difference between the observed maximum 48-hour and 24-hour total depths was less than 0.2 inch at 70 percent of the precipitation gages. The largest difference between the 24-hour and 12-hour depths was 2.5 inches, at the GLWA gage PG026to the southwest of downtown Detroit near W. Fort Street and the John C Lodge Freeway; the next largest differences were less than 0.5 inch.

The most intense periods of precipitation during the July 16 event were the 5-minute durations, for which the PG036 gage recorded a 5-minute depth with return period between 500 and 1,000 years. There were two other locations (GLWA gage PG013 and WeatherUnderground gage KMICANTO61) where the return period for the 5-minute depths was between 200 and 500 years. All three of these gages are in Wayne County; PG013 and PG036 are approximately 10 miles from the center of Detroit, to the north and northwest, respectively; KMICANTO61 is about 20 miles northwest of the center of Detroit (Figure 54). Total depths with return period between 50 and 200 years were observed for the 3-, 6-, 12-, and 24-hour durations at the GLWA PG026 gage and the WeatherUnderground KMIGROSS35 gage to the northeast of the center of Detroit along the north bank of the Detroit River near Belle Isle and at the City of Dearborn Outer Drive gage in western Wayne County near the intersection of Michigan Avenue and Outer Drive.

Comparisons of the average IDF curves for the Detroit area to the observed precipitation depths at the selected gage locations indicate the severity of the July 16 event was markedly less than that of the June 25/26 event across all durations. In addition, although there was variation in severity across all durations for the July 16 event, this variation was not as great as that observed for the June 25/26 Rainfall Event (Figure 61). The precipitation for the 5-minute duration at the KMICANTO61 and PG036 gage locations was close to or slightly larger than the 500-year event; however, the return period at these two locations decreased somewhat with increasing storm duration, so that at the 12- and 24-hour durations the return period of the observed precipitation for these gages was between 10 and 50 years. At the PG020 and Outer Drive locations, the return period of observed precipitation for all durations was between 5 and 50 years. At the remaining gage locations, KMIGROSS35 and PG026, the return period for durations less than 1 hour ranged from 5 to 50 years but increased to close to or greater than the 100-year event for the 12- and 24-hour durations. The July 16 event was not as severe as the relatively more severe June 25/26 event that occurred roughly 3 weeks prior; however, taken by itself it was still a severe storm event in terms of magnitude and damage caused.

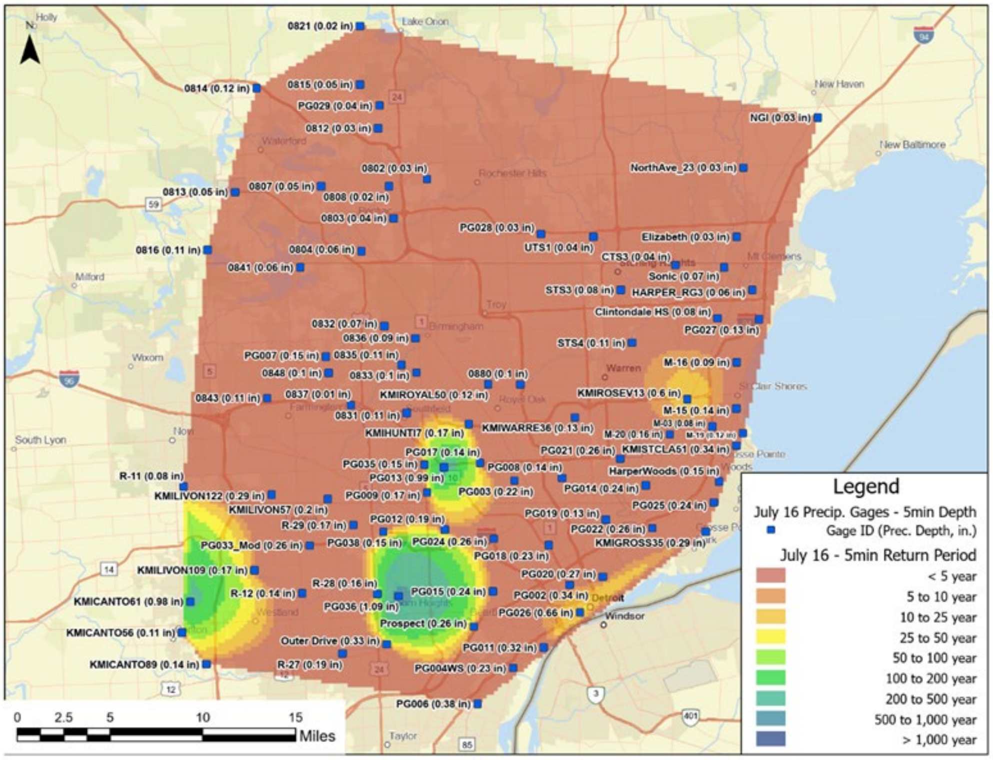


Figure 54: 5-minute Precipitation Depth and Return Period for July 16 Rainfall Event

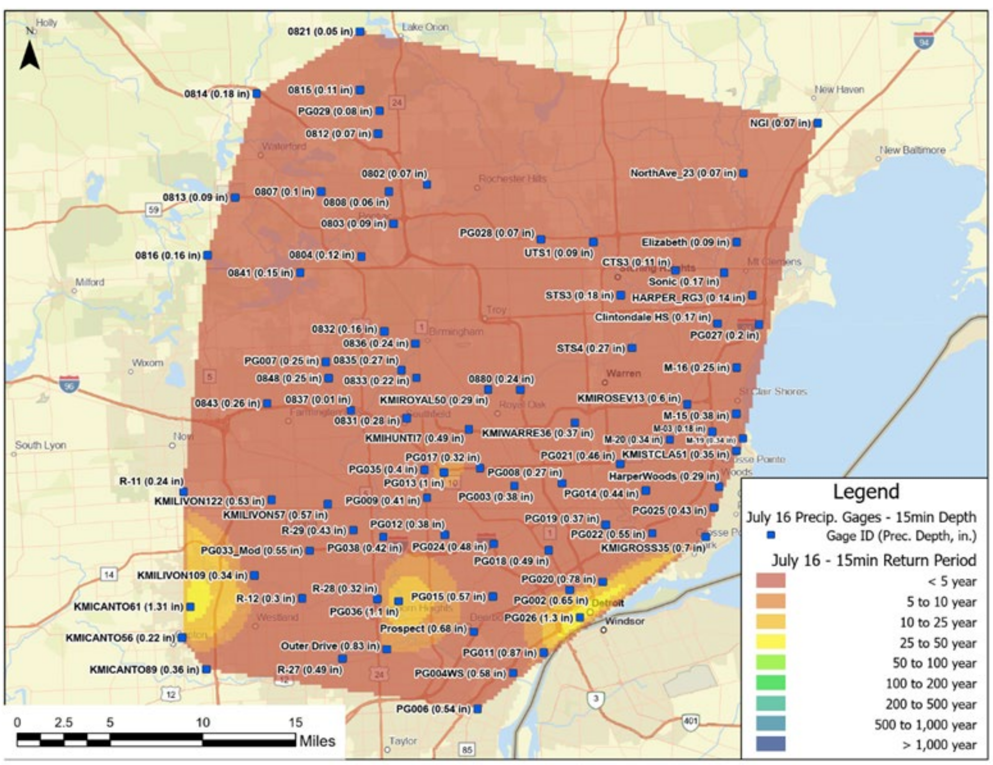


Figure 55: 15-minute Precipitation Depth and Return Period for July 16 Rainfall Event

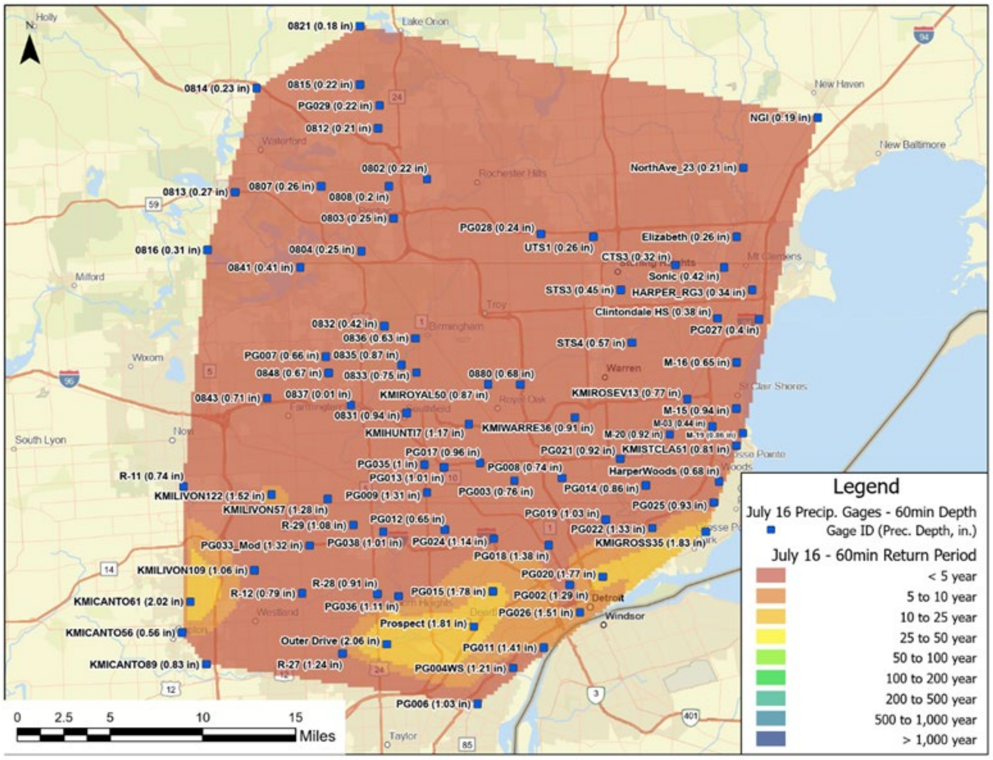


Figure 56: 60-minute Precipitation Depth and Return Period for July 16 Rainfall Event

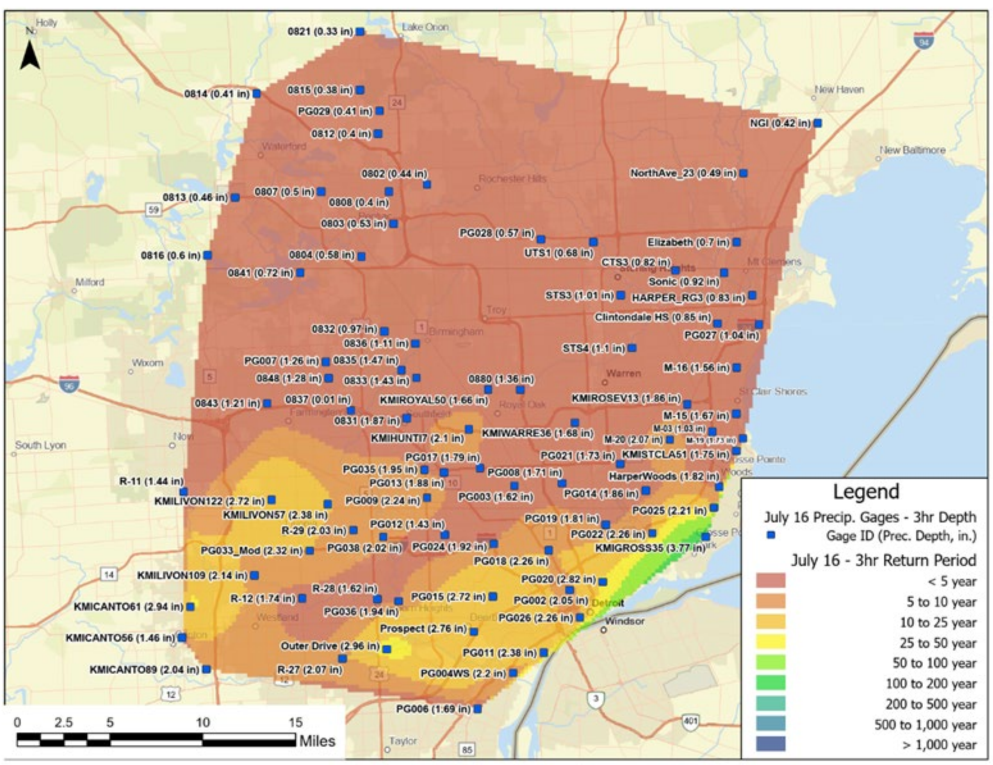


Figure 57: 3-Hour Precipitation Depth and Return Period for July 16 Rainfall Event

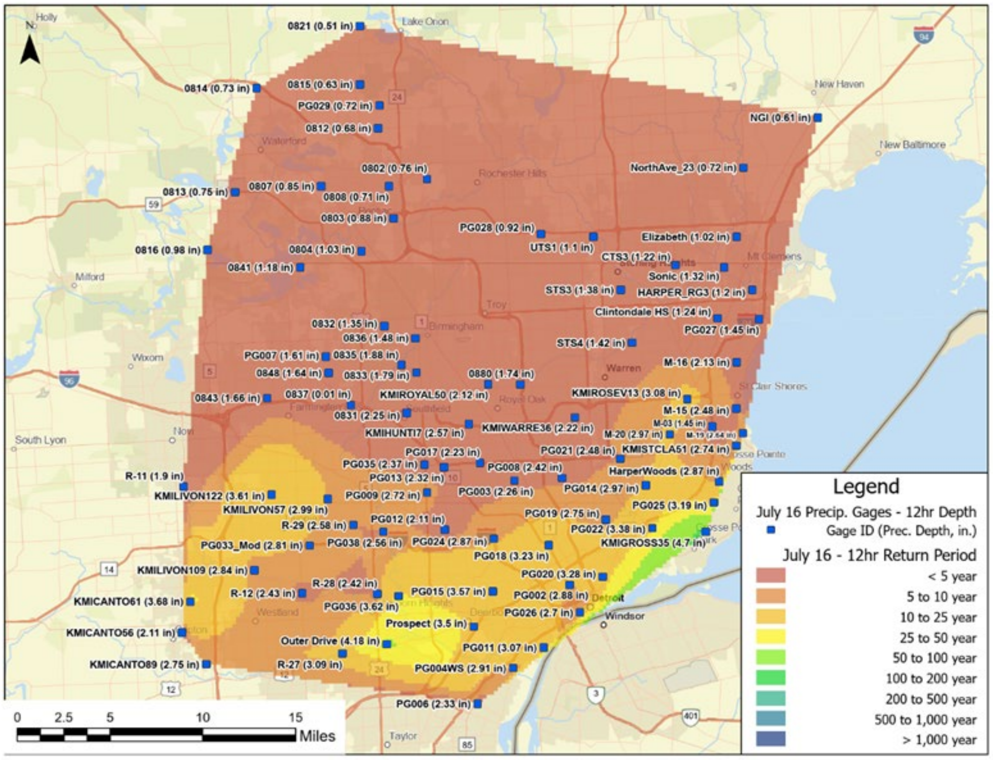


Figure 58: 12-Hour Precipitation Depth and Return Period for July 16 Rainfall Event

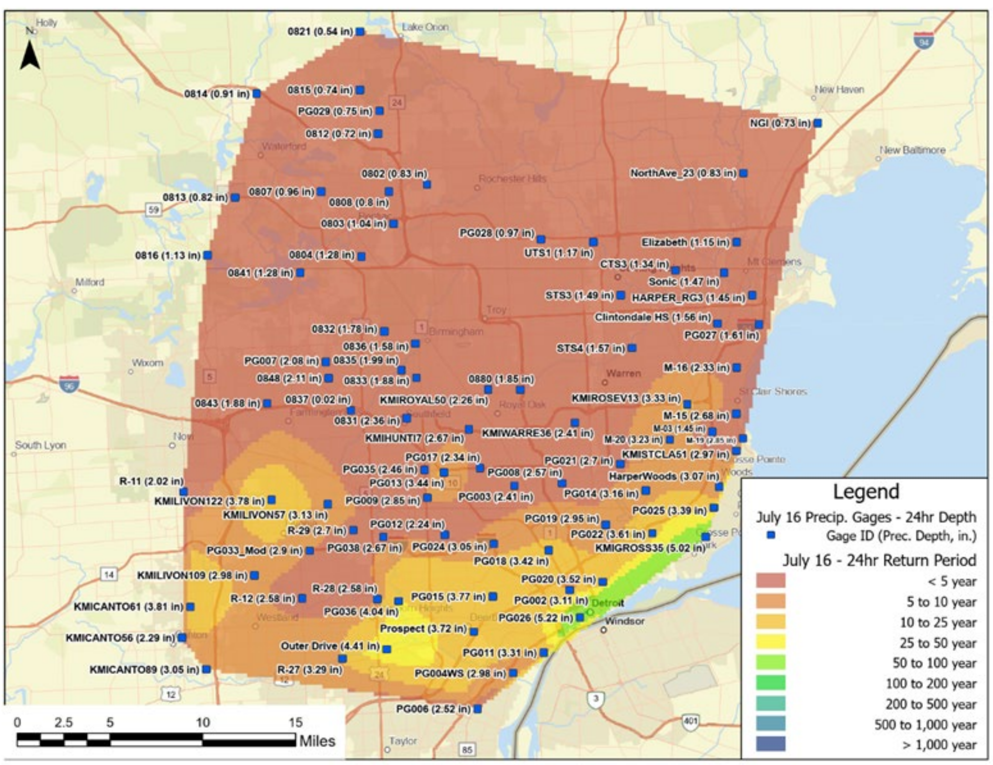


Figure 59: 24-Hour Precipitation Depth and Return Period for July 16 Rainfall Event

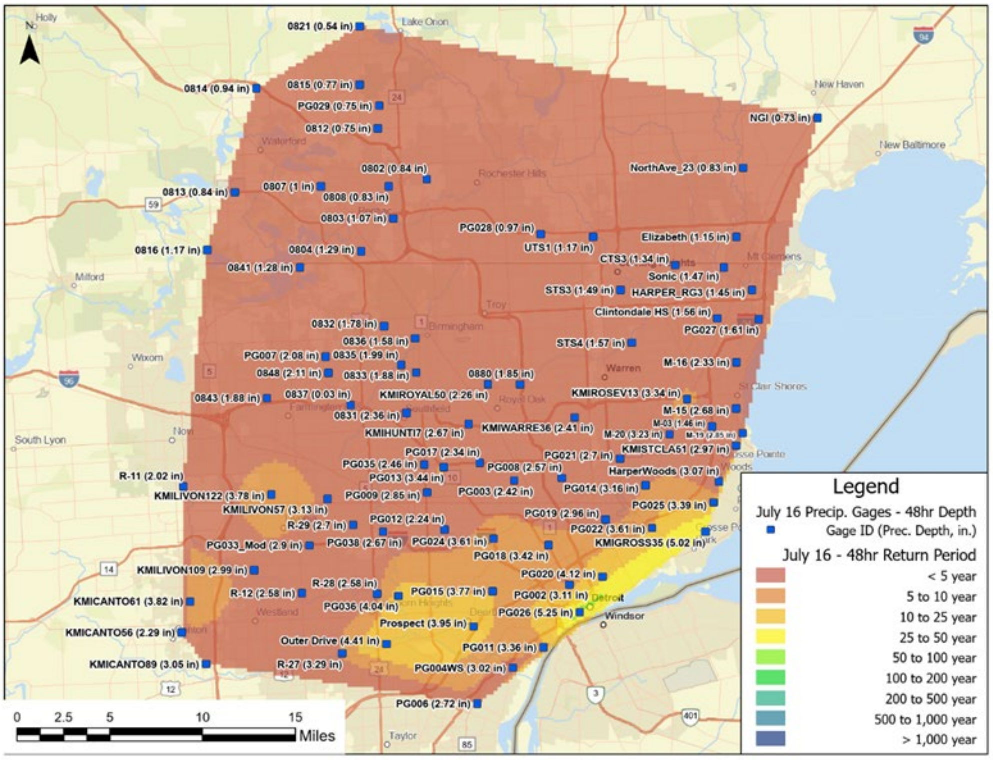


Figure 60: 48-Hour Precipitation Depth and Return Period for July 16 Rainfall Event

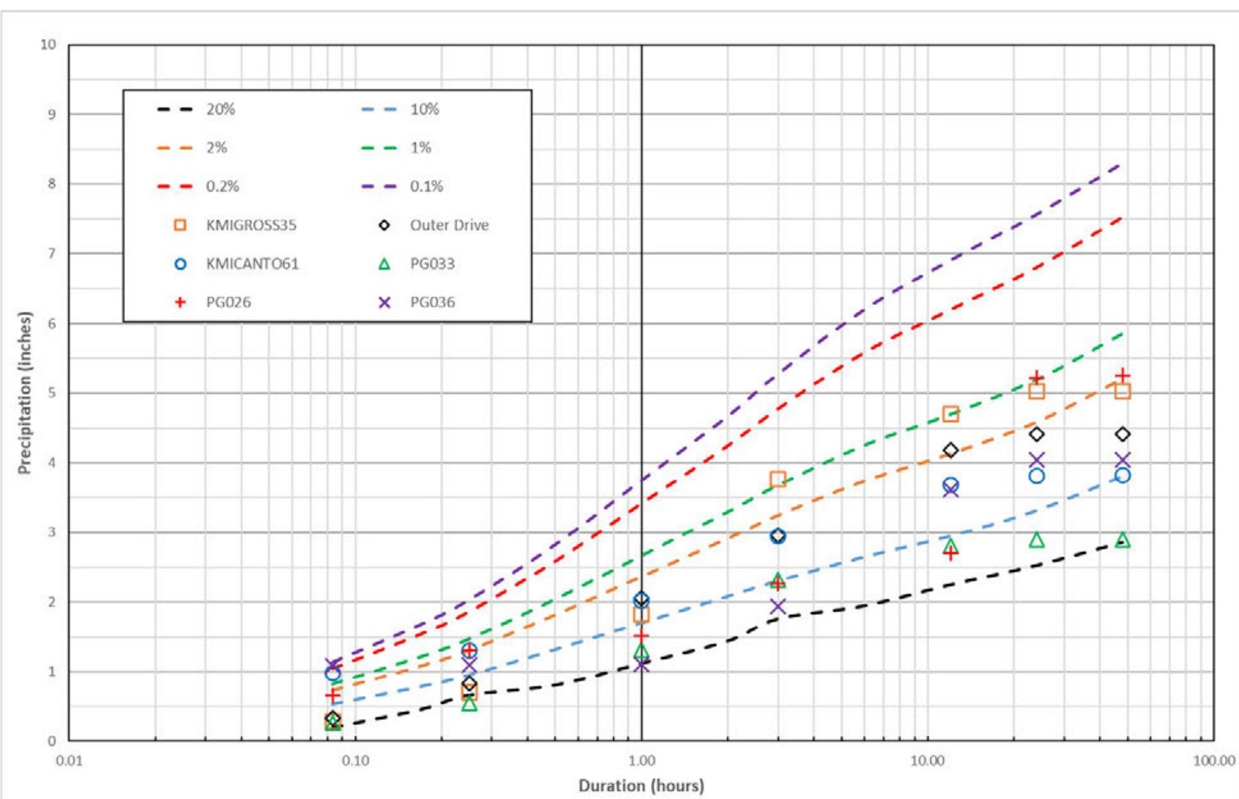


Figure 61: Intensity, Duration, and Frequency for Detroit Area Compared to Observed Precipitation Depths for July 16 Rainfall Event

APPENDIX C – HYDRAULIC MODELING

C1 – Data Collection, Model Verification and Analysis

Real field data that was available for the June 25/26 and the July 16 events was the DWSD flood complaint database, this data was provided by DWSD by a spreadsheet titled, "DWSD_WaterDepth_Scrape_Attempt.xls" (by Samuel Smalley at DWSD at the direction of Gary Brown). The June 25/26 and the July 16 database consists of 4,940 water-in-basement complaints collected from citizens who called in via a provided phone number by DWSD staff who documented the complaints in the database. DWSD provided two separate databases for the two events but much of the data in them overlapped. Most of the data only documented the depth of water within the homes. However, a small percentage included comments about street flooding and general descriptions of the depth of water outside of the homes. These eyewitness accounts may or may not have occurred during the peak water depth caused by the flood; therefore, the observation may not have captured the highest water level at these locations. However, some complaints listed in the database reported high water marks from neighbors at the same location. Both databases were reviewed and the best available data were used for validation.

The high-water mark for the eyewitness account along the locations and assumed water levels during the June 25/26 event is provided in Table 36.

Table 37: Selected Locations with High Water Elevations during the June 25/26 Event

Location of High Water Observation	Nearest Cross Street	Ground Elevation (ft-DD)	High Water Level	Comments
3800 Block of Cabot Street	John Kronk Street	108.063	3	Lidar
500 Block of S Park Street	Victoria Park Drive S	91.93298	3	Lidar
17800 Block of Strausburg Street	Gietzen Street	147.627	1	Lidar
500 Block of Marquette Drive	Freud Street	95.92999	4	Lidar
6500 Block of Asbury Park	Whitlock Avenue	122.82	4	Lidar
500 Block of Marquette Drive	Freud Street	98.18701	4	Lidar
600 block of Connor Street	Freud Street	95.21399	1.5	Lidar
500 block of Tennessee Street	Essex Drive	94.24902	1.3	Lidar
1400 block of Manistique Street	Kercheval Avenue	100.248	1	Lidar
1400 block of Manistique Street	Kercheval Avenue	100.059	1	Lidar
100 block of Nicolet Place	Rivard Street	122.581	1	Lidar
500 block of New Town Street	Victoria Park Drive S	95.96301	1.5	Lidar
6800 block of Bulwer Street	Martin Street	114.094	0.8	Lidar
500 block of Ashland Street	Essex Drive	95.133	0.8	Lidar
3700 West Warren Avenue	Roosevelt Street	129.894	1.5	Lidar
1200 block of Bagley Street	Brooklyn Street	116.935	0.5	Lidar
8800 block of Marlowe Street	Ellis Street	130.07	0.8	Lidar
4800 block of Ogden Street	Arnold Avenue	112.901	1	Lidar
7200 block of Pierson Street	West Warren Avenue	133.75	0.5	Google Earth

Location of High Water Observation	Nearest Cross Street	Ground Elevation (ft-DD)	High Water Level	Comments
6400 block of Burns Avenue	Harper Ave	145.461	0.8	Lidar
7400 block of Central Avenue	Majestic Street	125.932	1.5	Lidar
19300 block of Harlow Street	Vassar Drive	180.75	2	Google Earth
12700 block of Wilshire Drive	Dickerson Avenue	129.16	2	Lidar
16500 block of Murray Street	Florence Street	179.75	0.8	Google Earth
16600 block of Chandler Park Drive	Kensington Avenue	112.928	1.5	Lidar
15700 block of Wildemere Street	Midland Street	170.75	1	Google Earth
18100 block of Helen Street	Stockton Avenue	147.65	0.5	Lidar
6200 block of Farmbrook Street	Minerva Street	110.92	4	Lidar
600 block of Algonquin Street	Freud Street	95.12201	1.3	Lidar
6600 block of Oakman Boulevard	Littlefield Street	126.684	4	Lidar
8300 block of Sorrento Avenue	MacKenzie Street	126.188	3.5	Lidar
500 block of Chalmers Avenue	Essex Drive	95.11298	0.8	Lidar
6400 block of Minock Street	Whitlock Avenue	137	0.8	Lidar
5000 block of University Place	East Warren Avenue	107.398	1.3	Lidar
20100 block of Greeley Street	E Winchester Avenue	150.75	0.5	Google Earth
6400 block of Mettetal Street	Whitlock Avenue	123.481	1	Lidar
12500 block of Promenade Avenue	Annsbury Avenue	131.946	1.3	Lidar
13000 block of Simms Street	E McNichols Road	142.664	3	Lidar
5600 block of McMillan Street	Campbell Street	116.165	0.5	Lidar
1900 block of Outer Drive East	Charest Street	148.75	0.5	Google Earth
10200 block of Berkshire Street	Wayburn Street	123.026	3	Lidar
2400 block of Campbell Street	Plumer Street	111.203	1.5	Lidar
5000 block of Grand River Avenue	West Warren Avenue	131.191	3	Lidar
400 block of Ashland Street	Essex Drive	97.68201	4	Lidar
15600 block of W Chicago Road	Winthrop Street	136.112	1.5	Lidar
300 block of Ridgemont Avenue	Rockford Street	101.839	1.3	Lidar
2100 block of Belmont Street	Lumpkin Street	148.403	2	Lidar
3300 block of Harrison Street	Sycamore Street	115.313	2	Lidar
2600 block of Gratiot Street	Chene	141.531	2	Lidar
4400 block of Seyburn Street	E Canfield Street	135.511	1.5	Lidar
300 block of Eastlawn Street	Korte Street	94.854	2	Lidar
4500 block of Bishop Street	Cornwall Street	110.01	1	Lidar
1300 block of Lakewood Street	Kercheval Avenue	98.625	2	Lidar

Location of High Water Observation	Nearest Cross Street	Ground Elevation (ft-DD)	High Water Level	Comments
1300 block of Nicolet Place	Rivard Street	123.734	1	Lidar
2100 block of Oakman Boulevard	Dexter Avenue	163.75	1.5	Google Earth
11700 block of Maiden Street	Gunston Avenue	129.934	0.5	Lidar
5500 block of Grayton Street	Chandler Park Drive	112.182	0.5	Lidar
10400 block of Nottingham Street	Yorkshire Road	119.382	0.5	Lidar
8300 block of Chalmers Street	E Jefferson Avenue	96.13397	1.3	Lidar
6100 block of Connor Street	Freud Street	93.83301	3	Lidar
18000 block of East Warren Street	Farmbrook Street	104.219	4	Lidar

Notes:
DD = Detroit Datum
Lidar = light detection and ranging

C2 – Collection and Pumping System Modeling

C.2.1 GLWA PCSWMM Modeling History

Wade Trim Associates Westside model
Wade Trim contributed to the Westside section of this EPA SWMM model (GLWA_RWCS_EXC_20210831_ASI_Updates.inp) model before the GLWA Wastewater Master update by CDM Smith. The PCSWMM model provided by GLWA for the Westside was set up and calibrated by Wade Trim. This Westside model section includes the areas in the Rouge River and Hubbell-Southfield districts.

CDM Smith Detroit, part of Dearborn, Highland Park and Hamtramck model
The remainder of the cities of Detroit, part of Dearborn, Highland Park, and Hamtramck in the EPA SWMM model, were set up and calibrated by CDM Smith under the Wastewater Master Plan using data from the 2018 growing season to form the Regional Wastewater Collection System (RWCS) model. Sewersheds in the RWCS model were delineated under a sanitary sewer evaluation survey project in the 1990s. The RWCS model includes only the large sewers in Detroit.

Drainage areas are assumed to be equal to sewershed areas in the combined sewer areas of Detroit, which is an incorrect representation. Most interconnections between the large, combined sewers and the relief sewer system are included in the RWCS model, but pipe interconnections between smaller sewers are not represented.

Differing amounts of detail in the RWCS model were provided for the suburban areas. Some suburban systems were represented in a very simplified fashion. In other areas, more details were included in with the RWCS model. For example, SEMSD and Dearborn provided more details for the RWCS model.

The RWCS part that GLWA provided contains the large trunk sewers and facilities operated by GLWA but does not include the local sewers or only contains short sections of the local system where flow accesses the system. The model subcatchments assume that the storm and sanitary flows access a single point and in some cases, this may lead to artificially high water surface elevations in the system. In order to lessen the effect of direct loading to a single access point, the model was evaluated to the maintenance hole downstream of the loading point. In the city of Detroit, only large (i.e., greater than about 4 feet in diameter) combined sewers are included and represented in the RWCS model.

<u>Pump Stations and Flow Routing</u>

The eastside system include the Connors Creek, Freud, Bluehill and Fairview PSs. The service area includes the SEMSD, the east side of Detroit, Harper Woods, MRIDDD, and the Grosse Pointe communities.

There is an extensive network of sewers, PS, and RTBs upstream of the Fairview PS. The upstream RTBs include the Martin, Chapaton, Milk River and Connors Creek RTBs. The Detroit River Interceptor (DRI) runs into the Fairview PS wet well. The wastewater is lifted at the Fairview PS and is discharged into a downstream segment of the DRI. During the summer 2021, a temporary bypass PS existed at the Fairview PS while the station was being rehabilitated.

Flow inputs to the DRI include combined wastewater from DWSD owned gravity laterals between Fairview PS and Alter Road, the wastewater discharged from the Connors Creek PS sanitary pumps, the wastewater discharged from the Connors Creek Enclosure through regulator gates (VR-2a, 2b, and 2c) and the Grosse Pointe Park PS.

The Connors Creek PS receives wastewater from the East Jefferson Relief sewers that run in Jefferson Avenue to the east and west of the Connors Creek PS. The East Jefferson Relief sewer transports wastewater from DWSD owned gravity laterals between Fairview PS and Alter Road, wastewater from the Fox Creek regulator gates, the Freud PS sanitary pumps, and the Fox Creek and Mack Avenue Relief sewers. The Bedford and Three Mile sewers discharge by gravity into the Fox Creek and Mack Avenue Relief sewers, respectively.

The Connors Creek PS includes sanitary pumps that discharge dry weather and low wet weather flow rates to the DRI. Also, the Connors Creek PS includes storm water pumps that discharge wet weather flow rates into the Connors Creek outfall and into the downstream Connors Creek Pilot CSO Basin.

The Fox Creek Enclosure and the DWSD-owned Ashland sewer are tributary to the Fox Creek regulator gates. The Fox Creek Enclosure transports wastewater from the SEMSD, the MRIDDD, the City of Grosse Pointe Farms, Grosse Pointe Shores and the City of Grosse Pointe.

The Bluehill PS discharges combined wastewater from the Cornerstone area of the city of Detroit into the Fox Creek and Mack Avenue Relief sewers. The Bluehill PS has sanitary pumps that operate in dry weather and low flow conditions and storm pumps that operate in wet weather.

The CCE is a large triple box conduit from Warren to Jefferson avenues. The CCE ends at the forebay structure that is a large junction and includes regulator gates that discharge into the DRI and nine parallel in-system storage gates that discharge into an outfall conduit that runs into the Connors Creek Pilot CSO Basin. The Connors Creek Pilot CSO Basin was constructed and placed into service in about 2010.

The Freud PS receives wastewater from the Ashland Relief sewer and from the Fox Creek Relief sewer. There is an overflow structure on the East Jefferson Relief sewer at Algonquin and Jefferson that overflows into the Ashland Relief sewer whenever the Connors Creek PS storm wet well level exceeds about elevation 68 feet. Also, there is an overflow weir in a structure at Manistique and Jefferson that overflows toward the Freud PS whenever the upstream hydraulic grade line elevation exceeds about 68.5 feet. Therefore, the Connors Creek PS and Freud PS are hydraulically interconnected at wet well levels greater than about 68 feet.

There is a small amount of dry weather wastewater that is pumped by the sanitary/dewatering pumps to the East Jefferson Relief sewer at the Freud PS. The Freud PS also includes storm water pumps that discharge into the Connors Creek Pilot CSO Basin.

There are combined and storm sewers in Detroit, Harper Woods, SEMSD, and the cities of Grosse Pointe, Grosse Pointe Farms, and Grosse Pointe Woods that are tributary to Connors Creek, Freud and Bluehill PSs. In general, the combined sewers were designed to convey the flow rates generated by a 10-year design storm. Nearly all of these combined sewers were built prior to 1960 and no significant relief sewers have been built since. The combined sewers discharge dry weather and low wet weather and dewatering flow rates to GLWA generally within existing flow limits. Further, SEMSD and MRIDDD have CSO basins that can overflow in wet weather.

A detailed schematic of the eastside Detroit facilities is shown in Figure 62.

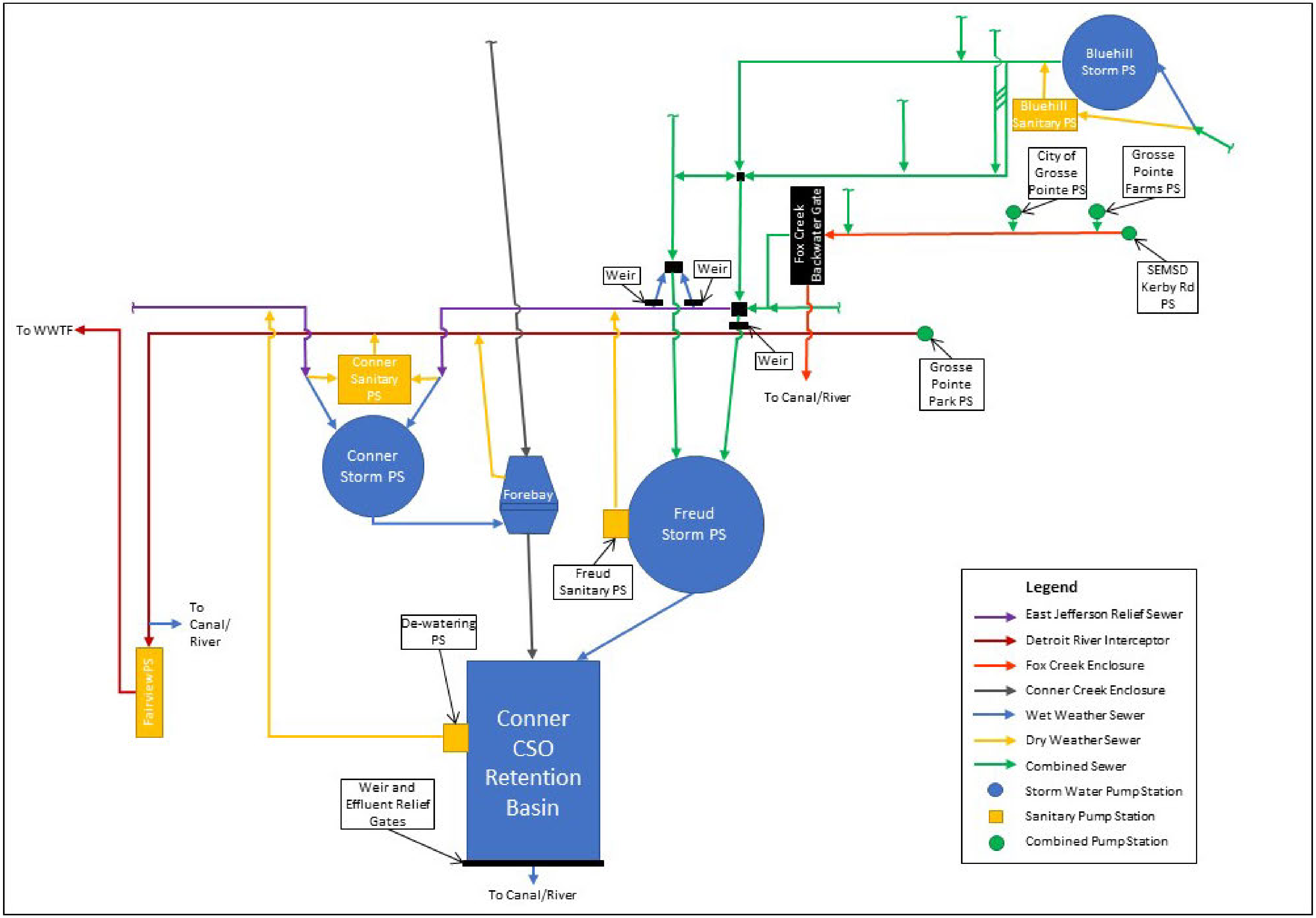


Figure 62: Eastside Collection System Facilities Schematic

C.2.2 Storm Water Modeling Background

The storm water flow rates in combined sewers are significantly higher than the sanitary flow rates. Consequently, the expected storm water flow rates usually dictate the size and slope of the required combined sewer pipe.

The storm water flow rates are estimated using the Rational Formula. For each pipe, the drainage area, percent impervious, and the time of concentration are estimated. The time of concentration (T_c), is the time for the peak runoff rate from the remotest part of the drainage area to reach the point of interest. The T_c includes the time for runoff to flow over the land surface, in the gutters of the streets and in any upstream combined sewer. Larger drainage areas will have larger T_c values. The combined sewer drainage areas in Detroit generally have T_c values between 15 minutes and 3 hours.

The peak runoff flow rate is then estimated with an equation:

Q = C x I x A,
Where C = the runoff coefficient (or percent impervious),
I = the rainfall intensity in inches/hour, and
A = the drainage area in acres.

A 10-year rainfall IDF relationship is used to obtain the value of rainfall intensity, I. Because nearly all of the combined sewers were designed prior to 1960, the relationships from TP-25 were likely used for Detroit.

When using an IDF relationship, the duration equals the T_c, and the rainfall intensity decreases with increasing Tc. For a 15-minute Tc, the rainfall intensity, I, used in the design of the combined sewer equaled about 4.5-inches/hour. For a 1-hour T_c, the rainfall intensity, I, used in the design of the combined sewer equaled about 2.0-inches/hour. For a 3-hour T_c, the rainfall intensity, I, used in the design of the combined sewer equaled about 0.85-inches/hour.

Therefore, whenever the rainfall depth versus time exceeds a 10-year IDF for durations less than about 3 hours, the combined sewers capacities may be insufficient. When this occurs, the combined sewers surcharge and create upstream backwater. The surcharging and backwater created will occur even if there are free discharge conditions downstream. However, if there is downstream backwater due to PS issues, then the surcharging and backwater would be even higher.

Multiplying the Tc duration with the rate per hour, the rainfall for combined sewer overloading is approximately:

1.1-inches in 15-minutes,
2.0-inches in 1-hour, or
2.6-inches in 3-hours.

These rainfall criteria were exceeded for most of the combined sewer areas in Metro-Detroit during the June/July 2021 Rainfall Events.

C.3.2.1 General Approach

The June/July 2021 Rainfall Events caused basement flooding in upwards of 30,000 residences, many of these homes are served by a collection system tied to GLWA's Connors Creek RTB. The Connors Creek RTB was designed to accept wet weather flows from an extensive network of gravity main including the Connors Creek Enclosure as well as the Connors Creek and Freud storm PSs.

The AECOM team modeled the GLWA and DWSD combined sewer collection systems and pumps for the June/July 2021 Rainfall Events to determine the extent of flooding during these storms. To do this, AECOM obtained an EPA SWMM model (GLWA_RWCS_EXC_20210831_ASI_Updates.inp) of the GLWA collection system with permission from GLWA through ASI and built a HEC-RAS 2D model. During the June/July 2021 Rainfall Events, various storm PSs did not have all pumps in operation.

The EPA SWMM model (GLWA_RWCS_EXC_20210831_ASI_Updates.inp) of the GLWA collection system represents the area upstream of Fairview PS in the city of Detroit and consists primarily of the large trunk main sewers and facilities that are operated by GLWA. The model flows include tributary hydrology (overland storm water flow) and sanitary inflows that are handled by the sewers. The EPA SWMM model belongs to GLWA and it includes relevant GLWA infrastructure.

ASI was contracted by GLWA to use the model to assist in design, operations, and updating the systems. Before AECOM received the model on October 1, 2021 to use it for the analysis here, there were subsequent updates based on issues identified by AECOM. Therefore, the following updates were completed and included by ASI:

The Fairview PS operational flows were updated to match the current operation while the PS was being upgraded.

Hydrographs representing the flows over time from the suburban customer connections were set as model inputs from gauge data. These included the Grosse Pointe Park PS, Grosse Pointe (Neff) PS, and Grosse Pointe Farms PS (with Dearborn and SEMSD exceptions). It is understood that ASI obtained this information from the GDRSS billing flow meters. Some of these data points are based on when the pumps were operating and wet well levels.

The pump curves at Connors Creek and Freud PSs conveyed higher flows then could be accommodated by wet well depth data provided. To accurately represent the wet well data, the pump curves were reduced by 20 percent to match.

The head loss curve at the outlet from the Fox Creek Backwater Gates was modified to more accurately represent the surface flooding documented upstream in the Fox Creek Enclosure.

The head loss curve for outfall B001 was updated to include frictional losses through the Fox Creek Canal that flows to the Detroit River.

After receiving the EPA SWMM model from ASI, the AECOM team used PCSWMM so that surface flood depths could be predicted with the 2D capabilities of the proprietary version. To do this, 2017-2018 SEMCOG lidar data representing the ground elevations in the area upstream of Fairview PS in Wayne County was acquired and used as a base and a 2D mesh in the model was created.

Pump operations data from the SCADA systems for the June 1 to July 31, 2021 was obtained for Connors Creek, Freud, Bluehill PSs. SCADA system data were from the computer systems that control the number, timing, and monitor these pumps and include the number of pumps operating and wet levels over time. These timeseries collected for the period from June 1 to July 31, 2021 were added to the model to accurately represent what occurred during the June/July Rainfall Events. The PCSWMM model including the SCADA system timeseries is referred to as the ACTUAL scenario because it includes the actual operation of the pumps during these storm events.

The AECOM team conducted further hydraulic analysis to show the capability of the pumps to determine if a possible reduction in flooding was possible if the Connors Creek, Freud, and Bluehill PSs had functioned as intended during the June/July 2021 Rainfall Events. The flood volumes and any additional flood volumes that could have been pumped were determined. The model for this analysis and results that use these standard operations of the PSs is referred to as the PCSWMM IDEAL scenario. This analysis uses the following updates to the model in place:

SCADA system data during the June 1 to July 31, 2021 for Connors Creek, Freud, Bluehill PSs were removed. Pump operations data from the SCADA systems for the June 1 to July 31, 2021 were included in the PCSWMM ACTUAL model simulation to accurately represent what occurred during the June/July 2021 Rainfall Events. To show the capability of the pumps in terms of additional flood volumes that could have been pumped if the Connors Creek, Freud, and Bluehill PSs had functioned as intended during the June/July 2021 Rainfall Events, the PCSWMM ACTUAL model was modified by removing the SCADA system timeseries pump controls.

Standard operations for Connors Creek, Freud, and Bluehill PSs used. The standard operations for three PSs were included in the original EPA SWMM model (GLWA_RWCS_EXC_20210831_ASI_Updates.inp) of the GLWA collection system provided by GLWA via ASI and used in this PCSWMM IDEAL model scenario.

Accurate representation of the wet well data to show the reduction of pump capacity by 20 percent is needed. The pump curves at Connors Creek and Freud PSs conveyed higher flows than could be accommodated by wet well depth data provided. To accurately represent the wet well data, the pump curves were reduced by 20 percent to match actual wet well levels.

C.3.2.2 Model Update Documentation

The Regional Wastewater Collection System model version was provided to AECOM from GLWA by Applied Science Incorporated. The following updates were made by ASI/AECOM:

- Fairview PS was updated to provide the current temporary pumping operation in effect during ongoing construction
- A 2D mesh was created for area of interest to better describe the overland flow
- The maintenance hole rim elevations were evaluated and updated in specific cases to match Lidar in the 2D mesh area
- Boundary condition files for the June/July 2021 storm event period were added to simulate the system events with real time event files
- Rainfall for June/July storm event period
- Storm and Sanitary Pump on/off settings for all pumps in the Connors Creek, Freud, and Bluehill PS

C.3.2.3 Fairview PS Adjustments

SCADA system logs during the event to better understand the timing of the Fairview pumps operation can be found in the report titled *Summary and Review of Data Collected for the Storms of June 25-26 and July 16, 2021, For the Great Lakes Water Authority Board of Directors Ad Hoc Committee*, dated May 25, 2022, by Karen E. Ridgway, P.E. of Applied Science, Inc.

The existing model pumps were placed out of service. Additional facilities were added to the Detroit River Interceptor upstream of Fairview PS to allow the maintenance hole directly upstream of the Fairview PS to remain surcharged by 1 to 3 feet.

Information from the ASI report is quoted as follows:

> Meter DT-S-8 is on the DRI downstream of Fairview PS and is located along Jefferson Avenue near Holcomb Street (outside the Jeffersonian apartment building). The DRI at this location is an 11-feet diameter conduit and there is only one sewer connection at McClellan Street between Fairview PS and Meter DT-S-8. Therefore, most of the flow rate at Meter DT-S-8 is discharge from the Fairview PS.

For the storm of June 25/26 Rainfall Event, the peak depth reached at Meter DT-S-8 was about 16 feet. Even though DRI depths were significantly greater than the eight-tenths point, a decision was made to continue pumping, except for two short duration shutdowns. The pumping records provided by the temporary bypass pumping contractor, Mersino Dewatering, Inc. (MDI), showed the following pumping operations on June 25/26.

At about 9 p.m. on June 25, all pumps were briefly turned off.

From about 9 p.m. on June 25 through 1 a.m. on July 26, two pumps were operating.

At about 1 a.m. on June 26, all pumps were briefly turned off.

From about 1 a.m. through about 7:25 a.m. on June 26, three pumps were operating.

From about 7:25 a.m. through about 9:30 a.m. on June 26, two pumps were operating.

From about 9:30 a.m. through about 3:30 p.m. on June 26, only one pump was operating.

From about 3:30 a.m. through about 5:30 p.m. on June 26, two pumps were operating.

Full pumping resumed at about 5:30 p.m. on June 26.

For July 16 Rainfall Event, the peak depth reached at Meter DT-S-8 was about 13.5 feet. Even though DRI depths were greater than the eight-tenths point, a decision was made to continue pumping through the peak of the storm. The pumping records provided by MDI showed the following temporary bypass pumping operations on July 16.

From about 9:40 a.m. to about 11:20 a.m., three pumps were operating.

From about 11:20 a.m. to about 12:15 a.m., only one pump was operating.

At about 12:15 p.m., all pumps were briefly turned off.

From about 12:15 a.m. to about 4:45 p.m., only one pump was operating.

From about 4:45 p.m. to about 7:15 p.m., no pumps were operating.

From about 7:15 p.m. to about 8:45 p.m., only one pump was operating.

From about 8:45 p.m. on July 16 to about 12:00 p.m. on July 17, two pumps were operating.

Full pumping resumed at about 12:00 p.m. on July 17.

The wet well depth at the temporary Fairview PS was measured with three level sensors by MDI. For the storm of June 25/26 Rainfall Event, the wet well level rose above the estimated Detroit River level for about 45 minutes during the peak of the storm (Figure 15). During this timeframe, the peak wastewater elevation was only about 2 to 3 feet below ground levels at the Fairview PS. This suggests that the backwater gates opened on the surge overflow along the boat canal and CSO occurred during the 45 minute timeframe. There are no proximity switches on these backwater gates that would confirm this CSO discharge.

Also, the Fairview PS wet well level increased and the bulkhead(s) that were isolating the Fairview PS from the DRI were reported to have failed and flooding of the wet and dry wells occurred.

For the storm of July 16 Rainfall Event, the wet well level rose to about elevation 88 feet (Figure 16). No CSO occurred from the backwater gates on the surge overflow on the DRI upstream of Fairview PS for the storm of July 16 Rainfall Event because the Detroit River levels were above 97 feet during this storm.

The SCADA system logs for Meter DT-S-8 and wet well levels for the Temporary Fairview PS Wet Well are shown in Figure 13 through Figure 16 of the ASI Report.

C.3.2.4 Create 2D mesh for Area of Interest

A 2D mesh was necessary to better understand how the overland flow of water contributed to flooding experienced during both events under investigation. A 2D mesh the extent of the model limit could have been used but would require long model runtimes with a majority of the area evaluated not contributing value to the analysis of the area of interest. Thus, AECOM determined the Area of Interest (AOI) for the 2D Mesh with the following procedure.

1. The model was run as provided by ASI for June 25/26 Rainfall Event with all facilities under standard operations.
2. The model was rerun model for June 25/26 Rainfall Event with pumps controlled identical to the SCADA system recorded on and off data.
3. The two model were used to identify the extent of flooding based on flooded maintenance holes.
4. The rim elevations were analyzed and corrected based on lidar in area tributary to Connors Creek RTB.
5. Each model from step 1 and 2 were rerun to find maintenance holes and to confirm the extent of flooding with the updated manhole rim elevations.
6. The boundary for the 2D mesh was then created based on all facilities upstream of the outfalls that receive flow from the flooded maintenance holes found in step 5.
7. A 2D nodes layer was create using the boundary created in step 6. This was done with an initial cell resolution of 30, 150, and 250 feet. A subsequent sensitivity analysis was done and the 150-foot resolution was used for this analysis. The 30-foot cell resolution was so small that the mesh took more than 5 hours to create and the run time would have been prohibitively long.
8. A downstream boundary condition was created with the Detroit River and the downstream eastern edge of the AOI.
9. The 2D cells were created with the AOI boundary, the downstream boundary, and the 2D nodes layer. The buildings were modeled as obstructions.
10. The storage above manholes in the bounded area was deleted to prevent double counting of storage.
11. The 2D Mesh was connected to the 1D nodes using 5-square-foot orifices in the sewers that are directly connected to catch basins; the large relief sewers and Fox Creek Enclosure are only connected to the ground surface through the individual maintenance holes. At these locations, a 2-foot circular orifice was used.

This combination of mesh size and orifice connections seems has a runtime of approximately 40 hours and provides results that match relatively well with the available high water mark data.

C.3.2.5 Development of Boundary Condition Files

GLWA provided 5-minute SCADA system data from the Ovation™ Enterprise Data Solutions (EDS) for the following facilities to ASI:

Bluehill wet well level and pump on/off data

Connors Creek wet well level and pump on/off data

Freud wet well level and storm pump on/off data

ASI is developing a supplemental document detailing the updates made to the model prior to handing off the model for this evaluation. A list of SCADA system data used by ASI to update the model is provided in Table 38.

Table 38: GLWA-Provided SCADA System Data

Facility Name	Location	Units	Comments
CON DIR SEWER LEVEL	DRI at Connors Creek	feet	Depth
CON SAN WET WELL LVL	Sanitary Wet Well Level	feet	Elevation
CON STATION TOTAL FLOW	Unknown	feet	

Facility Name	Location	Units	Comments
CON STORM WET WELL LVL	Storm Wet Well	feet	Elevation
CON EAST JEFFERSON RELIEF LVL	East Jefferson Relief Sewer Level	feet	Elevation
FOREBAY LEVEL	Connors Creek Forebay Level	feet	Elevation
PUMP STATION 1 WETWELL LEVEL	PS-1 at the WRRF Level	feet	Elevation
WET WELL 1 LEVEL (ELEVATION)	Wet Well #1 at PS-2 at the WRRF	feet	Elevation
WET WELL 2 LEVEL (ELEVATION)	Wet Well #2 at PS-2 at the WRRF	feet	Elevation
SM62/DT-S-13 Flow in CFS	Connors Creek Enclosure Flow Rate at DT-S-13	cfs	

Notes:
cfs = cubic feet per second
WRRF = Water Resource Recovery Facility
Source: ASI

With the SCADA system data provided, time series data files were created and loaded into the model to control the storm and sanitary pumps at the three PSs. No sanitary pump information was provided for the Freud PS and was assumed to not be in operation during the wet weather events.

Finally, with the above updates, AECOM ran the model simulation during the June and July events to create a baseline for calibration.

C3 – Model Results

Additional results are provided in the main body of the report.

Table 39: At-Risk Water in Basement by Neighborhood

	ACTUAL Simulation (acres)		IDEAL Simulation (acres)	
Neighborhood	June 25/26	July 16	June 25/26	July 16
Airport Sub	1824	20	1827	20
Arden Park	66	0	66	0
Aviation Sub	301	0	301	0
Bagley	0	0	0	0
Barton-McFarland	1084	0	1084	0
Belmont	0	0	0	0
Berg-Lahser	0	0	0	0
Bethune Community	0	0	0	0
Blackstone Park	0	0	0	0
Boston Edison	309	0	309	0
Boynton	57	86	57	86
Brewster Homes	19	0	19	0
Brightmoor	100	6	101	6
Brush Park	52	11	52	10
Buffalo Charles	82	10	82	10
Butler	0	0	0	0
Cadillac Community	0	0	0	0

Neighborhood	ACTUAL Simulation (acres) June 25/26	ACTUAL Simulation (acres) July 16	IDEAL Simulation (acres) June 25/26	IDEAL Simulation (acres) July 16
Cadillac Heights	0	0	0	0
Campau/Banglatown	6	1	6	1
Carbon Works	75	139	75	139
Castle Rouge	0	0	0	0
Chadsey Condon	1115	22	1116	22
Chalfonte	41	0	40	0
Chandler Park	490	0	489	0
Chandler Park-Chalmers	121	0	121	0
Claytown	1500	429	1500	429
College Park	0	0	0	0
Conant Gardens	0	0	0	0
Connor Creek	336	22	322	22
Connor Creek Industrial	981	66	972	56
Core City	355	5	355	5
Corktown	359	273	359	273
Cornerstone Village	981	10	980	7
Crary/St Marys	37	0	37	0
Cultural Center	204	0	204	0
Davison	6	0	6	0
Davison-Schoolcraft	139	0	138	0
Delray	259	440	236	443
Denby	222	0	222	0
Detroit Golf	5	0	5	0
Dexter-Fenkell	197	0	197	0
Dexter-Linwood	1028	9	1028	9
Douglass	2	0	2	0
Downtown	199	58	197	57
East Canfield	70	0	70	0
East English Village	402	46	402	43
East Village	787	11	764	11
Eastern Market	213	143	213	143
Eden Gardens	382	0	382	0
Elijah McCoy	239	0	239	0
Eliza Howell	2	0	2	0
Elmwood Park	407	100	408	100
Evergreen Lahser 7/8	0	0	0	0
Evergreen-Outer Drive	0	0	0	0
Far West Detroit	248	0	248	0
Farwell	281	10	275	10
Fiskhorn	160	0	160	0

	ACTUAL Simulation (acres)		IDEAL Simulation (acres)	
Neighborhood	June 25/26	July 16	June 25/26	July 16
Fitzgerald/Marygrove	0	0	0	0
Five Points	0	0	0	0
Forest Park	264	72	264	71
Fox Creek	425	0	424	0
Franklin	126	0	123	0
Franklin Park	496	8	502	8
Garden Homes	0	0	0	0
Garden View	162	0	162	0
Gateway Community	287	1	287	1
Gold Coast	60	0	60	0
Grand River-I96	102	0	101	0
Grand River-St Marys	4	0	4	0
Grandmont	150	0	150	0
Grandmont #1	158	0	156	0
Grant	336	0	337	0
Gratiot Town/Ketterring	113	0	113	0
Gratiot Woods	289	0	289	0
Gratiot-Findlay	210	0	212	0
Gratiot-Grand	164	0	164	0
Greektown	23	1	22	1
Green Acres	4	0	4	0
Greenfield	0	0	0	0
Greenfield Park	3	0	3	0
Greenfield-Grand River	0	0	0	0
Greenwich	0	0	0	0
Grixdale Farms	10	0	11	0
Hamtramck	1232	754	1231	754
Happy Homes	0	0	0	0
Harmony Village	0	0	0	0
Hawthorne Park	1	0	1	0
Henry Ford	139	0	138	0
Herman Kiefer	162	0	162	0
Highland Park	1384	517	1383	519
Historic Atkinson	43	0	43	0
Holcomb Community	0	0	0	0
Hubbard Farms	52	58	52	58
Hubbard Richard	144	113	144	114
Hubbell-Lyndon	0	0	0	0
Hubbell-Puritan	0	0	0	0
Indian Village	156	0	156	0

	ACTUAL Simulation (acres)		IDEAL Simulation (acres)	
Neighborhood	June 25/26	July 16	June 25/26	July 16
Islandview	309	0	309	0
Jamison	155	0	155	0
Jefferson Chalmers	890	410	897	182
Jeffries	79	0	79	0
Joseph Berry Sub	53	15	53	15
Joy Community	630	0	630	0
Joy-Schaefer	179	0	179	0
Krainz Woods	36	0	37	0
Lafayette Park	107	81	107	80
LaSalle College Park	125	0	125	0
LaSalle Gardens	184	0	184	0
Littlefield Community	159	0	159	0
Malvern Hill	37	29	37	29
Mapleridge	810	0	797	0
Marina District	215	0	218	0
Martin Park	19	0	19	0
McDougall-Hunt	380	3	382	3
McDowell	0	0	0	0
McNichols Evergreen	10	0	10	0
Medbury Park	44	1	44	1
Medical Center	201	7	201	7
Mexicantown	71	7	71	7
Michigan-Martin	128	124	128	124
Midtown	521	96	522	91
Midwest	1712	11	1712	11
Miller Grove	65	0	64	0
Milwaukee Junction	249	114	249	114
Minock Park	2	0	2	0
Mohican Regent	78	0	29	0
Morningside	964	154	964	153
Moross-Morang	503	1	503	1
Mount Olivet	362	0	363	0
Nardin Park	478	17	478	17
New Center	49	1	49	1
New Center Commons	41	0	41	0
Nolan	2	0	2	0
North Campau	12	0	12	0
North Corktown	379	33	379	34
North End	597	7	597	7
North LaSalle	162	0	162	0

Neighborhood	ACTUAL Simulation (acres) June 25/26	ACTUAL Simulation (acres) July 16	IDEAL Simulation (acres) June 25/26	IDEAL Simulation (acres) July 16
North Rosedale Park	28	0	27	0
Northeast Central District	4	0	4	0
Northwest Community	2	0	2	0
Nortown	302	0	303	0
NW Goldberg	313	0	313	0
Oak Grove	0	0	0	0
Oak Grove	10	6	10	6
Oakman Blvd Community	907	0	907	0
Oakwood Heights	42	360	42	359
O'Hair Park	0	0	0	0
Old Redford	0	0	0	0
Outer Drive-Hayes	913	2	913	2
Palmer Park	12	2	12	2
Palmer Woods	16	12	16	12
Paveway	27	0	27	0
Pembroke	0	0	0	0
Penrose	2	1	2	1
Pershing	2	0	2	0
Petoskey-Otsego	266	0	266	0
Piety Hill	179	0	179	0
Pilgrim Village	261	0	261	0
Pingree Park	163	0	163	0
Plymouth-Hubbell	382	0	382	0
Plymouth-I96	77	0	76	0
Poletown East	528	72	528	72
Pride Area Community	62	0	62	0
Pulaski	123	0	119	0
Ravendale	134	0	134	0
Regent Park	789	1	771	1
Riverbend	713	49	716	40
Riverdale	9	3	9	3
Rivertown	285	230	285	230
Rosedale Park	146	0	145	0
Rouge Park	640	59	641	59
Russell Industrial	264	48	264	48
Russell Woods	195	0	195	0
San Bernardo	0	0	0	0
Schaefer 7/8 Lodge	0	0	0	0
Schoolcraft Southfield	196	0	195	0
Schulze	0	0	0	0

	ACTUAL Simulation (acres)		IDEAL Simulation (acres)	
Neighborhood	June 25/26	July 16	June 25/26	July 16
Seven Mile Lodge	0	0	0	0
Seven Mile-Rouge	69	63	69	63
Sherwood	308	0	308	0
Sherwood Forest	0	0	0	0
South of Six	0	0	0	0
Southfield Plymouth	7	0	7	0
Southwest	885	289	853	292
Springwells	466	546	457	546
State Fair	11	9	11	9
Tech Town	77	11	77	11
The Eye	0	0	0	0
Tri-Point	0	0	0	0
University District	1	0	1	0
Virginia Park	15	0	15	0
Von Steuben	92	0	95	0
Wade	334	16	334	16
Warren Ave Community	505	0	505	0
Warrendale	1192	19	1191	19
Waterworks Park	113	21	113	20
Wayne State	239	4	239	4
We Care Community	340	0	340	0
Weatherby	0	0	0	0
West End	714	1	714	1
West Outer Drive	0	0	0	0
West Side Industrial	361	405	361	405
West Village	89	0	89	0
West Virginia Park	20	0	20	0
Westwood Park	2	0	2	0
Wildemere Park	171	0	171	0
Winship	0	0	0	0
Woodbridge	300	0	300	0
Yorkshire Woods	292	0	292	0

C4 – Recommendations for Future Model Enhancements

The recommendations for the advancement of this analysis include the following tasks:

- Develop a detailed model to identify bottlenecks between the local system and the larger trunk sewers (ICM All-Pipe Model).
- Evaluate radar-rainfall products to determine if forecasts together with operational data such as water levels at key locations can be used to assess whether a particular storm has the potential to cause widespread water in basement and surface flooding as it is occurring.
- Use a detailed model to determine whether the collection system operation can be modified in real time to mitigate flooding if a particular storm that has the potential to cause basement flooding or surface flooding can be identified. Mitigation measures may potentially include lowering overflow weirs or employing more storm pumps.
- Use a detailed model to determine if additional relief could be implemented for large events (in excess of the 10-year storm).

Large storm events are occurring more and more frequently, these larger events are greater than the current system capacity. To determine the appropriate level of service for the GLWA infrastructure, the next set of evaluations need to include the determination of the corresponding rainfall depth/duration associated with that level of service.

APPENDIX D – BACKGROUND FOR RETROFIT OF CONNORS CREEK PS

D1 – Existing Connors Creek PS Systems

D1.1 – Worthington Volute Pump X-S Drawing

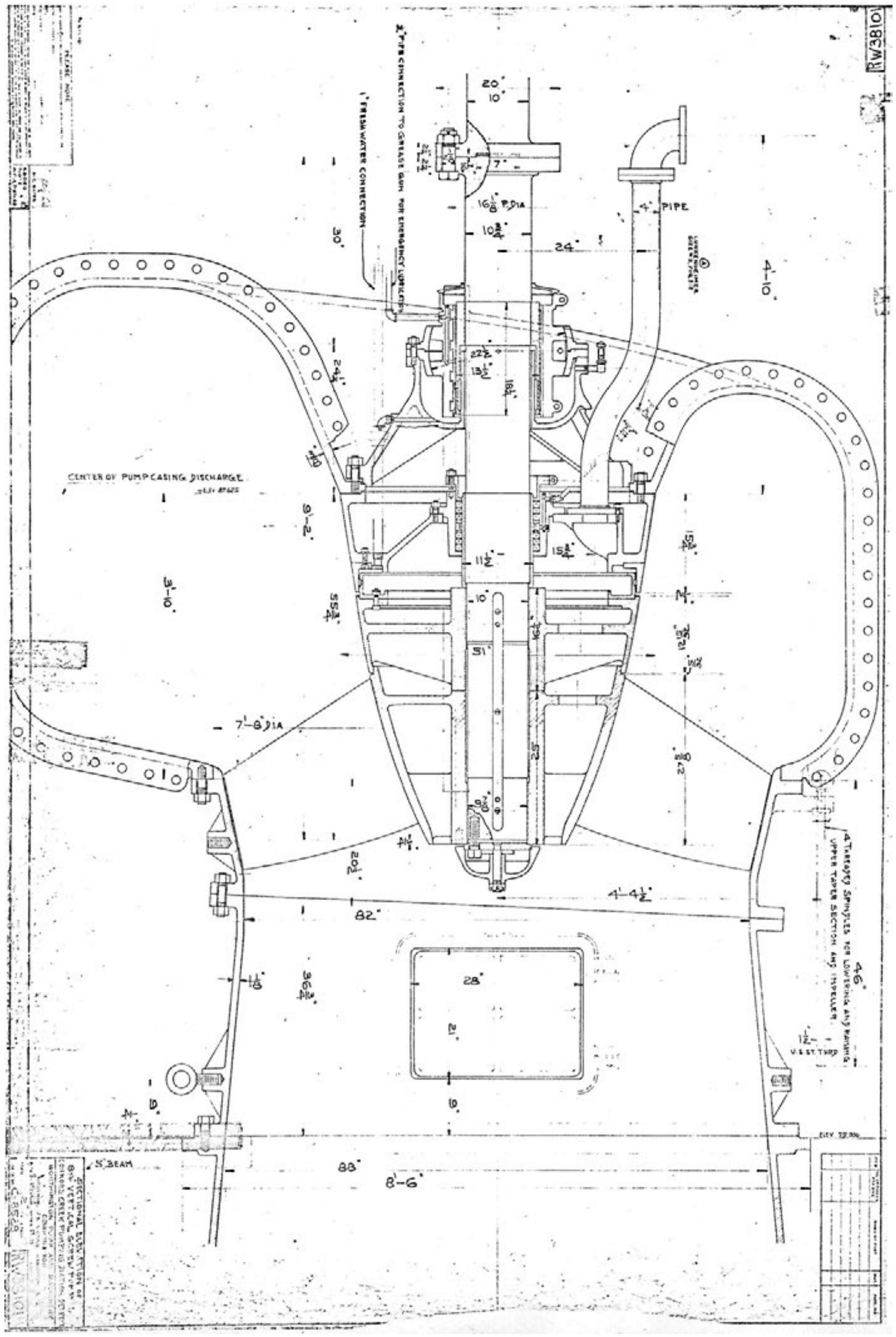


Figure 63: Connors Creek Stormwater Pumps – Worthington volute pump sectional assembly drawing

D1.2 – Seal Water Tank

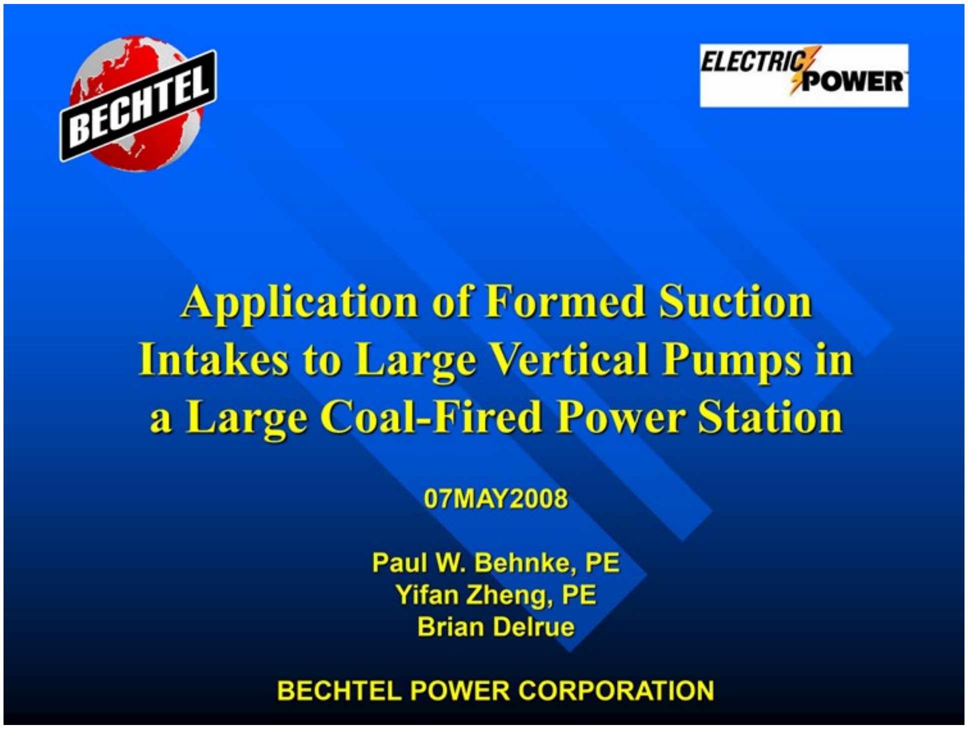
Figure 64: Seal Water Tank ~250 gallons (one tank for eight stormwater pumps)

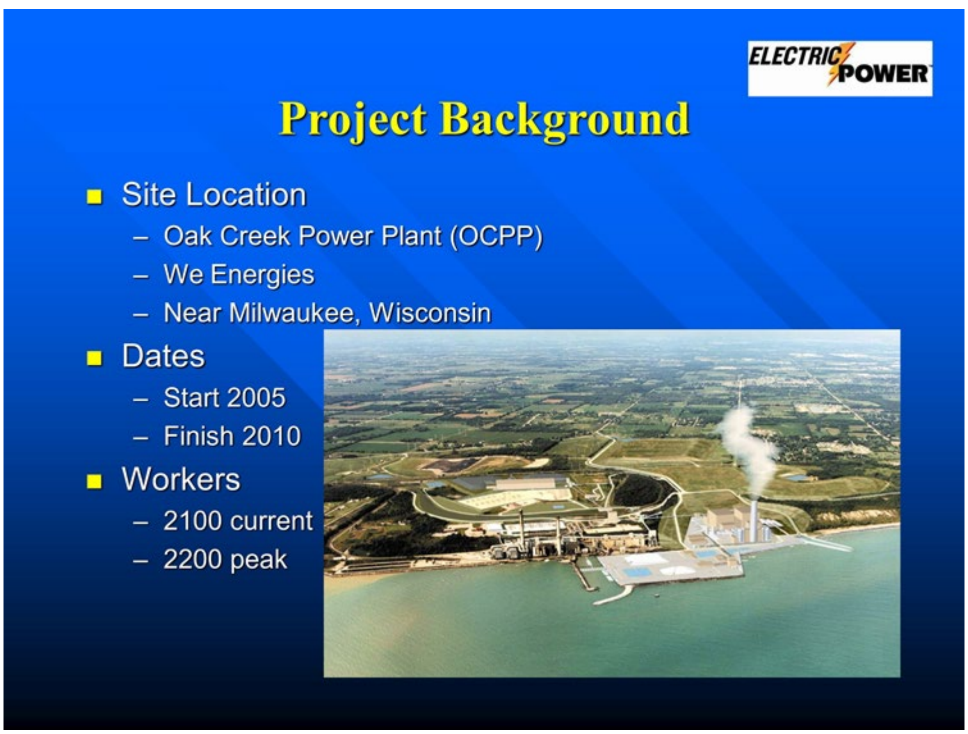
D1.3 – Vacuum System Piping

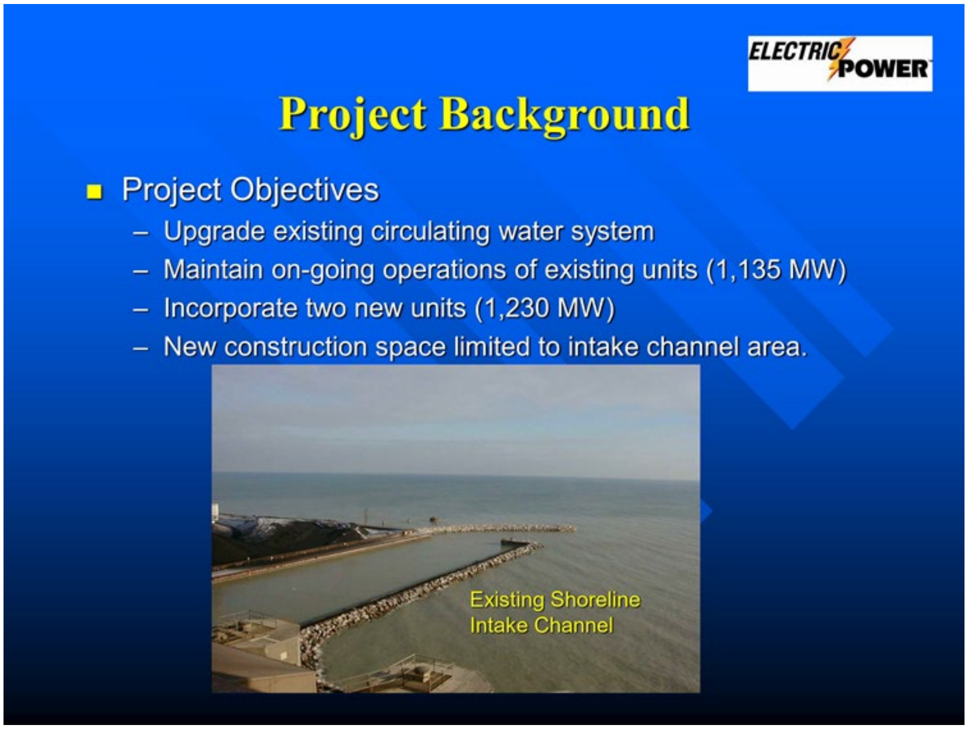
Figure 65: Vacuum System Piping New pipe transition to old pipe (heavy surface corrosion)

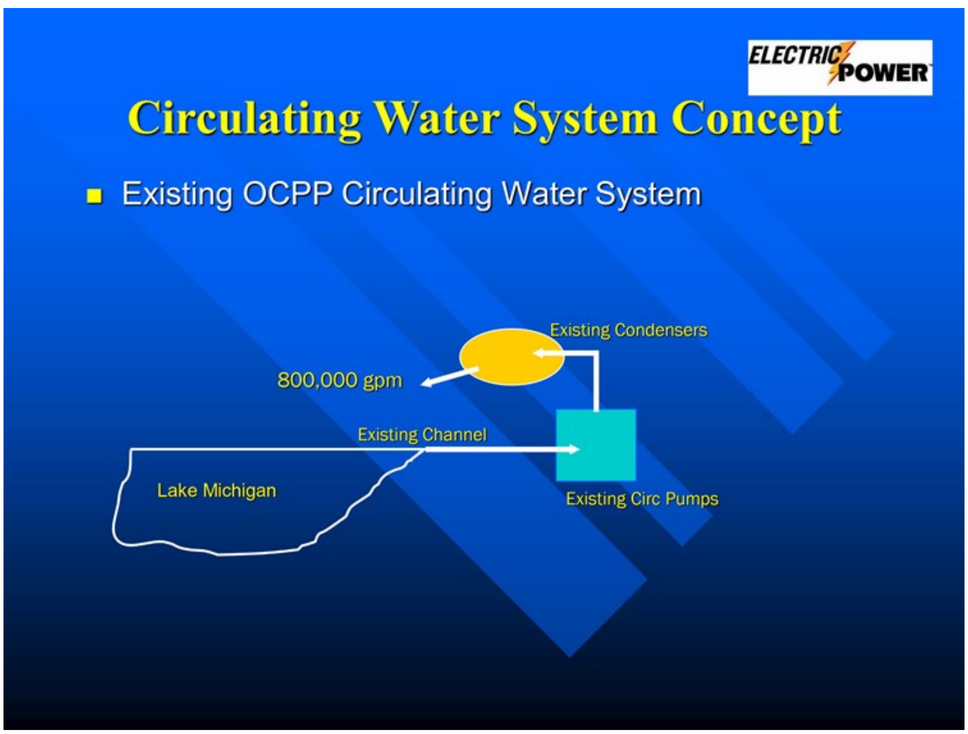
D2 – Connors Creek PS Retrofit

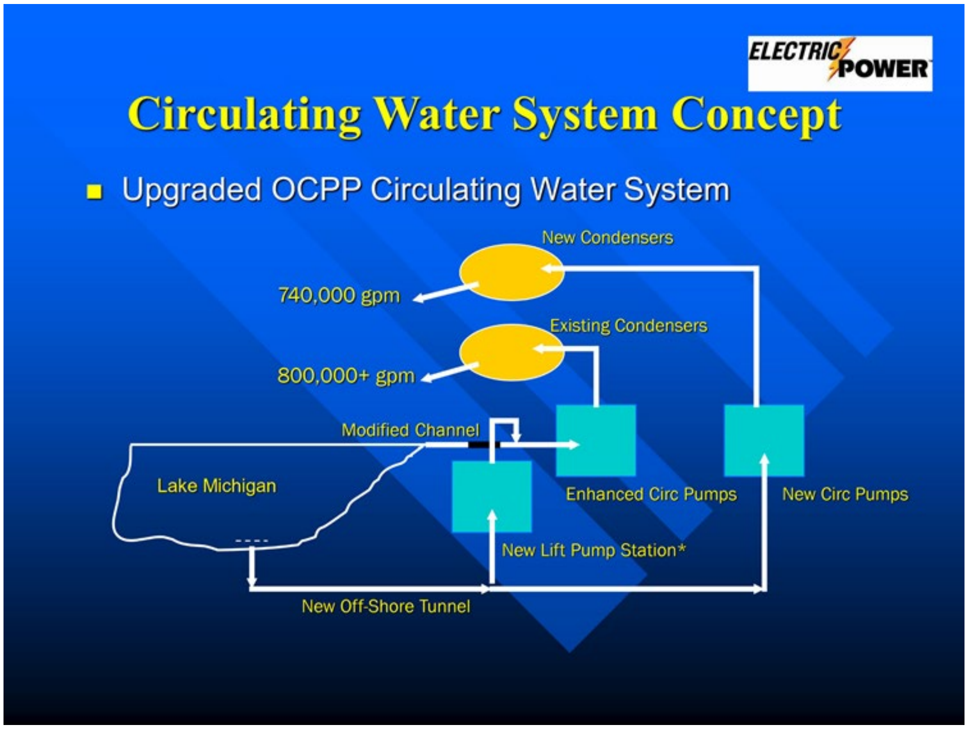
D2.1 – Type VS3i Pump Prior Example

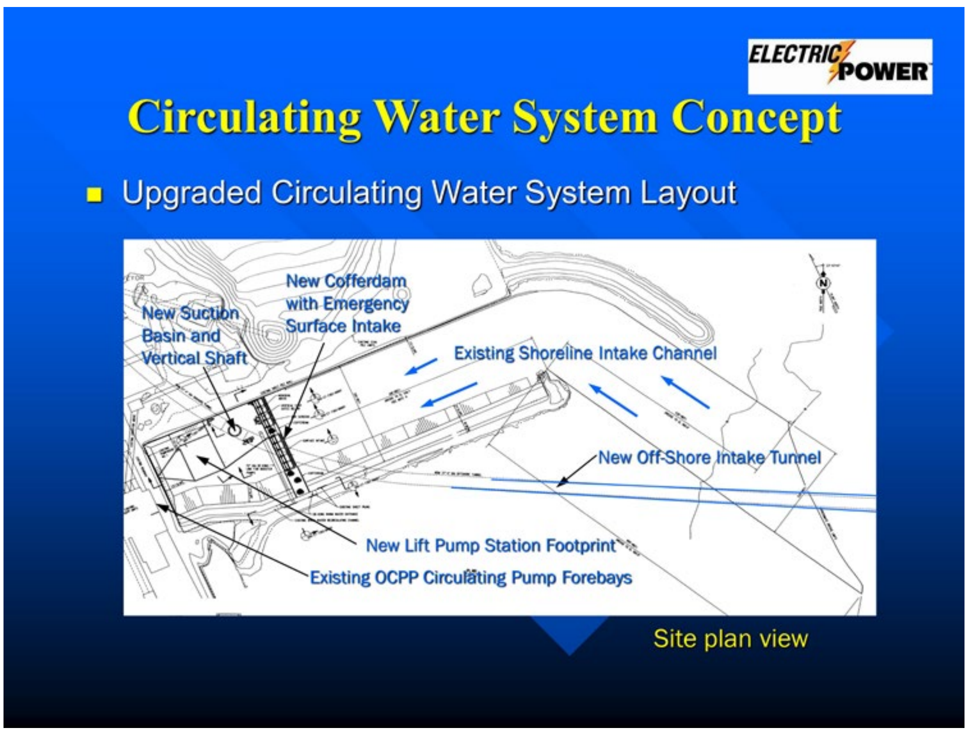


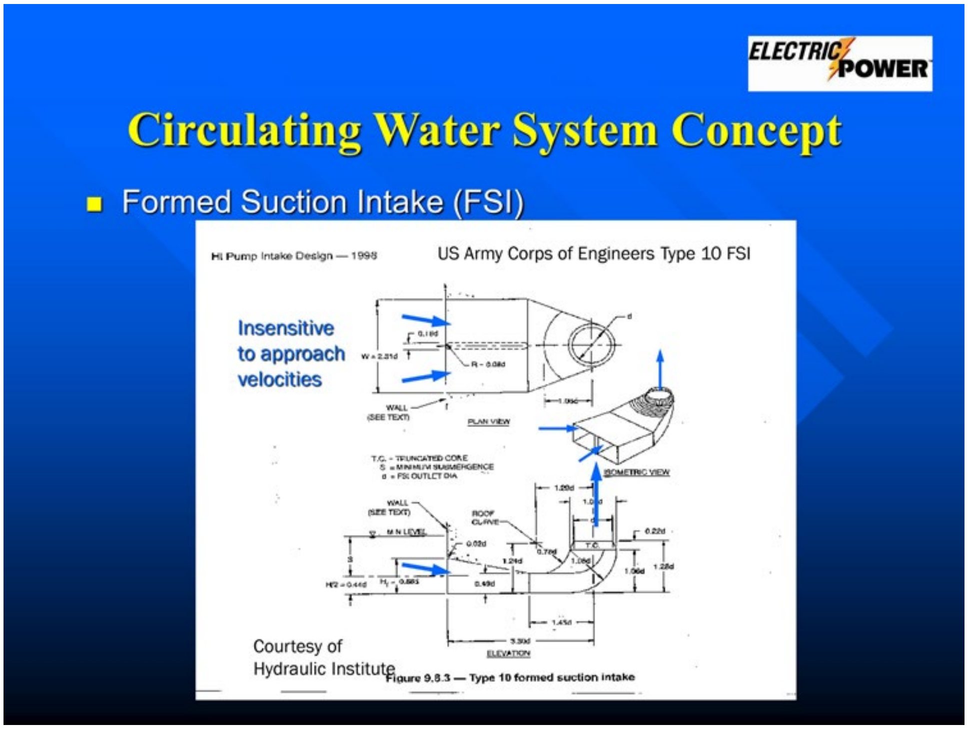


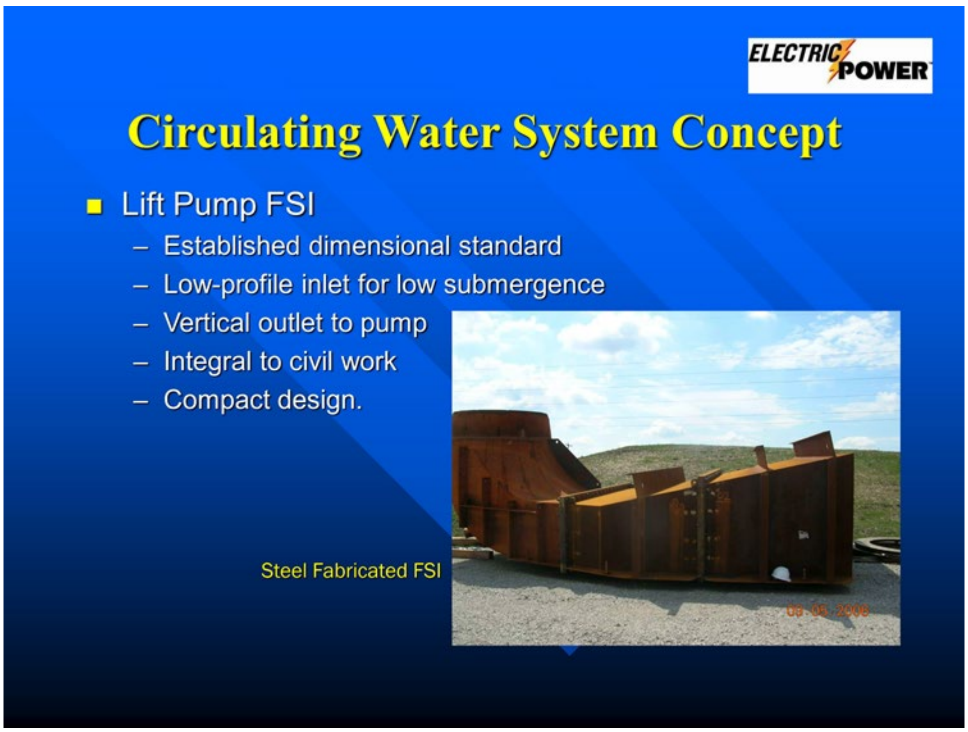

ELECTRIC POWER
Project Background
Project Objectives
– Upgrade existing circulating water system
– Maintain on-going operations of existing units (1,135 MW)
– Incorporate two new units (1,230 MW)
– New construction space limited to intake channel area.
Existing Shoreline
Intake Channel

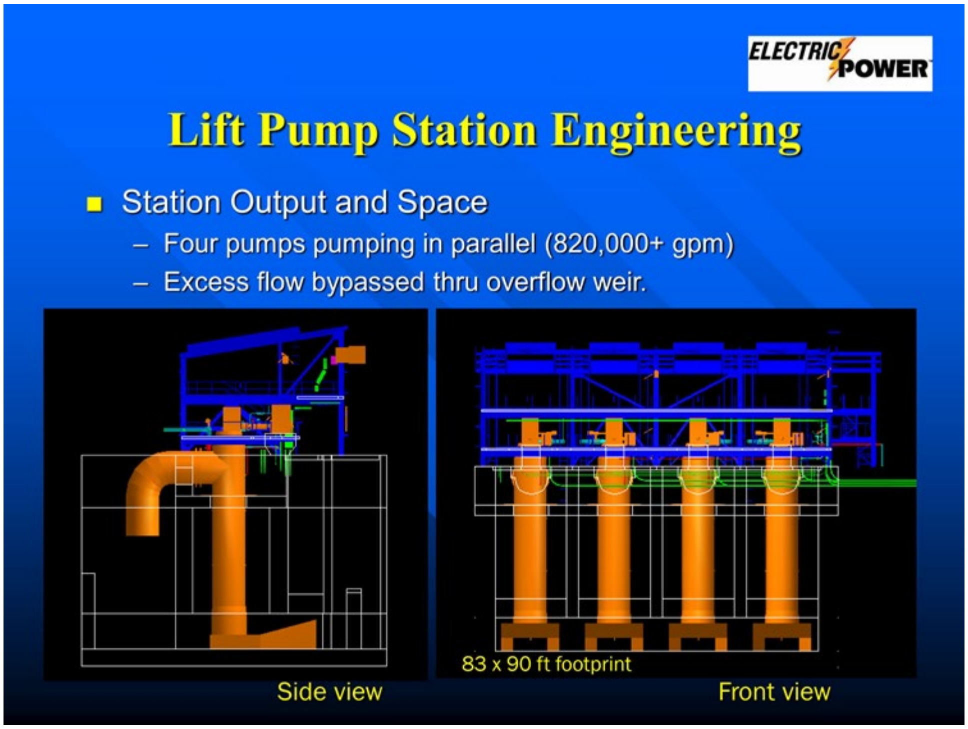

ELECTRIC POWER
Circulating Water System Concept
Existing OCPP Circulating Water System
Existing Condensers
800,000 gpm
Existing Channel
Lake Michigan
Existing Circ Pumps

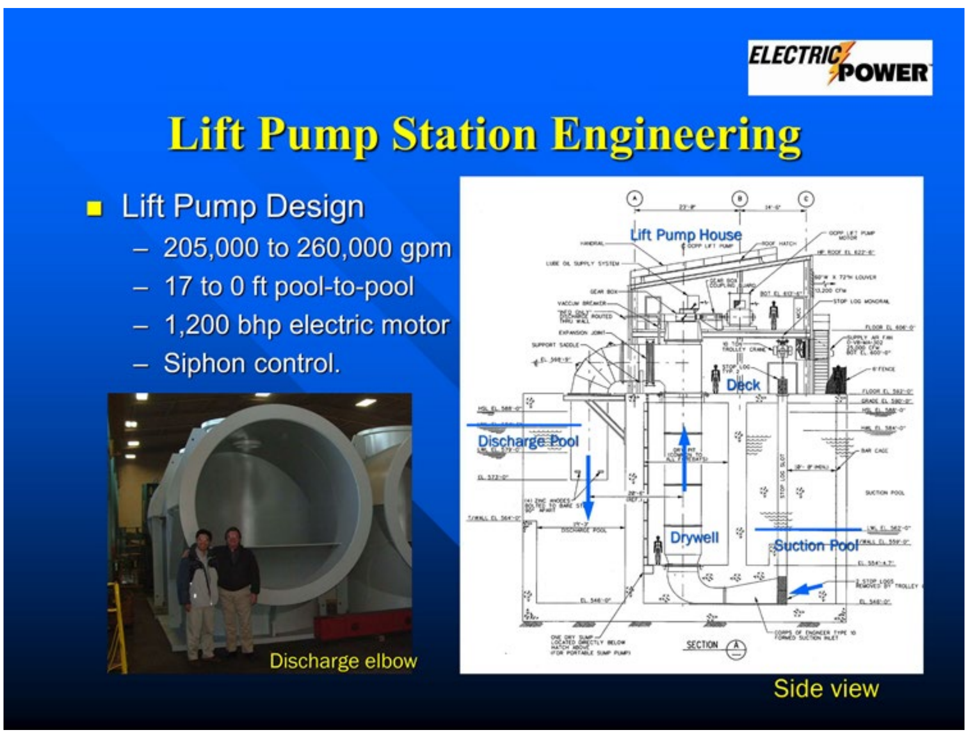

ELECTRIC POWER
Circulating Water System Concept
Upgraded OCPP Circulating Water System
New Condensers
740,000 gpm
Existing Condensers
800,000+ gpm
Modified Channel
Lake Michigan
Enhanced Circ Pumps
New Circ Pumps
New Lift Pump Station*
New Off-Shore Tunnel

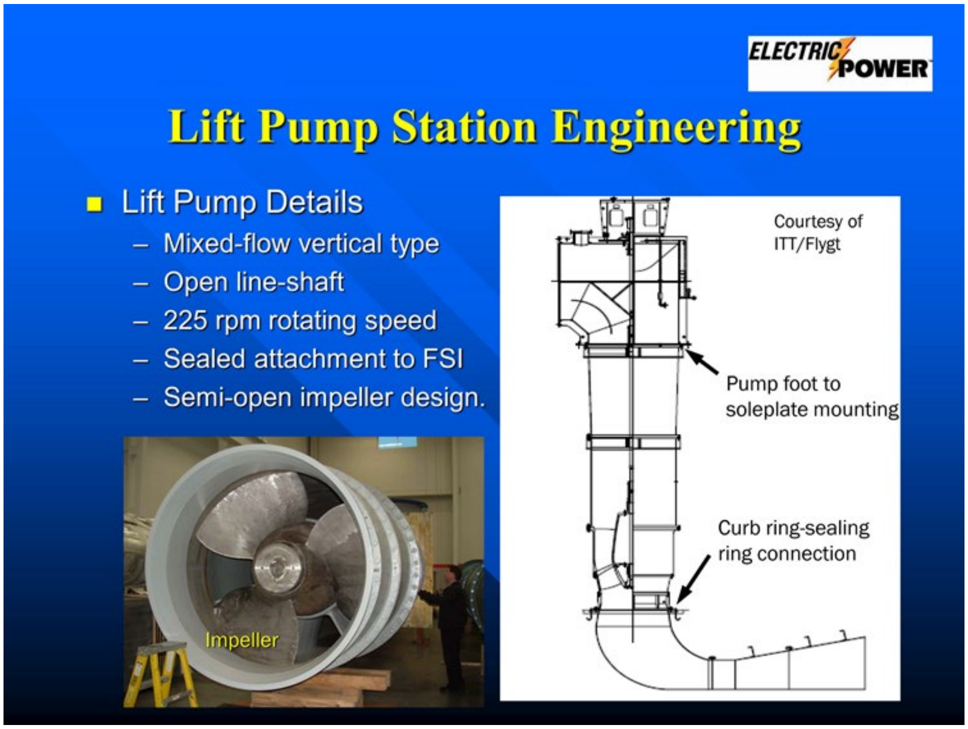

ELECTRIC POWER
Circulating Water System Concept
Upgraded Circulating Water System Layout
New Cofferdam with Emergency Surface Intake
New Suction Basin and Vertical Shaft
Existing Shoreline Intake Channel
New Off-Shore Intake Tunnel
New Lift Pump Station Footprint
Existing OCPP Circulating Pump Forebays
Site plan view

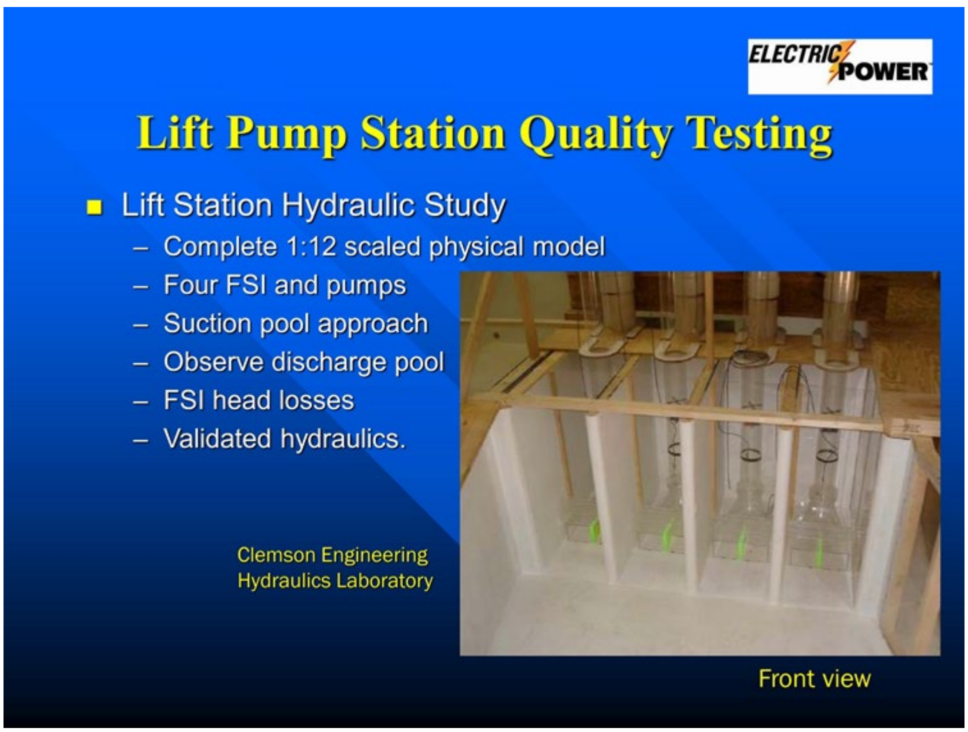

ELECTRIC POWER
Circulating Water System Concept
Formed Suction Intake (FSI)
HI Pump Intake Design — 1998
US Army Corps of Engineers Type 10 FSI
Insensitive to approach velocities
PLAN VIEW
ISOMETRIC VIEW
ELEVATION
Courtesy of Hydraulic Institute
Figure 9.8.3 — Type 10 formed suction intake

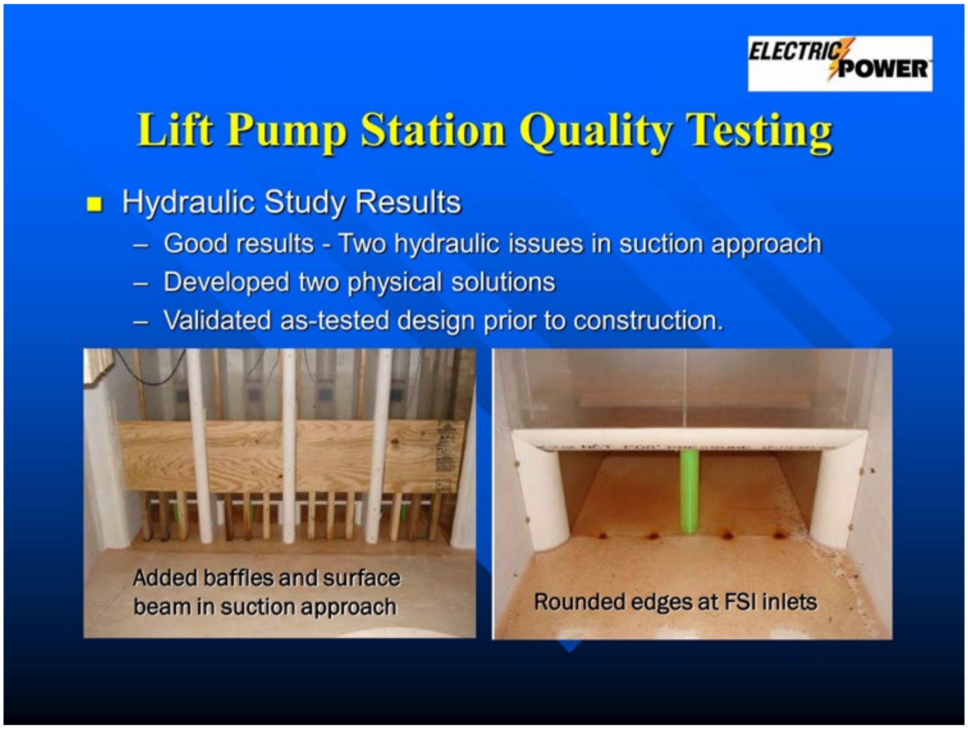

ELECTRIC POWER
Circulating Water System Concept
Lift Pump FSI
– Established dimensional standard
– Low-profile inlet for low submergence
– Vertical outlet to pump
– Integral to civil work
– Compact design.
Steel Fabricated FSI

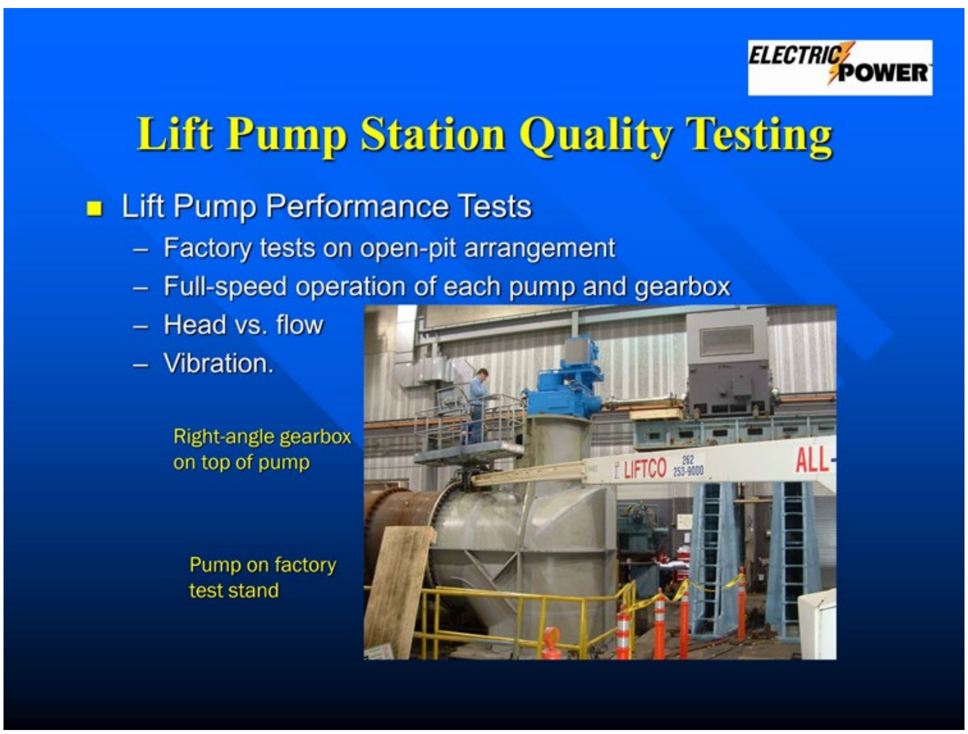

ELECTRIC POWER
Lift Pump Station Engineering
Station Output and Space
– Four pumps pumping in parallel (820,000+ gpm)
– Excess flow bypassed thru overflow weir.
83 x 90 ft footprint
Side view
Front view

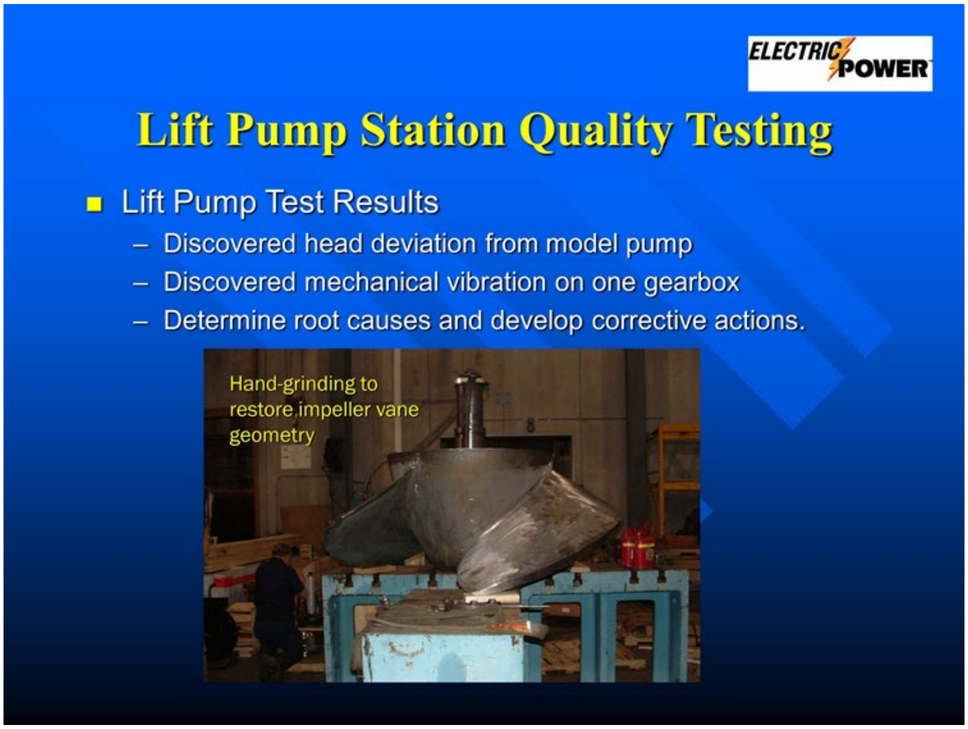

ELECTRIC POWER
Lift Pump Station Engineering
Lift Pump Design
– 205,000 to 260,000 gpm
– 17 to 0 ft pool-to-pool
– 1,200 bhp electric motor
– Siphon control.
Discharge elbow
Lift Pump House
Deck
Discharge Pool
Drywell
Suction Pool
Side view


ELECTRIC POWER
Lift Pump Station Engineering
Lift Pump Details
– Mixed-flow vertical type
– Open line-shaft
– 225 rpm rotating speed
– Sealed attachment to FSI
– Semi-open impeller design.
Impeller
Courtesy of ITT/Flygt
Pump foot to soleplate mounting
Curb ring-sealing ring connection


ELECTRIC POWER
Lift Pump Station Quality Testing
Lift Station Hydraulic Study
– Complete 1:12 scaled physical model
– Four FSI and pumps
– Suction pool approach
– Observe discharge pool
– FSI head losses
– Validated hydraulics.
Clemson Engineering Hydraulics Laboratory
Front view


ELECTRIC POWER
Lift Pump Station Quality Testing
Hydraulic Study Results
– Good results - Two hydraulic issues in suction approach
– Developed two physical solutions
– Validated as-tested design prior to construction.
Added baffles and surface beam in suction approach
Rounded edges at FSI inlets


ELECTRIC POWER
Lift Pump Station Quality Testing
Lift Pump Performance Tests
– Factory tests on open-pit arrangement
– Full-speed operation of each pump and gearbox
– Head vs. flow
– Vibration.
Right-angle gearbox on top of pump
Pump on factory test stand
LIFTCO


ELECTRIC POWER
Lift Pump Station Quality Testing
Lift Pump Test Results
– Discovered head deviation from model pump
– Discovered mechanical vibration on one gearbox
– Determine root causes and develop corrective actions.
Hand-grinding to restore impeller vane geometry


ELECTRIC POWER
Innovative Construction Execution
Brian Delrue – Bechtel Construction Engineer


ELECTRIC POWER
Innovative Construction Execution
Dock Sheet Piling
– Making land out of a lake.
Portion of channel isolated for lift pump station
Remaining open channel for operating OCPP units


ELECTRIC POWER
Innovative Construction Execution
Initial Civil Construction
Lift pump station foundation work
Vertical shaft from tunnel for suction approach
Cofferdam foundation work


ELECTRIC POWER
Innovative Construction Execution
FSI Fabrications Installed into Foundation Area
– Set, level, align, grout, inspect, & encase in concrete.


ELECTRIC POWER
Innovative Construction Execution
FSI Curb Ring Weld-up in Drywell Area
– Set, level, stitch weld, inspect, final weld, and grout.


ELECTRIC POWER
Innovative Construction Execution
Soleplate Set-up on Pump House Main Deck
– Four separate plates for each soleplate
– Position to FSI curb ring centerline locations.
Precision level work for vertical pumps

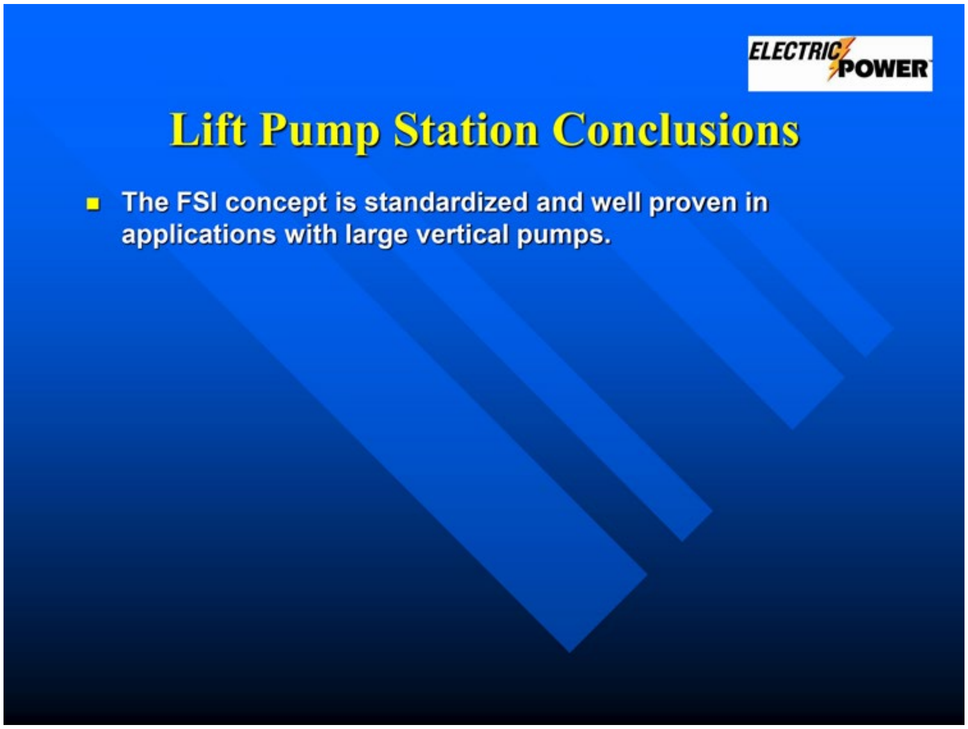

ELECTRIC POWER
Innovative Construction Execution
Lifting the Pumps to the Deck
1
2
3
Gantry crane to reduced ground bearing loads
12/07/2007 14:58

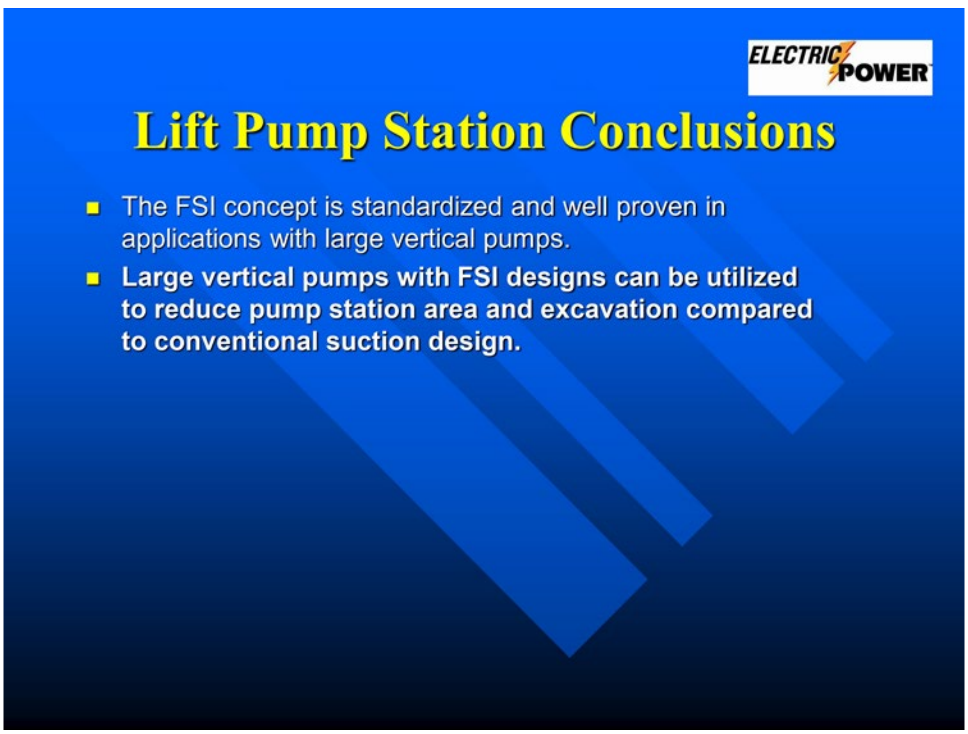

ELECTRIC POWER
Innovative Construction Execution
Setting the Pumps on the Deck
Pump set on soleplate
All four pumps installed in short order

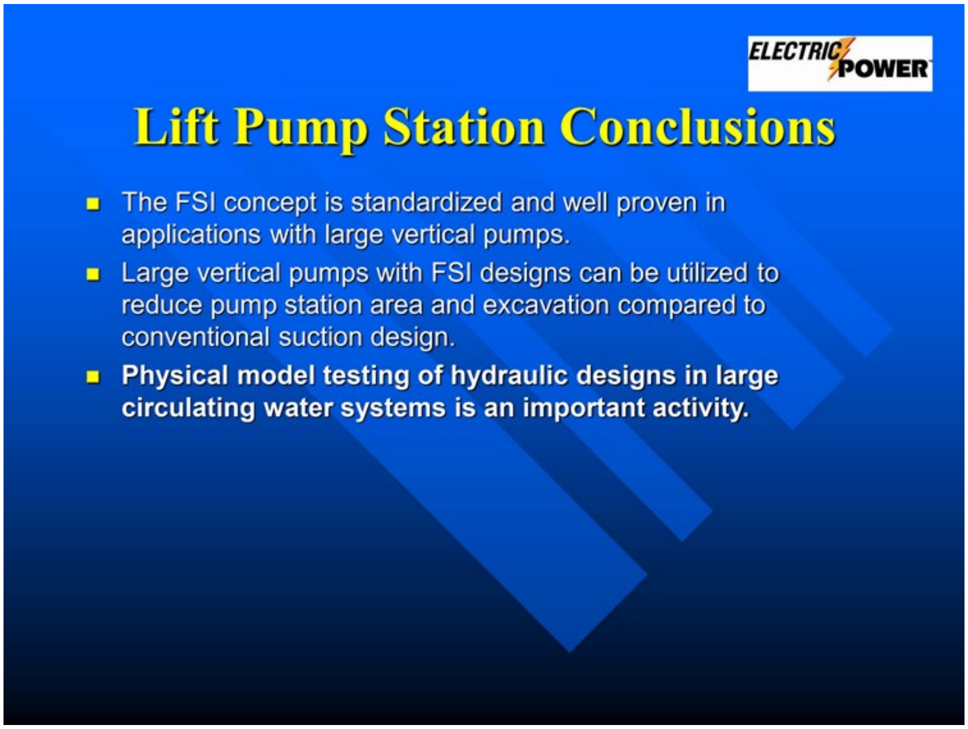

ELECTRIC POWER
Innovative Construction Execution
Bolting the Sealing Ring Tight in the Dry-Well
Installation flexibility and fit-up proved constructability of design

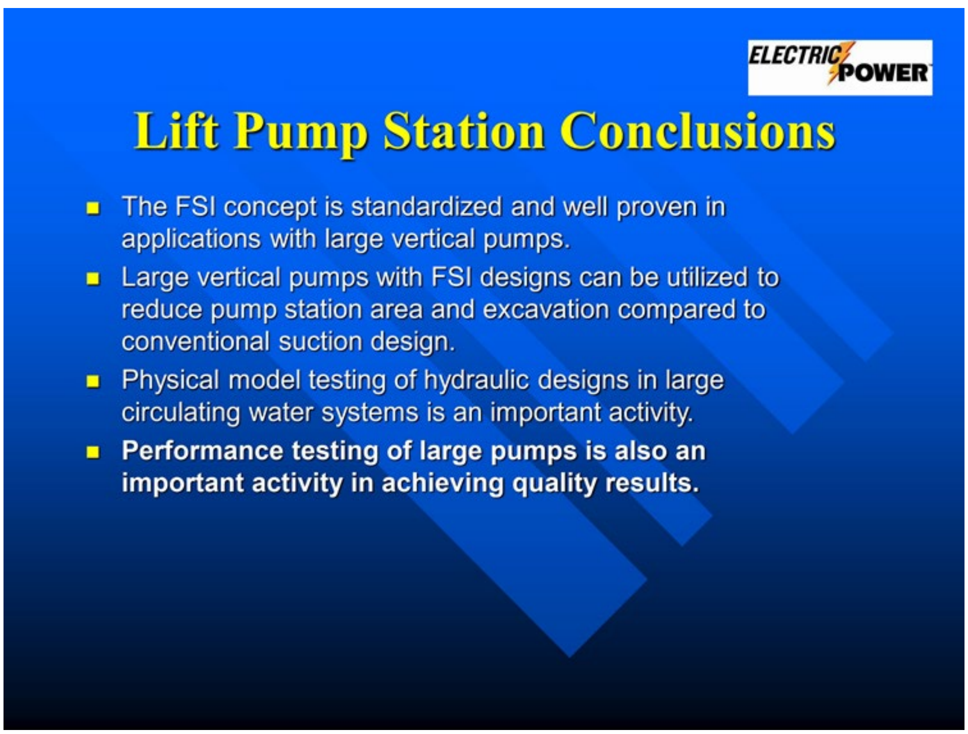

ELECTRIC POWER
Innovative Construction Execution
Installing the Discharge Pipes
Lifted as assemblies into position
Preassembled discharge spool, elbow, & draft tube


ELECTRIC POWER
Innovative Construction Execution
Work Performed in Wisconsin Winter Conditions
COLD temperatures; "bring your own Carhartt"


ELECTRIC POWER
Lift Pump Station Conclusions
The FSI concept is standardized and well proven in applications with large vertical pumps.


ELECTRIC POWER
Lift Pump Station Conclusions
The FSI concept is standardized and well proven in applications with large vertical pumps.
Large vertical pumps with FSI designs can be utilized to reduce pump station area and excavation compared to conventional suction design.


ELECTRIC POWER
Lift Pump Station Conclusions
The FSI concept is standardized and well proven in applications with large vertical pumps.
Large vertical pumps with FSI designs can be utilized to reduce pump station area and excavation compared to conventional suction design.
Physical model testing of hydraulic designs in large circulating water systems is an important activity.


ELECTRIC POWER
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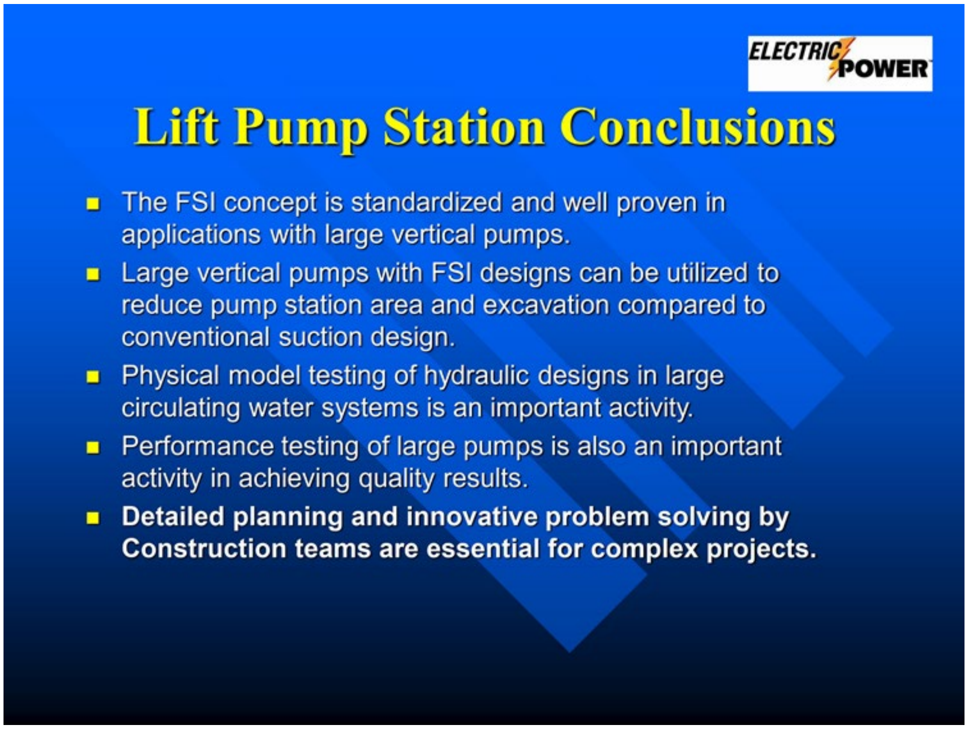
Performance testing of large pumps is also an important activity in achieving quality results.


ELECTRIC POWER
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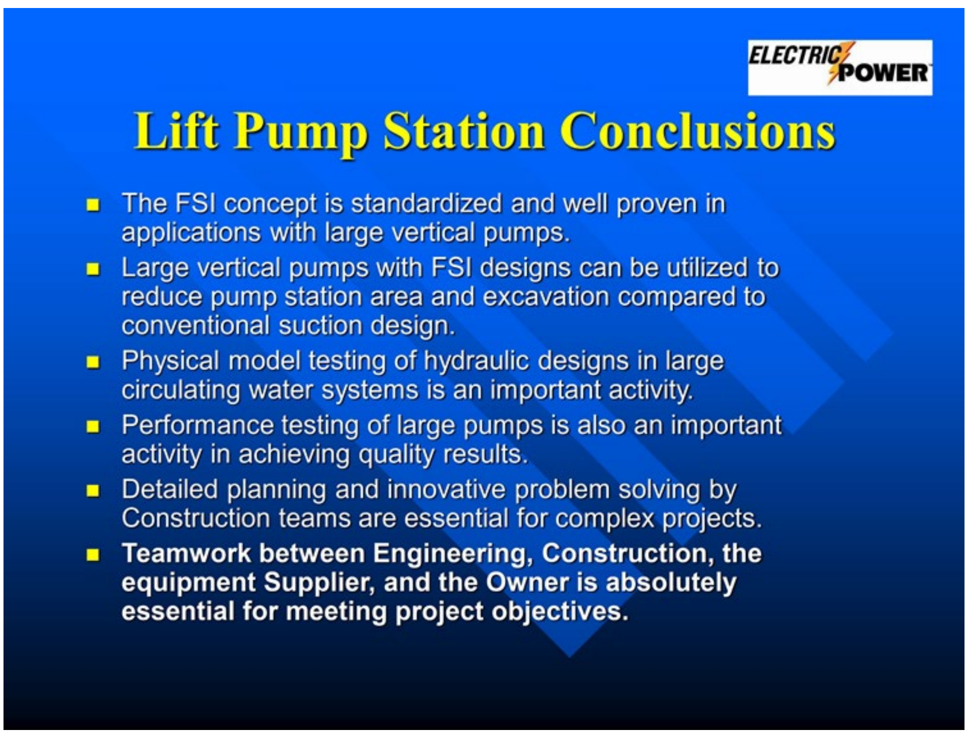
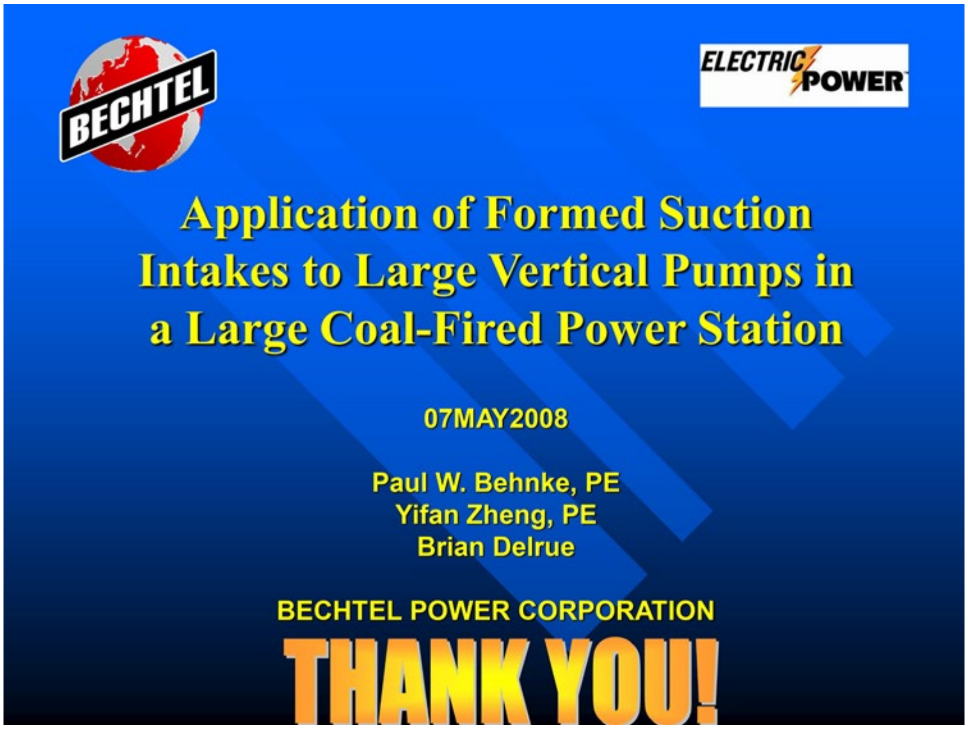
Performance testing of large pumps is also an important activity in achieving quality results.
Detailed planning and innovative problem solving by Construction teams are essential for complex projects.


ELECTRIC POWER
Lift Pump Station Conclusions
The FSI concept is standardized and well proven in applications with large vertical pumps.
Large vertical pumps with FSI designs can be utilized to reduce pump station area and excavation compared to conventional suction design.
Physical model testing of hydraulic designs in large circulating water systems is an important activity.
Performance testing of large pumps is also an important activity in achieving quality results.
Detailed planning and innovative problem solving by Construction teams are essential for complex projects.
Teamwork between Engineering, Construction, the equipment Supplier, and the Owner is absolutely essential for meeting project objectives.


BECHTEL
ELECTRIC POWER
Application of Formed Suction Intakes to Large Vertical Pumps in a Large Coal-Fired Power Station
07MAY2008
Paul W. Behnke, PE
Yifan Zheng, PE
Brian Delrue
BECHTEL POWER CORPORATION
THANK YOU!

D2.2 – Type VS3i Pump Retrofit Requirements

GLWA Connors Creek Storm Pump RFQ

Two VS3 pumps for installation in the existing Connors Creek PS as shown in the attached sketch.

Each pump rated for 230,000 gpm and 27 feet total dynamic head (TDH) with 257 rpm

Sole plates for mounting pumps on existing pump room floor (elevation 73 feet).

Separate suction bells/vortex suppressors mounted on the existing wet well floor (elevation 55 feet) and incorporating radial O-ring static seals and removable curb/sealing rings for flexible "pull-out pump" connection.

Enclosed line-shaft configuration to isolate all bearings

Discharge heads with pump thrust bearing housing, split mechanical seals and provision for Plan 32 seal/bearing flush

American Water Works Association discharge connection at specific elevation (interconnecting expansion joints and piping to existing discharge weirs by others.)

Pump materials:

- Impellers – A351 Grade CF3M stainless steel castings
- Pump shafts and couplings – Duplex stainless steel bars
- Suction bells/vortex suppressors – A36 carbon steel fabrications with stainless inlay at O-ring register fits and with epoxy coating.
- Bowls – A36 carbon steel fabrications with epoxy coating or iron castings with epoxy coating.
- Column pipes – A36 carbon steel fabrications with epoxy coating.
- Enclosing tubes – Type 316 stainless steel pipe.
- Discharge heads – A36 carbon steel fabrications with epoxy coating on internal wetted surfaces only.
- Wetted bolting – Type 316 stainless steel fasteners.

Two vertical 28-pole electric motors for installation on the existing motor floor (elevation 110 feet).

- 4600-volt utility power supply
- 257-rpm rotating speed maximum
- Lightweight Cardan shafting to connect motor and pump rotors
- Two variable frequency drives (VFDs) for variable pump speed control of each pump

Finite element analysis reports for structural natural frequencies and for torsional rotor natural frequencies. Natural frequency offsets based on Hydraulic Institute guidelines.

Physical model test in accordance with ANSI/HI 9.8 to include complete wet well with two new VS3 pumps and suction bell/vortex suppressors plus six existing volute pump draft tubes with new vortex suppressors retrofitted under each pump.

Field service supervision for installation and commissioning.

Figure 66: Existing Connors Creek PS Storm Water Pump House

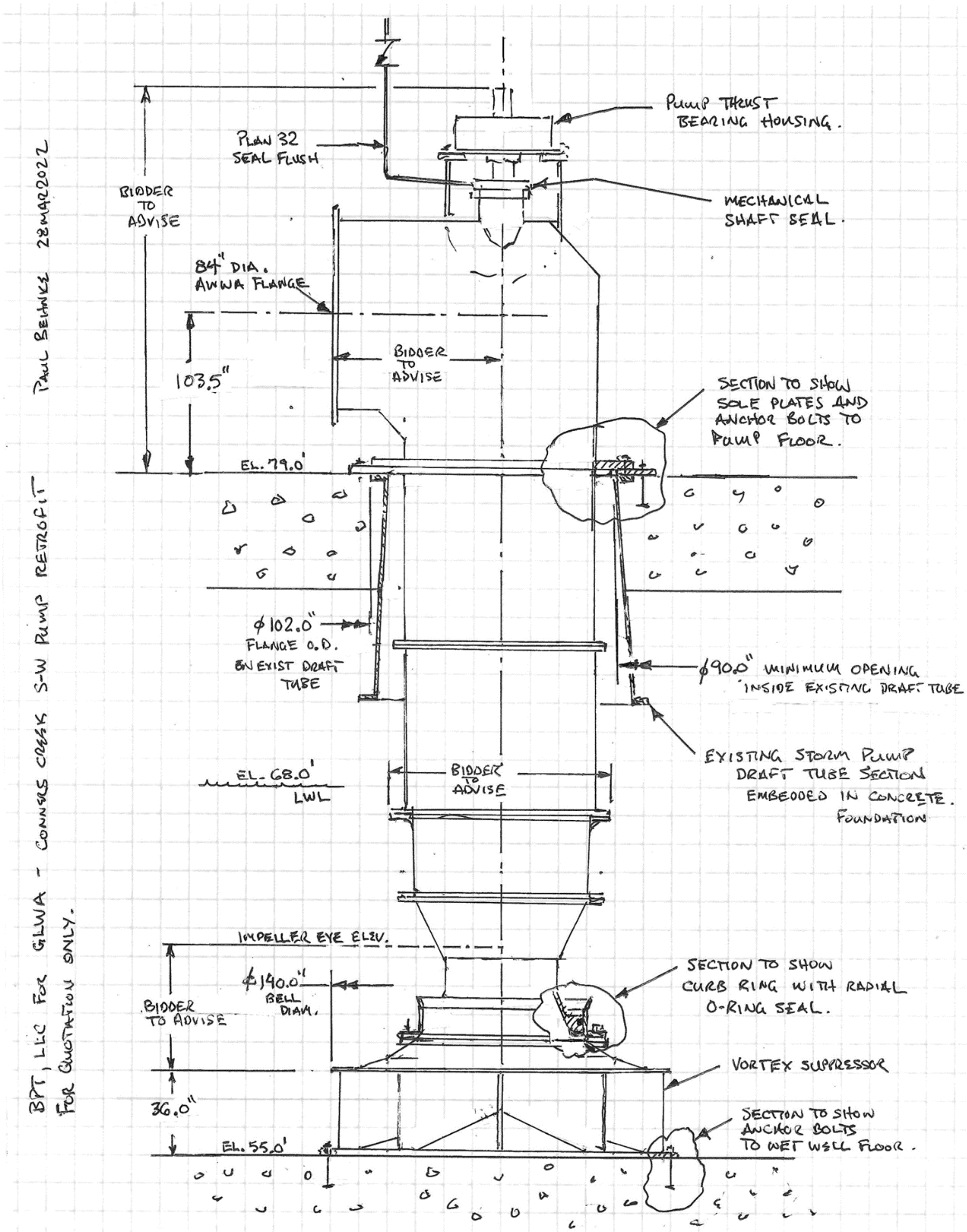


Figure 67: Type VS3i Pump Retrofit Sketch

D2.3 – Xylem A-C Type VS3i Pump Budgetary Quotation

Xylem A-C Budgetary Quote – April 8, 2022

Please see attached GA drawing and performance curve. We reduced the discharge size to accommodate the floor opening. Budget price based on your scope below is **$5,210,700** The only thing we changed is the mechanical seal. We would recommend a packed stuffing box. Estimated lead time is 8 - 12 weeks for submittals, 60 - 64 weeks after approval of submittals and release to manufacture. Let me know if you have any questions.

JD Pyncheon

Applications Engineer

Xylem, Flygt A-C Custom Pump

N27 W23293 Roundy Drive

Pewaukee, WI 53072
Phone:+1-262-548-8173

mailto:james.pyncheon@xyleminc.com

e-mail: james.pyncheon@xyleminc.com

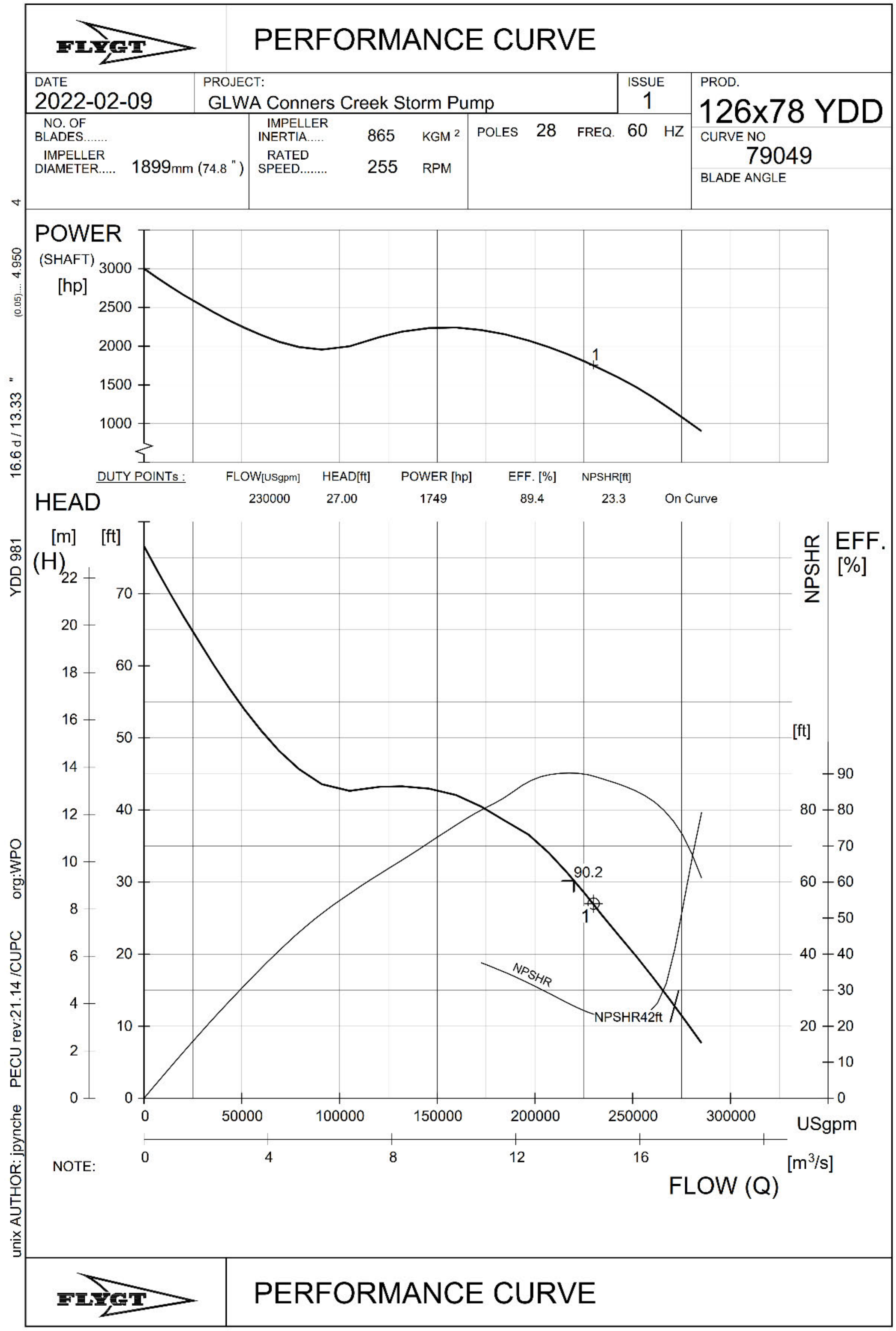
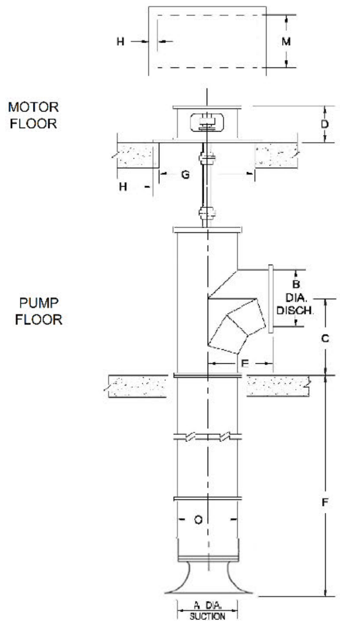


Figure 68: Flygt Performance Curve for Proposed Stormwater Pump



Dimensions	
A	126
B	78
C	103.5
D	56
E	78
F	252
G	90
H	7
O	78
M	90

NOTE :

1 All dimensions are " Approximate " and are subject to change

2

FOR TENDER PURPOSE ONLY

Weight of Pump	94000	lb
Weight of Motor	Later	lb
Total Dynamic Weight	Later	lb

All dimensions are in "in".

Deal Number	CP22012
Tag Number	
Client	GLWA
Project	GLWA Conners Creek PS
Pump Type	126x78 YDD

Title	Dimensional Drawing				
Drawing No.		Rev.	0	Date	4/8/2022

xylem Let's Solve Water — Xylem Water Solutions USA Inc.

Figure 69: General Pump Dimension Demonstrating Fit Through Existing Holes

D2.4 – Ebara Type VS3i Pump Budgetary Quotation

EBARA

"COMMERCIAL PROPOSAL"

EBARA Proposal No. : *CL01220019*

Requisition No. : -

Customer : *GLWA*

Final User : *GLWA*

Project : *Conners Creek Pump Station Upgrade*

Service : *Storm Water*

Revision No. : *0*

Proposal for : ***Mr. Paul Behnke***

QUOTATION

EBARA CORPORATION 11-1 HANEDA ASAHI-CHO,OHTA-KU, TOKYO 144-8510, JAPAN http://www.ebara.com/en/	QUOTATION No. *CL01220019* DATE *April 6, 2022*	YOUR REF No. - DATE -
MESSRS. *GLWA*	REMARKS Final User : *GLWA* Customer : *Conners Creek Pump Station Upgrade* Requisition Title : *Storm Water*	
TIME OF DELIVERY **Please see below.**		
TERMS & PLACE OF DELIVERY *FOB Seaport of Yokohama, Japan,*	TERMS OF PAYMENT **Please see below.**	
DESTINATION *USA*		
VALIDITY *May 6, 2022*		

Page 1 of 2

Quotation Rev. 0

I. PRICING

Please refer to attached "PRICING SUMMARY".
Please refer to attached "CL01220019 Technical Proposal Rev.0 ".

II. PAYMENT TERMS

To be discussed later

III. DELIVERY SCHEDULE

14 months after receipt of P.O.

IV. DETAIL CONTRACT TERMS AND CONDITIONS

Terms and conditions shall be discussed and mutually agreed before placing an order.

---to be continued ---

V. SERVICE PERSONNEL FEE

We will dispatch Ebara's supervisor(s) for the construction, commissioning, and start-up assistance work at the construction site upon customer's request with the following supervision fees.

for Pump : ***To be quoted at the time of installation***
for Motor : ***Sub-Vendor's condition will be applied.***
for Steam Turbine : ***Not Applicable.***
for Lub. Oil Unit : ***Not Applicable.***
for Mech. Seal / System : ***Not Applicable.***
for other Aux. Equipment or Special Instrument
: ***Sub-Vendor's condition will be applied.***

Terms and conditions for supervising service shall be discussed and mutually agreed before placing an order.

VI. NOTE

1. Any tax, duty, insurance and transportation costs beyond the point of FOB port of destination are not included.

2. The prices are firm and fixed for the duration of validity.

3. Ebara's guarantee period is 12 months from initial operation at site or 18 months from B/L data whichever comes earlier.

4. Any consequential damage or loss is out of Ebara's responsibility and attribution.

5. Ebara's maximum liability is limited to the purchase order value in any case.

6. Partial order is subject to EBARA's acceptance.

EBARA CORPORATION

Norio Kajita
Manager, Sales Section 2
Marketing and Sales Department, Custom Pump Division

PUMP PRICE LIST (BUDGETARY PRICE)

CUSTOMER'S REF No. -
PROJECT NAME Conners Creek Pump Station Upgrade
PROJECT OWNER GLWA
Item: Storm Water

PROPOSAL No. : CL01220019
DATE : 06-4-22
PREPARED BY : N. Nagamine
REV. : 0

No.	ITEM No.	SERVICE	Q'TY	PUMP DATA			Driver DATA		PUMP & DRIVER PRICE		Remarks
				PUMP MODEL	Flow (USGPM)	Head (ft)	Pole	HP	Unit (USD)	Total (USD)	
1	# 1 & 2	Storm Water	2	2100VSM	230000	27	28	2550	2,547,000	*5,094,000*	*Pump and Motor are included.*
			2	***TOTAL FOB Price***		***(USD)***			***5,094,000***		

Remarks:

1. Price Validity :May 6, 2022
2. Terms & Place of Delivery : FOB Seaport of Yokohama, Japan.
3. Expected delivery : 14 Months after received official P.O / L.O.I.
4. Following items are included in above price.
   -Pump, Motor, Coupling and Baseplate
5. Above Pump price is based on submitted technical proposal rev.0.
6. Optional Price for Sump Model Test for all (8) pumps: ***$*** *179,702*

APPENDIX E – INVESTIGATOR BIOGRAPHIES

Curriculum Vitae of the Independent Panel members are provided for reference.

Curriculum Vitae

Glen T. Daigger, PhD, PE, BCEE, DMASCE, Distinguished Fellow IWA, Fellow WEF NAE, CAE

EDUCATION

PhD, Environmental Engineering, Purdue University, 1979

MSCE, Environmental Engineering, Purdue University, 1975

BSCE, Purdue University, 1973

PROFESSIONAL REGISTRATION

Registered Professional Engineer: State of Indiana, Number 870309; State of Arizona, Number 47312

Board Certified Environmental Engineer, American Academy of Environmental Engineers

PROFESSIONAL EXPERIENCE

Professor of Engineering Practice, University of Michigan, 2015-Present

President and Founder, One Water Solutions, 2014-Present

Chief Technology Officer and Chief Wastewater Process Engineering, CH2M HILL (Now Jacobs), 1996-2014

Professor and Chair, Environmental Systems Engineering, Clemson University, 1994-1996.

Process Engineer, Assistance Director of Wastewater Reclamation, and Director Wastewater Reclamation, CH2M HILL (Now Jacobs), 1979-1994

Project Experience

As a practicing environmental engineer, Dr. Daigger has been involved in the planning, development, design, construction, startup, and operation of wastewater treatment facilities for municipalities and industries. Included in these activities have been many process studies and bench-scale and pilot-scale evaluations of wastewater treatment alternatives. He has been involved in facilities ranging in size from the smallest to the largest. Appendix A lists the facilities he has been involved with.

Dr. Daigger has also been involved with a number of industrial wastewater treatment facilities. Examples include the Burley, Idaho; Ontario, Oregon; and Plover, Wisconsin facilities for Ore-Ida foods; the Marcus Hook Refinery in Philadelphia, Wisconsin; the Kwinana Refinery in Perth, western Australia; the Bahrain Petroleum Company Refinery; two wet corn milling plants in Lafayette, Indiana, for the Staley Corporation; the Hubinger wet corn milling plant in Keokuk, Iowa; Columbia Nitrogen in Augusta, Georgia; Pendleton Woolen Mills, Pendelton, Oregon; ARCO; EXXON; and numerous pulp and paper facilities such as the Proctor and Gamble facility in Mahopany, Pennsylvania; and the Georgia Pacific facilities in Pensacola and Jacksonville, Florida.

MEMBERSHIPS IN PROFESSIONAL SOCIETIES

American Academy of Environmental Engineers and Scientists

American Society of Civil Engineers

American Water Works Association

Association of Environmental Engineering and Science Professors

Chi Epsilon

International Water Association (IWA)

National Academy of Engineering

Sigma Xi

Tau Beta Pi

Water Environment Federation

PROFESSIONAL ACTIVITIES

Member Review Panel for the Centre for Water Technology and Policy, The University of Hong Kong, 2021.

Keynote, 2021 Eckenfelder Lecture Series, Water Environment Association of Texas (Virtual).

Keynote, 5th International Conference on Integrated and Innovative Solutions for Circular Economy", October 5, 2021, Tainan, Taiwan.

Keynote, IWA Water in Industry Conference, Nanjing, China, August, 2021.

Member, Tomorrow Water Project Advisory Board, 2021.

Chair, National Water Research Institute Independent Advisory Panel to support City of Tampa PURE Project, 2021.

Member of the Water Management 2040 Future Scenarios Advisory Group, 2021.

Member of The Water Tower Institute Board of Directors, 2020 - Present

Member of the Economist Intelligence Unit City Water Optimization Index Independent Expert Panel, 2020 – Present.

Vice President International Association for Coastal Reservoir Research, 2020 - Present

Member National Alliance for Water Innovation (NAWI) Municipal Roadmapping Broader Team, 2020 – Present.

Review of the Chinese Academy of Sciences (CAS) Center for Excellence in Eco-environmental Sciences (CEEES), 2020.

Review of the Chinese Academy of Sciences (CAS) Research Center for Eco-Environment Sciences (RCEES), 2020.

Member Advisory Board of the journal *Frontiers of Environmental Science & Engineering (FESE)*, 2019 – Present.

Member National High-Level Foreign Experts for the Ministry of Science and Technology, People's Republic of China, 2019 – Present.

Member Editorial Board of the Journal *Water Environment Research*, 2019 – Present.

Advisory Board Member of the Journal *Environmental Science & Ecotechnology*, 2019 – Present.

Review Coordinator of Consensus Study Report: *Management of Legionella in Water Systems*, National academy of Engineering, National Academy Press, Washington, DC, 2019.

Reviewer of Consensus Study Report: *Independent Assessment of Science and Technology for the Department of Energy's Defense Environmental Cleanup Program*, National Academy of Engineering, National Academy Press, Washington, DC, 2019.

Reviewer of *Metrics for Successful Supercritical Water Oxidation System Operation a the Blue Grass Chemical Agent Destruction Plant*, National Academy of Engineering, 2019.

Member of the National Academy of Engineering Center for Engineering Ethics & Society (CEES) Advisory Group, 2019 – 2020.

Member of the National Academy of Engineering Online Ethics Center (OEC) Advisory Group, 2019 – 2020.

Member of the Chinese Research Academy of Environmental Sciences (CRAES) International Scientific Advisory Committee (ISAC), 2018 - Present

Member of The Water Research Foundation (TWRF) Board of Directors (2018 – 2020)

Chair of the National Water Research Institute (NWRI) Panel on Hampton Roads Sanitation District (HRSD) Sustainable Water Infrastructure for the Future (SWIFT) Program, 2016-Present

Member of the Water Environment & Reuse Foundation (WE&RF) Board of Directors (2016-2017), Co-Vice Chair (2016-2017)

Member of the BlueTech Technical Advisory Group, 2015-Present.

Chair of the International Advisory Committee (IAC) of the International Science & Technology Cooperation Center for Urban Alternative Water Resources Development (Int'l AWR Center), Xi'an, PRC, 2015-Present

Member, Expert Panel for the Integrated Validation and Demonstration Plan, Singapore PUB, 2015-2018.

Member of the Asian Development Bank Water Advisory Group, 2014-2017.

Member of the National Academy of Engineering Nominating Committee, 2014.

International Co-Chair of the Science and Technology Commission for the 7th World Water Forum, 2013-2015.

Member of National Academy Committee on the On-Site Reuse of Graywater and Stormwater: An Assessment of Risks, Costs, and Benefits, 2013-2015.

Member of National Academy Committee on Science and Technology Capabilities at the Department of State, 2013-2015.

Member of the Water Environment Research Foundation (WERF) Board of Directors, 2013-Present (Vice Chair 2015-2016).

Member of The Water Council Board of Directors, 2013-Present.

Member of National Academy of Engineering Committee on Membership, 2012-2013.

Member of National Academy Panel Regional Approaches to Urban Sustainability: A Focus on Portland – A Workshop, 2012-2-13.

Member of National Academy Panel on the Review of the Draft 2013 National Climate Assessment (NCA) Report, 2012-2013.

Member of the National Academy of Engineering Center for Engineering, Ethics and Society Advisory Group, 2012-2018.

Member of the National Academy Committee on Sustainability Linkages in the Federal Government, 2011 – 2013.

Member of the National Academy Committee on Economic Analysis of Final Water Quality Standards for Nutrients for Lakes and Flowing Waters in Florida, 2011-2012.

Member of the National Academy Committee on Regional Approaches to Urban Sustainability: A Focus on Metropolitan Houston, 2011-2012.

Member of the National Academy of Engineering Ethics Center Advisory Committee, 2011-2012.

Member of National Academy of Engineering Section 4 (Civil Engineering) Peer Committee, 2010-2013. Chair 2012-2013 and Vice Chair 2011-2012.

President, International Water Association (IWA), 2010–2014.

Member of the Board of Directors for the Environmental Engineering Foundation (Currently Vice-Chair and Previously Treasurer), 2009-2018.

Member of the National Academy Committee on Transitioning to Sustainability: The Challenge of Developing Sustainable Urban Systems. The National Academies Second Sustainability R&D Forum, 2009-2010.

Member of National Academy Roundtable on Science and Technology for Sustainability, 2007–2013.

Member of National Academy Committee on the Review of Water and Environmental Research Systems Network, 2007-2010

Senior Vice President, IWA, 2006–2010.

Member of the Environment and Water Industry Development Council (EWI), Singapore, International Advisory Panel, 2006-2009.

Member of National Academy of Engineering Committee on Engineering Education, 2005-2008.

Member of National Academy Committee on Energy Futures and air Pollution in Urban China and the United States, 2005-2007.

Member of the Water Environment Research Foundation (WERF) Research Council (2002–2008) and Chair (2004–2006).

Member of the Water Environment Research Foundation (WERF) Board of Directors, 2004-2006.

Chair of the Committee Leadership Council of the Water Environment Federation (WEF), 2004–2007.

Member (at-Large) of the WEF House of Delegates, 2004–2007.

Member of the WEF Board of Trustees, 2004–2006.

American Academy of Environmental Engineers (AAEE) trustee, 1998–2002.

Member of AAEE Long Range Planning Committee, 2002–2008.

Member of the USA National Committee (USANC) to IWA, 1996–2008.

Former Chair of the Water Environment Research Board of Editorial Review.

Former Chair of the WEF Technical Practice Committee.

Former Chair of WEF Manual of Practice No. 8 Task Force.

Member of the Scientific Committee for the IWA Leading Edge Drinking Water and Wastewater Treatment Technology Conferences in the Netherlands, Prague, Sapporo, Singapore (2), and Zurich, 2003–2009.

Member of the Organizing Committee for the 1994 ASCE Environmental Engineering Conference in Boulder, Colorado.

Member of the Panel on Source Control and POTW Technologies, Committee on Wastewater Management for Coastal Urban Areas, National Research Council, Water Science and Technology Board, 1990-1993.

Member of the Civil Engineering Research Foundation Implementation Task Force.

Member of WEF Committee on Manual of Practice (MOP) for Wastewater Treatment Plant Design (MOP 8). Contributing author to chapter 8, Activated Sludge, and Reviewer for chapter 11, Fixed Film Systems.

Member of WEF Committee on Clarifier Design. Co-author of Manual of Practice on Clarifier Design.

Member of the WEF Committee on Fixed Growth Reactors. Reviewer of Fixed Growth Reactor MOP.

Member of WEF Committee on Nutrient Control. Reviewer of Nutrient Control MOP.

Former member of WEF Awards Committee, and former chairman of the Gascoigne Medal Subcommittee.

Member of WEF Committee on Aeration.

Member of IWA Technical Group on the Design and Operation of Large Wastewater Treatment Plants.

Member of the IWA Technical Group on Biological Nutrient Removal.

Member of the IWA Technical Group on Population Dynamics.

Member of the IWA Technical Group on Biofilms.

Technical reviewer of papers submitted for publication in numerous professional Journals, such as *Water Environment Research*, *Water Science and Technology*, *Water Research*, and *Journal Environmental Engineering Division, American Society of Civil Engineers.* Also a frequent reviewer of manuals and reports. Examples include:

U.S. EPA, *Design Manual for Phosphorus Removal*, EPA/625/1-87/001, Water Engineering Research Laboratory (September, 1987).

U.S. EPA, *Handbook, Retrofitting POTWs*, EPA/625/6-89/020, Center for Environmental Research Information (July 1989).

WEF Manual of Practice, *Aerobic Fixed Film Reactors*, 2001

HONORS AND AWARDS

Excellence in Service Award, Michigan Water Environment Association, 2021.

With Sybil Sharvelle, Nancy G. Love, and Mazdak Arabi, Wesley W. Horner Award, American Society of Civil Engineers, 2021.

Elected to the Chinese Academy of Engineers, 2020.

With Avery Carlson, Martha Hahn Memorial Award, WEFTEC, for Highest-Rated Abstract in the Municipal Symposium, 2019.

Presented the Mathes Distinguished Lecture 2018 at Missouri S&T, October 19, 2018.

Received the Gascoigne WWTP Operational Improvement Medal, Water Environment Federation, 2018.

Keynote Address at the 2018 International Conference on Resource Sustainability, Beijing, Republic of China, June 29, 2018.

Singapore Water Academy Fellow, 2017.

Presented the John McClanahan Henske Distinguished Lecture in Chemical and Environmental Engineering, Yale University, New Haven, CT, December 7, 2016.

Received Frederick George Pohland Medal, Association of Environmental Engineering and Science Professors, 2016.

Life Member, American Society of Civil Engineers, 2016.

Named Most Influential Individual in Water for 2015 by Water and Wastewater International.

Keynote Lecture at the Joint Chemical & Environmental Engineering Seminar
Sponsored by the Chancellor's Distinguished Visitors Program and the Frank H. Schulte, Jr. Endowment for Chemical Engineering in Honor of Dean Henry E. Bent, Rice University, 2015.

Named Distinguished Fellow, International Water Association, 2014

Richart Lecture, University of Michigan, 2013.

McCarty Lecture, Stanford University, 2013.

Elected Distinguished Member of the American Society of Civil Engineering, 2012.

Named Water Environment Federation Fellow, 2012.

Named Distinguished Engineering Alumni, Purdue University, 2012.

Presented the Tsuan Hua Feng Distinguished Lecture at the University of Massachusetts at Amherst, October, 2011.

Received Purdue University Civil Engineering Alumni Achievement Award, 2010.

Named Fellow of the American Society of Civil Engineers, 2009.

Presented the 2008 Association of Environmental Engineering and Science Professors Lecture at the Research Symposium for the Water Environment Federation Technical Exhibition and Conference.

Received the 2008 Harrison Prescott Eddy Award from the Water Environment Federation.

Presented the 2006 Simon W. Freese Award & Lecture from ASCE.

With M. G. Noesen, D. Laffitte, T. Mc Allister, S. Clark, and B. Sprick, recognized by the Water Environment Federation for the best poster at the 2005 WEFTEC Conference, entitled "Peak Flow Treatment Alternatives Evaluated for the Eugene-Springfield Water Pollutions Control Facility, Oregon".

Elected to the National Academy of Engineers, 2003.

Received the 2002 Harrison Prescott Eddy Award from the Water Environment Federation.

Received the 2001 Harrison Prescott Eddy Award from the Water Environment Federation.

Presented the American Academy of Environmental Engineers (AAEE) Kappe Lecturer, 2001

Received the 1996 Phillip F. Morgan Award from the Water Environment Federation.

Named first Technical Fellow by CH2M HILL, 1996.

Presented the third annual James JC. Brown Design Lecture at the University of North Carolina at Chapel Hill, 1993.

Recognized by CH2M HILL for Outstanding Contribution to Innovation by the Firm. Recognized specifically for development of the WQIG and for the development of phosphorus removal technology at the Rock Creek Advanced Wastewater Treatment Plant, 1992.

Recognized by the American Consulting Engineering Council with a Grand Award for contribution to the development of the VIP plant project, 1992.

Recognized by Engineering News Record (ENR) for Outstanding Contribution to the Construction Industry, February 17, 1988.

Received the 1987 Radebaugh Award from the Central States Water Pollution Control Association for Noteworthy Advancement of Knowledge.

Outstanding Paper Presented at the 1985 Annual Conference of the Illinois Water Pollution Control Association Meeting.

Received the 1982 Gascoigne Award from the Water Pollution Control Federation for Significant Contribution to Operations.

Named a David Ross Fellow, 1975–1977.

Named a Purdue University Fellow, 1973–1975.

Named Outstanding Civil Engineering Senior by Indiana Section of ASCE.

Named Outstanding Junior by Purdue Student Chapter of Chi Epsilon.

Honorary Professorships

Zhejiang University Guest Professor, 2018.

Xi’an University of Architecture and Technology, 2016.

Tongji University, Advisory Professor, 2012.

Nanjing Institute of Environmental Sciences, Ministry of Environmental Protection, Honorary Professor, 2012.

Beijing University of Civil Engineering and Architecture, Visiting Professor, 2009.

PUBLICATIONS

Books, Monographs, and Book Chapters

Foundational

Houweling, D. and G. T. Daigger, *Intensifying Activated Sludge Using Media-Supported Biofilms*, IWA Press, London, 2019.

Sabba, F., J. Calhoun, B.R. Johnson, G.T. Daigger, R. Kovács, I. Takács, and J. Boltz, "Applications of Mobile Carrier Biofilm Modelling for Wastewater Treatment Processes,", In *Frontiers in Wastewater Treatment and Modelling*, Mannina, G. Ed., FICWTM 2017, Springer International Publishing AG, Cham, Switzerland, 2017.

Cavagnaro, P., C. Conn, C. Hill, B. Hannon, G. Daigger, K. McCormack, J. Zelski, N. Love, C. K. Osmoski, D. Mack, J. Harte, *Michigan's Water Resource Utility of the Future: A Vision for the Transformation of Michigan's Wastewater Industry to Water Resource Recovery Facilities*, MWEA, Bath, MI, 2017.

Catley-Carlson, M., G. T. Daigger, and C. van Steendam, *A Better Water future for Flanders: "Not too much; not too little"*, Royal Flemish Academy 2016 Thinkers Programme, 2016.

Daigger, G. T., "What is Water Worth?", In *The Value of Water: A Compendium of Essays by Smart CEO's*, Roa, D. V., Vincent Roa Group, Rockville, MD, 2014.

Daigger, G. T., "Ardern and Lockett Remembrance," In *Activated Sludge – 100 Years and Counting*, Jenkins, D., and J. Wanner, Ed., IWA Publishing, London, 2014.

Grady, C. P. L., Jr., G. T. Daigger, N. G. Love, and Carlos, D. M. Filipe, *Biological Wastewater Treatment*, Third Edition, CRC Press, Boca Raton, FL, 2011.

Grady, C. P. L., Jr., G. T. Daigger, and H. C. Lim, *Biological Wastewater Treatment*, Second Edition, Marcel Dekker, New York, New York (1999).

Daigger, G. T. and J. A. Buttz, *Upgrading Wastewater Treatment Plants*, Second Edition, Technomic Publishers, Lancaster, PA (1998).

Daigger, G. T. and J. A. Buttz, *Upgrading Wastewater Treatment Plants*, Technomic Publishers, Lancaster, PA (1992).

Solids Separation

Jenkins, D., M. G. Richard, and G. T. Daigger, *Manual on the Causes and Control of Activated Sludge Bulking, Foaming, and Other Solids Separation Problems*, 3rd Edition, Lewis Publishers, Boca Raton, FL, 2004.

Jenkins, D., M.G. Richard, and G.T. Daigger, *Manual on the Causes and Control of Activated Sludge Bulking and* Foaming, 2nd Edition, Lewis Publishers, Ann Arbor, MI, 1993.

Jenkins, D., M. G. Richard, and G. T. Daigger, *Manual on the Causes and Control of Activated Sludge Bulking and Foaming*, 1st Edition, Water Research Commission, Republic of South Africa (December, 1984).

Nutrient Removal

Daigger, G. T. and S. R. Polson, "Design and Operation of Biological Nitrogen Removal Processes," In *Principles and Practice of Phosphorus and Nitrogen Removal from Municipal Wastewater*, 2nd Ed., Sedlak, R. K., Ed. Lewis Publishers, Ann Arbor, MI (1992).

Daigger, G. T. and T. W. Sigmund, "Design and Operation of Chemical Phosphorus removal Facilities," In *Principles and Practice of Phosphorus and Nitrogen Removal from Municipal Wastewater*, 2nd Ed., Sedlak, R. K., Ed. Lewis Publishers, Ann Arbor, MI (1992).

Daigger, G. T. and S. R. Polson, "Design and Operation of Biological Phosphorus Removal Facilities," In *Principles and Practice of Phosphorus and Nitrogen Removal from Municipal Wastewater*, 2nd Ed., Sedlak, R. K., Ed. Lewis Publishers, Ann Arbor, MI (1992).

Resource Recovery

Daigger, G. T., "Designing and Implementing Urban Water and Resource Management Systems Which Recover Water, Energy, and Nutrients," In *Water-Energy Interactions in Water Reuse*, Lazarova, V., Choo, K-H, and Cornel, P., Ed., IWA Publishing, London, 2012.

Daigger, G. T., "A Vision for Urban Water and Wastewater Management in 2050," In *Toward a Sustainable Water Future: Visions for 2050*, Grayman, W. M., Loucks, D. P., and Saito, L., Ed., American Society of Civil Engineers, Reston, VA, 2012.

Daigger, G., "Integrating Water and Resource Management for Improved Sustainability," In *Water Infrastructure for Sustainable Communities: China and the* World, Hao, X., Novotny, V., and Nelson, V. Ed., IWA Publishing, London, 2010, 11-21.

Manuals

Foundational

Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits, The National Academies Press, Washington D.C., 2016, Committee Member.

Diplomacy for the 21st Century: Embedding a Culture of Science and Technology Throughout the Department of State, The National Academies Press, Washington D.C., 2015, Committee Member.

Sustainability for the Nation: Resource Connections and Governance Linkages, The National Academy Press, Washington D.C., 2013. Committee Member.

Pathways to Urban Sustainability: A Focus on the Houston Metropolitan Region, Summary of a Workshop, The National Academies Press, Washington, D.C., 2012. Task Force Member

Review of the Waters Network Science Plan, The National Academies Press, Washington D.C., 2010. Task Force Member

Aerobic Fixed-Growth Reactors, A Special Publication, Water Environment Federation, Alexandria, VA, 2000. Major Contributor

Research Priorities for Debottlenecking, Optimizing, and Rerating Wastewater Treatment Plants, Water Environment Research Foundation, Project 99-WWF-1, 1999. Major Contributor

Design of Municipal Wastewater Treatment Plants, Manual of Practice No. 8, 4th Edition, Water Environment Federation, Alexandria, VA, 1998. Task Force Chair

Managing Wastewater in Coastal Urban Areas, National Research Council Press, Washington, D.C., 1993. Major Contributor

Design Manual for Fine Pore Aeration Systems, United States Environmental Protection Agency, EPA/625/1-89/023, Risk Reduction Engineering Laboratory (September 1989). Major Contributor

Summary Report: Fine Pore (Fine Bubble) Aeration Systems, United States Environmental Protection Agency, EPA/625/8-85/010., Water Engineering Research Laboratory, October, 1985. Major Contributor

Nutrient Removal

Review of the EPA's Economic Analysis of Final Water Quality Standards for Nutrients for Lakes and Flowing Waters in Florida, The National Academies Press, Washington D.C., 2012. Committee Chair

Water Environment Research Foundation, *Characterizing Mechanisms of Simultaneous Biological Nutrient Removal During Wastewater Treatment*, Project 00-CTS-17UR, 2004. Major Contributor

Nitrogen Control Manual, United States Environmental Protection Agency, EPA/625/R-93/010, 1993. Major Contributor

Membrane Bioreactor

Membrane Bioreactors, Manual of Practice No. 36, Water Environment Federation, Alexandria, VA, 2011. Task Force Chair

Membrane Technology: Feasibility of Solids/Liquids Separation in Wastewater Treatment, Water Environment Research Foundation, Alexandria, VA, Website and CD-ROM, 2001. Principal Investigator

<u>Refereed Publications</u>

Foundational

He., H., B. M. Wagner, A. L. Carlson, C. Yang, and G. T. Daigger, "Recent Progress Using Membrane Aerated Biofilm Reactors for Wastewater Treatment," *Wat. Sci. & Tech.*, 2021, doi: 10.2166/wst.2021.443.

Xu, M. , G. T. Daigger, C. Xi, J. Liu, J. Qu, P. J. Alvarez, P. Biswas, Y. Chen, D. Dolinoy, Y. Fan, H. O. Gao, J. Hao, H. He, D. M. Kammen, M. C. Lemos, F. Liu, N. G. Love, Y. Lu , D. L. Mauzerall, S. A. Miller, Z. Ouyang, J. T. Overpeck, W. Peng, A. Ramaswami, Z. Ren, A. Wang, B. Wu, Y. Wu , J. Zhang, C. Zheng, B. Zhu, T. Zhu, W-Q. Chen, G. Liu, S. Qu, C. Wang, Y. Wang, X. Yu, C. Zhang, H. Zhang, "US-China Collaboration is Vital to Global Plans for a Healthy Environment and Sustainable Development," Envir. Sci. Tech., 2021, 9622-9626, https://doi.org/10.1021/acs.est.0c08750.

Yang, C., G. T. Daigger, E. Belia, B. Kerkez, "Extracting Useful Signals From Flawed Sensor Data: Developing Hybrid Data-Driven Approaches with Physical Factors," *Wat. Res.*, **185**, 2020. https://doi.org/10.1016/j.watres.2020.116282.

Cao, Y., Z, Xingcan , L. Zhixiao , M.C.M. Van Loosdrecht and G. T. Daigger, "The Bottlenecks and Causes, and Potential Solutions for Municipal Sewage Treatment in China", *Journal of Beijing University of Technology*, (2020) (In Chinese) https://kns.cnki.net/kcms/detail/11.2286.t.20200902.1535.002.html/doi: 10.11936/bjutxb2020040009, 14 pages.

Liang, S., Y. Yu, A. Kharrazi, B.D. Fath, C. Feng, G. T. Daigger, S. Chen, T. Ma, B. Zhu, Z. Mi, Z. Yang,, "Network Resilience of Phosphorus Cycling China has Shifted by Natural Flows, Fertilizer Use and dietary Transitions Between 1600 and 2012," *Nature Food*, **1**, June 2020, 365-375. doi.org/10.1038/s43016-020-0098-6

Cao, Y., M. C. M. van Loosdrecht, and G. T. Daigger, "The Bottlenecks and Causes, and Potential Solutions for Municipal Sewage Treatment in China," *Wat. Pract. & Tech.* **15**(1), 2020.160-169. doi: 10.2166/wpt.2020.006

Campbell, K, J. Wang, and G. T. Daigger, "Filamentous Organisms Degrade Oxygen Transfer Efficiency by Increasing Mixed Liquor Apparent Viscosity: Mechanistic Understanding and Experimental Verification," *Wat. Res.*, **173**, 2020, 1-13.

Yang, C., W. Barrott, A. Busch, A. Mehrotra, J. Madden, and G. T. Daigger, "How Much Data is Required for a Robust and Reliable Wastewater Characterization?," *Wat. Sci. & Techol.*, **79**(12), 2298-2309, 2019, doi: 10.2166/wst.2019.233.

Wang, X., G. Daigger, W. Vries, C. Kroeze, M., Yang, N.-Q. Ren, J. Liu, and D. Butler, "Impact Hotspots of Reduced Nutrient Discharge Shift Across the Globe with Population and Dietary Changes," *Nature Communications*, **10**(1), 2019, 1-12 https://doi.org/10.1038/s41467-019-10445-0, 2019.

Cao, Y.S., J. G. Tang, M. Henze, X. P. Yang, T. P. Gan, J. Li, H. Krois, M. C M. van Loosdrecht, Y. Zhang, and G. T. Daigger, "The Leakage of Sewer Systems and the Impact on the 'Black and Odorous Water Bodies' and WWTPs in China," *Wat. Sci. & Techol.*, **79**(2), 2019, 334 – 341.

Campbell, K., J. Wang, G. Liu, G. Daigger, "Activated Sludge Morphology Significantly Impacts Oxygen Transfer at the Air-Liquid Boundary," *Wat. Envir. Res.*, **91**, 500-509, 2019.

Liu, S., G. T. Daigger, J. Kang, G. Zhang, "Effects of Light Intensity and photoperiod on Pigments Production and Corresponding Key Gene Expression of *Rhodopseudomonas Palustris* in a Photobioreactor system," *Biores. Technol.*, **294**, 2019, 122172, doi.org/10.1016/j.biortech.2019.122172

Rittmann, B. E, J. P. Boltz, D. Brockman, G. T. Daigger, E. Morgenroth, K. H. Sorensen, I. Takacs, M. van Loosdrecht, and P. A. Vanrolleghem, "A Framework for Good Biofilm Reactor

Modeling Practice (GBRM), *Wat. Sci. & Techol.*, **77**(5), 2018, 1149 – 1164. Doi: 10.2166/wst.2018.021.

O'Callaghan P, Daigger G, Adapa L, Buisman C. Development and Application of a Model to Study Water Technology Adoption and Dissemination. *Water Envir. Res*., **90**, June, 2018, 563-574.

Daigger, G. T. and J. P. Boltz, "Oxygen Transfer in Moving Bed Biofilm Reactor and Integrated Fixed Film Activated Sludge Processes, *Water Envir. Res.*, **90**(7), July, 2018, 615-622. doi.org/10.2175/106143017X15054988926596

Boltz, J.P., B. Smets, B. E. Rittmann, M. C. M. van Loosdrecht, E. Morgenroth, G. T. Daigger, "From Biofilm Ecology to Reactors: A Focused Review," *Wat. Sci. Technol*., **75**(8), 1753-1760, 2017. doi: 10.2166/wst.2017.061

Daigger, G. T., "Flexibility and Adaptability: Essential Elements of the WRRF of the Future," *Water Practice & Technology*, **12**(1), 156-165, 2017. doi: 10.2166/wpt.2017.019.

Boltz, J. P., B. R. Johnson, I. Takács, G. T. Daigger, E. Morgenroth, D. Brockmann, R. Kovács, J. M. Calhourn J-M Choubert, and N. Derlon, "Biofilm Carrier Migration Model Describes Reactor Performance," *Water Science & Technology*, 2818-2828, 2017. DOI: 10.166/SWT.2017.160, 2017

Daigger, G. T., S. Murthy, N. G. Love, and J. Sandino, "Transforming Environmental Engineering and Science Education, Research, and Practice," *Environmental Engineering Science*, **34**(1), 42-50, 2017. DOI: 10.1089/ees.2015.0353.

Zaffaroni, C., Daigger, G., Nicol, P., Lee, T.W., "Wastewater Treatment Challenges Faced by the Petrochemical and Refinery industry, and Opportunities for Water Reuse," *Water Pract. & Tech.*, **11** (1), 104-117, doi: 10.2166/wpt.2016.012, 2016.

Novak, P. J., W. A. Arnold, B. Henningsgaard, R. M Hozalski, K. Kessler, T. L. LaPara, A. Parrella, L. Rogacki, C. Thompson, R. Thorson, R. A. Zimmerman, C. B. Bott, G. T. Daigger, J. B. Neethling, "Innovation Promoted by Regulatory Flexibility," *Env. Sci. & Tech.*, doi.org/10.1021/acs.est.5b05394, 2016.

Sicard, C., C. Glen, B. Aubie, D. Wallace, S. Jahanshahi-Anbuhi, K. Pennings, G. T. Daigger, R. Pelton, J. D. Brennan, C. D. M. Filipe," Tools for Water Quality Monitoring and Mapping Using Paper-Based Sensors and Cell Phones," *Water Research*, **70**, 360-369, 2014.

Graedel, T. E., D. Swackhamer, R. Anex, W. F. Carroll , Jr., G. T. Daigger, P. Ferrão, H. Frumkin, S. Katzen, A Palmisano, S. Polasky, L. Scarlett, R. Stephens, and L. Zeise, "Sustainability for the Nation: Resource Connections and Governance Linkages," *Envir. Sci. & Tech.*, **48**, 2014, 7197-7199. DOI 10.1021/es502328v.

Daigger, G. T., "A Practitioner's Perspective on the Uses and Future Developments for Wastewater Treatment Modelling," *Water Science & Technology*, **63**(3), 516-526, 2011.

Benedetti, L., J. Langeveld, A. Comeau, L. Corominas, G. Daigger, C Martin, P. S. Mikkelsen, L. Vezzaro, S. Weijers, and P. A. Vanrolleghem, "Modelling and Monitoring of Integrated Urban Wastewater Systems: Review of Status and Perspectives," *Water Science & Technology*, **68**(6), 1203-1215, 2013.

Plósz, B. G., L. Benedetti, L., Daigger, G. T. Langford, K. H. Larsen, H. F., Monteith, H., Ort, C., Seth, R., Steyer, J. P., and Vanrolleghem, P.A., "Modelling Micro-Pollutant Fate in Wastewater Collection and Treatment Systems: Status and Challenges," *Water Science & Technology*, **67(1)**, 1-15, 2013.

Daigger, G. T. and J. P. Boltz, "Trickling Filter and Trickling Filter-Suspended Growth Process Design and Operation: A State-of-the-Art Review," *Wat. Envir. Res.*, **83**(5), 388-404, 2011.

Daigger, G. T., "A Practitioner's Perspective on the Uses and Future Developments for Wastewater Treatment Modelling," *Water Science & Technology*, **63**(3), 516-526, 2011.

Boltz, J. P. and G. T. Daigger, "Uncertainty in Bulk-Liquid Hydrodynamics and Biofilm Dynamics Creates Uncertainties in Biofilm Reactor Design," *Water Science and Technology*, **61**(2), 307-316, 2010.

Boltz, J. P., B. R. Johnson, G. T. Daigger, and J. Sandino, "Modeling Integrated Fixed-Film Activated Sludge and Moving-Bed Biofilm Reactor Systems I: Mathematical Treatment and Model Development," *Water Environment Research*, **81(6)**, 555-575, 2009.

Boltz, J. P., B. R. Johnson, G. T. Daigger, J. Sandino, and D. Elenter, "Modeling Integrated Fixed-Film Activated Sludge and Moving-Bed Biofilm Reactor Systems II: Evaluation," *Water Environment Research*, **81(6)**, 576-586, 2009.

Boltz, J. P., Goodwin, S. J., Rippon, D., and Daigger, G. T., "A Review of Operational Control Strategies for Snail and Other Macrofauna Infestations in Trickling Filters," *Water Practice*, **2**(4), 2008.

Witherspoon, J. R., G. Adams, W. Cain, E. Cometto-Muniz, B. Forbes, L. Hentz, J. T. Novack, M. Higgins, S. Murthy, D. McEwen, H. T. Ong, and G. T. Daigger, "Water Environment Research Foundation (WERF) Anaerobic Digestion and Related Processes, Odour and Health Effects Study," *Water Science And Technology*, **50**(4**)**, 9-16, 2004.

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More than 200

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APPENDIX A: WASTEWATER TREATMENT PLANT EXPERIENCE

Plant	Capacity (m^3/day)
14 WWTP's with total of 1,200 mgd of capacity for New York City, NY	4,500,000
Changi Water Reclamation Plant, Republic of Singapore	2,400,000
Detroit Water Resource Recovery Facility, Detroit, MI	2,400,000
Hyperion WWTP, Los Angeles, CA;	1,500,000
Passaic Valley WWTP, Newark, NJ	1,500,000
Blue Plains WWTP, Washington, DC	1,440,300
Robert W. Hite Treatment Facility, Denver, CO	830,000
Tuas Water Reclamation Plant, Republic of Singapore	650,000 Domestic/150,000 Industrial
Duffin Creek Water Pollution Control Plant, Toronto, Ontario	640,000
Belmont WWTP, Indianapolis, IN	450,000
Southport WWTP, Indianapolis, IN	450,200
Central WWTP, Denver, CO	454,200
San Jose/Santa Clara Water Pollution Control Plant, CA	630,000
West Point WWTP, Seattle, WA	600,000
Central WWTP, Dallas, TX	570,000
North WWTP, Memphis, TN	510,000
Jones Island Wastewater Treatment Plant (WWTP), Milwaukee, WI	470,000
Hamilton, Ontario, Canada WWTP	450,000
EBMUD WWTP, Oakland, CA	450,000
Manakau WWTP, Auckland, NZ	450,000
Iona Island WWTP, Vancouver, BC	450,000
Bonnybrook WWTP, Calgary, AB	396,000
South Shore WWTP, Milwaukee, WI	380.000
Morris Foreman WWTP, Louisville, KY	380,000
Columbia Boulevard WWTP, Portland, OR	380,000
Western Treatment Plant, Melbourne, Australia	350,000
Southside WWTP, Dallas, TX	340,000
Eastern Treatment Plant, Melbourne, Australia	330,000
Southeast Water Pollution Control Plant, San Francisco, CA	320,000
South Valley WRF, Utah	300,000
Orange County Sanitation District, HPO Plant, CA	300,000
Lou Romano WWTP, Windsor, ON	273,000
Alexandria, VA, WWTP	265,000
Akron, OH, WWTP	265,000
F. Wayne Hill Water Resources Center, Gwinnett County, GA	260,000

McAlpine Creek WWTP, Charlotte, NC	240,000
Highland Creek Water Pollution Control Plant, Toronto, ON, Canada	217,000
Salt Lake City, UT Water Reclamation Plant	212,000
Fields Point WWTP, Narragansett Bay Commission, Providence, RI	208,000
Upper Occoquan Sewage Authority WWTP, Centerville, VA	204,000
South WRF, Orange County, FL	200,000
Green Bay, WI, WWTP	197,000
Rock Creek WWTP, Hillsboro, OR	191,000
Wyoming Valley WWTP, Wilkes-Barre, PA	189,000
Little Blue Valley WWTP, Independence, MO	189,000
Ina Road WRF, Pima County, AZ	189,000
Four plants, Jacksonville, FL, Electric Authority	189,000
Northside WWTP, Tulsa, OK	160,000
Riverside Park Water Reclamation Facility, Spokane, WA	150,000
VIP WWTP, Norfolk, VA	150,000
Duck Creek WWTP, Garland, TX	150,000
Pt. Woronzof WWTP Anchorage, AK	150,000
New Haven, CT, WWTP	150,000
Durham WWTP, Tigard, OR	150,000
South River WWTP, Atlanta, GA	150,000
R. L. Sutton WWTP, Cobb County, GA	150,000
Cedar Rapids WWTP, IA	150,000
Adams Field WWTP, Little Rock, AR	150,000
Riverside WRF, Spokane, WA.	150,000
Stockton, CA WWTP	150,000
Skyway WWTP, Region of Halton, ON	140,000
Brightwater Treatment Plant, King County, WA	136,000
Leon Creek WWTP, San Antonio, TX	132,000
Salado Creek WWTP, San Antonio, TX	132,000
Licunhe WPT, Qingdao, PRC	132,000
Kitchner WWTP, ON	120,000
Agua Nueva Water Reclamation Plant, Tucson, AZ	120,000
Allentown, PA WWTP	120,000
Fayetteville, NC WWTP	114,000
Lubbock, TX, WWTP	114,000
Missouri WWTP, Omaha, NB;	114,000
Bustamante WWTP, El Paso, TX	114,000
East WRF, Orange County, FL	114,000
Pine Creek WWTP, Calgary, AB	100,000
Crooked Creek Water Reclamation Facility, Gwinnett County, GA	98,000
South Bay International WWTP, San Diego, CA	95,000

Lions Gate WWTP, Vancouver, BC	95,000
Monterey Water Reclamation Plant, CA	95,000
H. L. Mooney Water Reclamation Facility, VA	91,000
Rowlett Creek WWTP, Garland, TX	90,000
Regional Plant No. 4, Chino Basin Municipal Utility District, CA	90,000
Hoboken, NJ, WWTP	90,000
Cross Creek WWTP, Fayetteville, NC	90,000
Bellingham, WA, WWTP	90,000
Yellow River Water Reclamation Facility, Gwinnett County, GA	83,000
Carbon Canyon WWTP, Chino Basin Municipal Utility District, CA	80,000
Govalle WWTP Austin, TX	75,000
LOTT WWTP, Olympia, WA	75,000
Oceanside WWTP, San Francisco, CA	75,000
Terminal Island WWTP, Los Angeles, CA	75,000
Palo Alto, CA, WWTP	75,000
Stamford, CT, WWTP	75,000
Merramec WWTP, St. Louis, MO	75,000
Lulu Island WWTP, Vancouver, BC	75,000
Lethbridge, Alberta, WWTP	49,000
Beloit, WI, WWTP	68,000
Sunnyvale, CA WWTP	68,000
Paul R. Noland WWTP, Fayetteville, AR	64,000
Ballenger-McKinney Wastewater Treatment Plant, Frederick County, MD	57,000
Cox Creek Water Reclamation Facility, Anne Arundel County, MD	57,000
West County WWTP, Louisville, KY	57,000
Seven Mile Beach WWTP for Cape May County Municipal Utilities Authority, NJ	57,000
Laguna WWTP, Santa Rosa, CA	57,000
Abiliene, TX, WWTP	57,000
Kanapaha WWTP, Gainesville, Fl;	57,000
Jordan Basin WRF, Utah	57,000
Caspar, WY, WWTP	53,000
North WRF, Orange County, FL	51,000
Loveland WWTP, CO	45,000
Visalia, CA, WWTP	45,000
Broad Run WWTP, Loudoun County, VA	45,000
Flat Creek WRF, Gainesville, GA	45,000
Tahoe-Truckee Sanitary Authority, Truckee, CA;	38,000
Tracy, CA, WWTP	38,000
Roseburg, OR, WWTP	38,000
Econchate WWTP, Montgomery, AL	38,000

Key West, FL, WWTP	38,000
Manhattan WWTP, KS	38,000
Grand Island WWTP, NB	38,000
Clear Creek WWTP, Redding, CA	38,000
West Camden, New South Wales, AU	36,000
Landis Sewage Authority WWTP, Landis, NJ;	32,000
Gippsland Water Factory, Tralagon, VIC, Australia	32,000
Tri-City WWTP, Oregon City, OR	31,000
Spokane County Regional Water Reclamation Facility, WA	30,000
Traverse City, MI WWTP	30,000
Southwest Water Reclamation Facility, Henderson, NV	30,000
Muskogee, OK, WWTP	28,000
Twin Falls, ID, WWTP	28,000
Parkway WWTP, Laurel, MD	28,000
Marcy Gulch WWTP, Highlands Ranch, CO	26,000
Chickasaw WWTP, Bartlesville, OK;	26,000
Grand Strand, SC, WWTP;	25,000
Morristown, NJ, WWTP	23,000
Wilsonville, OR, WWTP	20,000
Northern WWTP, Cairns, Northern Territories, AU	19,400
Southern WWTP, Cairns, Northern Territories, AU	19,400
Okmulgee WWTP, OK	19,000
Bonita Springs WWTP, FL	19,000
Leesburg, VA, WWTP	19,000
Stillwater WWTP, Redding, CA	19,000
Eagle River WWTP, Anchorage, AK	19,000
Laei WWTP, HI	19,000
Kearney WWTP, NB	19,000
Olivehurst, CA, WWTP	19,000
Linwood WRF, Gainesville, GA	19,000
Norwest Langley WWTP, Vancouver, BC	15,000
Port Townsend, WA, WWTP	17,000
Lower Township, NJ, WWTP	15,000
North Funen, DK, WRRF	11,500
Clovis Sewage Treatment/Water Reuse Facility, Clovis, CA	11,000
Benicia, CA, WWTP	11,000
Port Charlotte, FL, WWTP	11,000
Anacortes, WA, WWTP	11,000
Woodburn, OR, WWTP	9,500
Hillsboro, OR, WWTP	7,600
Mainside WWTP, Quantico Marine Base, VA	7,600

Harriman, TN, WWTP	7,600
West Jefferson WWTP, Evergreen Metro District, CO	3,800
Girdwood, AK, WWTP	2,800

Paul W. Behnke, PE (NJ & PA)
Behnke Pump Technologies, LLC
Owner and Principal Engineer

Mr. Paul Behnke is owner and principal engineer of Behnke Pump Technologies, LLC. BPT provides engineering services to EPC Contractors, equipment end-users, service providers, and manufacturers. BPT expertise includes:

- Pump markets and standards
- New product specification
- New product development
- Pump engineering and design
- Equipment manufacturing and quality
- Equipment test and vibration analysis
- System startup, commissioning, and operation
- System analysis, troubleshooting/optimization.

Mr. Behnke's 40-year career in the pump industry included employment with ITT Goulds Pumps as Executive Director where he led associates in Product Engineering, R&D, Hydraulic Design Technology, Materials Technology, Customer Service, and successfully developed new product designs and new technologies on a global basis. Before joining ITT, Mr. Behnke was employed by Bechtel as Manager Mechanical Equipment/Senior Principal Engineer where he worked with multiple project teams around the world to solve equipment and system problems in Energy, Nuclear Power, and Infrastructure businesses. Prior to Bechtel, he worked for Flowserve, Ingersoll Dresser Pump, and Ingersoll Rand in a wide variety of roles ranging from Product Design Engineer to Chief Engineer to General Manager.

Mr. Behnke is a licensed Professional Engineer by the State of New Jersey and the Commonwealth of Pennsylvania, inventor with 12 US Patents, and author of numerous technical publications. He serves as Vice President of Certification Programs and Performance Technical Section Leader at the Hydraulic Institute. He serves as Secretary Task Force Pumps (API 610 Standard) at the American Petroleum Institute. He is a past board member at the Hydraulic Institute and the Turbomachinery & Pump Users Symposium.

Mr. Behnke holds a BS in Mechanical Engineering from Rutgers University and an MBA in Business from Lehigh University, as well as MSME studies at Lehigh University.

WWE

Wright Water Engineers, Inc.

JONATHAN E. JONES, P.E., P.H., D.WRE

CHIEF EXECUTIVE OFFICER

CURRENT

Employed by Wright Water Engineers, Inc. (WWE) from June 1981 to the present. Consultant to public and private sector clients on many aspects of surface water and groundwater quantity and quality engineering with emphasis on stormwater quantity and quality; floodplain management; surface water hydrology and statistical hydrology; water resources planning, policy and design; physical and legal water supply, including water rights evaluations and watershed models; dam and reservoir design; groundwater quality and hydrology; interaction between surface water and groundwater; lake and river impact assessment studies; multiple aspects of Federal Clean Water Act including National Pollutant Discharge Elimination System (NPDES) permits and waterbody classifications and numeric standards; municipal and industrial wastewater treatment; erosion/sediment control, channel stability and sediment transport; risk assessment; water classifications and standards; engineering aspects of wetland permitting; and assignments involving Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

EDUCATION

M.E., Civil Engineering, 1981
University of Virginia

B.S., Civil Engineering, 1980
University of Virginia

REGISTRATION

Registered Professional Engineer

- Colorado (#22812)
- Arkansas (#12766)
- Hawaii (#PE16310)
- Indiana (#PE-10707888)
- Iowa (#19741)
- Kansas (#15784)
- Kentucky (#27122)
- Maine (#15657)
- Maryland (#4531)
- Massachusetts (#53626)
- Missouri (#028452)
- Nebraska (#E-9290)
- New York (#0898896-1)
- North Dakota (#10338)
- Ohio (#E-66327)
- South Dakota (#6551)
- Texas (#88335)
- Washington (#21012673)
- Wisconsin (#45904-6)
- Wyoming (#5072)

National Council of Examiners for Engineering and Surveying (#40434)
Professional Hydrologist # 16-H-8010
Diplomate of Water Resources, American Academy of Water Resources Engineers

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REPRESENTATIVE PROJECTS

Stormwater Quantity and Quality Management and Flood Control

International Stormwater Best Management Practice (BMP) Performance Database (www.bmpdatabase.org). On behalf of the American Society of Civil Engineers (ASCE), Urban Water Resources Research Council, and working under grant funding provided by the Water Environment & Reuse Foundation (WE&RF), the Environmental Protection Agency (EPA), Federal Highway Administration (FHWA), American Public Works Association (APWA), ASCE and others, has served as co-principal investigator/developer of the world's largest scientific database that summarizes urban stormwater BMP performance.

This database, which is widely referenced in engineering literature, includes nearly 800 BMP performance studies, including extensive statistical analyses of inflow/outflow, upstream/downstream water quality data. The team has expanded the Database to include special analysis of management issues for the Chesapeake Bay and agricultural BMP performance under targeted funding from the National Corn Growers Association, the United Soybean Board, and the Water Research Foundation. The Database was also broadened to include the water quality benefits of stream channel restoration projects. The Database contains many technical papers and topic summaries, BMP performance monitoring guidance (prepared under separate funding from EPA) and statistical summaries. For example, the hydrologic performance of LID/GI technology has been featured.

Smoky Hill River Renewal Project Preliminary Design. Provided peer review to HDR in their work on the preliminary design of the renewal project to restore the old channel of the Smoky Hill River through downtown Salina over a reach of approximately seven miles.

Mile High Flood District (MHFD), formerly Urban Drainage and Flood Control District [UDFCD]) and Cities and Counties in the Denver Metropolitan Area. Consultant on wide-ranging stormwater quantity/quality issues. Examples include: principal engineer and/or project manager of such documents as Volumes 1, 2, and 3 of the Urban Storm Drainage Criteria Manual (criteria for 42 cities and counties in the Denver Metropolitan area); Big Dry Creek Tributaries Master Plan; Beebe Seep Canal/Barr Lake Master Plan; and a book that reviews the performance of drainage infrastructure in the Denver Metro area in the landmark September 2013 flooding. Prepared the water rights and water quality chapters of the South Platte River Master Plan (through Metropolitan Denver). Advisor to MHFD on draft Phase 1 stormwater NPDES regulations. The Criteria manual includes such topics as Design Rainfall and Runoff, Planning, Policy, Law, Water Drainageways, Storm Drains, Streets and Inlets, Floodproofing, and Water Quality, among others.

Jones Gulch, Colorado, Debris/Flood Flow Evaluation. Evaluated debris flow, flood flow, and hazard potential on Jones Gulch, tributary to the Snake River, at the Keystone Resort in Summit County, Colorado.

EPA Post-construction Stormwater NPDES Regulation and Other Consulting for EPA. Principal-in-charge on subcontract assignment for the Cadmus Group and Geosyntec, Inc., assisting EPA in Washington, D.C., with engineering aspects of the new post-construction stormwater NPDES regulation (2011). Worked as a subconsultant to Tetra Tech, Inc., to assist with development of guidance documents related to urban stormwater quality management and permitting for the EPA in Washington, D.C. For example, served as one of three panelists in a February 2008 webcast concerning how to evaluate BMP performance, in which over 4,000 people from around the United States participated. Assisted Tetra Tech and the EPA with their development of portions of the EPA website pertaining to stormwater quality management and permitting, including the Urban BMP Performance Tool.

State of Colorado. Retained to evaluate the nature and causes of surface water damage at the campus of Colorado State University (CSU) in Fort Collins and state office buildings in Sterling during a July 1997 extreme rainfall event.

ExxonMobil. Assisted on multiple assignments in Colorado and Wyoming related to (for example) stormwater NPDES discharge permitting; planning and design of stormwater BMPs; floodplain evaluation and regulatory floodplain compliance; permitting under Section 404 of the Clean Water Act and ancillary regulatory concerns; debris flow evaluation and flood flow quantification; design of sedimentation basins, detention ponds, culverts and other facilities; dam feasibility design; pipeline crossings of stream channels; and water supply and wastewater treatment facilities.

City of Springfield and Greene County, Missouri and Watershed Committee of the Ozarks. Developed stormwater management policies, ordinances, and design criteria manual, working closely with local government staff. Conceptual design of stormwater wetlands. Watershed protection plan preparation. Airport drainage system design review. Review of long-term stormwater program financial options. Engineering analysis of surface water controls at Springfield municipal solid waste landfill. Integrated plan preparation as consultant to HDR (starting in 2015). Provided peer review for additional work regarding optimizing total municipal expenditures for environmental compliance.

Stapleton Airport Site Redevelopment Pattern Book. Working on a multidisciplinary team led by Matrix Design Group, served as coauthor of the Stapleton Airport Redevelopment Site Pattern Book, which provides a blueprint for stormwater management for this large site in the Denver Metro area. This book provides guidelines for stormwater quantity and quality management and was the foundation for the drainage system that was constructed as the site was redeveloped.

City of Fayetteville, Arkansas. Working as subconsultant to Geosyntec Consultants, Inc., planned and prepared conceptual designs for the retrofitting of four existing storm drainage facilities to provide enhanced phosphorus removal in the Beaver Reservoir watershed and to assist the City with compliance with its municipal NPDES permit.

Town of Manitou Springs, Colorado. Provided peer review of WWE design drawings for channel stabilization and debris basins, including associated planning, permitting, and design tasks.

City of Lincoln, Nebraska. Part of a multidisciplinary team preparing a water quality master plan for the restoration of Antelope Creek in Lincoln, Nebraska in association with municipal NPDES permit. Antelope Creek runs through a highly urbanized area and the University of Nebraska. The water quality in this reach of Antelope Creek has historically reported concentrations of fecal coliform, metals, and other analytes that have exceeded the Nebraska Surface Water Quality Standards, and the Nebraska Department of Environmental Quality has established total maximum daily loads (TMDLs) for this reach of the creek.

Nebraska Storm Drainage Consulting. In conjunction with Olsson Associates Consulting Engineers, prepared major drainageway master plans and storm drainage criteria manual for the City of Lincoln, Nebraska and the Lower Platte South Natural Resource District. Advisor regarding general aspects of local stormwater quantity and quality management program, channel stability, and sediment transport. Also advised City of Lincoln staff on stormwater NPDES permitting issues and maintenance/upgrading prioritization as subconsultant to JEO.

Kansas Department of Transportation. Evaluated flooding near confluence of Walnut River and Arkansas River, including rainfall and river flow frequency analysis and river hydraulics. Also conducted separate assignment regarding evaluation of feasibility of relocating irrigation ditch near Garden City, Kansas (subconsultant to Burns & McDonnell).

City of Rogers, Arkansas, and Crafton Tull. Consultant on storm drainage criteria, major drainageway master plans, ordinance enactment, erosion and sediment control, stormwater quality, financing, and stormwater NPDES regulations.

Simeon Residential Properties, Colorado. Working closely with Simeon (site developer) and downgradient affected parties, designed comprehensive and advanced stormwater quality management plans for two separate developments, Grant Ranch and Chatfield Green (TrailMark), in Littleton, Colorado. Both of these projects involved the application of numeric discharge standards for stormwater BMPs and provide a high level of protection for downgradient receiving waters (both surface water and groundwater). Worked closely with Carroll & Lange on final design of channels, wetlands, ponds, and other features. In addition, oversaw confidential assignments for Simeon Properties related to due diligence for various properties related to physical and legal availability of groundwater and surface water, natural hazards, drainage, etc. Provided consultation regarding potential availability of Denver Basin groundwater. Developed water supply from Coal Creek for new golf course near Erie, Colorado. Dam safety evaluations. Evaluation of water supply reliability for potential pipeline property.

Springdale, Arkansas. Evaluated river restoration feasibility as subconsultant to Alta Planning + Design.

Intrawest Resorts, Padre Island, Texas. Evaluated flood hazards (due to hurricanes) for potential development for Intrawest Resorts, including statistical hydrology related to hurricanes, storm surge, and associated flooding.

Intrawest Resorts, Florida and South Carolina. Assisted Intrawest Resorts with evaluating water engineering aspects of resort developments in Florida and South Carolina.

Houston, Texas, Floodplain Mapping Evaluation. Reviewed proposed federal flood insurance rate maps (FIRM) prepared by Harris County Flood Control District for major property owners and developers in Houston Metropolitan area.

Denver International Airport (DIA). Assisted with preparation of initial storm drainage criteria for DIA, working as subcontractor to Bechtel, and with major drainageway master planning of Lower Box Elder Creek on east side of DIA for DIA, Adams County, and MHFD.

University of Illinois. Assisted Professor Edwin Herricks with design of parking lot BMPs on campus in Urbana–Champaign.

Audubon, Arkansas. Evaluated adequacy of proposed stormwater quality management facilities for potential commercial development in Fayetteville.

Dover–Norriseal, Houston, Texas. Performed onsite and offsite drainage investigation.

Stormwater and Other Bypass Projects. Provided guidance on stormwater and other bypass projects (during construction and/or permanent) for Rocky Flats Site, Chatfield Green residential community, Grant Ranch residential community, Cotter Corporation, MHFD, Summitville Mine (for Colorado Department of Public Health and Environment [CDPHE]), Tippet Ranch, Water Supply and Storage Company, and others. These planning and conceptual design studies included flow-frequency analyses to optimize conveyance capacity and assess system behavior in large events.

Waste Management of Hawaii, Inc., Oahu, Hawaii. Comprehensive investigation of Waimanalo Gulch Sanitary Landfill stormwater management system, including evaluation of stormwater NPDES permit compliance. Evaluation of large rainfall and runoff events (statistical hydrology) that caused flooding at landfill and downslope areas.

Stabilization of Caulks Creek, Wildwood, Missouri. On behalf of the City of Wildwood, Missouri and working closely with Intuition & Logic of St. Louis, served as advisor/reviewer of stream channel stabilization measures that were constructed on Caulks Creek to address severe erosion problems that were threatening to damage a county highway, including flow-frequency, hydraulic, and tractive force analyse.

City and County of Denver. Project manager for preparation of two water quality/drainage-related guidance documents for the City and County of Denver: Denver Water Quality Management Plan in 2004 and Denver Storm Drainage Criteria Manual in 2006.

Los Alamos National Laboratory, New Mexico. Prepared sitewide drainage criteria memorandum that addressed stormwater quantity and quality. Prepared construction-related stormwater pollution prevention plan for RCRA site subject to remediation (site contains transuranic and hazardous wastes and drains to tributaries of the Rio Grande).

San Diego County, California. Consultant regarding revisions to the County Drainage Criteria Manual and implementation of stormwater quality mitigation measures.

City of Beaumont, Texas. Consultant on master drainage planning and drainage criteria development.

Knaust Brothers, New York. Provided engineering review and testimony on adequacy of proposed stormwater quality management facilities for industrial office park in karst setting, including probable migration of stormwater into underground caves.

Great Western Sugar Company, Johnstown, Colorado. Evaluated flood hazard potential (flow-frequency analysis) of Great Western Sugar Company's Johnstown, Colorado facility with respect to floods ranging from the 10-year to 500-year return frequency, along with groundwater contamination studies, land treatment of high-strength industrial wastewater, and field sampling of groundwater quality.

University of Colorado and City of Boulder, Colorado. Coauthored study of environmental impacts of proposed 95-acre University of Colorado Research Park in Boulder, Colorado. Prepared sitewide conceptual drainage plan. Also, in a separate assignment, analyzed flood hydraulics, regulatory constraints, and specific flood-proofing measures for research buildings located in the Boulder Creek floodway in Boulder. Developed floodwater surface profiles.

Colorado Ski Country, USA. Expert witness for Colorado Ski Country, USA (consortium of all Colorado ski resorts), in hearings involving the Colorado Water Quality Control Commission and staff with the Colorado Water Quality Control Division on water quality standards in wetlands and stormwater NPDES permitting. Also prepared written testimony for Colorado ski resorts that was submitted to the EPA in Washington, D.C., regarding Phase II of stormwater NPDES permitting. Regular consultant to the Colorado ski industry on wide-ranging water resources issues.

Keystone Resort and Keystone—Intrawest, Colorado. Consultant on advanced stormwater quantity and quality management to comply with stringent Summit County phosphorus regulations for Lake Dillon, wastewater treatment and beneficial reuse, Lake Dillon model review (lake impact model), NPDES permitting, erosion and sediment control, water supply/water rights, 404 permits, integrated pest management and pesticide-free golf course design, snow-storage facility design, water quality monitoring, drainage and flood control, debris flow, groundwater supply investigation, interaction of surface water and groundwater, and NPDES permitting.

Bekaert Steel, Arkansas. Performed stormwater quality and NPDES permitting assignment for facility in Bentonville, Arkansas.

UMETCO Minerals Corporation. Prepared industrial NPDES permit renewal for three mines in western Colorado, and a mine near Hot Springs, Arkansas.

City of Salina, Kansas, and "Friends of the (Smoky Hill) River." Performed river restoration feasibility evaluation, including water rights, stormwater quality, 404, 401, and NPDES permit issues, including comprehensive flow-frequency analysis of the river related to low flows, flood flows, and divertible flow, including effects of upstream storage.

Town of McCook, Nebraska. Evaluated surface water runoff from municipal solid waste landfill.

City of Sioux Falls, South Dakota. Performed river restoration feasibility, floodplain permitting, and river water quality analyses, including flow-frequency analysis in context of flood hazard evaluations.

Arkansas City, Kansas and Kansas Department of Transportation. Evaluated flooding on Walnut River related to construction of a highway, which served as a levee to protect the east side of Arkansas City.

City of Lamar, Colorado. Evaluated nature and causes of flooding along Willow Creek on the east side of the City of Lamar and sanitary sewer system evaluation.

City of Ogallala, Nebraska. Evaluated flooding at interchange of Highway 61 and I-80 (in collaboration with Nebraska Department of Roads).

City of Golden, Colorado. Prepared comprehensive review of nature and causes of flooding in Arapahoe Gulch and a tributary to Kenneys Run during large storms that occurred in June 2004, followed by master plan and preliminary design of improvements for Arapahoe Gulch. Worked on projects in close conjunction with Colorado Water Conservation Board, MHFD, City staff, and neighborhood residents. Findings presented to City Council.

City of Woodland Park, Colorado. Evaluated flooding damages in mobile home park, including assessment of whether recent channel modifications had aggravated flooding.

Fassnight Creek Floodplain Evaluation, Springfield, Missouri. On behalf of Springfield, Missouri Department of Public Works, conducted independent evaluation of proposed floodplain acquisition/ channelization project on Fassnight Creek. This included generating peak flows and associated areas of inundation for a range of floods, from frequent to infrequent.

Stormwater-related NPDES permits. Consultant for such public and private entities as:

- Allstate Consulting Engineers
- ARCO Coal Company
- Aspen Earth Moving Company
- Bad River Band of Lake Superior Chippewa
- Bar S Foods Company
- Bekaert Steel (Bentonville, Arkansas)
- Boeing Corporation
- BP
- Cabela’s, Inc.
- Cherry Creek Basin Authority (Board Member)
- City and County of Denver, Colorado
- City of Lincoln, Nebraska
- City of Rockford, Illinois
- City of Rogers, Arkansas
- City of Salina, Kansas
- City of Springfield, Missouri
- Continental Homes
- Coors Brewing Company
- Crafton Tull Consulting Engineers
- Deltic Timber Company
- Denver Urban Drainage and Flood Control District
- EVRAZ Steel
- Exxon Mobil
- Frost Creek Development
- Futura Aluminum Company
- Geosyntec Consulting Engineers
- Gunnison Energy Co.
- Intrawest Resort Development
- J.F. Laing Homes
- Jensen Precast
- JEO Consulting Engineers
- John Morrell Company Union Carbide
- Keystone Resorts
- L.G. Everist
- Laing Village Homes
- Lennar Homes
- Los Alamos National Laboratory
- Monarch Casino
- Olsson Associates Consulting Engineers
- Rocky Flats Site
- Simeon Residential Communities
- United States Department of Energy
- Vail Associates
- Village Homes
- Waste Management, Inc.
- Watershed Committee of the Ozarks
- Winter Park Resort
- Xcel Energy
- United States Department of Justice
- United States Environmental Protection Agency

EPA Office of Water in Washington, D.C. Advisor on a variety of issues such as: indicators for monitoring the effectiveness of “wet weather” control measures (1993 for EPA directly and 1995 for the Rensselaerville Institute), national case studies for advanced industrial stormwater management (1993 and 1994), stormwater BMP effectiveness (from 1995 to present), and flow measurement in irrigation systems. Also reviewed 1996 draft version of document Wet Weather Research Plan and Stormwater Pollution Prevention for Industrial Activities and Stormwater Pollution Prevention for Construction Site Activities (focused on erosion and sediment control/channel stability), published by the Office of Wastewater Enforcement and Compliance, EPA. (See “Professional Activities” for additional projects involving EPA.)

Denver Regional Council of Governments. Coauthor of three-volume set of erosion control manuals in 1982 to 1983, which focused on how to prepare erosion control plans, costs of erosion control measures, and design recommendations for control measures best suited to Denver Metro area.

Representative Clients Involving Floodplain Delineation, Management, Flow-Frequency Analysis, Regulation, Damages Analysis, Channel Stability and Sediment Transport, and Related Topics:

- Coors Brewing Company in Colorado
- Coors Brewing Company at Harrisonburg, Virginia brewery
- ExxonMobil in Colorado and Wyoming
- BP–America
- City of Pueblo, Colorado and Pueblo Urban Renewal Authority
- Sloan's Lake tributaries in Denver, Colorado
- Invesco Field at Mile High Stadium in Denver, Colorado
- Pepsi Center in Denver, Colorado
- City of Lincoln, Nebraska major drainageways (subconsultant to Olsson Associates)
- City of Springfield, Missouri major drainageways
- Philips Farm in Columbia, Missouri (subconsultant to Allstate Consultants)
- City of Wildwood, Missouri (in association with stream channel stabilization)
- Salina, Kansas
- Sioux Falls, South Dakota
- Adam's Rib Resort in Eagle County, Colorado
- Keystone Resort in Summit County, Colorado
- Copper Mountain Resort in Summit County, Colorado
- Jordan River in Salt Lake City, Utah
- Urban Renewal Authority of the Town of Estes Park, Colorado
- Santa Susana Field Laboratory in Ventura County, California (Boeing Corporation and the State of California)
- West Elk Mine near Paonia, Colorado
- Airport Authority of Springfield, Missouri
- Intrawest Resort Development—Assignments on Padre Island, Texas, Gulf Coast of Florida and South Carolina coastal resorts
- Office of Risk Management and State Attorney General's Office of the State of Colorado
- City of Golden, Colorado
- Mile High Flood Control District (formerly Urban Drainage and Flood Control District) in Denver, Colorado
- City of Westminster, Colorado
- City of Broomfield, Colorado
- Adams County, Colorado
- City and County of Denver, Colorado
- City of Rogers, Arkansas (subconsultant to Crafton Tull)
- Groundwater Management District No. 3 in Garden City, Kansas
- Dover–Norriseal in Houston, Texas
- U.S. Fish and Wildlife Service for projects in Midwest Region (subconsultant to GEI, Inc.)
- U.S. Department of Energy and its prime contractors at former Rocky Flats Plant Site in Colorado and Los Alamos National Laboratory in New Mexico
- State of Kansas Attorney General's Office
- Arkansas City, Kansas
- Colorado Intergovernmental Risk Sharing Agency
- University of Colorado
- City of Boulder, Colorado
- City of Lamar, Colorado
- Winter Park Resort in Grand County, Colorado
- Village Homes in Colorado

- John Laing Homes in Colorado
- Simeon Residential Communities in Colorado
- Lennar Homes
- Centex Homes
- United States Department of Justice
- United States Environmental Protection Agency

Water Quality

Santa Susana Field Laboratory, California. Selected by the Boeing Company, with review and approval by the State of California Los Angeles Regional Water Quality Board and local environmental groups, to serve as one of five members of the Santa Susana Field Laboratory (SSFL) Surface Water Expert Panel. The SSFL site is approximately 2,500 acres and is located roughly 30 miles northwest of downtown Los Angeles. The site is jointly owned by National Aeronautics and Space Administration (NASA), Boeing, and the U.S. Department of Energy. The site was historically used for rocket engine testing and testing of small-scale nuclear reactors. Certain contaminants have been detected in stormwater runoff from the site, including, as examples, dioxin and heavy metals. The Los Angeles Regional Water Quality Board has imposed stringent numeric limits on approximately two to three dozen compounds in stormwater discharges from the site. The role of the panel is to provide advice and guidance on how to plan, design, construct, and maintain stormwater treatment facilities that will best enable discharges to comply with the relevant permit limits. Pollutant sources include historic rocket engine test facilities, solid waste landfills, other waste disposal locations, a shooting range, and others. Project includes gathering and statistically analyzing flow and water quality data from dozens of locations around site.

Boeing Facilities in Seattle, Washington. Consultant on wide-ranging stormwater quality and receiving water impact issues for the Boeing Company in Seattle, serving as one of three members of an expert panel, with technical support from Geosyntec Consultants. The panel has interacted with EPA Region X staff regarding enforcement of numeric limits for polychlorinated biphenyls (PCBs) in stormwater discharges from North Boeing Field into the Duwamish River, including stormwater quality assessment, BMP planning/design/review, and long-term monitoring, in the context of both CERCLA and the Clean Water Act. The panel assisted Boeing with defining the implications of having to meet strict numeric limits for *E. coli* in stormwater discharges. The panel worked with Boeing staff and consulting engineers to Boeing regarding the design of stormwater treatment facilities for "Plant 2," an approximately 140-acre site that has strict numeric discharge limits under RCRA and the Clean Water Act. Tidal fluctuation issues and utilization of valves to stop tidal backflows have been important considerations. Projects have included statistical analyses of flow and water quality data.

Rogers, Arkansas Utilities, Northwest Arkansas Regional Planning Commission, Northwest Arkansas Council, and Coalition of Major Municipal NPDES Permit Holders. Performed review of proposed total phosphorus TMDL for the Illinois River, which flows from Arkansas into Oklahoma, including review of water quality modeling for river proposed by EPA Region VI. Assessed economic impacts and NPDES permit implications of alternative regulatory scenarios and statistical analyses of river flow and water quality data. Also worked closely with Arkansas Department of Environmental Quality staff on this project.

Xcel Energy, Arkansas River. Evaluated bacterial loading to tributary of Arkansas River from onsite cooling, stormwater, and wastewater ponds. NPDES permit compliance.

State of Florida Stormwater Quality Design Criteria Review. Working initially for Versar, Inc. (EPA consultant) and then for the Center for Watershed Protection as member of an expert panel, reviewed the 2007 report Evaluation of Current Stormwater Design Criteria within the State of Florida for the Florida Department of Environmental Protection. The review focused on the statistical characterization of effluent quality of stormwater control facilities, the feasibility of stormwater treatment goals, the quality of the data from the studies used in the document, and the applicability of studies from areas outside Florida. Submitted a letter report summarizing opinions.

Total Petroleum, Colorado. Consultant on two separate matters involving the CRC refinery on Sand Creek in Commerce City, Colorado. Both cases centered on defining groundwater hydrology and subsurface contaminant movement. Also defined the significance of alleged NPDES violations and receiving water impacts in Sand Creek.

Monarch Casino NPDES (Colorado Discharge Permit System) Permit Feasibility. Working with casino planning and design team to define permitting implications of discharging foundation drain water with potentially elevated metals concentrations into North Clear Creek.

Long Pine Creek Watershed Management Plan, Nebraska. Project principal and reviewer of watershed modeling services for JEO Consulting Group for the Long Pine Creek Watershed in central Nebraska. Review of spreadsheet-based, in-house watershed model to identify sources and quantify the existing volume of annual pollutant loads to the watershed's primary receiving water, Long Pine Creek.

Clear Creek Watershed Management Plan, Nebraska. Served as project principal and reviewer for modeling of the Clear Creek Watershed. Utilized an EPA STEP-L model in conjunction with a lake model (BATHTUB) in order to reasonably estimate existing pollutant loads to Pibel Lake, the primary receiving waterbody in the watershed. The lake model, which was calibrated and validated utilizing long-term water quality data, was used to calibrate the watershed model so that it could be used to reasonably quantify and identify the primary sources of existing annual pollutant loads from the watershed to the lake.

Philips Farm, Missouri. Consultant (with local engineers Allstate Consultants, Inc.) for development of comprehensive water quality protection plan for proposed 500-acre residential/commercial development known as Philips Farm in Columbia, Missouri. Development located adjacent to two streams (Gans Creek and Clear Creek) that were considered to be sensitive and subject to stringent discharge requirements.

BP Products North America, Inc., Colorado. Assisted on numerous projects involving water quality and wetlands protection including, for example, evaluation of beneficial surface reuse alternatives for waters produced in association with coal bed methane. In addition, evaluated spills, produced water treatment technologies, and associated NPDES permit considerations.

City of Wildwood, Missouri. Evaluation of nature and causes of water quality degradation in two large residential lakes (Chesterfield Lakes) in the northeast part of Wildwood, including assessment of adequacy of erosion and sediment control practices at approximately 100-acre construction site.

City of Rockford, Illinois. Evaluated stormwater NPDES permitting and general issues related to City's stormwater program. Audited City compliance with NPDES permit.

EVRAZ Steel Corporation (Rocky Mountain Steel Mills), Pueblo, Colorado. Performed Use Attainability Analysis of Salt Creek. Industrial NPDES permit renewal. Synthesized stream flows for Salt Creek through industrial site. Section 316b (cooling water intake) rule compliance evaluation and consulting.

Johnson County, Kansas. Working as subconsultant to Olsson Associates, evaluated performance data of multiple BMPs to assist County with NPDES compliance.

Southern Hills Lakes, Springfield, Missouri. Provided assessment of nature and causes of water quality degradation in three lakes on the east side of Springfield, known as Southern Hills Lakes. Prepared action plan for addressing problem. Worked closely with neighborhood residents and presented findings to City Council.

Front Range Energy. Peer reviewed industrial NPDES evaluation related to potential stream standards changes in South Platte River.

National Renewable Energy Laboratory (NREL), Colorado. Performed stormwater BMP performance monitoring at Wal-Mart store in Aurora, Colorado for three years.

Lennar Homes. Provided assistance with stormwater permitting throughout the United States, with emphasis on Nevada, Arizona, California, and South Carolina.

Vail Associates, Potential Ski Resort in Idaho. Retained by Vail Associates to conceptually evaluate engineering feasibility of potential ski resort near Cascade Reservoir, with emphasis on potential impacts to reservoir.

National Cooperative Highway Research Program (NCHRP). Subconsultant to Geosyntec Consultants regarding stormwater quality research and report preparation.

Kansas Livestock Association. Provided assistance with stormwater runoff issues and regulatory review by EPA regional office.

Associated Ditches of Kansas. Provided assistance with TMDLs on Upper Arkansas River in Kansas, and numerous other planning, permitting and design projects for large-scale surface water and groundwater irrigation facilities. Extensive river flow and water quality frequency analysis, along the river, beginning at Colorado State line and focused on sulfate and TDS.

Little Sac River and Wilson Creek, Missouri. Assisted City of Springfield with evaluation of bacteria TMDL and implications for City NPDES permit.

Wilson Creek Mine, Hot Springs, Arkansas. Beginning in the mid 1990s, worked for UMETCO (subsidiary of Union–Carbide) to plan, design, and implement comprehensive mine reclamation practices, including buried solid waste in part of site. Project has included such features as wetlands, wetland channels, stream channel restoration, spoils regrading, treatment and revegetation, groundwater remediation, mechanical water treatment, floodplain evaluation, and others. Reviewed Use Attainability Analysis studies and assisted with NPDES permitting. Statistical hydrology for onsite streams and receiving waters.

Town of Silverthorne, Colorado. Retained by Town to evaluate potential adverse hydrologic impacts to wetlands as a consequence of existing and proposed residential construction. Investigation included construction of approximately 50 soil test pits and piezometers; interaction of surface water and groundwater; site hydrologic mass balance; groundwater hydraulics in response to development features such as foundation drains, road cuts, etc., and evaluation of measures to mitigate potential hydrologic modifications. Also worked closely with Town on behalf of Intrawest to prepare 1999 water quality and wetland protection ordinance.

Golf Course Water Quality Impact Mitigation Plans. Performed water quality planning for such courses/entities as Applewood (Jefferson County); Keystone River Course; Keystone Ranch Course; Adam's Rib (Eagle County); Maroon Creek Club (Pitkin County); Greene County, Missouri, and The Greens, Springfield, Missouri. Prepared 1996 Golf Course BMP Manual for CDPHE and Denver Regional Council of Governments.

Confidential Mining Client in Jefferson County, Colorado. Provided assistance regarding design of approximately 3,500-foot-long pipeline to temporarily bypass a creek through a mine site, to enable restoration of mine site to occur, including extensive flow-frequency analysis of Ralston Creek. Development of short-term and long-term mitigation and restoration plans for creek and associated riparian corridor. Assisted with water quality evaluations and NPDES permitting, including evaluation of applicable stream classifications and standards. Made multiple presentations to federal and state regulatory authorities and to Denver Water regarding project.

Agricultural Water Supply and Water Quality Issues. Consultant on various assignments including nonpoint source pollution, TMDLs, endangered species, and related subjects for ranchers, water right purchasers, and irrigation districts and companies. Representative clients include The Garden City Company (Kansas), Kansas Livestock Association, The Associated Ditches of Kansas, Coors Brewing Company (Coors owns agricultural properties), Greenland Ranch (Douglas County, Colorado), ranches purchased by Colorado Open Lands for historic preservation, and irrigated lands in North Dakota related to the Garrison Diversion project of the U.S. Bureau of Reclamation and cosponsors of the agricultural model of the International Stormwater BMP Database (www.bmpdatabase.org). Many of these projects have included hydrologic modeling in the context of flow-water quality relationships, minimum stream flows, water rights (diversion potential), and threatened/endangered species.

Bentonville, Arkansas TMDL and MS4. Consulted with the Town regarding impacts of potential phosphorus instream standard on NPDES permit as subconsultant to Geosyntec Consultants.

Colorado Stone, Sand, and Gravel Association (Coalition of Colorado Rock Products Companies). Evaluated impacts of new proposed regulation regarding selenium to NPDES discharge permits.

Climax Mining Company, Colorado. Provided testimony regarding statewide water quality standard for selenium.

Kansas City, Kansas. As subconsultant to Design Studios West, provided water quality and drainage planning on Shoal Creek for large proposed development tract owned by Zion Properties near Kansas City International Airport.

Salt Lake City, Utah Golf Course. Provided saline soils and water supply investigation for golf course in Salt Lake City owned by Zion Properties.

Coalition of Keystone, Breckenridge, Copper Mountain, Vail, Winter Park, and Silver Creek Ski Resorts and L.G. Everist, Inc. Consultant regarding negotiations with Northwest Colorado Council of Governments (NWCCOG) on water quality standards for the NWCCOG jurisdictional area, including Dillon Reservoir. These standards addressed such topics as stormwater quantity and quality management, erosion and sediment control, wetlands protection, protection of hydrologic balance, hazardous materials management, and sensitive watershed development. Earlier assignments included the design of “pound for pound” mitigation plans for proposed ski area development to protect Lake Dillon and phosphorus trading.

Futura Aluminum, Utah. Prepared industrial stormwater NPDES permit.

Copper Mountain Resort, Colorado. Prepared Water Quality Protection Plan for entire base area of resort. Evaluated adequacy of water and wastewater systems in response to projected major growth increases. Designed dewatering facilities for large underground parking areas, including comprehensive groundwater monitoring and modeling effort, and defined relationship between surface flows and groundwater levels. Designed underground parking drainage and pretreatment facilities. Assisted with stormwater quantity and quality design and lake water quality investigations. Acquisition of various NPDES permits. Provided stream impact assessment, including biological monitoring.

State of Utah Department of Environmental Quality. Assisted with preparation of regulation regarding statewide wetland water quality standards as subconsultant to Sear Brown Group.

ARCO Coal Company. Project manager for various assignments in Wyoming (Black Thunder Mine and Coal Creek Mine) and Colorado. Reviewed adequacy of water-related sections of an Environmental Impact Statement for a proposed 3,200-acre expansion of Black Thunder Mine; worked with Colorado Division of Minerals and Geology to design restoration plan for large coal refuse pile on the Purgatoire River west of Trinidad, Colorado; evaluated groundwater quality issues; evaluated 404 permitting requirements; and performed general water resources consulting, including water rights.

Town of Snowmass, Colorado. Prepared Brush Creek Watershed Plan. Provided comprehensive water quality monitoring program for Town; designed stream channel stabilization and restoration, and interacted on such topics as riparian corridor protection and wetland protection.

Lone Star Landfill, Salt Lake City, Utah. Provided water quality data interpretation for legal counsel (Arnold & Porter) for landfill owner.

City of Winnipeg, Manitoba, Canada. Consultant regarding measures to be implemented to enhance the water quality of 200 lakes within the City of Winnipeg. Project began with assessment of the causes of observed problems and study of receiving water impacts.

Representative Projects Involving Refuse Piles, Mine Tailings and Spoils Piles. Locations included Clear Creek watershed for Coors Brewing Company (Colorado), London Mine (Colorado), coal strip mines (Pennsylvania), ARCO Coal Company (Wyoming and Colorado), tailings along San Miguel River (Colorado), UMETCO (Colorado and Arkansas), Purgatoire River coal refuse piles (Colorado), and Xcel Energy Cameo Power Plant (Colorado).

Lowry Landfill, Denver, Colorado. Project manager for a comprehensive surface water monitoring program and surface water hydrology evaluations, including interaction of surface flows with alluvial groundwater. Work conducted as a subcontractor to CH2M-Hill under an EPA Superfund contract. Detailed hydrology/hydraulic analysis of specific flood that transported water onsite.

Jefferson County Commissioners, Colorado Regarding Leyden Landfill. Retained to evaluate the engineering feasibility of reopening and enlarging an existing landfill near the community of Leyden in Jefferson County. Of particular concern to the Commissioners was the potential for contamination of downgradient groundwater resources. This assignment culminated with a report to the Commissioners.

Amako Resort Contractors, Colorado. Prepared dewatering and construction NPDES permits.

Lake Eldora Resort, Colorado. Evaluated water quality impacts of ski area development. NPDES permitting.

Centex Homes. Assisted with questions on construction NPDES permits.

Silverthorne–Dillon Joint Sewer Authority, Colorado. Evaluated the technical feasibility of using composted, Class "A" municipal sludge for reclaiming mine tailings. Considerations included groundwater, surface water interaction, and contaminant movement.

ASARCO, Inc., Colorado. Gave testimony for ASARCO before the Colorado Water Quality Control Commission in 1991 relative to proposed groundwater classifications and standards on the South Platte alluvium in Metropolitan Denver. Testimony addressed water quality data, implications of proposed regulations relative to ongoing clean-up under CERCLA, and generalized aspects of proposed standards for other industries in Denver Metro area. On a separate matter, WWE was selected by ASARCO to be their engineering expert on litigation that involved alleged groundwater contamination—the plaintiffs ultimately dropped this complaint.

Vail Associates, Colorado. Provided water quality monitoring, NPDES permitting, and watershed protection planning and design.

United States Department of Justice (DOJ). Expert testimony for the DOJ on cases involving water quality, hydrology, NPDES permitting, wetlands, and related topics. Additional information available upon request, subject to disclosure restrictions.

Watershed Management

Ozark Cavefish Habitat Assessment. Worked with Crafton Tull, Ozark Underground Laboratory, and the Nature Conservancy to prepare a comprehensive hydrologic assessment and protection plan (as the area urbanizes) for the 20-square-mile Fulbright Spring recharge area in northwest Arkansas. The area provides habitat for a federally listed threatened species of blind cavefish. Our work was developed for such entities as the United States Fish and Wildlife Service, Arkansas Department of Transportation, multiple local governments, and private property owners.

Deltic Timber Corporation and Lake Maumelle Watershed, Little Rock, Arkansas. Advised Deltic Timber regarding the practical implications of limitations related to proposed land development in the Lake Maumelle Watershed Management Plan. Lake Maumelle serves as public water supply for most of the Little Rock Metropolitan area, and the watershed management plan and County development ordinance established a series of stringent development requirements including, as examples, minimum open space and undisturbed land area requirements, compliance with numeric limits on certain constituents in stormwater discharges, and special commitments regarding treatment/discharge of sanitary wastewater. Work involved interaction with representatives of Central Arkansas Water and Pulaski County. Flow-frequency analysis of major tributaries discharging into Lake Maumelle, including associated sediment and nutrient loads.

Cherry Creek Stream Restoration, City of Glendale, Colorado. Worked as part of multidisciplinary team to develop a stream restoration/enhancement plan for the reach of Cherry Creek through Glendale, Colorado, in association with urban redevelopment project.

Sioux Falls, South Dakota. Worked closely with a large group of planners, architects, environmentalists, citizens, and others, and served as subconsultant to Brian Clark + Associates, planning and designing improvements to Big Sioux River through downtown Sioux Falls, South Dakota. Flow-frequency and regulatory floodplain analysis.

Salina, Kansas, Channel Restoration. Working closely with The Friends of the River and the City of Salina, planned and conceptually designed improvements to restore the old channel of the Smoky Hill River through downtown Salina over a reach of approximately seven miles. Design Studios West, Inc., was project planner and landscape architect. Project included extensive statistical analyses of Smoky Hill River.

Catawba Riverkeeper Foundation, Charlotte, North Carolina. Assisted with conceptual evaluation of impacts of proposed interbasin transfer to provide additional water supply for Charlotte suburbs.

The Garden City Company and The Associated Ditches of Kansas. Consultant regarding upper Arkansas subbasin management plan, TMDLs, state water quality standards, endangered species issues, Ogallala Aquifer management plan, Kansas water plan, and general water rights issues. These wide-ranging assignments involved regulatory review, planning, and engineering. The Associated Ditches of Kansas is a coalition of the five major diverters from the Arkansas River in southwestern Kansas. Extensive statistical analysis of river, focused on both high and low flows and river water quality.

Watershed Committee of the Ozarks, City of Springfield Public Works Department, City Utilities and Greene County, Missouri. Prepared the Fulbright Spring Protection Study, which evaluated the existing groundwater and surface water hydrology of Fulbright Spring and its associated watershed, and which suggested a watershed management strategy to protect spring water quality and water supply. Study defined and evaluated risks from significant potential pollutant sources including highways, residential, commercial and industrial development, golf course, solid waste landfill, and others.

Gunnison Energy Company, Colorado. Provided assessment of potential impacts to water resources (groundwater and surface water) of oil and gas development in Gunnison and Delta Counties in Colorado.

Rocky Mountain Shambhala Center, Colorado. Provided water supply development and water rights testimony.

Big Sky Ski Resort, Bozeman, Montana. Conducted consumptive use study for snowmaking system. Analysis was reviewed and approved by multiple Montana regulatory agencies. Analysis was integrated into a water rights application prepared by the resort.

Town of Vail, Vail Valley Consolidated Water Users, Upper Eagle Valley Water and Sanitation District, Vail Associates and others, Colorado. Consultant for the preparation and implementation of the Gore Creek Watershed Management Plan, which provides a blueprint for the future management of the stream.

Big Dry Creek Watershed Association and Gore Creek Watershed Alliance, Colorado. Reviewer of data and documents for two watershed groups in Colorado on wide-ranging, non-point issues, streamflow hydrology, water rights, habitat enhancement, and other subjects.

Aspen Skiing Company—Burnt Mountain Environmental Impact Statement and Other Consulting, Colorado. Consultant for the Aspen Skiing Company regarding the water resources impacts of a 6,600-skier-at-one-time expansion of the Snowmass ski area. Subjects evaluated include adequacy of water rights, land treatment of wastewater, impact on aquatic ecosystems of proposed ski area, channel morphology/stability, changed basin hydrology in response to clear cutting and other development, water quality degradation from point and non-point sources including soil erosion, planning and design of mitigation measures, field sampling and evaluation, endangered species assessment, hydrologic modeling/hydrologic mass balance, and groundwater impacts.

General Water Resources Management, Including Municipal, Agricultural, and Industrial Water Supply, Water Rights, Wastewater, Water Treatment, and Related Topics

Dam/Reservoir Consultation. Representative dam and reservoir projects and clients have included the following (all aspects of dam/reservoir planning; permitting; hydrology, including flow-frequency analysis and calculations of design floods up to the full probable maximum flood; hydraulics; design; maintenance/inspection; emergency preparedness; public safety; and others):

- Coors Brewing Company (Colorado)
- Water Supply and Storage Company (Colorado)
- Mile High Flood District (Colorado)
- ExxonMobil (Colorado)
- U.S. Bureau of Reclamation (North Dakota)
- Olsson Associates Consulting Engineers (Nebraska)
- Donald Dorman, Developer (New Mexico)
- U.S. Fish and Wildlife Service (North and South Dakota) (Subconsultant to GEI Consulting Engineers)
- Boeing Company (California)
- Colorado Intergovernmental Risk Sharing Agency (Colorado)
- Upper Arkansas Water Conservancy District (Colorado)
- Simeon Residential Communities and associated metropolitan districts (Colorado)
- City of Springfield (Missouri)
- Crafton Tull Associates Consulting Engineers (Arkansas, Missouri)
- Intrawest Resorts (Colorado)
- ARCO Coal Company, West Elk Mine (Colorado)
- Union Carbide, UMETCO (Colorado, Arkansas)
- Multiple local governments in Denver Metro area (Colorado)
- Waste Management of Hawaii
- Boy Scouts of America, Denver Area Council (Colorado)
- Laing Village Homes (Colorado)
- Shambhala Mountain Center (Colorado)

- L.G. Everest Rock Products and The Everist Company (Colorado)
- City of Salina (Kansas)
- Garden City Company and El Pomar Foundation (Kansas)
- Pueblo Urban Renewal Authority (Subconsultant to Design Studios West) (Colorado)
- Estes Park Urban Renewal Authority (Subconsultant to Design Studios West) (Colorado)
- Winter Park Resort (Colorado)
- Town of Idaho Springs (Colorado)
- Cabelas (Nebraska)
- Siegrist Rock Products (Colorado)
- Deltic Timber Company (Arkansas)

Water Supply Consultation. Provided consultation on surface water and/or groundwater supplies for the following representative entities (planning, permitting, statistical analysis focused on drought conditions and divertible flows, raw water quality, masterplanning, and related topics):

- Homestake Mining Company (Lead, South Dakota)
- ExxonMobil (Colorado)
- BP/Amoco (Colorado and Wyoming)
- Coors Brewing Company (Colorado, California, Idaho)
- Adam's Rib Resort (Colorado)
- Arapahoe County Water and Wastewater Authority (Colorado)
- Vail Associates (Idaho)
- Big Sky Resort (Montana)
- U.S. Bureau of Reclamation (North Dakota, California, Nevada, Arizona)
- ARCO Coal Company (Colorado)
- Water Supply and Storage Company (Colorado)
- City of Springfield and Greene County (Missouri)
- University of Colorado
- U.S. Department of Energy (Colorado)
- Denver Area Council of Boy Scouts of America (Colorado)
- Various Indian tribes including:
  - Umatilla (Oregon)
  - Hopi (Arizona)
  - Council of Energy Resource Tribes (Rocky Mountain Region)
  - Confidential tribe (name available on request)
- Intrawest Resorts (Florida, South Carolina, Colorado)
- Ski areas (Colorado, Montana, Colorado Ski Country, USA)

South Platte River Downstream Working Group (Coalition of Littleton, Arapahoe County, Englewood, Sheridan, and others) and the South Platte Greenway Foundation, Colorado. Performed analysis on impacts to South Platte River downstream of Chatfield Dam due to proposed reservoir allocation project and feasibility of providing instreamflow in river to benefit water quality and aquatic life.

BP–America, Colorado. Multiple assignments for the Durango, Colorado, Operations Center (San Juan Basin wellfield) related to Colorado water rights evaluation and testimony, determination of tributary versus nontributary groundwater, review of proposed Colorado Oil and Gas Conservation Commission regulations, planning and engineering for water rights augmentation plan, and design of stormwater impoundment.

Santa Teresa Development near Las Cruces, New Mexico. Working as a subconsultant to the Matrix Design Group, assisted with wide-ranging water resources issues related to the potential development of over 10,000 acres near Las Cruces, including wastewater and stormwater NPDES discharge requirements into the Rio Grande, wastewater and water master planning, evaluation of the water rights implications of wastewater reuse, stormwater and floodplain management, and optimizing the cost effectiveness of overall water resources management.

Groundwater Management District No. 3, Garden City, Kansas. Performed conceptual feasibility study of multiple projects to promote water conversation in southwest Kansas.

Intrawest Due Diligence and Site Feasibility Evaluations. Consulted for Intrawest Resorts in Texas, Florida, and South Carolina regarding the feasibility of either purchasing existing resorts or constructing new resorts, from the standpoint of water resources engineering issues such as water supply, wastewater treatment plant design, environmental permitting, floodplain regulation, building construction issues, hurricane storm surge (including statistical analyses of hurricane and storm surge data and floodplain studies).

Homestake Mining Company, South Dakota. Provided quantification of historic municipal water use from 1870s to the present for water system owned and operated by Homestake Mining Company. Expert testimony before state of South Dakota water resources board. Flow-frequency analysis of streams that Homestake diverted from, oriented toward defining flow rates that could potentially be dedicated to instream habitat protection.

Contra Costa Water District, California. Evaluated source water supply as subconsultant to Carollo Engineers.

Eagle's Nest Resort (3 Peaks) Development in Summit County, Colorado. Project manager on assignments related to groundwater investigations; site hydrologic mass balance; landslide evaluation, including field installation of four inclinometers, one dozen piezometers, and numerous test pits; testimony and detailed work with Town of Silverthorne to prepare and implement a Wetland Protection Ordinance; water rights and water supply; water quality and wetland protection and mitigation; and other water resource studies.

Industrial Site Location for Major Food Products Company. Searched multiple western states for suitable location for industrial site in western United States, with dependable supply of high-quality water as primary objective.

Estes Park Urban Renewal Authority, Colorado. Subconsultant to Design Studios West for major river improvements in downtown Estes Park, Colorado.

City of Rocky Ford, Colorado. Groundwater investigation related to water leakage from lake in Town Park.

J.F. Laing Homes and Village Homes, Colorado. Consultant on water supply and water quality impacts and NPDES permit implications for proposed 800-acre golf course/residential development to be located immediately upstream from Aurora Reservoir, which serves as public water supply for City of Aurora. Responsible for planning/conceptual design of stormwater quantity and quality management facilities. Responsible for developing irrigation water supply, including the evaluation of multiple alternatives such as utilization of Denver Basin (nontributary) groundwater, raw water from reservoir, stormwater reuse, and others. In addition, evaluated feasibility of creating wetlands in onsite arroyos.

Pueblo Urban Renewal Authority, Colorado. Subconsultant to Design Studios West for major river improvements in downtown Pueblo, Colorado, known as Historic Arkansas River Project.

L.G. Everist, Inc., Rock Products, Colorado. Consultant and advisor on wide-ranging topics including wetlands permitting, wetlands banking, surface water and groundwater hydrology, water rights, water supply, environmental permitting, and other subjects.

Cabela's Specialty Retail Company, Sydney, Nebraska. Performed water supply evaluation for major residential development including parks, recreational lakes, irrigation, 404 permitting, and assistance on floodplain permitting.

Wyoming Water Development Commission. Working closely with representatives of the Wyoming Water Development Commission and oil companies, developed streamflow and water quality model for the Powder River Basin in Wyoming, including flow-frequency analysis and statistical analysis of river quality data focused on TDS.

City of Brighton, Colorado. Provided expert testimony regarding the capability of the City of Brighton to provide municipal water supply for the Bromley Park subdivision versus the comparative capability of a local municipal water district. Approach was to perform a side-by-side comparison of the capabilities of the City versus the District on such subjects as suitability of existing infrastructure, past compliance history, financial capability, adequacy of groundwater, surface water supply quantity and quality, staff capabilities, etc.

Mountain Coal Company, Colorado. Prepared permit text for submittal to Colorado Department of Minerals and Geology regarding all aspects of surface water and groundwater quantity and quality impacts associated with mining-induced ground subsidence. Performed assessment and modeling of surface and groundwater hydrology and sediment transport, including effects of storing large quantities of water underground in mined-out panels. Prepared site hydrologic mass balance, landslide evaluations, water rights, and augmentation planning. Performed wastewater treatment feasibility studies and NPDES permit evaluations. Performed river morphology/stability evaluation and design. Performed 404 permitting.

Final Design of Rehabilitation Plans and Specifications for Upper Arkansas Water Conservancy District Dams, Colorado. Developed plans and specifications for the rehabilitation of two high mountain reservoirs.

Infrastructure Projects for Boy Scouts of America, Colorado. Conducted reconnaissance and prepared preliminary and final design projects for lake for the Peaceful Valley Boy Scout Ranch in Elbert County. Formulated water rights augmentation and operation plans. Designed water wells and water supply and wastewater treatment systems.

Lower Colorado River Basin Study for the U.S. Bureau of Reclamation. Analyzed return flow characteristics associated with non-contractual diversions (including wells) from the Colorado River in the reach from Davis Dam to the Mexico border. This included assessing the probable drawdown characteristics of wells in the proximity of the lower Colorado River.

Reconnaissance-Level Dam Study for Water Supply and Storage Company, Colorado. Analyzed 32 potential reservoir sites with respect to geology, hydrology (flood flows, drought flows, analysis of storable flow, flow-frequency analysis), water rights, dam sizing, spillway requirements, and probable environmental impact in the Cache la Poudre basin.

Preliminary Design for Trap Lake II, Colorado. Analyzed proposed reservoir site including water rights, basin yield, flood hydrology, financing, and all civil engineering and environmental issues leading to the preliminary design of a 4,400-acre-foot reservoir with a dam height of 85 feet.

Water Resources Development for EXXON Company, USA, Colorado. Pump-tested Battlement Mesa Colorado River alluvial supply wells and interpreted data. Categorization and ranking of irrigation water requirements for Battlement Mesa. Performed water supply study. Performed feasibility study of proposed reservoir on Monument Gulch. Performed transit loss studies.

Reservoir and Lake Water Quality Assessments and Feasibility Studies. Representative clients include: ExxonMobil (Colorado); City of Springfield (Missouri); Bowles Metropolitan District (Colorado); City of Winnipeg (Manitoba, Canada); Coors Brewing Company (Colorado); Water Supply and Storage Company (Colorado); City of Rockford and Forest Preserve District (Illinois); ARCO Coal Company (Colorado); McStain Residential Communities (Colorado); City of Boulder (Colorado); City and County of Denver (Colorado); U.S. Department of Energy (Golden); and Simeon Residential Properties (Colorado).

General Engineering Work for Irrigation/Ditch Companies. Wide-ranging engineering investigations (water supply, inflow/outflow analysis, consumptive use studies, water rights evaluations, design of ditch facilities such as measuring devices, bank protection, headgates, turnouts, and other facilities) for such entities as the Garden City Company (Garden City, Kansas); Associated Ditches of Kansas (southwest Kansas); Groundwater Management District No. 3 (Kansas); coalition of Kansas interests on the Republican River (northwest Kansas); FMIC Ditch (Colorado Springs, Colorado); Water Supply and Storage Company (Fort Collins, Colorado); various ditches in which the Coors Brewing Company has significant ownership stakes; and ditches at various mountain resorts and ski areas in western Colorado.

Slope Stability Investigations, Colorado. Evaluated water engineering aspects of slope stability investigations at Three Peaks development in Summit County, Colorado; Maryland Creek Ranch in Summit County; Keystone Resort in Summit County; and the West Elk Mine in Delta County.

Ground Subsidence Caused by Coal Mining, Colorado. Performed subsidence evaluations for West Elk Mine in Colorado, ARCO Coal, Arch Coal, and Weld County Landfill.

Coors Brewing, Ceramics, Glass, and Real Estate Companies, Colorado. Project manager, managing principal, senior engineer, or staff engineer for the following representative projects:

- Clear Creek water quality and habitat investigations
- Groundwater supply investigations, including surface water-groundwater interaction and testimony
- Water rights implications of relocating historic spring diversions
- Clear Creek “Cosmic” Agreement to resolve longstanding water quality issues (testimony in water court)
- Chicago Creek Reservoir enlargement (testimony in water court)
- Coors Augmentation Plan and various water rights exchanges
- NPDES permitting
- Stormwater quantity and quality management projects including drainage criteria/standards
- Groundwater classifications and standards, groundwater contamination studies, groundwater management strategies, and groundwater supply/hydrology (testimony in administrative hearings)
- Standley Lake water quality study
- Drainage and erosion control plans for 400-acre Coors Technology Center
- Water resources evaluation of Great Western Sugar Company’s Johnstown, Colorado, high fructose corn syrup plant with respect to water rights, groundwater, and surface water hydrology, wastewater treatment, and water supply of the Town of Johnstown
- Rolling Hills Country Club, Welch Ditch landslide
- Preliminary and final design of multiple dams and reservoirs
- Testimony regarding water quality classifications, standards, data, receiving water impacts, and related topics for Clear Creek and South Platte River
- Dam and reservoir inspections
- Coors Clear Creek water rights operations computer model
- Various water rights evaluations
- Cooling water system evaluation
- Pesticide-free golf course design and monitoring (Applewood)
- Drought and flood risk assessment
- Detailed review of stormwater and erosion control plans for numerous developments adjoining Coors’ properties
- Engineering assessment of the feasibility of utilizing the Coors Parfet clay pits, located in the City of Golden, Colorado, for the disposal of fly ash for the Public Service Company of Colorado

General Water and Wastewater Treatment Experience

- BP (Colorado)
- Northshore, Inc. (Colorado)
- Coors Brewing Company (Colorado)
- UMETCO (Arkansas)

- ARCO Coal Company (Colorado)
- Great Western Sugar Company (Colorado)
- Summit County Ski Resorts (Colorado)
- Homestake Mining Company (Colorado)
- John Morell Company (South Dakota)

Rocky Flats Site (Former Rocky Flats Plant Site) in Denver, Colorado (Kaiser–Hill, Inc., Rockwell International, EG&G, Inc., Rocky Mountain Remediation Services, and U.S. Department of Energy). Project manager and/or managing principal for the following representative assignments:

- Surface water hydrology, sediment yield and sediment transport modeling, and report preparation focused on the amount of offsite export of plutonium and other radioactive constituents
- Flow-frequency analysis of onsite and offsite streams and ditches for various current and future site water management strategies
- Testimony on stream classifications and standards before the Colorado Water Quality Control Commission
- Testimony before the Colorado Water Quality Control Commission on site-specific groundwater classifications and standards
- Principal author of the Rocky Flats Surface Water Management Plan, a document designed to bring Rocky Flats into full compliance with all local, state, and federal surface water regulatory requirements
- Principal auditor of proposed engineering facilities and associated costs for the roughly $100 million Option B project, consisting of dams, reservoirs, pipelines, pump stations, new raw water supplies, new water treatment plant, and other features to protect and replace downstream public water supplies
- Written testimony regarding biomonitoring standards
- Written testimony regarding statewide organic standards
- Written and verbal testimony regarding radionuclide standards, treatability, and economic impacts.
- Principal engineer for Rocky Flats Drainage and Flood Control Master Plan, a comprehensive drainage and flood control plan for 10-square-mile site, which included numerous sites regulated by CERCLA and RCRA, solid waste landfills, wastewater treatment plants, and extensive industrial infrastructure
- Consultant on stormwater-related and sanitary wastewater treatment plant NPDES permit matters
- A-, B-, and C- series and Landfill Pond Interim Measures and Interim Remedial Action Plan
- Consultant on water rights
- Groundwater contamination characterization, movement, interception, and treatment
- Gravel mine impacts on localized groundwater hydrology
- Auditor of groundwater monitoring program (approximately 500 wells), which resulted in deletion of over 100 wells and streamlined monitoring, at considerable cost savings
- Principal engineer on Rocky Flats Watershed Management Plan, which focuses on erosion and sediment control, channel stability, and pesticide management and selection
- In meetings with representatives of the cities of Broomfield and Westminster and in testimony before the Colorado Water Quality Control Commission, addressed questions regarding probable groundwater pollution sources on the Rocky Flats site, including, for example, the solar ponds, existing landfill, proposed landfill, 881 hillside, and various other operable units
- Assistance with various aspects of facility NPDES permit compliance

Adam's Rib Recreational Area, Colorado. Consultant for the Adam's Rib Recreational Area on water supply, wetland, and water quality issues pertaining to the development of a 2,000-acre resort originally planned to accommodate 10,000 users, including 9,000 skiers at one time. Broad work categories include:

- Comprehensive groundwater monitoring
- Vassar Meadow and Joe Goode Meadow hydrologic mass balances
- Section 401 of Clean Water Act permit
- Section 402 of Clean Water Act permit and wastewater treatment plant design

- Section 404 of Clean Water Act permit
- Pesticide-free golf course
- Statistical hydrology and special studies, including flow-frequency analysis, regarding surface water and groundwater hydrology
- Preparation of Water Quality Mitigation Plan for the entire development, a document which addresses all known point and non-point source pollution impacts of the development in the context of Colorado's water quality regulations
- Characterization of wetland functions under the 404(b)(1) guidelines
- All aspects of physical and legal water supply and impacts on minimum streamflows
- Many written and verbal presentations to the EPA, U.S. Army Corps of Engineers (USACE), U.S. Forest Service, Colorado Division of Wildlife, U.S. Fish and Wildlife Service, Colorado Water Quality Control Division, environmental organizations and other groups on the issues described above along with general water resources planning matters
- Erosion/sediment control and stream channel stability engineering design to meet no net/sediment increased performance standard, sediment transport, debris flows, channel stability
- NPDES permitting

Native American Tribes. Project manager for such tasks as: vulnerability assessments of tribal water supplies, risk assessment of pesticide usage, adequacy of proposed erosion and sediment controls, formulation of groundwater and surface water sampling programs and mitigation strategies to address observed problems, development of water supplies, overview of environmental laws, and likely adverse water quality impacts of existing or proposed industrial/commercial development. Projects were completed for the following tribes:

- Bad River Band of Lake Superior Chippewa
- Umatilla Indian Tribe (Oregon)
- Hopi Tribe (Arizona)
- Council of Energy Resource Tribes in Denver (technical staff for 52 Indian tribes)
- Rosebud Sioux
- Native American Fights Fund
- Other (confidential, available upon request)

Wetlands

Representative clients/projects for work associated with planning, permitting, design and performance evaluation of wetlands under Sections 401, 402, and 404 of the Federal Clean Water Act, along with "waters of the United States" issues, include, as examples:

- Coors Brewing Company/Molson Coors, Golden, Colorado
- City of Glendale, Colorado
- City of Sioux Falls, South Dakota
- Kansas Groundwater Management District No. 3
- Deltic Timber Corporation in Arkansas
- ARCO Coal Company in Gillette, Wyoming
- Municipalities on South Platte River downstream of Chatfield Reservoir, Denver Metro area
- Smoky Hill River channel restoration for City of Salina, Kansas
- Amazon Ditch Company in Garden City, Kansas
- Frontier Ditch Company in Syracuse, Kansas
- City of Springfield, Missouri and Greene County, Missouri
- Grant Ranch Residential Development in Littleton, Colorado
- Chatfield Green Residential Development in Littleton, Colorado
- Aspen–Snowmass Ski Resort in Pitkin County, Colorado
- Adam's Rib Resort in Eagle County, Colorado
- Colorado Ski Country USA (Coalition of Colorado Ski Areas)
- *International Stormwater BMP Database* developed for ASCE, APWA, WE&RF, FHWA, EPA, and others regarding wetland pollutant removal capabilities

- Mile High Flood District and multiple Denver area municipalities regarding major drainageway master plans
- Maryland Creek Ranch in Summit County, Colorado
- Three Peaks Resort in Summit County, Colorado
- Town of Silverthorne, Colorado
- Santa Susana Field Laboratory in Ventura County, California (for the Boeing Corporation)
- Winter Park Resort in Grand County, Colorado
- UMETCO (subsidiary of Union Carbide) regarding Wilson Mine near Hot Springs, Arkansas
- L.G. Everist Rock Products in Colorado
- City of Lincoln, Nebraska and Lower Platte South Natural Resources District, as subconsultant to Olsson Associates, JEO Consulting Engineers, and EA Engineering regarding stormwater master plans and drainage criteria involving wetlands
- Exxon–Mobil regarding Darby Mountain in Wyoming and Piceance Basin in Colorado
- Cotter Corporation in Jefferson County, Colorado
- EVRAZ Steel Mill in Pueblo, Colorado
- Keystone Ranch Golf Course in Summit County, Colorado
- Xcel Energy in Eagle County, Colorado
- Town of Vail, Colorado
- Lake Catamount Resort in Routt County, Colorado
- Coalition of local governments in Northwest Arkansas and Northwest Arkansas Regional Council of Governments
- Water Supply and Storage Company in Fort Collins, Colorado
- West Elk Coal Mine near Paonia, Colorado
- State of Utah as subconsultant to Sear Brown Group
- United States Department of Energy and prime contractors at Rocky Flats Environmental Technology Site in Jefferson County, Colorado
- Rocky Mountain Shambhala Center near Red Feather Lakes, Colorado
- University of Colorado–Boulder and City of Boulder, Colorado
- Watershed Committee of the Ozarks in Springfield, Missouri
- City and County of Denver, Colorado
- Intrawest Resorts regarding Frostfire Wetlands near Keystone, Colorado
- Phillips Farm Residential/Commercial Development in Columbia, Missouri

Expert Testimony

Qualified as expert witness in federal and state courts and in formal administrative and regulatory hearings for plaintiffs and defendants in the following areas from 1984 to the present:

- Stormwater Quantity and Quality Management (Construction and Post-Construction)
- Water Classifications and Standards and NPDES Permitting
- Receiving Water Impact Analysis
- Public Health Implications of Standards Exceedances
- Surface Water and Groundwater Hydrology and Interrelationships
- Water Quality and Pollution Control (Surface Water and Groundwater)
- Flood Hazard Mitigation and Stormwater Quantity and Quality Management
- Municipal, Industrial and Agricultural Water Supply
- Water Rights/Water Supply/Water Demand/Basin Modeling
- Hydraulics
- Engineering Design and Cost Estimating
- Erosion and Sediment Control, Channel Stability, and Sediment Transport

Testified or was deposed in the following cases in the past four years:

- Ideker Farms, Inc., et al., v. The United States, Case No.1:14-cv-00183-NBF (2020).
- Jamison Ranch, Inc., a Nebraska Corporation v. Arthur Brownlee III and Brownlee Family L.P., a Nebraska Limited Partnership, Case No. CI 19-39 (2020).

- United States of America v. R. M. Packer, CO, Inc., Case No. 16-CV-10769 (2019).
- William Furlan, Individually Jo Lynn Furlan, as Next Friend for Haleigh Furlan, Dominic Furlan, and Lacey Furlan, Minors, Nathan Whipple, Individually, and Paula Whipple, Individually, v. Webber, LLC, A.R. Daniel Construction Services, Incorporated, Bear Creek Construction, LLC, Brazos Valley Contracting Co. and BMP Specialists, LLC (2017).

INSTRUCTOR FOR PROFESSIONAL DEVELOPMENT COURSES, SEMINARS AND CONFERENCE WORKSHOPS

Conferences offered by the ASCE, Urban Watersheds Research Institute (UWRI), University of Wisconsin Extension Service, Continuing Legal Education, American Society of Landscape Architects (ASLA) and University of Colorado at Denver Department of Continuing Engineering Education. Subject matter addressed included:

- Overview of Environmental Laws
- Erosion and Sediment Control and Channel Stability
- Receiving Water Impacts of Pollutant Discharges and NPDES Permitting
- General Surface Water and Groundwater Quantity and Quality Issues
- Stormwater Quality Management
- Urban Hydrology
- Design of Urban Drainage Systems
- Hydrology and Hydraulics
- Floodplain Management
- Multipurpose Drainage Design
- Risk Assessment and Benefit/Cost Analysis

OTHER EXPERIENCE

U.S. Environmental Protection Agency, Washington, D.C., 1979 to 1981 (approximately 1/3 time while a college student.) Performed comparison of engineering and economic feasibility of land treatment with other forms of municipal wastewater treatment. Prepared guidance for communities concerning acceptable application rates of municipal sludge from the standpoint of nitrate loading. Prepared guidance for communities concerning fee simple acquisition versus leasing of land required for land treatment wastewater systems. Prepared reports relating to “innovative and alternative” forms of wastewater treatment. Investigated reclamation of strip-mined areas in Pennsylvania utilizing domestic sludge as a fertilizer and soil conditioner. Assessed onsite wastewater treatment.

PROFESSIONAL ACTIVITIES

Reviewer for the technical paper “SILTspread: A Performance-Based Approach for the Design and Installation of Silt Fence Sediment Barriers” published by Journal of Irrigation and Drainage Engineering, May 2021.

Panel Member on Florida Atlantic University 2021 Annual Environmental Science Retreat, April 2021.

Reviewer of “Engineering’s Public-Protection Predicament”, Stuart Walesh, 2021.

for the guidance manual *Urban Stormwater BMP Performance Monitoring* for EPA, WE&RF Federal Highway Administration and Environmental and Water Resources Institute of ASCE, published October 2009 and available on the website of the International BMP Database

Commencement Speaker for the Department of Civil, Environmental and Architectural Engineering at the University of Colorado–Boulder, May 2020.

Member of the Task Committee and Reviewer of the update of *Manual of Practice 77, Design and Construction of Urban Stormwater Management Systems*. Urban Water Resources Research Council, 2020.

Panel Member on American Society for Civil Engineers Headquarters LID Parking Lot Retrofit Sustainability Leadership and Demonstration Project, 2020.

Member (2016-18) and Chair (2019–20) of the American Academy for Water Resources Engineering Awards Committee, which evaluates nominees for three different categories of awards.

Annual Guest Lecturer for University of Colorado–Boulder Department of Civil, Environmental and Architectural Engineering “Senior Design” class. Lead Instructor: Professor Matthew Morris. 2012–2019 and 2021.

Interviewee (along with B. Jones) for Stewart, Brett. “The importance of teaching and learning fundamental skills” in *Communiqué*, AXA XL Newsletter, March 2020.

Member of the Board of Directors for the Green Infrastructure Center, Charlottesville, Virginia, May 2018 to Present.

Organizer, Moderator, and Presenter for a seminar on Overview of Water Quality Regulations and Compliance provided by the Urban Watersheds Research Institute, in Denver, Colorado. February 2017.

Member of Advisory Board and Associate Editor of *IMPACT* magazine, a publication of the American Water Resources Association (AWRA). Associate editor of multiple issues.

Member of Focus Group identifying member and industry needs for new American Water Works Association Standards on Stormwater, formed in January 2015. Chairman: Chi Ho Sham, Current AWWA president. Providing ongoing assistance with preparation of standard. 2018–present.

Member of Steering Committee for Colorado State University’s Colorado Stormwater Center, Director: Tyler Dell, P.E. 2017.

Member of Board of Directors, Urban Watersheds Research Institute, Denver, Colorado. 2006–present.

Chairman of National Committee that prepared *Public Safety Guidance for Urban Stormwater Facilities* for the ASCE, APWA, National Association of Floodplain and Stormwater Management Agencies, Water Environment Foundation (WEF), ASLA, American Planning Association, and AWRA, 2012–2014.

Member of Board of Advisors, University of Colorado–Boulder, Department of Civil and Environmental Engineering, 2009–2013.

Invited Member of three-person panel on Stormwater Management Challenges, Annual Meeting of ASLA, Denver, November 2014.

Member of Expert Panel Regarding Santa Susana Field Laboratory Stormwater Runoff. Panel assesses stormwater runoff and water quality issues at an industrial site in Southern California that must meet strict numeric standards for multiple constituents, 2008–present.

Reviewer of *Guidelines for Evaluating and Selecting Modifications to Existing Roadway Drainage Infrastructure to Improve Water Quality in Ultra-Urban Areas.* National Cooperative Highway Research Program, Transportation Board, National Research Council, Washington, D.C., 2012.

Invited Panelist of Chesapeake Bay TMDL Urban Retrofit Innovation Roundtable: Next Generation LID/GI Technology and Financing Solutions: The National Experience. Sponsored by EPA Region III and LID Center, Inc., and chaired by Mr. Larry Coffman in Annapolis, Maryland, April 21–22, 2012.

Reviewer of *Pathogens in Urban Stormwater Systems* prepared by Urban Water Resources Research Council Pathogens in Wet Weather Flows Technical Committee, Environmental and Water Resources Institute, ASCE, August 2014.

Member of blue-ribbon panel that reviewed the WEF/ASCE Manual of Practice 87 *Design of Urban Stormwater Controls,* 2011.

Member of Board of Directors of American Academy of Water Resources Engineers, three-year term, October 1, 2007–September 30, 2010.

Member (appointed by the Governor of Colorado) of the Cherry Creek Basin Water Quality Authority Board of Directors from 2006 to 2010. Testimony before the Colorado Water Quality Control Commission on behalf of the Authority Board regarding adjustments to existing water quality standards in Cherry Creek Reservoir, 2010.

Chapter Writer of *Colorado Floodplain and Stormwater Criteria Manual*, published by the Colorado Water Conservation Board, 2008.

Editor of *Great Works on Urban Water Resources (1962–2001)*, published by ASCE and Environmental and Water Resources Institute, 2006.

Reviewer for the guidance manual *Urban Stormwater BMP Performance Monitoring* for EPA, WE&RF Federal Highway Administration and Environmental and Water Resources Institute of ASCE, published October 2009 and available on the website of the International BMP Database (www.bmpdatabase.org).

Invited Reviewer for the *Journal of Hydrology,* 2006.

Conference Chairman of *Experiences with Urban Stormwater BMPs in Colorado* Co-Sponsored by Denver UDFCD and CASFM, April 9, 2003.

Co-chairman of the Conference: *Linking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation*, Snowmass Village, Colorado, sponsored by the United Engineering Foundation, Environmental and Water Resources Institute of ASCE and EPA. (Proceedings available from ASCE, Reston, Virginia), August 2001.

Advisory Committee Member to the University of Virginia and Colorado State University Departments of Civil and Environmental Engineering.

Member of the research team conducting a study for the WE&RF titled Protocol for *Wet Weather Effect Assessment and Technology Performance Evaluation*, 1999.

Member of Conference Organizing Committee for the 1998 ASCE symposia in Chicago, Illinois, Coordination: Water Resources and Environment and Water Resources: A New Era for Coordination.

Coauthor of policy statement that emerged from symposia, which was signed by approximately 15 senior members of ASCE regarding National Water Resources Policy, titled *A New Approach to Coordination of Water Development and Environmental Regulations.* Published by AWRA, 1999.

Technical Reviewer of Chapter 8 Engineering (Codes, Standards, Practices, Control, and Protection Works), in the *Final Report of the Second National Assessment of Research Needs in Natural Disasters*. Published by the National Science Foundation, 1998.

Contributing Author of the reference *Urban Runoff Quality Management*, published by WE&RF and ASCE (WE&RF MOP No. 23 and ASCE MOP No. 87), 1998.

Invited Member of Technical Review Committee for the Land and Water Fund Stormwater facility construction project in Boulder, Colorado (1 of 25 national pilot projects selected by the National Geographic Society), 1997–1998.

Instructor at the WE&RF Workshop on Research Needs in Urban Stormwater on October 5, 1996, at the Annual Meeting of the WEF in Dallas, Texas, June 1997.

Invited Instructor for the Emerging Trends in Stormwater Quality Workshop at the National Precast Concrete Association Annual Convention in Denver, Colorado, February 1997.

Presenter at Town of Snowmass Village Seminar on Sediment and Erosion Control Techniques and Regulatory Requirements at the Snowmass Village Conference Center, October 10, 1996.

Member of the research team selected by the EPA to prepare the *Guidance Manual for Integrated Wet Weather Flow Collection and Treatment Systems for Newly Urbanized Areas.* Project directed by Dr. James Heaney with the University of Colorado, Boulder, 1998.

Reviewer of submittals to the WE&RF publication titled *Water Environment Research* (1997–1999).

Chairman and Principal Author of the ASCE and WEF *Manual of Practice for the Design and Construction of Urban Stormwater Management Systems* (ASCE MOP No. 77). A Task Committee of approximately 100 engineers from around the United States and Canada prepared this document (724 pages), which was jointly published by ASCE and WEF, 1992.

Chairman of the ASCE Urban Water Resources Research Council (1992 to 1996) and Secretary of Council, 1989–1992. Also member of Special Committee (four members) of ASCE Water Resources Planning and Management Division to evaluate the future role of this Division, given ASCE's 1996 Strategic Plan for the future.

Reviewer of the McGraw–Hill *Handbook of Hydrology*; David R. Maidment, Principal Editor, published by McGraw–Hill, 1993.

Reviewer for WE&RF and ASCE of various draft technical and policy documents prepared by the EPA and USACE, early-mid 1990s.

Invited Reviewer of draft EPA document titled Wet Weather Research Plan (invited by the EPA), through the ASCE Urban Water Resources Research Council, August 1996.

Session Chairman and Conference Co-organizer of Effects of Watershed Development and Management on Aquatic Ecosystems with co-sponsors ASCE, Engineering Foundation, and EPA (including financial support) held at the Snowbird Resort in Utah, August 4–9, 1996.

Conference Organizing Committee Member and Session Chair of Effects of Watershed Development and Management on Aquatic Ecosystems, funded by the EPA, APWA, and United Engineering Foundation, Snowbird, Utah, 1996.

Chairman of the Planners, Engineers and Waterways Conference sponsored by ASCE, AWRA, American Water Works Association, Colorado Division of Wildlife, ASLA, APWA, UDFCD, Denver Regional Council of Governments, and other organizations, Denver, Colorado, February 1996.

Reviewer of *Greenways, A Guide to Planning, Design and Development*. By C.A. Flink and R. M. Searns and published by the Conservation Fund, 1995.

Reviewer of USACE *Handbook for Stormwater Pollution Prevention Plans* at the request of the Civil Engineering Research Foundation in 1995.

Presenter of Seminar on *Stormwater-Related NPDES Permitting and its Relationship to Comprehensive Stormwater Management* at the Annual Meeting of the ASLA, San Antonio, Texas, October 1994.

Session Chairman of *Stormwater NPDES Related Monitoring Needs*. Conference sponsored by the EPA, Engineering Foundation, and ASCE in Crested Butte, Colorado, August 1994.

Chairman of a national conference titled *National Water Resources Regulation—Where Is the Pendulum Now?* sponsored by ASCE, American Bar Association (ABA), EPA, U.S. Geological Survey, USACE, AWRA, American Geophysical Union, APWA and others, held in Washington, D.C., January 31–February 1, 1994.

Liaison between the ASCE Urban Water Resources Research Council and ASCE's Water Resources Planning and Management Division for the organization of the Annual Meeting of the ASCE Water Resources Planning & Management Division in Seattle, Washington, May 1993.

Reviewer for the *Irrigation and Drainage Engineering* journal published by ASCE, 1991–1994.

Conference Co-chairman of the *Effects of Urban Runoff on Receiving Systems: An Interdisciplinary Analysis of Impacts, Monitoring and Management*, Mount Crested Butte, Colorado. Sponsored by the Engineering Foundation, American Association of Civil Engineers (ASCE) and Water Pollution Control Federation (WPCF) with speaker funding provided by EPA, August 4–9, 1991

Program Co-chairman of Colorado Environmental Regulation—Where Is the Pendulum Now? Two-day conference in Denver, Colorado, sponsored by the Colorado Bar Association, ASCE, APWA, AWRA, Water Pollution Control Agency, Central Ground Water Authority, CHWS, and Urban Drainage and Flood Control District, April 24–25, 1991.

Invited Engineering Consultant to provide verbal and written presentation titled Technical and Engineering Aspects of EPA Stormwater NPDES Regulations prepared for the Utility Water Act Group, a consortium of American Electrical Power Companies, February 1991.

Technical Reviewer for Van Nostrand Reinhold Publishing Company, New York, 1991.

Control Group Member of the ASCE Task Committee to Evaluate Impacts to Aquatic Life Forms Posed by Urban Runoff Pollution, 1990–1991.

Advisor to the WEF and ASCE on Continuing Engineering Education Programs, 1989–1991.

Technical Reviewer for Prentice–Hall, 1990.

Consultant to State of Colorado Board of Registration for Professional Engineers and Land Surveyors for the investigation of professional practice charges against professional engineers, late 1980s.

Program Chairman of the Denver Metropolitan Area Urban Runoff Quality Conference held at the Stapleton Airport Holiday Inn (co-sponsored by ASCE, APWA, AWRA, and Denver Urban Drainage and Flood Control District, October 1988.

Member, Conference Organizing Committee and Session Chairman of the ASCE and Engineering Foundation EPA Conference on Urban Runoff Quality Mitigation Measures held at Trout Lodge in Potosi, Missouri, July 1988.

Reviewer of professional papers for the ASCE *Journal of Water Resources Planning and Management Division,* 1986 and 1987.

Session Chairman of the ASCE/Engineering Foundation/EPA Conference: Urban Runoff Quality: Its Impacts, Quality and Enhancement. Henniker, New Hampshire, 1986.

AWARDS

2018 Outstanding Stormwater Research Project Award from the California Stormwater Quality Association for the International Stormwater BMP Database.

2013 Outstanding Stormwater BMP Implementation Award from the California Stormwater Quality Association for a biofilter system at the Santa Susana Field Laboratory (SSFL) site in Ventura County to the SSFL Surface Water Expert Panel (of which Mr. Jones is a member), Geosyntec Consultants, Inc., and the Boeing Company.

2011 Honor Award for Planning from the Colorado Chapter of the ASLA for WWE's work with Design Studios West on the Smoky Hill River Renewal Master Plan.

2007 Land Stewardship Award and the 2007 President's Award of Excellence in Design from the Colorado Chapter of the ASLA for WWE's work with Design Studios West on the Estes Park Riverwalk.

2006 Engineering Excellence Honor Award from the American Consulting Engineers Council of Nebraska for the urban drainage study WWE performed for the City of Lincoln, Nebraska as a subconsultant to JEO Consulting Group along with Black & Veatch and the Heartland Center for Leadership Development.

2005 Award for Outstanding Service from the Environmental and Water Resources Institute Urban Water Resources Research Council.

2003 ASCE State-of-the-Art Civil Engineering Award for development of the EPA/ASCE International Stormwater BMP Database. Co-recipients Eric Strecker, P.E., Geosyntec, and Ben Urbonas, P.E., UDFCD.

Corporate and Staff Awards for Wright Water Engineers, Inc. Chief Executive Officer and major owner of WWE, which has received various awards including the 1996 Colorado Ethics in Business Award, 1999 Society of Financial Professionals National Ethics Award and project and staff awards from such organizations as the American Consulting Engineers Council, CASFM, and CDPHE. (See WWE website [www.wrightwater.com] for more information.)

Honorary Member of Chi Epsilon, inducted December 4, 2013. Nominated jointly by the University of Virginia and the University of Colorado.

REPRESENTATIVE PRESENTATIONS

Coauthor of Use of the State Department of Transportation Portal to the International Stormwater BMP Database with co-presenters Marc Leisenring, Paul Hobson, Daniel Pankani, Lucas Ngyuen, Jane Clary, Haley Rogers and Eric Strecker. Prepared for AASHTO Committee on Environment and Sustainability as part of NCHRP Project 25-25, Task 120, National Cooperative Highway Research Program. March 2020.

Coauthor of International Stormwater BMP Database: WRF Lunch and Learn with co-presenters Harry Zhang, P.E. Ph.D., Jane Clary, Marc Leisenring, P.E., and Eric Strecker, P.E. Water Research Foundation. September 2018.

Presenter of Engineering and Scientific Approaches for Evaluating the Relative Permanence of a Hydrologic Connection with co-presenters Noah Greenberg and Natalie Phares at Annual Meeting of Society of Wetland Scientists. May 31, 2018.

Invited Presenter of Case Studies of Public–Private Partnerships Around the United States at Kansas City Water Congress Annual Meeting. February 6, 2018.

Coauthor of Summary of EWRI Public Safety Guidance for Urban Stormwater Facilities with co-presenters Charles Rowney, P.Eng, and Ben Urbonas, P.E., at EWRI Operation & Maintenance of Stormwater Control Measures Specialty Conference. November 7, 2017.

Coauthor of Considerations for Evaluations of *Relatively Permanent* Water Status. Presented by coworkers Natalie Phares and Noah Greenberg at Annual USEPA Region 8 Wetlands Conference. October 3–5, 2017.

Coauthor of Low Impact Development Retrofit after 20 Years at a Boulder, Colorado, Office Building. Presented by coauthor Natalie Phares at Colorado Association of State Floodplain Managers 2017 Annual Conference, Breckenridge Colorado. September 20, 2017.

Coauthor of International Stormwater BMP Database New Tools for a Long-Term Resource with co-presenters Jane Clary, Eric Strecker, P.E., Marc Leisenring, P.E., and Harry Zhang, P.E., Ph.D. May 2017.

Integrated Stormwater Management for Highway and Transportation Sector: Database and Modeling Tools, Part 1: International Stormwater BMP Database: What's in it for DOTs? with co-presenters Jane Clary, Marc Leisenring, P.E., Eric Strecker, P.E., and Harry Zhang, P.E., Ph.D. April 2017.

Coauthor of International Stormwater BMP Database: New Tools for a Long-term Resource, Great Lakes and St. Lawrence Green Infrastructure Conference, Integrated Stormwater Management from Duluth to Quebec with co-presenters Jane Clary, Marc Leisenring, P.E., Eric Strecker, P.E., and Harry Zhang, P.E., Ph.D. Detroit, Michigan. March 2017.

Coauthor of Stream Restoration Crediting Guidance and Database. Water Environment & Reuse Foundation Webinar with co-presenters Brian Bledsoe, P.E., Ph.D., Rod Lammers, Jane Clary, Marc Leisenring, P.E., Eric Strecker, P.E., Scott Struck, Ph.D., and Adam McGuire. October 26, 2016.

Coauthor of Urban Stormwater BMP Database Tools and Performance Analysis Findings. WEF Technical Conference (WEFTEC), New Orleans, Louisiana with co-presenters Eric Strecker, P.E., Marc Leisenring, P.E. and Jane Clary. September 27, 2016.

Coauthor of Agricultural BMP Database: Initial Performance Findings. WEFTEC, New Orleans, Louisiana with co-presenters Jane Clary, Eric Strecker, P.E., and Marc Leisenring, P.E. September 27, 2016.

Coauthor of Development of a Stream Restoration Practices Database: Initial Progress. WEFTEC, New Orleans, Louisiana with co-presenters Brian Bledsoe, P.E., Ph.D., Eric Strecker, P.E., Scott Struck, Ph.D., Marc Leisenring, P.E., Jane Clary, Rod Lammers, and Adam McGuire. September 27, 2016.

Coauthor of the Agricultural BMP Database—A Growing Repository of Field Performance Data. EWRI 10th International Drainage Symposium, Minneapolis, Minnesota with co-presenters Marc Leisenring, P.E., Eric Strecker, P.E., and Jane Clary. September 9, 2016.

Coauthor of International Stormwater BMP Database 20 Years Later: Developing a Centralized Resource for BMP Performance. EWRI Annual Congress, West Palm Beach, Florida with co-presenters Jane Clary, Eric Strecker, P.E., Scott Struck, Ph.D., Marc Leisenring, P.E., Adam McGuire, Brian Bledsoe, P.E., Ph.D., Rod Lammers, Robert Pitt, P.E., Ph.D., and Alex Maestre, P.E., Ph.D. May 2016.

Presenter on the Agricultural BMP Database and its Application to Watershed Management Plans. Nebraska Water Resources Association Monthly Roundtable Meeting, Lincoln, Nebraska with co-presenter Adam Rupe of JEO Consulting. February 10, 2016.

Coauthor of Making the Most of National Water Quality and BMP Performance Databases as Tools to Address Nutrient Challenges: Urban Stormwater BMP Database. AWRA Annual Conference, Special Session 107, Denver, Colorado with co-presenters Eric Strecker, P.E., Marc Leisenring, P.E., and Jane Clary. November 16–19, 2015.

Coauthor of Stream Restoration: A New BMP Database Module That May Support Water Quality Crediting. AWRA Annual Conference, Special Session 107, Denver, Colorado with co-presenters Brian Bledsoe, P.E., Ph.D., Eric Strecker, P.E., Scott Struck, Ph.D., Marc Leisenring, P.E., Jane Clary and Rod Lammers. November 16–19, 2015.

Presenter on Water Quality Forum: Nutrient Trading—Recent Additions to the *International Stormwater BMP Database* that will Facilitate Trading. 60th Annual Midwest Groundwater Conference in Bentonville, Arkansas. October 13–15, 2015.

Presenter on Results of the Recharge Area Study—Cave Springs Cave, Arkansas with co-presenters Tom Aley (Ozark Underground Laboratory) and Tom Hopper (Crafton Tull). 60th Annual Midwest Groundwater Conference in Bentonville, Arkansas. October 13–15, 2015.

Coauthor of Stormwater BMP Performance: What Every Landscape Architect Should Know. Annual Meeting and Expo of the American Association of Landscape Architects, Denver, Colorado, with co-presenters Heather Whitlow (Landscape Architecture Foundation), Bill Wenk (FASLA, Wenk Associates), and Jason Berner (EPA). November 21–24, 2014.

Coauthor of Developing a Consolidated Resource for Agricultural BMP Performance. Association of Clean Water Administration and the State of Iowa (with Support from the EPA) Confined Animal Feeding Operation National Roundtable, Des Moines, Iowa, with co-presenters Theresa Conner (WE&RF), Jane Clary (WWE), and Eric Strecker and Marc Leisenring (Geosyntec Consultants). October 7–9, 2014.

Presenter at Colorado Intergovernmental Risk Sharing Agency and Wright Water Engineers, Inc., 2013 Colorado Flood Seminar, Conclusions and Lessons Learned. November 19, 2013.

Member of Panel on Governmental and Business Land Use Development at the Restoration of Our Rivers Conference of the Illinois River Watershed Partnership, Bentonville, Arkansas. October 3, 2013.

Presenter at A Watershed Event conference at the Watershed Committee of the Ozarks, Springfield, Missouri. The Economic Benefits of River Restoration with Don Brandes of Matrix Design Group. October 2, 2013.

Presenter to the University of Colorado Department of Civil, Architectural, and Environmental Engineering faculty regarding future trends in the workplace related to engineering graduates and what qualities employers are seeking in engineering graduates. May 14, 2013.

Coauthor of seminar at the World Environmental and Water Resources Congress, Showcasing the Future, Cincinnati, Ohio. One-half day seminar on Effective Use of the International Stormwater BMP Database with co-presenters Jane Clary, Andrew Earles, Eric Strecker, Marcus Quigley, Marc Leisenring, and Aaron Poresky. May 20–22, 2013.

Presenter at the 8th Annual WE&RF Research Forum, Stormwater BMP Performance: A Summary of Current Knowledge, at the Chicago Hilton, with Eric Strecker. January 29–30, 2013.

Coauthor of paper presented at the 8th Annual Conference of the California Stormwater Quality Association, Solving the Stormwater Compliance Puzzle, at the Hilton San Diego at Mission Bay, Adaptive Stormwater Management at an Industrial Site with Numeric Effluent Limits: Santa Susana Site, with Brandon Steets, P.E., and Megan Otto, P.E., of Geosyntec Consultants and Robert Pitt, Ph.D., P.E., BCEE, D.WRE, University of Alabama. November 5–7, 2012.

Presenter at The Restoration of Our Rivers: A National and Regional Perspective on Urban Stormwater, sponsored by the Illinois River Watershed Partnership, Crystal Bridges Museum, Bentonville, Arkansas, Urban Stormwater and Riverfront Restoration, with Donald H. Brandes, Jr., RLA, Vice President, Matrix Design Group, Inc., and Northwest Arkansas Water Quality Issues—Past and Emerging Environmental and Engineering Issues. Regional Case Study: City of Rogers, Arkansas with Tom Hopper, Chairman of the Board, Crafton Tull. October 3–4, 2012.

Presenter at Current Issues in Storm Water Management at Lorman Education Services in Denver, Colorado. June 13, 2012 and February 29, 2008.

Presenter at New Storm Water Regulations and Techniques seminar at the Georgia Institute of Technology (Georgia Tech) sponsored by the Georgia Tech Hispanic Alumni Network and the Georgia Tech Water Alliance. April 16, 2012.

Presenter at Rocky Mountain Land Use Institute, The Wilderness City: Nature, Culture and Economy in the Next West, Annual Conference. The Economic Development of River Restoration. Presented with Donald Brandes of Design Studios West and Thomas Martin of ConsultEcon, Inc. March 1–2, 2012.

Presenter/Panel Member of Managing Fecal Coliform Conference: Science and Solutions to Regulatory Challenges. Washington Stormwater Center. Member of Interactive Panel: Techniques, Design, Equipment, Caveats, and Pitfalls. Puyallup, Washington. October 20, 2011.

Presenter of Stormwater Treatment Planning for an Industrial Permit with Numeric Limits. California Stormwater Quality Association (www.casqa.org) 7th Annual Stormwater Conference in Monterey, California. Presentation was given with Brandon Steets, P.E., of Geosyntec, Robert Pitt, Ph.D., P.E., of the University of Alabama, and Michael Stenstrom, Ph.D., P.E., of UCLA and included a Panel question and answer session regarding stormwater control planning for site with numeric action limits/numeric effluent limits. September 26–28, 2011.

Presenter for Santa Susana Field Laboratory Expert Panel. Presentations at multiple public meetings and Los Angeles Region Water Quality Board hearings from 2009 through 2014 in Ventura County, California. Also presentations on Panel activities and advanced stormwater management practices at annual meetings of California Association of Stormwater Quality Agencies (CASQA). 2011 and 2012.

Guest Lecturer for University of Colorado–Boulder, Department of Civil and Environmental Engineering, Senior Design Class. 2010 and 2011.

Guest Speaker for University of Colorado–Boulder, Student Chapter of ASCE. From School to Work. February 7, 2011.

Presenter at WE&RF Green Infrastructure Webcast. Quantifying Performance, Costs, and Multiple Benefits. December 7, 2010.

Seminar at UCLA Rocky Flats Environmental Test Site Closure Approach, seminar for graduate and undergraduate students and faculty of the Department of Civil and Environmental Engineering. November 30, 2010.

Speaker at the meeting of the Kansas City Chapter of APWA, Emerging Trends in Water Resources. July 15, 2009.

Presenter at the 2009 ASLA Colorado Spring Conference: Tools for Change, Keeping It Clean Trends in Water Resources at the University of Denver. May 15, 2009.

Speaker on Interstate Water Supply/Quality Conflicts and Consensus at the conference, Our Water Future: A Regional View—Sharing Information, Exchanging Ideas, sponsored by the Tri-State Water Coalition, Missouri State University and the Watershed Committee of the Ozarks, Joplin, Missouri. September 11–12, 2008.

Speaker at American Ecological Engineering Society Conference on Urban Stormwater Quality Management: Contemporary Issues at Beyond Wetlands: Engineering the Landscape. Conference of the American Ecological Engineering Society, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. June 11, 2008.

Keynote Speaker at the Missouri Floodplain and Stormwater Managers Association conference, Lake of Ozarks, Missouri. April 8, 2008.

Presenter at EPA BMP Performance Webcast (webcast slides can be downloaded from EPA Stormwater NPDES Permit website). February 6, 2008.

Presenter at Seminar on Emerging Issues in Water Resources Engineering, EPA Research Laboratory, Edison, New Jersey. January 31, 2008.

Presenter on Positive Signs for American Watersheds in 2005, at the meeting of AWRA in Tucson, Arizona, regarding National Water Policy Dialogue, with co-presenter Jane Clary. February 2005.

Presenter on Overview of Volumes 1 and 2 of the June 2001 Urban Storm Drainage Criteria Manual. Annual Meeting of the Colorado Association of Stormwater and Floodplain Managers (CASFM), Steamboat Springs, Colorado, with co-presenter Ken MacKenzie. September 2001.

Presenter on Best Management Practices for Development Projects in the Rocky Mountains at the Inaugural Session of the Water Congress of the ASCE Environmental and Water Resources Institute, Orlando, Florida, Washington, D.C., with co-presenter T. Andrew Earles. May 20–24, 2000.

Coauthor of Case Studies of Local Strategies for Control of Non-Point Source Pollution in Colorado (USA), NATO Advanced Research Workshop on Source Controls, St. Marienthal, Germany, with coauthors T. Andrew Earles and Wayne F. Lorenz. November 8–12, 2000.

Presenter on Development of National Stormwater BMP Database. Southeast Stormwater Manager's Conference, Orlando, Florida, with coauthors Jane Clary, John O'Brien, Ben Urbonas, Eric Strecker, and Marcus Quigley. June 28, 2000.

Presenter on Western United States Water Rights, at Watershed '99—Watershed Management Policy, Science and Technology, a forum at the Doubletree Hotel, Charlottesville, Virginia, sponsored by the University of Virginia School of Engineering and Applied Science and National Taipei University of Technology, Taiwan, ROC, co-sponsored by EPA Office of International Activities, National Taiwan University and Overseas Chinese Environmental Engineers and Scientists Association. April 8–9, 1999.

Presenter on Overview of Stormwater Quantity and Quality Management—Regulatory and Engineering Considerations at the ASLA—Colorado Section Annual Meeting, Vail, Colorado. September 1994.

Presenter of Citizen Initiatives from Around the United States to Protect Water Resources, luncheon talk prepared for the Annual Meeting of the Watershed Committee of the Ozarks, Springfield, Missouri. July 1993.

Presenter on Colorado Environmental Regulation: Where Is the Pendulum Now? Introduction and Perspective. Colorado Environmental Regulation: Where Is the Pendulum Now? Symposium sponsored by the APWA, ASCE, and others, Denver, Colorado. April 24–25, 1991.

Presenter of Overview of a Potential Water Quality-Monitoring Program for the Colorado Ski Industry. Workshop of the Colorado Ski Country and U.S. Forest Service, Snowmass, Colorado with co-presenter C.H. Hendricks. June 1983.

Presenter on The Implications of Altering Selected Regulations of the United States Environmental Protection Agency Pertaining to Land Treatment of Wastewater and Land Application of Sludge, at Virginia Section of the Water Pollution Control Federation, Natural Bridge, Virginia. April 1981.

Presenter on Is There a Future for Innovative and Alternative Technology in Wastewater Treatment? at Virginia Section ASCE Annual Conference, Old Dominion University, Virginia. May 1980.

PUBLICATIONS

(Note: Some of the publications described in this section were presented at conferences.)

Pitt, R., M. Otto, A. Questad, S. Isaac, M. Colyar, B. Steets, R. Gearheart, J. Jones, M. Josselyn, M. Stenstrom, S. Clark, and J. Wokurka. 2021. Laboratory Media Test Comparisons to Long-term Performance of Biofilter and Media Filter Treatment-train Stormwater Controls. *Journal of Sustainable Water Built Environment,* 7(4): 04021015.

Pitt, R., M. Otto, A. Questad, S. Isaac, M. Colyar, B. Steets, R. Gearheart, J. Jones, M. Josselyn, M. Stenstrom, S. Clark, P. Costa, and J. Wokurka. 2020. Can Laboratory Column Studies Really Predict Field-scale BMP Performance? A Comparison of 10 Years of Field-scale Performance Data with Original Bench-Scale Test Results. California Stormwater Quality Association Conference. September.

Bodine, E., J.E. Jones, T. Downing, J. Miriovsky, and L. Jha. 2020. The Engineering Basics of Planning, Designing & Constructing Singletrack Bike Trails. *APWA Reporter*. Vol. 87, No. 7. July.

Jones, J.E., J.K. Clary, E. Strecker, M. Leisenring, and H. Zhang. 2019. International Stormwater Database Technical Paper. *AIH Bulletin.* Vol. 35, No. 1. Summer.

Jones, J.E., J.K. Clary, E. Strecker, M. Leisenring, and H. Zhang. 2019. International Stormwater Database 2019 Update. *EWRI Currents.* Vol. 21, No. 2. Spring.

Jones, J.E., N. Phares, W. Wenk, J. Figueroa, M. Figurski, and E. Barnes. 2018. 20 Year Engineering Assessment of LID Facility in Boulder, Colorado. *Stormwater Magazine.* January/February.

Tillack, S., J.E. Jones, M. Shoulders, and R. Merry. 2017. Adam's Rib Water Quality Monitoring and Mitigation Plan in Eagle, Colorado. *Proceedings of Colorado Association of Stormwater and Floodplain Managers Annual Conference,* September 19–21. Denver, Colorado.

Leisenring, M., J.K. Clary, B. Bledsoe, R. Lammers, E. Strecker, and J.E. Jones. 2017. Stream Restoration as a BMP: Development of a National Performance Database and Crediting Guidance. *Proceedings of the Water Environment Federation Technical Exhibition and Conference (WEFTEC),* September 30–October 4, Chicago, Illinois.

Clary, J., Jones, J.E., Strecker, E., and Leisenring, M., Zhang, H. 2017. International Stormwater BMP Database: New Tools for a Long-Term Resource, WEFTEC, Chicago, Illinois. October 2.

Bledsoe, B., R. Lammers, J.E. Jones, J.K. Clary, E. Strecker, and M. Leisenring. 2017. Stream Restoration BMP Database: Version 1.0 Summary Report. WE&RF.

Bledsoe, B., R. Lammers, J.E. Jones, J.K. Clary, A. Earles, E. Strecker, M. Leisenring, S. Struck, and A. McGuire. 2016. Stream Restoration as a BMP: Crediting Guidance. Water Environment & Reuse Foundation: WERF1T13.

Leisenring, M., J.K. Clary, E. Strecker, and J.E. Jones. 2016. The Agricultural BMP Database—A Growing Repository of Field Performance Data. *Proceedings of 10th International Drainage Symposium*, University of Minnesota Water Resources Center, American Society of Agricultural and Biological Engineers, Minneapolis, Minnesota. September.

Jones, J.E. 2016. Introduction. *Impact Magazine—Drought: Response, Adaptation and Long Term Planning in a Changing Environment.* Vol. 18, No. 2, March. American Water Works Association.

Clary, J.K. and J.E. Jones. 2015. Developing a Consolidated Resource for BMP Performance Studies. *World Water: Stormwater Management.* Vol. 3, Issue 3, June/July.

Jones, J.E. 2015. Introduction. *Impact Magazine—Water and Energy Resource Development.* Vol. 17, No. 2. American Water Works Association. March.

Jones, J.E., Editor and Chair, Task Committee for Public Safety for Urban Stormwater Management Facilities. 2014. *Public Safety Guidance for Urban Stormwater Facilities*. B.R. Urbonas, P.E., D.WRE, Vice-chair, and A.C. Rowney, Ph.D., P.Eng, D.WRE, Secretary. Sponsored by ASCE/Environmental Water Resources Institute (EWRI) (led by the Urban Water Resources Research Council); WEF; National Association of Flood & Stormwater Management Agencies; APWA; AWRA; and American Planning Association. ASCE Press: Reston, Virginia.

Clary, J.K., E. Strecker, J.E. Jones, and M. Leisenring. 2014. Developing a Centralized Resource for Agricultural BMP Performance. *Proceedings of World Environmental & Water Resources Congress*. Portland, Oregon. June.

Jones, J.E., B.R. Urbonas, and A.C. Rowney. 2014. New Guidance from EWRI Protecting Public Safety at Urban Water Facilities. *EWRI Currents*. Vol. 16, No. 1. Winter.

Clary, J., J.E. Jones, M. Leisenring and E. Strecker. 2014. Enhancements to the International BMP Database. *APWA Reporter*. Vol. 81, No. 2. February.

Jones, J.E. 2014. Potential Factors Affecting Agricultural Water Resources Management. *Water Resources IMPACT.* Vol. 16, No. 1. January.

Earles, A., J.E. Jones, S. Tillack, K. Wright, and K. MacKenzie. 2013. Denver Metropolitan Area Fares Well During Severe Precipitation Event in September 2013. *Flood Hazard News*. Urban Drainage and Flood Control District; Denver. Vol. 43, No 1. December.

Otto, M., P. Hobson, R. Kampalath, B. Steets, R. Pitt, J.E. Jones, M. Stenstrom, R. Gearheart, M. Josselyn, and D. Taege. 2013. A New Statistical Methodology. *Stormwater*. Vol. 14, No. 6. September.

Jones, J.E., A.C. Rowney, and B.R. Urbonas. 2013. Public Safety at Stormwater Management Facilities. *The Stormwater Report.* Vol. 3, No. 5. May 2. http://stormwater.wef.org/2013/05/public-safety-at-stormwater-management-facilities/.

Clary, J., B. Steets, J.E. Jones, E. Strecker, and M. Leisenring. 2012. Fecal Indicator Bacteria Reduction in Urban Runoff: Updates from the BMP Database and Lessons Learned from TMDL Implementation. *Stormwater.* Vol. 13, No. 7. October.

Jones, J.E., J. Clary, E. Strecker, M. Quigley, and J. Moeller. 2012. BMP Effectiveness for Nutrients, Bacteria, Solids, Metals, and Runoff Volume: *International Stormwater BMP Database* Reaches the 500-BMP Milestone. *Stormwater.* Vol. 13, No. 2. March/April.

Brandes, D.H., J.E. Jones, and T.J. Martin. The Economic Development of Riverfront Restoration. Presented at The Wilderness City: Nature, Culture and Economy, in the *Proceedings of Next West, 21st Annual Rocky Mountain Land Use Institute Conference*, Sturm College of Law. University of Denver, March 1 and 2, 2012.

Clary, J., M. Leisenring, A. Poresky, A. Earles, and J.E. Jones. 2011. BMP Performance Analysis Results for the International Stormwater BMP Database. *Bearing Knowledge for Sustainability: Proceedings of the 2011 World Environmental and Water Resources Congress.* Palm Springs, California. May.

Clary, J., M. Quigley, A. Poresky, A. Earles, E. Strecker, M. Leisenring, and J.E. Jones. 2011. Integration of Low Impact Development into the International Stormwater BMP Database. *Journal of Irrigation and Drainage Engineering*. Vol. 137, No. 3. March.

Guo, J.C.Y., J.E. Jones, and A. Earles. 2010. Method of Superimposition for Suction Force on Trash Rack. *Journal of Irrigation and Drainage Engineering.* Vol. 136, No. 11. November.

Clary, J., M. Quigley, A. Earles, J.E. Jones, E. Strecker, and A. Poresky. 2010. Expanding the International Stormwater BMP Database Reporting, Monitoring and Performance Analysis Protocols to Include Low Impact Development (Part 1). *Proceedings of the 2010 International Low Impact Development Conference,* San Francisco. April 11–14.

Clary, J. and J.E. Jones. 2010. Challenges in Attaining Recreational Water Quality: Can the Standards Be Met? *IMPACT*. Published by AWRA. Vol. 12, No. 2. March.

Jones, J.E. 2010. Zero Impact Development. *IMPACT*. Published by AWRA. March. Vol. 12, No. 2.

Guo, J.C.Y. and J.E. Jones. 2010. Pinning Force during Closure Process at Blocked Pipe Entrance. *Journal of Irrigation and Drainage Engineering.* Vol. 136, No. 2. February.

Clary, J., J.E. Jones, and A. Earles. 2009. Trends in Water Resources Changing the Landscape. *Colorado Green*. Vol. 25, No. 6. November/December.

Clary, J.K., T.A. Earles, J.E. Jones, J.E. O'Brien, and B.R. Urbonas. 2009. Expanding the International Stormwater BMP Database Reporting, Monitoring and Performance Analysis Protocols to Include Low Impact Development. *Proceedings of CASFM 20th Annual Conference*, Crested Butte, Colorado. September.

Clary, J., M. Quigley, A. Earles, M. Leisenring, E. Strecker, and J.E. Jones. 2009. Integration of Low Impact Development Studies into the International Stormwater BMP Database. *Great Rivers: Proceedings of ASCE Environmental and Water Resources Institute, World Environmental and Water Resources Congress.* Kansas City, Missouri. May 17–21.

Clary, J., J.E. Jones, and B.R. Urbonas. 2009. Challenges in Attaining Recreational Stream Standards for Bacteria: Setting Realistic Expectations for Management Policies and BMPs. *Great Rivers: Proceedings of ASCE Environmental and Water Resources Institute World Environmental and Water Resources Congress*. Kansas City, Missouri. May 17–21.

Clary, J., J.E. Jones, M. Quigley, and E. Strecker. 2008. The International Stormwater BMP Database: What's in it for You? *Proceedings of Environmental and Water Resources Institute World Congress.* Honolulu, Hawaii. May.

Clary, J., C. Haines, and J.E. Jones. 2008. Green Building Alternatives to Rainwater Harvesting in Colorado. U.S. Green Building Council, *Colorado Chapter Newsletter.* May.

Clary, J., J.E. Jones, B.R. Urbonas, M. Quigley, E. Strecker, and T. Wagner. 2008. Can Stormwater BMPs Remove Bacteria? New Findings from the International Stormwater BMP Database. *Stormwater*. Vol. 9, No. 3. May/June.

Jones, J.E., T. A. Earles, J. O'Brien, M. Claffey, and S. Kribs. 2008. You Were Collecting Stormwater Samples and *What* Happened? *Stormwater*. Vol. 9, No. 2. March/April.

Jones, J.E., J. Clary, E. Strecker, and M. Quigley. 2008. 15 Reasons You Should Think Twice Before Using Percent Removal to Assess BMP Performance. *Stormwater*. Vol. 9, No. 1. January/February.

Strecker, E., J. Clary, M. Quigley, and J.E. Jones. 2007. International Stormwater BMP Database Update. *The Water Report.* November 15.

Clary, J., M. Quigley, J.E. Jones, and E. Strecker. 2007. International Stormwater BMP Database Enhancements and Updated Findings. *Proceedings of WEFTEC 80th Annual Water Environment Federation Technical Exhibition and Conference*. San Diego, California. October 13–17.

Clary, J., J.E. Jones, E. Strecker, and M. Quigley. 2007. Coalition Enhances International Stormwater BMP Database. American Water Resources Institute (AWRI*) Currents*. Vol. 9, No. 4. Fall.

Clary, J., J.E. Jones, E. Strecker, and M. Quigley. 2007. Assessing Performance: Using BMP Database Protocols. *Urban Water Management*. July.

Jones, J.E., T.A. Earles, and S. Kribs. 2007. Water Quality Protection for Development in Mountainous Areas. *Proceedings of the 5th International Conference on Urban Watershed Management and Mountain River Protection and Development*. Chengdu, China. April 3–5.

Earles, T.A., J.E. Jones, J.E. Clary, and D. Rapp. 2006. Consideration of Residual Floodplain and Onsite Detention in Watershed Master Planning. *Proceedings of Colorado Association of Stormwater and Floodplain Managers Annual Conference*. Glenwood Springs, Colorado. September 27–29.

Jones, J.E., D. Rapp, W. Wenk, and P. Thomas. 2006. Impediments to Innovative Urban Water Resources Management. *Proceedings of Colorado Association of Stormwater and Floodplain Managers Annual Conference.* Glenwood Springs, Colorado. September 27–29.

Jha, L., D. Biesecker, J.E. Jones, J.E.D. Johnson, and S. Kribs. 2006. Drainage Improvement Prioritization in Lincoln, Nebraska. *Stormwater.* Vol. 7, No. 3. May/June.

Clary, J.K., J.E. Jones, E.S. Strecker, and M. Quigley. 2006. Documented Performance: International Database Helps Improve Selection and Design of Stormwater Best Management Practices. *Civil Engineering News.* February.

Jones, J.E., J. Guo, B.R. Urbonas, and R. Pittinger. 2006. Safety at Urban Stormwater Ponds. *Stormwater*. Vol. 7, No. 1. January/February.

Jones, J.E., T. A. Earles, T. Browning, B. Hyde, D. Hartman, B. DeGroot, and B.R. Urbonas. 2005. Flood Hazard Notification on Small Tributaries Not Mapped by FEMA. *Proceedings of Colorado Association of Stormwater and Floodplain Managers Annual Conference*. Steamboat Springs, Colorado. September 21–23.

Farahmandi, S., B.R. Urbonas, A. Sorrel, T. Christianson, J.E. Jones, and J. Clary. 2005. City and County of Denver Storm Drainage Criteria Manual Update. *Proceedings of Colorado Association of Stormwater and Floodplain Managers Annual Conference*. Steamboat Springs, Colorado. September 21–23.

Baus, T., J.E. Jones, J.E. Wulliman, and P. Thomas. 2005. Denver Water Quality Management Plan: Process Overview and Lessons Learned. *Proceedings of Emerging Technologies and Practices in Urban Stormwater Management.* Urban Drainage and Flood Control District. Denver. April 28.

Jones, J.E., T.A. Earles, E.A. Fassman, E.E. Herricks, B. Urbonas, and J.K. Clary. 2005. Urban Storm-Water Regulations—Are Impervious Area Limits a Good Idea? *Journal of Environmental Engineering*. ASCE. February.

Earles, T.A., and J.E. Jones. 2004. Colorado (USA) Water Rights: Ideas for China. *Proceedings of the 4th International Conference on Watershed Management*, ASCE, Environmental & Water Resources Institute Shenzhen, China. December 13–15.

Baus, Terry, J.E. Jones, and J.K. Clary. 2004. Overview of Denver Water Quality Protection Plan. *Proceedings of the 2004 Annual Meeting of the Colorado Association of Stormwater and Floodplain Managers*. September.

Jones, J.E. 2004. Introduction: Multipurpose Water Resource Planning and Design, *Water Resources IMPACT,* AWRA, Middleburg, Virginia. Vol, 6, No. 5. September.

Strecker, E.W., M.M. Quigley, B.R. Urbonas, and J.E. Jones. 2004. Analysis of the Expanded EPA/ASCE International BMP Database and Potential Implications for BMP Design. *Salt Lake City EWRI Conference Proceedings*. Proceedings available from ASCE in Reston, Virginia.

Strecker, E., M. Quigley, B.R. Urbonas, and J.E. Jones. 2004. Stormwater Management: State of the Art in Comprehensive Approaches to Stormwater. *The Water Report—Water Rights Water Quality and Water Solutions in the West.* August 15.

Jones, J.E., T.A. Earles, E.A. Fassman, J.T. Doerfer, and J.E. Carroll. 2004. Grant Ranch Stormwater-Quality Management Program. *Stormwater*. Santa Barbara, California. January.

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PERSONAL

Sits on the Board of Trustees of the Frasier Meadows Retirement Community. June 2016 to present.

Married since 1981. Three children born in 1988, 1991, and 1997.

Eagle Scout.

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SALIL KHARKAR, P.E.
DC Water
1385 Canal Street SE
Washington DC 20003
202-812-0013 – salil.kharkar@dcwater.com

EDUCATION:

M.E., Environmental Engineering, 1984
B.E., Civil Engineering, 1980

PROFESSIONAL REGISTRATIONS:

Registered Professional Engineer - PE District of Columbia
ABC Level IV Certified Wastewater Treatment Operator
Certified Maintenance and Reliability Professional (CMRP)
PROSCI Change Management Certification

GENERAL BACKGROUND:

Thirty-eight years of experience in process control, planning, design, construction, start up, training, and operation of treatment plants, asset management, project management, team management, as well as department and division management. Experience in biological nutrient removal systems, adoption of new technologies, and change management. Active in regional and national professional organizations in treatment, utility management, and asset maintenance.

PROFESSIONAL EXPERIENCE:

20 Years in a range of positions within DC Water

DC Water, DC. Current Position **-** Senior Technical Advisor to the Chief Operating Officer of the District of Columbia Water and Sewer Authority. Provides technical support on issues related to the operating divisions under the COO.

DC Water, DC. Senior Vice President of Operations and Engineering for the District of Columbia Water and Sewer Authority. The position was created to bridge gaps between operations and engineering divisions within DC Water. DC Water has two linear asset divisions (Water and Sewer), and two vertical asset divisions (Pumping and Wastewater), along with multiple engineering sections (Linear Assets, Vertical Assets, Tunnel, Control Systems).

Blue Plains WWTP, DC. Director of Operations for the District of Columbia Water and Sewer Authority at the Blue Plains Advanced WWTP. The position included oversight of

Operations and Maintenance at the plant. During this period, the approach to maintenance was revamped to focus on Reliability Centered Maintenance and the use of technology to predict failures. A multiyear Change Management effort was undertaken to not only train maintenance, but also operators, procurement, and management on the need to have a common language and understand the interrelated dependencies of the previously disparate teams. Included training and startup of the world's largest and first in the US thermal hydrolysis (CAMBI) digestion plant and a 225 MGD Deep Tunnel Dewatering pump station and high rate treatment plant.

Blue Plains WWTP, DC. Director of Process Engineering for the District of Columbia Water and Sewer Authority at the Blue Plains Advanced WWTP. The position was created as the Process Engineering Team expanded with the planned adoption of state-of-the-art technologies and there was a need to separate Process Control Automation oversight from Process Engineering. An ambitious plant was undertaken to develop in-house talent to ultimately in-source the consultant led OMAP Program.

Blue Plains WWTP, DC. Manager of Process Engineering for the District of Columbia Water and Sewer Authority at the Blue Plains Advanced WWTP. The position was responsible for creation of a Process Engineering Team where one did not exist. The team was responsible for working with engineering and the automation consultant to ensure successful implementation and adoption of automation at Blue Plains, along with process control to optimize the plant operations and meet permit. Process Engineering team consisted of process engineers, process technicians, and field laboratory personnel.

18 Years of Experience as a Consultant

Blue Plains WWTP, DC. Senior Process Engineer with the Operations and Maintenance Assistance Program (OMAP) at the Blue Plains Advanced WWTP. This consultant contract was required due to the absence of a strong Process Engineering team within DC Water Operations. The OMAP project was an O&M contract which develops innovative solutions for operations and maintenance issues at the plant, performs operability and maintainability reviews on engineering designs, and conducts maintenance and operations training on new processes as they are brought on-line, and on existing processes as they are optimized through this program.

Nutrient Removal Project, New York City, NY. Project Manager and Lead Process Engineer for evaluating cost effective, space saving BNR (Nitrogen) retrofit options for New York City plants. The work included (1) suspended growth BNR process retrofit analysis of all 14 of the New York City plants, and (2) evaluation, design and pilot testing of proven and innovative BNR technologies that could be retrofitted into all 14 of New York City plants. All of the NYC plants were analyzed and recommendations made for their upgrade for total nitrogen removal to meet established nitrogen reduction limits.

Jamaica WPCP, NY. Project Manager and Lead Process Engineer for improvements to the 100 mgd wastewater treatment plant. The $120 million improvements to the plant were designed to allow the plant to meet its SPDES permit. In addition to the plant upgrade design, work tasks included plant analysis for incorporation of suspended growth nitrification and denitrification, analysis of the secondary clarifier operation to optimize the system against short circuiting and density currents.

Point Loma WWTP, San Diego, CA. Process Engineer for the preliminary design of sludge pumping system for the 240 mgd wastewater treatment plant. The project included pilot testing of sludge screening efficiencies resulting in the selection and incorporation of Parkson sludge screens into the sludge handling system design. The digested sludge from this plant is pumped 27 miles to the Fiesta Island Replacement Project, where it is dewatered and stabilized.

Fiesta Island Replacement Project, San Diego, CA. Process Engineer for the conceptual evaluation of alternate sludge stabilization methods utilizing lime. Methods evaluated included the patented RDP system versus excess lime systems to achieve Class A sludges, and modifications to the excess lime systems to achieve Class A sludges while minimizing lime usage.

Sod Run WWRP, Harford County, MD. Project Manager and Lead Process Engineer for the expansion of the wastewater treatment plant to 20 mgd including retrofit for Biological Nutrient Removal. Process design included maintaining operation with two secondary processes, activated sludge and trickling filters, while the upgrade was underway. Alternate methods of scum handling such as lime stabilization of scum were evaluated as part of the design. Additional features of this plant included scum handling, construction of new anaerobic digesters, gravity belt thickeners, belt filter presses, and chemical feed systems.

Little Patuxent WWTP, Howard County, MD. Lead Process Engineer for the design and full-scale pilot testing of the anaerobic/anoxic/oxic ($A^2/0$) suspended growth biological nutrient removal process. As part of this pilot testing effort worked on developing a cost effective deoxygentation zone for recycling nitrates to the anoxic zone. Customized the process configuration to optimize it for the low soluble BOD influent conditions under which It was operating.

Opequon Reclamation Facility, VA. Project Manager and Process Engineer for the design of the upgrades and improvements to the 9.4 mgd advanced waste treatment facility in Winchester, Virginia. The $8 million improvements to the plant were required primarily for additional industrial capacity, and will permit the plant to increase its BOD capacity by 50%.

City of Salisbury WWTP, MD. Project Manager and Process Engineer for the full scale demonstration testing of an innovative fixed film BNR process. The plant was originally designed as a two stage BOD removal facility with trickling filters. The demonstration testing maintains the two stage configuration while incorporating nitrification and denitrification into the same footprint. The plant receives significant industrial waste including high strength (TKN and BOD) waste from chicken processors.

Los Osos WWTP, California. Process Engineer developing the suspended growth nitrification/denitrification design for the Los Osos WWTP. The design was based on utilizing the selector zone concept to optimize plant operations and improve settling.

Mafco Worldwide Corporation, NJ. Project Manager and Process Engineer for the evaluation of the high strength fixed film industrial waste treatment facility at this licorice manufacturing plant. Special issues that were addressed included high temperature wastes and its effect on media, oxygen transfer and treatment, and compliance with revised permit conditions.

Samsung Engineering Ltd., Korea. Project Manager and Process Engineer for the review and evaluation of an innovative BNR process for fixed film plants. Project involved the evaluation of pilot and demonstration plants, cost benefit analysis and market research. Additionally, the innovative process was further modified to allow its benefits to be utilized at plants with suspended growth processes.

Patuxent WWTP, Anne Arundel County, MD. Project Manager and Process Engineer for the evaluation of miscellaneous upgrades to the 12 mgd BNR plant. The upgrades included a detail evaluation of the existing grit system, scum handling system and the failure of the non-potable water system piping.

Anne Arundel County Centralized Septage Facility, MD. Project Manager for the conceptual design and facility siting study for a centralized septage receiving facility in Anne Arundel County, MD. The county receives septage at three of its waste treatment plants, all of which have BNR and are negatively impacted by the septage.

Melanie Kueber Watkins, Ph.D., P.E.

Summary

Civil engineer with over twenty years of experience in the infrastructure industry:

- designed numerous water resources management structures and geometrics for highways and industrial developments, asset management,
- prepared environmental surveys for wetland mitigation,
- oversaw consultant contracts,
- coordinated with the FHWA, municipalities, agencies, stakeholders and councils for project implementation,
- materials science and chemistry experience includes testing and characterization of industrial materials for beneficial reuse,
- mentoring experience includes on the job and research training for junior engineers and interns
- computer experience includes: Microstation, GeoPak, AutoCAD, ArcGIS, water resources design software including Aquaveo 2D SRH SMS Riverine Pro, HECGeoRAS, HEC-RAS, Linux, OpenFOAM, and
- instructed college students through professional engineers; subjects' range:
  water resources management, soils engineering, materials, asset management, and pavement evaluation surface rating, senior design, international senior design in Panama.

Education

Ph.D. Civil Engineering, Michigan Technological University, May 2013
M.S. Project Management/Civil Engineering, Northwestern University, 2002
B.S. Civil Engineering, Michigan Technological University, 1998

Employment History & Professional Experience

May 2018- present, Michigan Technological University, Research Assistant Professor
Jan 2018 to May 2018, GEI Consultants, (on call, Marquette, MI)
May 2017 to Jan 2018, Atlas Engineering (http://www.aegroupltd.com/) (part time telecommute – Chicago)
2015 to 2017, M3 Engineering Group (www.m3eg.com) (part time telecommute – St. Louis)
2015 to present, Adjunct Appointment: Graduate Faculty, Civil & Environmental Engineering, Michigan Tech
2015 American Journal Experts, Independent Contract Editor
2013 to 2015 Owner, MK Watkins Engineering, LLC; mkw-eng.com
2011 to 2015 Michigan Technological University, Center for Technology & Training/Facilities Management
2007 to 2011, Graduate Research and Teaching Assistant, Michigan Technological University
2004 to 2007, Christopher B. Burke Engineering, Ltd. (www.cbbel.com)
1999 to 2004, Illinois Department of Transportation (www.dot.state.il.us)
Summer 1998, STS Consultants, Ltd.
Professional Engineer, Illinois 62058394 (since 2005), Michigan 6201055058 (since 2008), Missouri 2019045797

Engineering Experience

Michigan Technological University

Senior Design Instructor Fall 2019, Spring 2020, Fall 2020, Spring 2021. Instructor for senior design capstone. Sponsored projects included: Proposed All-Season Route US41 to M-38 Connector, Baraga County Road Commission, MnDOT I-35W Stormwater Storage Facility, Brierley Associates, MDOT US-41 Reconstruction from East of Macinnes Dr to Isle Royal St, City of Houghton, MTU Facilities Management parking lot North of Lot 21 and South of Lot 21, MDOT reconstruction of US-2 from Powdermill Creek bridge to Old US-2 in Bessemer, MDOT US-41/M-28 R&R from the Front Street Roundabout west to Wright Street, gapping the Grove Street and Hospital Roundabout in the City of Marquette, Support of Excavation (SOE) & Maintenance of Traffic (MOT) Design and Temporary Site Civil & Maintenance of Flow for Stormwater &

Sanitary Sewer Design for Northeast Boundary Tunnel (NEBT) in Washington, DC with Brierly and Associates, reconstruction of the I-69 mainline from I-96 to Airport Rd north of Lansing, MI in Clinton County with HNTB.

HNTB Sponsored MDOT US-31/I-94 BL interchange and 2.9 miles of I-94 from west of East Britain Avenue to east of the I-196 interchange in Benton Township, Berrien County. Advised hydraulics and hydrology team using Michigan State LIDAR data and Aquaveo SMS 2D RiverPro to analyze water shed using ArcPro and size culverts using embedded HY-8. Completed channel stamping of Blue Creek for the project.

Coordinated with industries on a regular basis to provide students with exposure to industry professionals and ensured their review of student projects. Coordinated with industries to secure rigorous projects for future sections of senior design. Reviewed student design, estimates, and construction schedules and design plans including water detention/retention, wetland mitigation, storm sewer, road alignment, MOT, traffic, retaining wall, culvert, and bridge plans.

Water Resources Modeling Graduate Certificate. Worked with Michigan Tech faculty to lead the development of this certificate where students will gain in-depth modeling experience using real-world case studies in hydrologic, hydraulic, and 2D hydrodynamic systems. This certificate includes development of new course **CEE 46/5610 Water Resources System Modeling & Design** offered Spring 2021 where students will Solve complicated, open-ended real-world water resources problems in natural and built systems by developing and executing models using state of the practice technologies. Includes programming to manage large datasets and validation or calibration and optimization of models for design.

Grant Writing Experience. As a Research Assistant Professor, worked on over 65 proposals assisting faculty and several as PI including multidisciplinary research and contributed to successfully funded research proposals and activities.

Highway Hydraulic Engineering State of Practice: NCHRP Project 20-05 Synthesis Topic 50-02. The objective of this synthesis is to document significant changes that state DOTs have made to their hydraulic engineering policies and practices over the past decade. The study will highlighted the trends and factors driving these changes (PI). The study featured advanced 2D hydraulic modeling among other topics. Funding Agency: Transportation Research Board of the National Academies of Science, Program Director: Jo Allen Gause. Phone: 202-334-3826 jagause@nas.edu $45k (November 2018 – October 2019, published July 2020).

Real-Time Monitoring and Modeling of Scour, with MTRI, Genex Systems LLC, Awarded FHWA: $49k. Reviewed bank elevation data acquired during the recent bathymetric and Lidar field data acquisition that occurred on August 17-18, 2020 that was further refined, points filtered, then merged with bathymetry to develop a continuous point cloud. Merging contiguous point cloud containing bank and bathymetry and refining terrain model generation; developing mesh and a 2D hydraulic model, to produce channel velocities for existing flood flow frequencies as available from FEMA to compare with OpenFOAM hydrodynamic model.

Wastewater System Modeling for SARS-CoV-2 Detection, Awarded Michigan Tech: $24.5k. Watkins, D. W., Becker, J. G., Seagren, E. A., Watkins, M. K. Expand wastewater-based surveillance of the COVID-19 virus in the Houghton/Hancock area and support pandemic response decision making at the University and community levels. Hydraulic modeling of the Houghton and Hancock wastewater collection systems will be performed to estimate dilution factors at each sampling location, and geographic information system (GIS) maps of the collection system network (Fig.1) will be developed for the geospatial display of results. Review infrastructure data and advise graduate student work on the wastewater collection system model.

***CE4620 Instructor, Fall 2016, 2017, 2019, 2020*.** Instructor for river and flood plain hydraulics. Developed course materials for instruction for this course that includes theory and analysis of open channel systems, including natural channels, designed channels, flow transitions, non-uniform flow, and unsteady flow. Also included HY-8 for culvert sizing and intensive use of HEC-RAS. FHWA Toolbox Calculator for channel lining design. SMS Aquaveo 2D Riverine Pro software use and design using LIDAR, sonar, and photogrammetry dem; validation of software output data. The lab for this class is a computational lab, this includes: 2 Weeks - ArcGIS design project component using photogrammetry or LIDAR dem data, 2 Weeks - Aquaveo SMS Riverine Pro tutorials/assignments using LIDAR/sonar elevation data, 3 Weeks - Aquaveo SMS Riverine Pro design project including validation of software results. Design projects included MDOT sponsored M35 over the Carp River, Negaunee, MI – modeled 2x7'x10' CMP culverts and bridge using Aquaveo SMS Riverine Pro.

OpenFOAM CFD Modeling: C++, Essential, Applied, CFD Direct, Summer 2020. Synchronous Remote Learning Course.Creating a C++ program, compilation, scope, namespace, header files,boundary conditions: overview, common conditions, entrainment, useful outlets and inlets, time-varying. Introduction to turbulence: what it is, scales and mixing, Reynolds number, turbulent closure, k-epsilon model. Turbulence modelling essentials: industry-standard modelling, initialisation, boundary layers, wall functions, meshing strategy.

SAT 2711 Linux Fundamentals, Michigan Technological University, Houghton, MI, United States.
Linux system installation and configuration in an enterprise environment. Topics include: Linux System Architecture, Linux Installation and Package Management, GNU and UNIX Commands, Linux Filesystems, Filesystem Hierarchy Standard, Shells, Scripting and Data Management, User Interfaces and Desktops, Administrative Tasks, Essential System Services, Networking Fundamentals and Security

NHI Continuing Ed: Two-Dimensional Hydraulic Modeling of Rivers at Highway Encroachments**.** Learned background data necessary to support a model, hydraulic modeling parameters, mesh development, model simulation parameters, model calibration, hydraulic structures, and reviewing two-dimensional model results. ***Model Terrain Development with Various Data Sources WCT, Course FHWA-NHI-135095B.*** Learned how to process and effectively use LIDAR and other elevation format types in defining geometry for 2D hydraulic models.

ASCE Continuing Ed: Stream Restoration: What Works and What Doesn't Work. Refreshed skills on a synthesis of available data regarding effectiveness of selected stream restoration approaches, identifying key factors that lead to success or failure. These factors may be combined in an overall semi-quantitative assessment of the risk of project failure to produce stream restoration projects that more closely approach stakeholder expectations.

EGLE WMP. Continued work and coordination with UPEA and EGLE to update expired WMP. ***Huron Creek Watershed Modeling, Houghton, MI*****.** Advise masters student development of HEC-RAS models with HECGeoRAS using survey and USGS ArcGIS data for the floodplain mapping research project for this this FEMA and state disaster area. Cut cross sections from USGS digital elevation model using HECGeoRAS and ArcMap.

ASCE EXCEED, Omaha, Nebraska, June 2019. Professional development practicum that provided engineering educators with an opportunity to improve their teaching abilities. The workshop learning objectives were: explaining what constitutes effective teaching; applying learning style models to the organization and conduct of a class, using classroom assessment techniques to assess student learning, organizing a class, delivering classroom instruction, assessing a class from a student's perspective, self-assessing your own class.

Esri, Migrating from ArcMap to ArcGIS Pro, July 2019. Professional development course, then led students to update course modules from ArcMap to ArcPro.

ETOM Online Teaching Certification Course October-Nov. 2019. Designed a general course framework, including an organizational scheme (using Canvas) and course management policies in this online course.

Senior Design, Fall 2018. Advised senior design students for the MDOT reconstruction of both sides of I-69 from Ballenger Highway to Fenton Road in Flint, MI, capstone project. This project included reconstruction of existing pavement, alignment and profile shift, storm sewer design, and compensatory storage analysis in a FEMA designated floodway.

CEE Curriculum Committee. Facilitated skills survey and worked with CEEPAC to discuss their input and requested they provide a recommendation as to the status of skills that should be provided by the CEE curriculum upon students graduation.

CE3620 Instructor, Fall 2018**.** Instructor for Water Resources Engineering, hydrologic engineering, including rainfall-runoff modeling and hydrologic frequency analysis, as well as the analysis and design of hydraulic systems, such as pipe networks and stormwater management systems.

CE3101 Instructor, Fall 2018**.** Instructor for properties and behavior of typical civil engineering materials, including wood, metals, aggregates, asphalt cement concrete, Portland cement concrete, and composites. Laboratory exercises demonstrate selected engineering mechanics principles, including elastic, inelastic, and time-dependent material behavior. Additional topics include testing techniques, materials standards, report writing, and presentation of experimental data.

MEEM 2110 Instructor, Spring 2019**.** Instructor for principles of static equilibrium by applying Newton's laws of motion to solve engineering problems. Emphasis is placed on drawing free body diagrams and self-checking strategies. Topics include introduction to forces; 2D and 3D equilibrium of particles and rigid bodies; center of gravity and centroids; distributed loading and hydrostatics; friction; analysis of truss structures. Vector algebra used where appropriate.

Ground Tire Rubber Asphalt for Durable Pavements for Heavy Traffic Road for Michigan's Wet-Freeze Environment. Senior project personnel. ~200k awarded to Dr. Zhanping You where Michigan Tech will conduct the following on a 5-mile-lane pavement section of Cascade Road in Kent County, MI: a performance evaluation of GTR modified asphalt for wet-freeze environment, evaluation of composite structures and field survey, sampling and testing, analysis and reporting on test sections.

GEI Consultants

City of Marquette, Noquemanon Trail Network
Prepare DEQ/USACE Joint permit application for proposed bridge crossing the Carp River for all season trail access. Prepare exhibits using ArcMap and draft proposed structure plan and profile using AutoCAD.

SEMCO, S10 and S17 Escanaba River Crossings
Prepare existing and proposed hydraulic models using HECGeoRAS and HEC-RAS. Cut cross sections from USGS digital elevation model using HECGeoRAS and ArcMap. Import channel information into HEC-RAS for existing and proposed models, add bridge geometry per proposed plans.

Atlas Engineering Group, Ltd.

IL Route 31 ADA Feasibility Analysis, McHenry, IL. Used Microstation and GeoPAK to analyze new geometry for ADA compliant ramps at intersections. Results from analysis were to be used to modify the existing geometry further to allow for compliant infrastructure along the route prior to construction document completion.

IDOT District One: PTB 171, Phase II Engineering, I·55 (Stevenson Expressway) and Adjacent Frontage Roads from Lemont Road to IL 83 (Kingery Highway) Hydraulics & Hydrology Project Manager. Responsible for the hydraulic analysis of three locations as flagged by a drainage investigation to be deficient and recommended repair or replacement. These locations included proposed replacement of an existing 30” corrugated metal pipe with RCP under I-55 frontage road using HY-8, ditch capacity calculations and rip-rap sizing for the three locations, and a grate opening calculation for grate sizing using the FHWA Hydraulic Engineering Toolbox, Rip-rap Design Systems, and IDOT Standards. The CMP was in a great state deterioration as this discharge pipe was corroded and exposed. Difficulties included tight ROW constraints, addition of an offsite drainage diversion area as identified in the drainage investigation, and existing adverse slope. Additionally, the television report indicated that the 30" RCP to the north of the CMP portion under mainline I-55 appeared to be in fairly good condition but the next section has a cracked joint in the pipe. In order not to disrupt traffic, as a rehabilitation practice, Atlas recommended a CIPP liner instead of replacement.

PTB 170 Item 7 Washington Street over US 41 & UPRR
Hydraulics & Hydrology Project Manager. Completed Location Drainage Technical Memorandum for Washington Street over US 41 & UPRR. Drainage site analysis, completion of existing and proposed drainage plans, and report for submission to the Illinois Department of Transportation for this bridge deck overlay and replacement project.

M3 Engineering Group

Caulks Creek Force Main Rehabilitation, Metropolitan St. Louis Sewer District (MSD) MSD desires rehabilitation of 37,300 LF of 20-inch to 30-inch sanitary sewer force main and appurtenances to alleviate several local package treatment plants. Researched methods, performed preliminary design calculations using several material options, and spoke with several rehabilitation manufacturers and installers for information as to determine the appropriate rehabilitation method for the force main. Recommend design thickness and materials based on calculations and design parameters. Performed a pump station evaluation for calibration and completed a report on the EPASWMM model of the approximately 7-mile Caulks Creek Force Main that included 11 pumps and wet wells.

Cityshed A Planning, St. Louis Metropolitan Sewer District. Converted 2011 XPSWMM model to XPSWMM 2016 model, assessed the usability of the model in its current condition via a calibration verification and review of the model as to its inclusion of structures near the Jennings Station Rd/North Baden Basin. Forty meter and gauge data files with peak events from 2004, 2005, and 2006 were reviewed and the model was analyzed with the largest 3-hour and 24-hour storms. The average flowrates were compared with the meter data and statistical analysis performed to find the 10% min-max and 20% min-max scatter to assess the state of the calibration. The model includes six pump stations and five outfalls.

Old Halls Ferry Road over Halls Ferry Creek, St. Louis County, MO; Ferguson, MO St. Louis County Project Number: Ar-1647, Federal Project Number: Brm-5610(609). Completed No-Rise Study for Old Halls Ferry Road Bridge No. 107 including hydraulic report, HEC-RAS analysis, and calibration for structure removal and replacement.

Gravois Trunk Sanitary Storage Facility (Pardee Lane and Pardee Road), Phase II, St. Louis County, Metropolitan Sewer District. Completed FEMA Flood Insurance Study Data Request. Conducted hydraulic floodplain impact analysis/no-rise study hydraulic report and calibrated models for the proposed Gravois Trunk Sanitary Storage Facility that will be located at the City of Crestwood's Department of Public Works (DPW) Facility at 8645 Pardee Lane using HEC-RAS.

Cole Creek Flood Reduction Study, City of St. Charles, MO. Inventoried and documented all properties located in the designated 1% annual chance area for USACE Risk-Based Analysis for Flood Damage Reduction. Completed a protection measures inventory report. In effort to reduce WSELs using the regulatory HEC-RAS model: added the Elm Point Storage Facility with ArcMap/ArcGIS data and weir calculations, widened Elm Point Road and RR structures and added sloping abutments, widened channel choking areas, updated and widened the Runnymede Road structure.

Sherwood Forest Camp, MO Reviewed new water distribution design including water supply unit calculations, EPAnet model, pump selection, and water tank location. Reviewed size of water tank, revised elevation of placement, and sized pressure tank. Reviewed construction technical memorandum and permit application.

Metropolitan Sewer District RDP Tributaries & Upper RDP CSO Controls & Lower Meramec System Improvements RDP Tributaries (Deer Creek) CSO Tunnel – Planning Reviewed documents for utility and existing bridge pier conflicts, calculate potential underground locations, draft 48" sewer profiles and alignments using AutoCAD.

The Village of Harwood Heights, IL The Village of Harwood Heights does not have the option to improve storm water storage capacity downstream of the village so flood volumes resulting from runoff from the village must mitigated. Conducted technical and regulatory investigation exploring the feasibilities of flood mitigation via infiltration versus detention in the Village of Harwood Heights, Illinois.

Eastman Chemical Company Krummich Plant, Sauget, IL Researched AREMA railroad load design requirements for track expansion. Calculated earth and live loads via embankment and trench conditions for 24", 30", 8" VCP pipes. Compared calculated loads to D0.01 load tables and made recommendations.

City of St. Charles, Blanchette Updated survey information from ArcGIS to XPSWIMM model.

City of St. Charles Comprehensive Stormwater Management Plan Phase I / Data Development. Collected side slope data for stream channel restoration/flood mitigation estimates from contours using ArcGIS.

Deer Creek DC02 Phase 4, St. Louis County, Metropolitan Sewer District. Drafted structure details for contract plans for 48" pipes including junction chambers for storm sewers using MicroStation. Calculated rip rap thicknesses and specified aggregates for contract plans using Rip Rap Design System and FHWA Hydraulic Toolbox.

Northside Regeneration Program, St. Louis Development Corp., Metropolitan Sewer District, SLDC. Draft drainage areas, sewers, and structures for Camp Springs sewer shed using ArcMap/ArcGIS for use in overall PCSWMM model. Draft sewers and structures for additional sewer sheds.

City of Chicago 2016 Pipeline Inspection. Review and documented televised inspection results of water main inspection for 36" PCCP and DI water main on Lake Shore Drive and South Indiana Avenue.

Forest Park Forever. PASER rate all roads in the park for asset management. Complete PASER road database in ArcGIS ArcMap.

Creve Coeur Creek Sanitary Trunk Sewer Relief Phase VI. Calculated rip rap thicknesses and specified aggregates for contract plans using Rip Rap Design System and FHWA Hydraulic Toolbox. Calculated earth loads for PVC and VCP 12" and 24" PVC and VCP pipes.

Michigan Technological University

CE4620 Instructor, Fall 2016, 2017**.** Instructor for river and flood plain hydraulics. Developed course materials for instruction for this course that includes theory and analysis of open channel systems, including natural channels, designed channels, flow transitions, non-uniform flow, and unsteady flow. Also included HY-8 for culvert sizing and intensive use of HEC-RAS.

CE/ENVE 4507 Instructor, Spring 2016, 2017, 2018**.** Developed course materials to cover the basic civil and environmental engineering principles for water distribution systems, storm and wastewater collection systems, including their appurtenances and pumps with emphasis on design including EPAnet, SewerCAD, and EPASWMM.

Senior iDesign, Fall 2017. Advised senior civil and environmental engineering students in the field for water distribution and pump projects. Helped identify water sources, contaminants, and layouts for these projects and relations with indigenous people. The project site was located in the village of Cerro Gallina located in the indigenous Ngäbe-Buglé Comarca rainforest in the Chiriqui province of Panama.

Senior Design, Fall 2016. Advise two senior civil engineering student on watershed analysis project for continuation and updates to tailing impoundments site for White Pine Mine. This project included reservoirs and routing using HEC-HMS and HEC-RAS.

Paint River Watershed, Iron County, MI. Advise masters student and put together HEC-RAS models using survey and USGS ArcGIS data for the research project: *Informing Great Lakes connectivity decisions: An enhanced online portal for high-resolution barrier data and species-specific benefit analyses*. This project will expand the existing online decision-support tool to enable managers and agencies to assess trade-offs of barrier removals throughout the Great Lakes basin. We will inventory road crossings in the Paint River watershed, and create an index of habitat quality for priority fish species. The website will enable integration of new barrier data, flexible visualization of species-specific habitat loss due to barriers, and customized analysis of optimal barrier removals for a given budget.

Michigan Tech CTT/Facilities Management

- Preparation of contract documents, request for proposals for consultant hire, estimates for campus maintenance, space use studies, pavement evaluation for pavement management plans, estimates, specifications, and designs for renovation and maintenance projects, erosion control and wetland documents, grant proposals and collaboration.
- Coordination with contractors, consultants, regulatory agencies, local government, faculty, and Michigan Tech maintenance staff.
- Monitored accounts, work orders, Michigan Tech Grounds and Trades project work.

Projects included:
Mont Ripley Conducted monthly coordination with ski hill manager to monitor earth movement and erosion control. Completed Houghton County Soil Erosion Control Permit revisions for the tube park earthwork. Completed MDEQ application and map documents using ArcGIS for the pre-application for wetland walk-through.

Portage Lake Golf Course Coordination with golf course manager and composed the request for proposal and contract for consultant hire for design and construction oversight for this proposed renovation project. Solicited for proposals and awarded consultant contract. Manager of the consultant contract and account. Coordination with DEQ for wetland delineation and potential mitigation.

Ford Center Composed the request for proposal and contract for consultant hire for testing of former UST water monitoring wells. Solicited for proposals and awarded consultant contract. Managed the consultant contract and account for completion of testing. Composed the request for proposal and hired consultant for MDEQ closure report. Solicited for proposals and awarded consultant contract. Manager of the consultant contract and account. Coordinated with DEQ.

Lower Daniel Heights Student Apartments Performed inspections and prepared an estimate and schedule for indoor maintenance for this $6 million maintenance project over 25 buildings. Additionally, prepared bid documents including specifications for re-roofing project and estimates and design for sanitary sewer improvements including a force main system with pumps.

Theta Tau Property Managed Michigan Tech Grounds & Trades winterization and culvert replacement project.

DEQ Coastal Zone Management Program Prepared grant application including the budget for Lakeshore Corridor Enhancements: Walking/Bike Trail. If awarded, the constructed project will improve the Michigan Tech corridor connecting the adjacent east and west portions of the City of Houghton paved waterfront trail with the addition of a ten foot wide concrete sidewalk and handrail constructed per ADA requirements, improvements to traffic safety, vegetation to filer storm water, and heritage signs.

DEQ Pavement Grant Facilities Management grant collaboration with Michigan Tech Civil & Environmental Engineering for this Scrap Tire Regulatory Program. If funded, Michigan Tech will construct approximately 900 SY of concrete paving area with a special mix design that will be tested for freeze-thaw performance and chloride durability for future road applications.

Campus Pavement Management Evaluated campus pavement using PASER and initial preparation of a campus wide pavement management plan.

MEEM UST Prepared estimates for removal.

Characterization of Unpaved Road Condition Through the Use of Remote Sensing: State of the Practice of Unpaved Road Condition Assessment Performed literature review and participated in team effort to prepare document on joint project with Michigan Tech Research Institute. November 2011.

Characterization of Unpaved Road Condition Through the Use of Remote Sensing: Software and Algorithms to Support Unpaved Road Assessment by Remote Sensing Participated in team effort to prepare document on joint project with Michigan Tech Research Institute. October 2012.

Activity Travel Behavior, February 2011 Analysis and documentation of a study comparing the benefits of webinars using Michigan LTAP data.

TAMC PASER QC/QA, 2012, 2013 Update of existing PASER rating quality control plan and assessment report with new 2012 collection data and user survey data.

RE: MDOT Enterprise Asset Management System: Roadsoft Capabilities, 2013 Marketing document outlining functions of Roadsoft.

TAMC PASER Training Instructor for roadway engineers for the Michigan Transportation Asset Management Council sponsored mandatory rater training for Pavement Surface Evaluation Rating of asphalt, concrete, and seal coat roads. Instruction includes conducting webinars and onsite training for rating rules, surface distress identification to assign a PASER rating to roads. Instructed five onsite trainings and three webinars as part of a training team.

TAMC PASER Certification Team establishment of new certification exam policy and exam documents. Organized records to establish a list of eligible individuals. Co-administer of exam.

TAMC AM for EO Instructor for local governments for the Michigan Transportation Asset Management Council sponsored Transportation Asset Management for Elected Officials. This training includes instruction of basic pavement asset management principles for county, city, and township officials; the role of asset management in Michigan; and brief overview of PASER. Solely conducted over fifteen onsite workshops.

TAMC Asset Management Pilot Projects Effort for Michigan Transportation Asset Management Council sponsored pilot project. Provided guidance to a county engineer to establish a pavement asset management plan. This included establishing road improvement strategies using RoadSoft to make best use the budget, milestones, and documentation.

LTAP Webinars Main coordinator for technical webinars sponsored by the Local Technical Assistance Program. Researched applicable topics and subject matter experts. Contacted and corresponded with subject matter technical experts. Prepared advertisement materials. Moderated webinars with technical experts. These webinars included:

Warm Mix Asphalt June 2011
Thin Asphalt Overlays August 2011
Using Chip Seals and Fog Seals in Pavement Maintenance February 2012
Cold In-place Asphalt Recycling June 2012

Recycling Asphalt Pavements June 2012
The Hole Story: Potholes April 2013

The Bridge, A Quarterly newsletter from Michigan's Local Technical Assistance Program Articles:

Unconventional Pavement Maintenance Chip seals can extend pavement life from both ends of the spectrum. Kueber Watkins M. October 2011.
http://michiganltap.org/sites/ltap/files/publications/bridge/bridge_25_2.pdf

Extreme Makeover: Road Edition Wright Street, Successful Road Diet in Marquette, Marquette, MI Kueber Watkins M. December 2012. Vol. 26, No. 3.
http://michiganltap.org/sites/ltap/files/publications/bridge/Bridge26-3.pdf

Fly Ash – One of Several Options for Stabilizing Soil Before Building a Road
Ryyannen J, Kueber Watkins M. September 2012. Vol. 26, No. 2.
http://michiganltap.org/sites/ltap/files/publications/bridge/Bridge26-2%20.pdf

County Engineers Workshop, February 2013, 2104 Main coordinator for technical workshop for the County Road Association of Michigan. Contacted and corresponded with subject matter technical experts. Prepared advertisement materials. Prepared budget.

Christopher B. Burke Engineering, Ltd.

- Contract plans and specifications completion independently and as part of a team for: IDOT and municipal heavy highway alignments, profiles, cross sections, water management, utility, floodplain, erosion control, storm water runoff and wetland mitigation.
- Report preparation and modeling for: project feasibility, roadway design, bridge replacement, culvert construction and replacement, storm sewer, and IDNR/OWR permit procurement.
- Contributed to a well-mentored workforce by professionally supervising two junior engineers and two interns to transform theory into buildable infrastructure designs through hands-on experience.
- Facilitated completion of highly challenging design projects as a team.

Projects

Stearns Road Corridor Wetland Mitigation Site (IL Route 25 to the Fox River): Earthwork and Grading Phase Prior to Road Construction, http://www.co.kane.il.us/dot/foxbridges/stearnsrd.aspx
Project Engineer for the team collaboration of the plans, specifications, and estimates for IDOT's Federal Letting of November 2006.

This project contract phase included mass grading, detention and compensatory storage for the roadway embankment and earthwork and bike path. The Stearns road project site was located in unincorporated Kane County, west of Illinois Route 25, east of the Fox River, south of the Illinois Central Railroad. The site was approximately 70 acres of area without a road.

This portion of the Stearns Road project was estimated at $5.7 million. The site statistics included: 11.7 acres of wetland mitigation, 12.8 acres of compensatory floodplain storage, 1500 feet of stream bank restoration, 5 detention basins for storm water management, Stearns Road embankment on new alignment from the Fox River to IL Route 25, special waste removal, tree preservation, several planting and seeding zones, and an extensive storm water pollution plan. The site provided all of the wetland mitigation and compensatory storage for the entire Stearns Road Corridor. Responsibilities included:

- **Calculations, storage design and modeling, report preparation and filing of Illinois Department of Natural Resources/OWR and Kane County permits.** Difficulties included careful engineering and accounting to provide approximately 13 acre-ft of compensatory storage for all the fill in the flood fringe and the floodplain within the project site. The structures compensated for included the roadway embankment and 5 structures; abutments for Stearns Rd. on the east side of the proposed Fox River, the proposed Stearns Road over the North Arm of Brewster Creek, IL 25 over Brewster Cr., IL 25 E Br. Brewster Cr., and Dunham Rd. over east Brewster Cr. This was accomplished by designing the hydraulics for 5 ponds with restrictors using TR-20; 3 were interconnected.

- **The design met the Kane County Ordinance compensatory storage requirements of 1.5:1 from ground to 10-year which is more stringent than the IDNR requirements.**
- Complex earthwork analysis including unsuitable/special waste removal. Difficulties included that there were 6 categories of earthwork that had to be accounted for in the construction plans: topsoil cut, cut, topsoil fill, fill, porous granular fill, and unsuitable.
- Stormwater management including restrictor sizing, approximately 3000' of storm sewer design and modeling, **work on soil erosion control plans for stormwater pollution prevention**. No drainage structures previously existed on the project site.
- Responsibilities included construction plan preparation, specifications and special provision writing and compilation, estimates, and final plan submittals.

DuPage Technology Park, N.F.P., West Chicago
Water resources engineer for the hydraulic design of 5000' of storm sewer and a 128' 48"x78" elliptical culvert with HydraFlow modeling, plan preparation, and quantities including trench backfill for DuPage Technology Park Loop Road. Drafted culverts and storm sewer systems on contract plans using Microstation and GeoPak. Responsibilities also included report preparation for **DuPage County Stormwater Management Permit**. Difficulties 100-year storm conveyance was required for the storm sewer design and this was a relatively flat location.

The DuPage Technology Park (http://www.dupageairport.com/dfc/documents/DNTPbrochure.pdf) project consisted of the development of the subdivision for the industrial park including mass grading and site infrastructure. Site statistics included: 7 storm water detention facilities and 4 regional storm water detention facilities providing approximately 230 AC/FT of storm water storage in accordance with the DuPage County Countywide Storm water and Floodplain Ordinance and the City of West Chicago.

Lawrence Avenue Streetscape, Harwood Heights
Project engineer for phase I corridor plans including developing neighborhood-friendly uses, pedestrian-oriented architecture, first floor commercial uses, new lighting, widening in the existing right-of-way, and streetscape improvements where the goal was to unite new and existing development while improving safety for roadway users and pedestrians. Responsibilities for this project included conceptual planning then producing engineering documents including: the project development report, roadway plans and cross sections, location drainage report including storm sewer design and detention calculations, and contract drainage plans for IDOT Bureau of Local Roads.

CCHD, 153rd Street, from Wolf Road to West Avenue, Orland Park
Water resources engineer for the reconstruction improvement of 153rd Street. Responsibilities included hydrologic and hydraulic analysis including routing for culvert and storm sewer design for contract plans. Hydraulic analysis included: using HY-22 to space inlets, interpreting geometric plans, profiles, and cross sections to size storm sewers with Hydraflow, in-line detention design to meet storage volume requirements by allowable flow analysis, hydraulic grade line analysis, and restrictor sizing. Also analyzed an existing detention basin using topographic maps, existing subdivision plans, and NRCS Soil Maps. Modeled the basin system including weir flow via stage-storage-discharge relationship, used TR-20 with Bulletin 70 to find design flows, and used HY-8 to size a culvert. Completed contract plans using Microstation.

Downtown Redevelopment, Olde Half Day Road, Lincolnshire
Water resources engineer for the associated hydraulic analysis for downtown redevelopment improvements including roadway, infrastructure and parking lot construction. Responsibilities included storm sewer design.

WCDOH, 135th Street, from New Avenue to Archer Avenue, Will County

Water resources engineer for the Motor Fuel Tax funded widening, reconstruction, and realignment at the east end of the project where 135th Street intersected Archer Avenue at a 90-degree angle. Responsibilities included revisions to storm water designs, ESRF submittals, and contract plans including erosion control plans and culvert design.

Butterfield Road - Harding Ave. to IL Rte 137 (Buckley Rd.), Phase II, Libertyville
Water resources engineer for the widening improvement. Responsibilities included design of **storm sewer, in-line detention following Lake County release rate requirements** and contract preparation. Determined inlet spacing using HY-22, and interpreted geometric plans, profiles, and cross sections to size storm sewers using Hydraflow. **Specified storm water treatment system/low impact development measures for outlet pollution control using separation technology with design flows to maintain discharge water quality.** Drafted storm sewer system including profiles on contract plans using Microstation and Geopak.

I-88 East-West Tollway Mainline Roadway Widening & Construction
Responsibilities included re-sizing two proposed culverts with HY-8 culvert modeling software.

IL 19 at Meacham Creek
Water resources engineer for removal and replacement of a 12'x9' box culvert. Responsibilities included: hydraulic report and hydraulic analysis completion using WSP2, profile and cross-section preparation for sizing the new opening.

I-80 over Hickory Creek and Two Tributaries to Hickory Creek, IDOT Various
Water resources engineer for the replacement of a 6'x5' box culvert, 8'x6' box culvert, and an 8-span structure. Responsibilities included preparation of three hydraulic reports including hydrologic and hydraulic analyses: analyzed hydraulic atlas contours and topographic maps to confirm drainage subdivides for contributory drainage areas, analyzed existing depressions using topographic and NRCS soil maps, modeled weir flow via stage-storage-discharge relationship, and used TR-20 with Bulletin 70 to find flows, and completed models using HEC-2 and HEC-RAS.

Prairie Holding
Project engineer for preparation of special provisions, contract plans, and sewer design. Drafted storm sewer system, including profiles on contract plans using Microstation and Geopak.

North Industrial Special Assessment, Bensenville
Project engineer for existing storm sewer and proposed storm sewer profiles. Drafted storm sewer system, including profiles, on contract plans using Microstation and Geopak.

131st Street over Long Run Tributary BA, Cook County Highway Department
Water resources engineer for the replacement of the existing box culvert with a 72' precast box culvert with span length of 6' and depth of 8' carrying 131st Street over Long Run Tributary BA. The existing culvert of size 6'x8' was in a great state of deterioration and the roadway embankment side slopes had overgrown.

Responsibilities included completion of hydraulic reports, hydraulic analysis using HEC-2, and HY-8 models for design, sensitive flood receptor survey analysis, **report preparation and IDOT Permit Summary for Floodway Construction**. Difficulties of this project included that there were two regulatory models: a CLOMAR HEC-2 and a FIS WSP2, and decisions how combine the most relevant information for analysis had to be made.

131st Street over Long Run Tributary B, Cook County Highway Department
Water resources engineer for the replacement of the existing box culvert with a 64' precast box culvert with span length of 8' and depth of 8' carrying 131st Street over Long Run Tributary B. The existing culvert of size 2x6.8'Hx8.7'W and length of 49.2' was in a great state of deterioration.

Responsibilities included completion of hydraulic reports, hydraulic analysis using WSP2, and HY-8 models for design, sensitive flood receptor survey analysis, **report preparation and IDOT Permit Summary for**

Floodway Construction. Difficulties of this project included that the regulatory model arrived as a hard copy; an electronic copy had to be produced and executed for analysis, and that the datum correlation between the FEMA models and the CBBEL survey could not be established so separate models for permit and design each had to be used.

Illinois Department of Transportation: Bureaus of Planning & Programming, Local Roads & Streets, Design

- Project and consultant management independently and as part of an engineering team. Responsibilities included contract negotiation (including man-hours and budgets), contract management, project program database management, and engineering documents review and revisions including reports, plans, cross sections, alignments, highway capacity analysis, storm water management plans, models, and field assessments.
- FHWA, municipality, agency, stakeholder and council coordination: implementation of project and design documents including environmental surveys, and environmental class action determination documents records.
- Development and presentation of conceptual and design plans with emphasis on safety, operational effectiveness, and minimizing impacts to adjacent properties.
- Field inspection and developer coordination for: access permits to ensure safety requirements, concrete workability and placement, soil testing and reinforcement requirement assurance.
- Supervised three entry-level engineers.

Projects

Interstate 94/90 (Dan Ryan Expressway), 31st Street to Interstate 57
Engineer in a team effort for consultant management of the reconstruction and reconfiguration of a multi-lane expressway. Responsibilities included contract negotiation and management, and engineering document review including phase I plans and project report. Responsibilities also included public hearing attendance, FHWA, park district, and CTA coordination.

I-59 (I-55 to the DuPage River)
Consultant engineer for an extensive highway widening and interchange modification with right-of-way acquisition including extensive drainage improvements and floodplain modifications. Responsibilities included consultant management: contract negotiation, contract management, and engineering document review and revisions, FHWA, municipality, and council coordination. Engineering documents included: phase I plans, project report, location drainage report and storm water models, hydraulic report and bridge waterway models, and drainage plans.

IL Route 53 (Elgin-O'Hare Expressway to Army Trail Road)
Consultant engineer for a reconstruction and add-lanes project with right-of-way acquisition including drainage improvements to correct extensive flooding problems. Responsibilities included consultant management, contract negotiation, contract management, and engineering document review and revision. Engineering documents included: phase I plans, alignment, capacity analysis, project report, location drainage report and storm water models, environmental documents, and roadway and drainage contract plans. Responsibilities also included public hearing attendance, FHWA, municipality, and council coordination.

I-57 at Stuenkel Road
Consultant engineer for new construction of an interchange. Responsibilities included consultant management, contract negotiation, contract management, and engineering document review and revision. Engineering documents included phase I plans, alignment, capacity analysis, project report of interchange design options, and environmental documents.

US 20 at McLean Boulevard

Consultant engineer for new construction of an interchange. Responsibilities included consultant management including contract negotiation, contract management, and engineering document review and revision. Engineering documents included: phase I plans, alignment, capacity analysis, environmental documents, and location drainage report. Also participated in FHWA, municipality, and council coordination.

US Route 6/Illinois Route 7 (I-355 to US Route 45)
Consultant engineer for reconstruction and add-lanes project with constrained right-of-way acquisition. Responsibilities included consultant management, contract negotiation, contract management, and engineering document review and revision. Engineering documents included: phase I plans, project report, capacity analysis, and roadway and drainage plans. Responsibilities also included public hearing attendance, FHWA, municipality, and council coordination.

5th Avenue over Silver Creek
I-55 (East Frontage Road) over Sunnyland Drain
Wentworth Avenue over Little Calumet River
Dixie Highway over Butterfield Creek
Consultant engineer for various bridge improvement projects that included total replacements, superstructure, and deck replacements. Responsibilities included consultant management, contract negotiation, contract management, and engineering document review and revision. Engineering documents included bridge condition reports, hydraulic reports, plans and cross sections, models, floodplain compensatory storage plans, and permit applications.

IL Route 31 at IL Route 176
Consultant engineer for the reconstruction of an intersection. Responsibilities included consultant management including contract negotiation, contract management, and engineering document review and revisions. Engineering documents included: project report, location drainage report, contract drainage plans, cross sections, highway capacity analysis, and environmental documents. Responsibilities included public hearing attendance, FHWA, municipality, and council coordination.

Torrence Avenue (US 12/20), 95th Street to 124th Street
Consultant engineer for re-pavement improvements in industrial hazardous waste/brown field environment. Responsibilities included project initiation meetings to discuss environmental surveys, and environmental class action determination documents record requirements, preliminary plans, cross sections, and capacity analysis. Responsibilities also included FHWA, municipality, and forest preserve district coordination.

Other Projects
Design engineer for various re-paving and patching projects. Responsibilities included site assessment and drafting of contract plans including profiles, cross sections, alignments using Microstation and Geopak.

STS Consultants, Ltd., Deerfield, IL

Construction Quality Insurance Management, Internship
Daily field inspection including soils, reinforcement, concrete compliance and testing. Report writing.

Bannockburn Center at College Park, 1200 Lakeside Dr., Bannockburn, IL
Inspected footing rebar, concrete, CA7 backfill compaction. Constructed by Pepper Construction.
http://www.peri-usa.com/projects.cfm/fuseaction/showreference/reference_ID/316/referencecategory_ID/25.cfm

Oak Brook Parking Deck No. 5, 100 Oakbrook Center, Oak Brook, IL
Conducted soil bearing capacity tests, removable of unsuitable soil, lean concrete backfill; inspected cassion, footing, ramp, and column concrete and rebar; CA7 backfill compaction of trenches with Dynamic Cone Penetrometer. Post tensioned cable structure constructed by Corrigan Construction.

Hilton Garden Inn Chicago/Oakbrook Terrace, 1000 Drury Lane, Oakbrook Terrace, IL
Inspected trench work; footing, elevator shaft, and lintel concrete; rebar; mortar. Constructed by Novak Construction.

Alexian Brothers Hospital, 800 Biesterfield Rd, Elk Grove Village, IL
Emergency Department Additions/Alterations.
Inspected lean concrete as back fill for unsuitable soil removal; 3” stone compaction; welded wire mesh placement; foundation wall rebar and concrete; CA7 backfill with Dynamic Cone Penetrometer; slab concrete. Constructed by Pepper Construction.

Inspected rebar and concrete for various new construction and additions at:
Sherwood Conservatory, 1312 S. Michigan Ave. Chicago, IL. - west side of auditorium walls.
57 E. Delaware Place Condos - footing concrete, Power Construction.
Seasons of Glenview Place, 4501 Concord Ln, Northbrook, IL – column concrete, Pepper Construction.
Dexter Chemical, Waukegan, IL.
Gray Elementary School, 3730 N. Laramie, Chicago, IL.
Hyatt Parking Garage
United Airlines Credit Union
Rosemont Hyatt Parking Garage
DePaul University
BFI Waste Management Dupage
Ameritech
Shops at Schaumburg, Osmond Construction
North Parkway No. 4

Computer Proficiency

Hydrologic & Hydraulics Programming & Modeling
HY-22 Inlets, Hydraflow Storm Sewers, TR-20, HY-8, HEC-RAS/HEC-2, WSP2, EPAnet, SewerCAD, EPASWMM, XPSWMM, PCSWMM

Transportation & Industrial Programming & Modeling
Microstation, GeoPak, AutoCAD, 3D IDEAS SDRC, HCS, ArcMap ArcGIS for Data Procurement and mapping

Scheduling, Planning, and Estimating Software
Primavera, Timberline

Misc.
MS Office, HTML, C Programming, Database Management

Michigan Tech Graduate Research & Educational Experience

Evaluation of Specifications for Fly Ash Used in Highway Concrete, NCHRP 18-13 The overall goal of this externally funded research project is to recommend modifications to the existing specifications and test methods for beneficial use of coal fly ash in concrete as a supplementary cementitious material. Interdisciplinary team collaboration has provided a broader understanding of carbon properties and measurement methods. Contributions include improvements to existing laboratory test methods and development of new scientific methods, written drafts of methods and results for reports, journal paper drafts, material management and acquisition, data acquisition and management, conducting user surveys, and also supervision of two undergraduate assistants in avenues for new research opportunities.

The Coal Fly Ash Industry and Public Policy Review of literature and composition using public policy frameworks to model industry problems with incorporation of engineering and science to understand how a multidisciplinary solution would allow for the continued use of fly ash in concrete.

Natural Pozzolans for Use in Concrete, Tanzania 3-week initiative in July 2009 practicing investigative research to assess current, natural pozzolan use in concrete. Evaluated the availability of natural materials and their current use in roads, structures, and concrete floors for houses by studying available literature and explorations. The goal for research is to ultimately suggest innovative solutions to be implemented locally to address transportation, poverty, and sanitation problems with the possibility to retrofit these solutions to address the global concerns in other developing nations.

Publications

Characterization of Coal Fly Ash by the Absolute Foam Index Kueber Watkins M, Ahmed Z, Sutter L, Hand D. ACI Materials Journal, May 2015.
https://www.concrete.org/publications/internationalconcreteabstractsportal.aspx?m=details&ID=51686972

A Review of the State of the Practice of Data Collection Techniques for Unpaved Roads Melanie Kueber Watkins,Timothy Colling, Colin Brooks, Chris Roussi, Rick Dobson. Submitted to ASCE Journal of Transportation Engineering April 2014.

Advances in Gravel Road Management Start with Condition Assessment Melanie Kueber Watkins, Chris Roussi, Timothy Colling, Colin Brooks, Richard R. Dobson, Gary Schlaff, Luke Peterson, David Dean. Submitted to ASCE Magazine April 2014.

Fly Ash Iodine Number for the Measuring the Adsorption Capacity of Coal Fly Ash Measurement of iodine adsorption by coal fly ash. Ahmed Z, Hand D, Sutter L, Kueber Watkins M. ACI Materials Journal, July 2014.
http://www.concrete.org/Publications/ACIMaterialsJournal/ACIJournalSearch.aspx?m=details&ID=51686582

Combined Adsorption Isotherms for the Measurement of AEAs Adsorption by Fly Ash in Concrete Ahmed Z, Hand D, Sutter L, Kueber Watkins M. ACS Sustainable Chemistry & Engineering, March 2014. DOI: 10.1021/sc500043s http://pubs.acs.org/doi/ipdf/10.1021/sc500043s

Air Entraining Admixtures Partitioning and Adsorption by Coal Fly Ash in Concrete Ahmed Z, Hand D, Kueber Watkins M, Sutter L. ACS Industrial and Engineering Chemistry Research, March 2014. DOI: 10.1021/ie4018594. http://pubs.acs.org/doi/pdf/10.1021/ie4018594

Characterization of Coal Fly Ash-Cement Slurry by Absolute Foam Index Development of the foam index test to characterize coal fly ash, standard procedure, statistical analysis, and correlations to adsorption isotherms, AEA isotherms, and mortar. Dissertation, Kueber Watkins M. May 2013. http://digitalcommons.mtu.edu/cgi/viewcontent.cgi?article=1492&context=etds

Collecting Decision Support System Data via Remote Sensing of Unpaved Roads The development of a market-ready unmanned aerial vehicle system to detect unpaved road distress that are compatible with a decision support system. Dobson RJ, Colling T, Brooks C, Roussi C, Kueber Watkins M, Dean D. Transportation Research Record, August 2013. http://docs.trb.org/prp/14-5076.pdf

Integrated Environmental and Economic Comparison of Continuously Reinforced and Jointed Plain Concrete Pavements Economic and environmental study of resources and their life cycle projection. Muga H, Mukherjee A, Mihelcic J, Kueber M. Journal of Engineering Design and Technology, October 2008.
http://www.emeraldinsight.com/Insight/viewContentItem.do?contentType=Article&contentId=1779207

Extreme Makeover: Road Edition Wright Street, Successful Road Diet in Marquette, Marquette, MI

Kueber Watkins M. The Bridge, A Quarterly newsletter from Michigan's Local Technical Assistance Program, December 2012. http://michiganltap.org/sites/ltap/files/publications/bridge/Bridge26-3.pdf

Fly Ash – One of Several Options for Stabilizing Soil Before Building a Road
Ryyannen J, Kueber Watkins M. The Bridge, A Quarterly newsletter from Michigan's Local Technical Assistance Program, September 2012.
http://michiganltap.org/sites/ltap/files/publications/bridge/Bridge26-2%20.pdf

Proposal Collaboration

Developing a Snow and Ice Control Environmental Best Management Practices Manual Joint effort for a proposal to develop the best available deicer product, application, and impact information. Russell Alger, Melanie Kueber Watkins, Timothy Colling, Shaughn Kern. Submitted to Clearroads.org August 2013.

Use of Mature Fine Tails in Concrete and Asphalt Joint effort for a proposal investigation and use of recyclable materials. Melanie Kueber Watkins, David W. Hand, Robert Fritz, Jean Leav. Michigan Tech Transportation Institute: $10k funded September 2013.

Iodine Number Joint proposal effort for refining the iodine number test that is used for directly measuring adsorption capacity of coal fly ash. Ahmed Z., Hand D, Perram D, Kueber Watkins M. 2013.

Evaluation of Adsorption Inhibitors for Beneficial Uses of High Carbon Fly Ash Kueber M, Ahmed Z, Sutter L, Hand D. Proposal for UTC 2009 Summer Scholars Program.

Fibers in Concrete Participated in the preliminary literature review for joint effort for a proposal to develop a state-of-the-art report based on the most recent research regarding the use of fibers in concrete. 2007.

Recycled Concrete In Transportation Infrastructure Participated in the preliminary literature review for a proposal to develop practice based on current information to meet economic challenges while fulfilling environmental and safety requirements. 2007.

Report Writing

Characterization of Unpaved Road Condition Through the Use of Remote Sensing: State of the Practice of Unpaved Road Condition Assessment Performed literature review and participated in team effort to prepare document on joint project with Michigan Tech Research Institute. November 2011.

Characterization of Unpaved Road Condition Through the Use of Remote Sensing: Software and Algorithms to Support Unpaved Road Assessment by Remote Sensing Participated in team effort to prepare document on joint project with Michigan Tech Research Institute. October 2012.

Activity Travel Behavior, February 2011 Analysis and documentation of a study comparing the benefits of webinars using Michigan LTAP data.

TAMC PASER QC/QA, 2012, 2013 Update of existing PASER rating quality control plan and assessment report with new 2012 collection data and user survey data.

RE: MDOT Enterprise Asset Management System: Roadsoft Capabilities, 2013 Marketing document outlining functions of Roadsoft.

A Closer Look at the Day to Day Administration of the Illinois Department of Transportation Northwestern. December 1999.

Reviews and Editing

General Purpose (GP) Cement with Higher Limestone Content in Australia. American Concrete Institute. Reviewed September 2015.

Update Existing Climatic Files and Add New Weather Stations for Pavement ME Design in Michigan using ASOS/AWOS database. Michigan Tech for TRB Publication. Reviewed July 2015.

Report on the Use of Fly Ash in Concrete (ACI 232.2R). American Concrete Institute. Reviewed July 2015.

Guide to Design and Proportioning of Concrete Mixtures for Pavements (ACI 325.XR). American Concrete Institute. Reviewed June 2015.

Runoff Impacts and LID Techniques for Mansionization Based Stormwater Effects in Fairfax County, VA. Journal of Sustainable Water in the Built Environment. Reviewed May 2015.

ACI Committee 304.2 Placing Concrete by Pumping Methods. Reviewed September 2013.

Particle Size and Specimen Preparation Effects on the Iowa Pore Index. ACI Materials Journal. Reviewed May 2013.

Research Dissemination

Michigan Tech RIM (Recovered Industrial Materials) Education and Research Initiatives Kueber, M.; Sutter, L.; Hoy, B. American Coal Ash Association (ACAA) Presenter, Invitee to mid-year conference, Alexandria, VA, July 2008.

Fly Ash and Surfactant Interactions: The Role of Solution Chemistry and Interfacial Science in Test Design and Application PhD Proposal Defense, December 15, 2010.

Featured Articles

Precast Solutions Collaborative Article Effort: ***Researchers Increase Concrete's Durability and Recycled Content*** *Precast Solutions,* Summer 2009 Issue, 16-20. National Precast Concrete Association. http://precast.org/2010/07/researchers-increase-concretes-durability-and-recycled-content/

Making Concrete Greener Gagnon, J., Featured article, Michigan Tech Research Magazine 2009, p. 24.
http://www.mtu.edu/research/archives/magazine/pdf/Research%20Magazine%202009.pdf
http://www.mtu.edu/research/archives/magazine/2009/stories/grad/

Graduate Student Mentoring

MS Graduate Committee Member for Jean Leav. *Mature Fine Tailings (MFTs): A Study of Compressive Strength and Rheological Properties of Athabasca Oil Sands Petroleum Mining Waste Applied in Concrete Mixtures*. MS Report advising/editing, December 2013.

MS Graduate Committee Member for Brie Rust. *Beneficial Reuse of Locally-available Waste Materials as Lightweight Aggregate in Lightweight Concrete*. MS Report advising/editing, 2014.

MS Graduate Committee Member for Toni Larche. MS Geology. Pending Fall 2015.

PhD Graduate Committee Member for Mohammad Fard. PhD Environmental Engineering Pending Spring 2018.

Other Teaching Experience

1999, Northwestern University – Engineering First Taught a recitation section of first year engineering students interdisciplinary engineering fundamentals. Assisted with homework and projects.

1996 to 1997, Michigan Technological University – Geotechnical Soils Engineering Mechanics Lab Taught several laboratory sections of third and fourth year engineering students soil and foundation mechanics fundamentals. Assisted with and graded laboratory reports and homework problems.

September 2010 to 2011, Michigan Technological University – Civil Engineering Materials Lab Taught several laboratory sections of third and fourth year engineering students. Topics included metal fracture, aggregate properties, and concrete and asphalt fundamentals. Assisted with and graded laboratory reports.

Honors and Awards

Graduate Student Representative Graduate Education Day, April 13, 2010 during Michigan Graduate Education Week. Michigan State Capitol Building, East Lansing, MI.
http://www.mtu.edu/news/stories/2010/april/story25543.html

Graduate Student of the Year - Danielle Ladwig Award for Graduate Excellence Michigan Technological University, Department of Civil and Environmental Engineering, May 2009. CEE 2010, Department News, p. 7. http://www.cee.mtu.edu/news/Newsletters/CEE_newsletter_2010.pdf

Integrated Graduate Education Research Trainee, **Southern University & A&M College, Historically Black Colleges and University (HBCU), Baton Rouge, Louisiana: National Exchange Student Spring Semester 2008** *(IGERT, www.sfi.mtu.edu/IGERT)* Multidisciplinary program that included engineering and public policy collaboration with the goal of advancing the science of sustainability. August 2007 Recipient. Assessment Committee Member for IGERT Renewal Proposal, Fall 2008.

University Transportation Center (UTC)-Michigan Sustainable Transportation Institute Student of the Year Award and Fellowship *(MiSTI, www.misti.mtu.edu)* November 2008 Recipient. U.S. Department of Transportation (USDOT), UTC outstanding student award Washington, D.C. MiSTI Transportation News, Vol. 1, p. 3. http://www.misti.mtu.edu/pdf/misti_v3_n1_web.pdf

Community Service & Hobbies

Portage Township Planning Commission. Board member, June 2013 to present. Chair, 2015 to present. December Worked with the Planning Commission and the consultant for completion of the Master Plan. Worked with the Planning Commission and the consultant for completion of the Zoning Ordinance. Reviewed site plans. Revised the Zoning Application June 2016. Drafted civil infraction ordinance and rental ordinance for enforcement of the Zoning Ordinance.

ACEC Illinois. Member July 2016 to present. Pump station committee chair, November 2016.

KUUF. Finance Committee Member, October 2016 to present. Board member, May 2013 to May 2015. Interim Vice President, February 2014 to May 2015. Participated on the committee to hire an Interim Minister. Participated with the former choir director to hire a new choir director.

City of Houghton Stormwater Ordinance. Reviewed draft copy and provided comments to Jay Green, City of Houghton Planning Commission. May 2013. Adoption by Houghton 2017.

Race Volunteer Roadway crossing and safety volunteer: Canal Run, Kuparisaari Triathlon, Deer Chase, FatTire, ChainDrive. Keweenaw Cyclocross.

Travel Experience. **International:** Argentina, Brazil, British Virgin Islands, Canada, Chile, Czech Republic, Ecuador, Galapagos Islands, Germany, India, Italy, Mexico, Panama, Peru, Tanzania, U.S. Virgin Islands. **Domestic:** Alaska, Alabama, Arkansas, Arizona, California, Colorado, Florida, Georgia, Hawaii, Illinois, Indiana, Iowa, Kentucky, Louisiana, Maine, Maryland, Michigan, Minnesota, Mississippi, Missouri, Nevada, New Hampshire, New Mexico, Ohio, Oregon, Pennsylvania, Rhode Island, Tennessee, Texas, Utah, Virginia, Washington, Washington DC, Wisconsin.

Outdoor Activities Cycling, hiking, camping, canoeing, swimming, kayaking, downhill skiing, cross country skiing, back country skiing, snow shoeing.

Classical Arts Piano lessons: 10 years. Undergraduate Thematic Studies: Theater History, Musical Theater History, Black Film, Jazz History.

Johanna L. Mathieu

Department of Electrical Engineering and Computer Science
University of Michigan – Ann Arbor
✉ jlmath@umich.edu

Education

University of California, Berkeley — **Berkeley, CA**
Ph.D., Mechanical Engineering — *2012*
Advisors: Duncan Callaway & Ashok Gadgil

University of California, Berkeley — **Berkeley, CA**
M.S., Mechanical Engineering — *2008*

Massachusetts Institute of Technology — **Cambridge, MA**
S.B., Ocean Engineering — *2004*
Minor in Ancient and Medieval Studies

Positions

University of Michigan — **Ann Arbor, MI**
Associate Professor with Tenure, EECS (Electrical and Computer Engineering Division) — *Sep 2020 - Present*
Assistant Professor, EECS (Electrical and Computer Engineering Division) — *Jan 2014 - Aug 2020*

National Renewable Energy Laboratory — **Golden, CO**
Collaborative Appointment — *Oct 2020 - Mar 2021*

ETH Zurich — **Zurich, Switzerland**
Postdoctoral Researcher, Power Systems Laboratory — *Jul 2012 - Dec 2013*

Lawrence Berkeley National Laboratory — **Berkeley, CA**
Affiliate, Environmental Energy Technologies Division — *Feb 2007 - Aug 2012*

Bangladesh University of Engineering and Technology — **Dhaka, Bangladesh**
Visiting Researcher, Department of Civil Engineering — *May 2008 - Jul 2008*

MIT Sea Grant College Program — **Cambridge, MA**
Research Assistant, Center for Coastal Resources — *Dec 2005 - Jun 2006*

U.S. Peace Corps — **Morogoro & Mahiwa, Tanzania**
Education Volunteer — *Sep 2004 - Oct 2005*

Woods Hole Oceanographic Institution — **Woods Hole, MA**
Summer Student Fellow, Advanced Engineering Laboratory — *Summer 2003*

University of Southampton — **Southampton, United Kingdom**
Visiting Researcher, Institute for Sound and Vibration Research — *January 2003*

Massachusetts Institute of Technology — **Cambridge, MA**
Undergraduate Researcher, Deep Sea Archaeology Research Group — *Fall 2001, Spring 2002, Fall 2002*

University of Rhode Island Graduate School of Oceanography — **Narragansett, RI**
Summer Undergraduate Research Fellow in Oceanography — *Summer 2002*

Teaching

UM EECS 460, Control System Analysis & Design **Ann Arbor, MI**
Instructor *Winter 2020*

UM EECS 463, Power System Design and Operation **Ann Arbor, MI**
Instructor *Winter 2014; Fall 2015, 2018, 2021*

UM EECS 498, Grid Integration of Alternative Energy Sources **Ann Arbor, MI**
Instructor *Winter 2015*

UM EECS 534, Analysis of Electric Power Distribution Systems and Loads **Ann Arbor, MI**
Course Developer & Instructor *Fall 2014, 2016; Winter 2019*

UM EECS 536, Power System Markets & Optimization **Ann Arbor, MI**
Course Developer & Instructor *Fall 2019; Winter 2016, 2018, 2022*

Short Course: Grid 101 **Ann Arbor, MI**
Course Developer (with I. Hiskens) & Instructor *May 2018*

UC Berkeley CE 290, Design for Sustainable Communities **Berkeley, CA**
Graduate Student Instructor *Spring 2009, 2010*

Mahiwa Secondary School, Physics & Mathematics **Mahiwa, Tanzania**
U.S. Peace Corps Volunteer & Secondary School Teacher *Jan - Oct 2005*

St. Walburg's Hospital Adult Education Program, Physics **Nyangao, Tanzania**
U.S. Peace Corps Volunteer & Adult Education Teacher *Spring 2005*

Guest Lectures

- Earth Day at 50 Teach-Out: Reimagining the Future of Sustainability, *A Sustainable Power Grid*, Mar 2020.
- Technical University of Denmark Center for Electric Power and Energy Summer School, *Data-Driven Distributionally Robust Optimization*, Jun 18, 2019.
- UM ESE 501, *A Brief Introduction to the Grid*, Oct 9, 2019.
- UM ESE 501, *A Brief Introduction to the Grid*, Oct 10, 2018.
- UM EECS 500, *Coordinating Electric Loads to Improve Power System Reliability and Economics*, Oct 16, 2015.
- UM EECS 500, *How Your Refrigerator Can Help Get More Renewable Energy on the Power Grid*, Oct 3, 2014.
- UM CEE 679, *Energy Arbitrage with Thermostatically Controlled Loads*, Feb 24, 2014.
- UC Berkeley ERG 254, *Demand Response*, Nov 29, 2011.

Awards & Honors

- National Academy of Engineering EU-US Frontiers of Engineering Symposium Participant, 2021.
- National Academy of Engineering US Frontiers of Engineering Symposium Presenter, 2021.
- Henry Russel Award, 2021.
- Outstanding Reviewer for IEEE Transactions on Sustainable Energy, 2020.
- National Academy of Engineering US Frontiers of Engineering Symposium Participant, 2019.
- NSF CAREER Award, 2019.
- Ernest and Bettine Kuh Distinguished Faculty Award, 2018.

- Senior Member of the IEEE, 2018.
- ACEEE Summer Study on Energy Efficiency in Buildings paper selected for a special issue of *Energy Efficiency*, 2018. (with A. Keskar, D. Anderson, J.X. Johnson, and I.A. Hiskens)
- A Best Paper on Distribution Systems, Microgrids, and Renewables, IEEE PES General Meeting, 2018. (with G.S. Ledva and S. Peterson)
- Honorable Mention, INFORMS Junior Faculty Interest Group Paper Competition, 2017. (with B. Li and R. Jiang)
- Energy Policy Research Conference paper selected for a special issue of *The Electricity Journal*, 2017. (with S. Forrester, A. Zaman, and J.X. Johnson)
- IEEE PES PowerTech Conference High Quality Paper Award, 2017. (with M. Yao and D.K. Molzahn)
- Power Systems Computation Conference paper selected for a special issue of the *International Journal of Electrical Power and Energy Systems*, 2014. (with O. Mégel and G. Andersson)
- A Best Paper on Markets, Economics, and Planning, IEEE PES General Meeting, 2014. (with T.B. Rasmussen, M. Sørensen, H. Jóhannsson, and G. Andersson)
- First Prize in Global Poverty Reduction Category, UC Berkeley Bears Breaking Boundaries White Paper Competition, 2007. (with T. Khan, K. Jahani, M. Seflek, and A.J. Gadgil)
- UC Berkeley Chancellor's Fellowship, 2006.
- National Defense Science and Engineering Graduate Research Fellowship, 2006.
- Honorable Mention, National Science Foundation Graduate Research Fellowship Program, 2006.
- MIT Department of Ocean Engineering Robert Bruce Wallace Prize, 2003.
- Best Undergraduate Paper, Society of Naval Architects and Marine Engineers New England Section Paper Night, 2004. (with M.B. Greytak, K.S. Wasserman, A.K. Baker, J.D. Chambers, and B.M. Mueller)
- Best Undergraduate Paper, Autonomous Undersea Systems Institute Symposium on Unmanned Untethered Submersible Technologies, 2003.
- Best Undergraduate Paper, Society of Naval Architects and Marine Engineers New England Section Paper Night, 2003.
- MIT Sea Grant College Program Dean A. Horn Award, 2003.
- Marine Technology Society Remotely Operated Vehicle Scholarship, 2002.

Publications

Journal Papers

[J39] K. Girigoudar, M. Yao, **J.L. Mathieu**, and L. Roald. "Integration of centralized and distributed methods to mitigate voltage unbalance using solar inverters". In: (review).

[J38] M. Yao, S. Roy, and **J.L. Mathieu**. "Using demand response to improve power system small-signal stability". In: (review).

[J37] A. Andrews, J. Roth, R.K. Jain, and **J.L. Mathieu**. "Data-driven examination of the impact energy efficiency has on demand response capabilities in commercial buildings". In: (review).

[J36] J. Buchsbaum, C. Hausman, **J.L. Mathieu**, and J. Peng. "Multi-product firms in electricity markets: Implications for climate policy". In: (review).

[J35] S. Lei, **J.L. Mathieu**, and R.K. Jain. "Performance of existing methods in baselining demand response from commercial building HVAC fans". In: *ASME Journal of Engineering for Sustainable Buildings and Cities* 2.2 (2021), p. 021002.

[J34] M. Yao, I.A. Hiskens, and **J.L. Mathieu**. "Mitigating voltage unbalance using distributed solar photovoltaic inverters". In: *IEEE Transactions on Power Systems* 36.3 (2021), pp. 2642–2651.

[J33] S.C. Ross and **J.L. Mathieu**. "Strategies for network-safe load control with a third-party aggregator and a distribution operator". In: *IEEE Transactions on Power Systems* 36.4 (2021), pp. 3329–3339.

[J32] L. Herre, **J.L. Mathieu**, and L. Söder. "Impact of market timing on the profit of a risk-averse load aggregator". In: *IEEE Transactions on Power Systems* 35.5 (2020), pp. 3970–3980.

[J31] A. Stuhlmacher and **J.L. Mathieu**. "Chance-constrained water pumping to manage water and power demand uncertainty in distribution networks". In: *Proceedings of the IEEE* (*Special Issue on Multi-Energy Systems*) 108.9 (2020), pp. 1640–1655.

[J30] G.S. Ledva and **J.L. Mathieu**. "Separating feeder demand into components using substation, feeder, and smart meter measurements". In: *IEEE Transactions on Smart Grid* 11.4 (2020), pp. 3280–3290.

[J29] A. Keskar, D. Anderson, J.X. Johnson, I.A. Hiskens, and **J.L. Mathieu**. "Do commercial buildings become less efficient when they provide grid ancillary services?" In: *Energy Efficiency* (*Special Issue for the 2018 ACEEE Summer Study on Energy Efficiency in Buildings*) 13.3 (2020), pp. 487–501.

[J28] B. Li, R. Jiang, and **J.L. Mathieu**. "Distributionally robust optimal power flow assuming unimodal distributions with misspecified modes". In: *IEEE Transactions on Control of Network Systems* (*Special Issue on Analysis, Control, and Optimization of Energy Networks*) 6.3 (2019), pp. 1223–1234.

[J27] M. Yao, D.K. Molzahn, and **J.L. Mathieu**. "An optimal power flow approach to improve power system voltage stability using demand response". In: *IEEE Transactions on Control of Network Systems* (*Special Issue on Analysis, Control, and Optimization of Energy Networks*) 6.3 (2019), pp. 1015–1025.

[J26] S.C. Ross, G. Vuylsteke, and **J.L. Mathieu**. "Effects of load-based frequency regulation on distribution network operation". In: *IEEE Transactions on Power Systems* 34.2 (2019), pp. 1569–1578.

[J25] M. Vrakopoulou, B. Li, and **J.L. Mathieu**. "Chance constrained reserve scheduling using uncertain controllable loads, Part I: Formulation and scenario-based analysis". In: *IEEE Transactions on Smart Grid* 10.2 (2019), pp. 1608–1617.

[J24] B. Li, M. Vrakopoulou, and **J.L. Mathieu**. "Chance constrained reserve scheduling using uncertain controllable loads, Part II: Analytical reformulation". In: *IEEE Transactions on Smart Grid* 10.2 (2019), pp. 1618–1625.

[J23] B. Li, R. Jiang, and **J.L. Mathieu**. "Ambiguous risk constraints with moment and unimodality information". In: *Mathematical Programming* 173.1-2 (2019), pp. 151–192.

[J22] N.A. Ryan, Y. Lin, N. Mitchell-Ward, **J.L. Mathieu**, and J.X. Johnson. "Use-phase drives lithium ion battery life cycle environmental impacts when used for frequency regulation". In: *Environmental Science & Technology* 52.17 (2018), pp. 10163–10174.

[J21] G.S. Ledva, L. Balzano, and **J.L. Mathieu**. "Real-time energy disaggregation of a distribution feeder's demand using online learning". In: *IEEE Transactions on Power Systems* 33.5 (2018), pp. 4730–4740.

[J20] G.S. Ledva, E. Vrettos, S. Mastellone, G. Andersson, and **J.L. Mathieu**. "Managing communication delays and model error in demand response". In: *IEEE Transactions on Power Systems* 33.2 (2018), pp. 1299–1308.

[J19] S. Forrester, A. Zaman, **J.L. Mathieu**, and J.X. Johnson. "Policy and market barriers to energy storage providing multiple services". In: *The Electricity Journal* (*Special Issue for the Energy Policy Institute's Seventh Annual Energy Policy Research Conference*) 30.9 (2017), pp. 50–56.

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[C2] ****J.L. Mathieu** and A.K. Hansen. "A chemical sensor to aid in the search for underwater archaeological sites". In: *Proceedings of the Autonomous Undersea Systems Institute (AUSI) International Symposium on Unmanned, Untethered Submersible Technologies (UUST)*. Durham, NH, Aug. 2003, (Student paper competition winner).

[C1] ****J.L. Mathieu** and A.K. Hansen. "A chemical sensor to aid in the search for underwater archaeological sites". In: *Proceedings of the Society of Naval Architects and Marine Engineers (SNAME) New England Section Student Paper Night*. Cambridge, MA, Feb. 2003, (Best undergraduate paper award).

Technical Reports, White Papers, and Discussion Papers

[R13] S. Lei, **J.L. Mathieu**, and R. Jain. *Performance of existing baseline models in quantifying the effects of short-term load shifting of campus buildings*. Tech. rep. SLAC-R-1131. SLAC National Accelerator Laboratory, Sept. 2019.

[R12] B. Li, R. Jiang, and **J.L. Mathieu**. *The value of including unimodality information in distributionally robust optimal power flow*. arXiv:1811.10217v2. Aug. 2019.

[R11] P.D. Howe and **J.L. Mathieu**. *Age and perceived benefits are associated with willingness to participate in an electric load control program*. SocArXiv Paper. doi:10.31235/osf.io/rpg46, July 2018.

[R10] M. Vrakopoulou, S. Chatzivasileiadis, E. Iggland, M. Imhof, T. Krause, O. Mäkelä, **J.L. Mathieu**, L. Roald, R. Wiget, and G. Andersson. *Closure of "A unified analysis of security-constrained OPF formulations considering uncertainty, risk, and controllability in single and multi-area systems"*. Prepared Discussion. IREP Symposium on Bulk Power System Dynamics and Control, Rethymnon, Greece, Sept. 2013.

[R9] D.S. Callaway, **J.L. Mathieu**, M.E.H. Dyson, M. Kamgarpour, S. Koch, and J. Lygeros. *Mitigating renewables intermittency through non-disruptive distributed load control*. Technical Report. PSERC Industry-University Meeting on Preparing for the Future Grid, Madison, WI, May 2013.

[R8] **J.L. Mathieu**, T. Haring, and G. Andersson. *Harnessing residential loads for demand response: engineering and economic considerations*. White Paper. Interdisciplinary Workshop on Smart Grid Design and Implementation, Gainesville, FL, Dec. 2012.

[R7] **J.L. Mathieu** and D.S. Callaway. *The value of real-time data in controlling electric loads for demand response*. White Paper. Carnegie Mellon University Conference on the Electricity Industry: Data Driven Sustainable Energy Systems, Pittsburgh, PA, Mar. 2012.

[R6] S. Oren, D. Callaway, **J.L. Mathieu**, A. Papavasilou, T. Mount, M. Zhang, R. Thomas, G. Gross, and A. Dominguez-Garcia. *Renewable energy integration and the impact of carbon regulation on the electric grid*. White Paper. PSERC Future Grid Initiative, 2012.

[R5] G. Ghatikar, **J.L. Mathieu**, M.A. Piette, E. Koch, and D. Hennage. *Open automated demand response dynamic pricing technologies and demonstration*. Technical Report LBNL-3921E. Lawrence Berkeley National Laboratory, Aug. 2010.

[R4] **J.L. Mathieu**, T. Khan, K. Jahani, M. Seflek, and A.J. Gadgil. *Berkeley arsenic alleviation group*. White Paper. UC Berkeley Bears Breaking Boundaries Competition, 2007, (First prize – 'Global Poverty Reduction' category).

[R3] **J.L. Mathieu**. *A long range optical hydrothermal plume detector*. Technical Report. Woods Hole Oceanographic Institution, Project supervisor: A. Bradley, 2003.

[R2] **J.L. Mathieu**. *Acoustic backscatter from sediment and archaeological wood*. Technical Report. University of Southampton Institute for Sound, Vibration Research & MIT Undergraduate Research Opportunities Program, Project supervisors: J. Dix, and D. Mindell, 2003.

[R1] **J.L. Mathieu** and A.K. Hansen. *A chemical sensor to aid in the search for underwater archaeological sites*. Technical Report No. 2003-1. University of Rhode Island, 2002, pp. 55–62.

Theses

[T2] **J.L. Mathieu**. "Modeling, analysis, and control of demand response resources". PhD thesis. University of California, Berkeley (LBNL-5544E), May 2012.

[T1] **J.L. Mathieu**. "Design of a rural water provision system to decrease arsenic exposure in Bangladesh". MS project report. University of California, Berkeley (LBNL-1422E), Dec. 2008.

Abstracts with Oral Presentations (**presenter, *contributed equally)

[A29] J. Buchsbaum, C. Hausman, **J.L. Mathieu**, and J. Peng. *Spillovers from ancillary services to wholesale power markets: Implications for climate policy*. American Economic Association Meeting. Jan. 2022.

[A28] *K. Girigoudar, *M. Yao, **J.L. Mathieu**, and L. Roald. *Control strategies to mitigate voltage unbalance using solar PV inverters*. INFORMS Annual Meeting, Anaheim, CA. Oct. 2021 (to appear).

[A27] A. Stuhlmacher, L. Roald, and **J.L. Mathieu**. *An adjustable robust optimization model for drinking water pumping as a flexible load*. INFORMS Annual Meeting, Anaheim, CA. Oct. 2021 (to appear).

[A26] J. Buchsbaum, **C. Hausman, **J.L. Mathieu**, and J. Peng. *Multi-product firms in electricity markets: Implications for climate policy*. Association of Environmental and Resource Economists Summer Conference (virtual). June 2021.

[A25] J. Buchsbaum, **C. Hausman, **J.L. Mathieu**, and J. Peng. *Multi-product firms in electricity markets: Implications for batteries and climate policy*. Western Economic Association International Conference (virtual). Mar. 2021.

[A24] J. Buchsbaum, **C. Hausman, **J.L. Mathieu**, and J. Peng. *Spillovers from ancillary services to wholesale power markets: Implications for climate policy*. University of California Energy Institute POWER Conference (virtual). Mar. 2021.

[A23] A. Keskar, D. Anderson, **J.X. Johnson, I.A. Hiskens, and **J.L. Mathieu**. *Buildings as batteries: An experimental investigation into energy efficiency impacts of demand response*. International Symposium on Sustainable Systems and Technology, Portland, OR. June 2019.

[A22] **A. Keskar, D. Anderson, J.X. Johnson, I.A. Hiskens, and **J.L. Mathieu**. *Buildings as batteries: An experimental investigation into energy efficiency impacts of demand response*. Engineering Sustainability Conference, Pittsburgh, PA. Apr. 2019.

[A21] ****J.L. Mathieu** and S.C. Ross. *Distribution network-aware load coordination architectures and control strategies*. Conference on Information Sciences and Systems, Baltimore, MD. Mar. 2019.

[A20] **B. Li, R. Jiang, and **J.L. Mathieu**. *Distributionally robust chance-constrained optimal power flow assuming log-concave distributions*. INFORMS Annual Meeting, Phoenix, AZ. Nov. 2018.

[A19] **S.C. Ross and **J.L. Mathieu**. *Stability of electrical grids with 100% renewable generation*. Michigan University-Wide Sustainability & Environment Conference, Ann Arbor, MI. Feb. 2018.

[A18] **D.K. Molzahn, M. Yao, and **J.L. Mathieu**. *A multi-period OPF approach to improve voltage stability using demand response*. INFORMS Annual Meeting, Houston, TX. Oct. 2017.

[A17] B. Li, **R. Jiang, and **J.L. Mathieu**. *Ambiguous risk constraints with moment and unimodality information*. INFORMS Annual Meeting, Houston, TX. Oct. 2017.

[A16] **J.L. Mathieu and J. Taylor. *Reducing degradation in batteries used for frequency regulation via nonlinear control*. INFORMS Annual Meeting, Houston, TX. Oct. 2017, Invited.

[A15] **D.K. Molzahn, M. Yao, and **J.L. Mathieu**. *A multi-period optimal power flow approach to improve power system voltage stability using demand response*. FERC Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software, Washington, DC. June 2017.

[A14] **N. Ryan, Y. Lin, N. Mitchell-Ward, **J.L. Mathieu**, and J.X. Johnson. *Life cycle environmental impacts of using lithium ion batteries for power system reserves and strategies for mitigation*. International Society for Industrial Ecology and International Symposium on Sustainable Systems and Technology Joint Conference, Chicago, IL. June 2017.

[A13] **N. Ryan, Y. Lin, N. Mitchell-Ward, **J.L. Mathieu**, and J.X. Johnson. *Life cycle environmental impacts of using lithium ion batteries for power system reserves and strategies for mitigation*. Association of Environmental Engineering and Science Professors Biennial Conference, Ann Arbor, MI. June 2017.

[A12] **N. Ryan, Y. Lin, N. Mitchell-Ward, **J.L. Mathieu**, and J.X. Johnson. *Life cycle environmental impacts of using lithium ion batteries for power system reserves and strategies for mitigation*. Engineering Sustainability Conference, Pittsburgh, PA. Apr. 2017.

[A11] **B. Li, R. Jiang, and **J.L. Mathieu**. *Distributionally robust risk-constrained optimal power flow using moment and unimodality information*. INFORMS Annual Meeting, Nashville, TN. Nov. 2016, Invited.

[A10] Y. Lin, N. Mitchell-Ward, **J.L. Mathieu**, and **J.X. Johnson. *Examining life cycle environmental impacts of energy storage for power system reserves*. INFORMS Annual Meeting, Nashville, TN. Nov. 2016, Invited.

[A9] Y. Lin, **J.L. Mathieu**, **N. Mitchell-Ward, and J. Johnson. *Examining life cycle environmental impacts of energy storage for power system reserves*. International Symposium on Sustainable Systems and Technology, Phoenix, AZ. May 2016.

[A8] **J. Taylor and **J.L. Mathieu**. *Strategic price bidding in electricity markets with only renewables*. INFORMS Annual Meeting, Philadelphia, PA. Nov. 2015, Invited.

[A7] **J.L. Mathieu, O. Mégel, and G. Andersson. *Scheduling energy storage resources to provide multiple services*. INFORMS Annual Meeting, Philadelphia, PA. Nov. 2015, Invited.

[A6] **J.L. Mathieu, Y. Zhang, S. Shen, and B. Li. *Chance-constrained optimal power flow with uncertain reserves*. INFORMS Annual Meeting, Philadelphia, PA. Nov. 2015, Invited.

[A5] **J.L. Mathieu, S. Shen, Y. Zhang, and B. Li. *Data-driven optimization approaches for optimal power flow with uncertain reserves from load control*. FERC Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software, Washington, DC. June 2015.

[A4] **J.L. Mathieu, M. Vrakopoulou, G. Andersson, and S. Shen. *Stochastic optimal power flow with uncertain reserves from flexible loads*. FERC Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software, Washington, DC. June 2014.

[A3] **J.L. Mathieu and. E. Vrettos and G. Andersson. *Control of thermostatic loads using moving horizon estimation of individual load states*. Midwest Workshop on Control and Game Theory, Columbus, OH. Apr. 2014.

[A2] **J.L. Mathieu, M.E.H. Dyson, and D.S. Callaway. *Using residential loads like grid-scale batteries: The resource, potential revenues, and costs*. Los Alamos National Laboratory Conference on Optimization and Control for Smart Grids, Santa Fe, NM. May 2012.

[A1] **J.L. Mathieu and D.S. Callaway. *Using residential electric loads in energy and ancillary services markets*. Trans-Atlantic INFRADAY Conference on Applied Infrastructure Modeling and Policy Analysis, Pre-conference Event at FERC, Washington, DC. Nov. 2011.

Posters (**denotes presenter)

[P32] **C. Bertcher, A. Stuhlmacher, and **J.L. Mathieu**. *Comparison of linearized three-phase unbalanced power flow models*. IEEE Power & Energy Society General Meeting Student Poster Competition (virtual). July 2021.

[P31] **N. Ozay and **J.L. Mathieu**. *Scalable and safe control synthesis for systems with symmetries*. NSF CPS PI Meeting (virtual). May 2021.

[P30] **O. Oyefeso, G.S. Ledva, **J.L. Mathieu**, and I.A. Hiskens. *Aggregate modeling and asynchronous, anonymous coordination of distributed air conditioning load resources under packetized energy management*. UM Engineering Research Symposium (virtual). Feb. 2021.

[P29] ****J.L. Mathieu**. *Overcoming the technical challenges of coordinating distributed load resources at scale*. ARPA-E 2018 OPEN Grid Projects Kick-off Meeting, New Orleans, LA. Feb. 2020.

[P28] N. Ozay and ****J.L. Mathieu**. *Scalable and safe control synthesis for systems with symmetries*. NSF CPS PI Meeting, Arlington, VA. Nov. 2019.

[P27] **B. Hicks, H. Lee, S. Lei, and **J.L. Mathieu**. *Alternative technique in the approximation of comparative baselines for the energy efficiency evaluation of HVAC systems during demand response events*. UM Summer Research Opportunities Program Symposium, Ann Arbor, MI. July 2019.

[P26] **C. Bertcher, A. Stuhlmacher, and **J.L. Mathieu**. *UM bus electrification: Challenges and solutions*. University of Michigan Undergraduate Research Symposium, Ann Arbor, MI. Apr. 2019.

[P25] **A. Stuhlmacher and **J.L Mathieu**. *Stochastic water distribution network operation considering power distribution network constraints*. UM Engineering Research Symposium, Ann Arbor, MI. Nov. 2018.

[P24] **S.C. Ross, G. Vuylsteke, and **J.L Mathieu**. *Effects of load-based frequency regulation on distribution network operation*. University of Vermont Future of Energy Workshop, Burlington, VT. Sept. 2018. (Best poster award).

[P23] **B. Li, R. Bent, H. Nagarajan, R. Jiang, and **J.L. Mathieu**. *Decomposition and cutting-plane based algorithm for stochastic climate adaptation problem using special ordered sets*. Los Alamos National Laboratory Student Symposium, Los Alamos, NM. July 2018. (Outstanding poster award - computing).

[P22] **A. Keskar, S. Afshari, P. Giessner, D. Anderson, I. Hiskens, J.X. Johnson, and **J.L. Mathieu**. *Using University of Michigan buildings as batteries*. Michigan University-Wide Sustainability & Environment Conference, Ann Arbor, MI. Feb. 2018.

[P21] **M. Yao, D.K. Molzahn, and **J.L. Mathieu**. *The impact of load models in an algorithm for improving voltage stability via demand response*. UM Engineering Research Symposium, Ann Arbor, MI. Nov. 2017.

[P20] **A. Kern, O. Mégel, J.X. Johnson, and **J.L. Mathieu**. *Approximation methods for scheduling battery energy storage for multiple services*. UM Engineering Research Symposium, Ann Arbor, MI. Nov. 2017.

[P19] **A. Stuhlmacher, **J.L. Mathieu**, and V. Gupta. *Water-power distribution network coupling for optimal pumping to reduce energy costs and promote resilience*. UM Engineering Research Symposium, Ann Arbor, MI. Nov. 2017.

[P18] **A. Keskar, S. Afshari, I. Hiskens, J.X. Johnson, and **J.L. Mathieu**. *Quantifying energy efficiencies of buildings providing ancillary services*. UM Engineering Research Symposium, Ann Arbor, MI. Nov. 2017.

[P17] **S.C. Ross, G. Vuylsteke, and **J.L Mathieu**. *Impacts on the local power network when residential loads provide energy balancing services to the regional network*. UM Engineering Research Symposium, Ann Arbor, MI. Nov. 2017.

[P16] **A. Keskar, S. Afshari, I. Hiskens, J.X. Johnson, and **J.L. Mathieu**. *Improving the energy efficiency of buildings participating in power system ancillary services*. MCubed Symposium, Ann Arbor, MI. Nov. 2017.

[P15] **P. Giessner, I. Hiskens, **J.L. Mathieu**, J. Johnson, S. Afshari, and A. Keskar. *Energy storage through building HVAC systems*. UM Undergraduate Research Opportunities Program Symposium, Ann Arbor, MI. Aug. 2017.

[P14] **M. Yao, **J.L. Mathieu**, and D.K. Molzahn. *Using demand response to improve electric power system stability margins*. UM Engineering Research Symposium, Ann Arbor, MI. Nov. 2016.

[P13] **S. Crocker, A. Stuhlmacher, and **J.L. Mathieu**. *Effects of aggregate load control on the physical components of distribution networks*. IEEE Power & Energy Society General Meeting Student Poster Competition, Boston, MA. July 2016.

[P12] **A. Stuhlmacher, S. Crocker, and **J.L. Mathieu**. *Effects of aggregate load control on the physical components of distribution networks*. UM Summer Research Opportunities Program Symposium, Ann Arbor, MI. July 2016.

[P11] **S. Crocker and **J.L. Mathieu**. *Adaptive state estimation and control of thermostatic loads for real-time energy balancing*. UM Engineering Research Symposium, Ann Arbor, MI. Oct. 2015.

[P10] **B. Li and **J.L. Mathieu**. *Chance-constrained optimal power flow with uncertain load control*. UM Engineering Research Symposium, Ann Arbor, MI. Oct. 2015.

[P9] **Y. Lin, **J.L. Mathieu**, and J. Johnson. *Environmental impacts of using distributed energy storage for power system reserves*. International Symposium on Sustainable Systems and Technology, Dearborn, MI. May 2015.

[P8] **G.S. Ledva, E. Vrettos, S. Mastellone, G. Andersson, and **J.L. Mathieu**. *Applying networked estimation and control algorithms to address communication bandwidth limitations and latencies in demand response*. UM Engineering Research Symposium, Ann Arbor, MI. Nov. 2014.

[P7] **G. Vuylsteke, **J.L. Mathieu**, and P. Howe. *Tangible benefits of using non-disruptive demand response to help the power grid*. UM Undergraduate Research Opportunities Program Symposium, Ann Arbor, MI. Aug. 2014.

[P6] ****J.L. Mathieu** and D.S. Callaway. *Mitigating renewables intermittency through non disruptive load control*. PSERC Future Grid Initiative Workshop, Berkeley, CA. Dec. 2011.

[P5] ****J.L. Mathieu**, S. Koch, and D.S. Callaway. *Modeling, state estimation, and control of thermostatically controlled loads for load following and regulation*. UC Berkeley Energy Symposium, Berkeley, CA. Oct. 2011.

[P4] ****J.L. Mathieu**, S. Koch, and D.S. Callaway. *Modeling, state estimation, and control of thermostatically controlled loads for load following and regulation*. Lawrence Livermore National Laboratory Current Challenges in Computing Conference: Energy Resources Modeling, Napa, CA. Aug. 2011.

[P3] ****J.L. Mathieu**, A.J. Gadgil, D.S. Callaway, P.N. Price, and S. Kiliccote. *Response of commercial and industrial facilities to dynamic electricity prices*. UC Berkeley Energy Symposium, Berkeley, CA. Mar. 2010.

[P2] **M. Seflek, **T. Khan, **J.L. Mathieu**, K. Jahani, and A.J. Gadgil. *Arsenic-free Bangladesh*. National Collegiate Inventors and Innovators Alliance Annual Conference, Tampa, FL. Mar. 2007.

[P1] **K. Wasserman, M.B. Greytak, **J.L. Mathieu**, A.K. Baker, J.D. Chambers, and B.M. Mueller. *From waves to watts: A wave energy conversion device for the Charles river basin*. Marine Technology Society & IEEE OCEANs Conference Student Poster Session, Kobe, Japan. Feb. 2004.

Funding

UM Research Catalyst and Innovation (RCI) Program Anti-Racism Grant **$50k**
Enhanced Energy Monitoring for Energy Justice in Detroit
Sep 2021 - Aug 2022
PI, with team members Tony Reames (SEAS), Carina Gronlund (Institute for Social Research), Marie O'Neill (Public Health), Rachel Jenkins (Pecan Street), Gibran Washington (Ecoworks)

NSF Smart and Connected Communities Grant (Track 1) **$2,100k**
Reducing Barriers to Residential Energy Security through an Integrated Case-management, Data-driven, Community-based Approach
Sep 2020 - Aug 2024
Co-PI, with PI Tony Reames (SEAS) and Co-PIs Carina Gronlund (Institute for Social Research), Barbara Israel (Public Health), and Marie O'Neill (Public Health)

NSF I-Corps Grant **$50k**
Fast Timescale Residential Demand Response
Jun 2020 - Nov 2021
Technical Lead, with Entrepreneurial Lead Gregory Ledva and Industry Mentor Hawk Asgeirsson

ARPA-E OPEN Project **$2,900k**
Overcoming the Technical Challenges of Coordinating Distributed Load Resources at Scale
Jun 2019 - Jun 2022
PI, with team members Ian Hiskens, Duncan Callaway, Drew Geller (LANL), and Scott Hinson (Pecan Street)

NSF CAREER Award & REU Supplement **$516k**
Stochastic Capacity Scheduling and Control of Distributed Energy Storage Enabling Stacked Services
Feb 2019 - Jan 2024
PI

Alfred P. Sloan Foundation Grant **$250k**
Price, Generation, Emissions, and Transmission Impacts of Energy Storage in PJM
Jan 2019 - Dec 2021
Co-PI, with PI Catherine Hausman (Public Policy)

NSF CPS Grant (Small) **$500k**
Scalable and Safe Control Synthesis for Systems with Symmetries
Jan 2019 - Dec 2021
Co-PI, with PI Necmiye Ozay

DOE Building Technologies Office – Subcontract from SLAC National Accelerator Laboratory **$525k**
I-DREEM: Impact of Demand Response on short and long term building Energy Efficiency Metrics
Feb 2018 - Feb 2022
UM PI and Lead Co-PI, with Lead PI Rishee Jain and team members Ian Hiskens and Jeremiah Johnson
Full project funding: $1,700k

DOE Solar Energy Technologies Office – Subcontract from Argonne National Laboratory **$220k**
Mitigating Phase Unbalance for Distribution Systems with High Penetrations of Solar PV
Nov 2018 - Dec 2019
UM PI, with Lead PI Daniel Molzahn and team members Ian Hiskens, Line Roald, and David Pinney (NRECA)
Full project funding: $750k

NSF Engineering Research Center Planning Grant **$100k**
Comprehensive Energy Storage Solutions in Electrified Transportation
Sep 2018 - Aug 2019
Co-I, with PI Anna Stefanopoulou and Co-PIs Heath Hofmann, Don Siegel, Christian Lastoskie, and Chris Mi

Michigan Institute for Computational Discovery and Engineering Catalyst Grant **$75k**
Computational Energy Systems
Apr 2017 - Mar 2018
Co-PI, with PI Pascal Van Hentenryck and Co-PIs Jon Lee, Ruiwei Jiang, and Eunshin Byon

UM College of Engineering Team Development Seed Funding **$7k**
Harnessing Highly Distributed Load Resources for Renewable Integration
Sep 2016
Collaboration with Ian Hiskens

UM Office of Research Seminar Grant & Renewal **$15k**
Seminar Series on Emerging Topics in Sustainable Electric Power Systems
Jul 2016 - Jun 2018
PI, with organizational team Ian Hiskens, Pascal Van Hentenryck, Ruiwei Jiang, and Jeremiah Johnson
Matching funds from ECE, IOE, SNRE/SEAS, UMEI: $11.5k

UM Graham Sustainability Institute MCubed Sustainability Block Grant **$10k**
Urban Sustainability: Energy, Food and Health
Jun 2016 - May 2017
Collaboration with Marie O'Neill and Ming Xu

UM MCubed Program Grant **$60k**
Improving the Energy Efficiency of Buildings Participating in Power System Ancillary Services
Oct 2015 - Dec 2017
Collaboration with Jeremiah Johnson and Ian Hiskens

NSF EAGER: Renewables **$279k**
Demand Response Algorithms to Improve Electric Power System Stability Margins
Sep 2015 - Aug 2018
PI

NSF Environmental Sustainability Grant **$310k**
Environmental Impacts of Using Distributed Energy Storage for Power System Reserves
Sep 2015 - Aug 2019
Co-PI, with PI Jeremiah Johnson

NSF EPCN Grant & REU Supplement **$408k**
Inferring the Behavior of Distributed Energy Resources from Incomplete Measurements
Aug 2015 - Jul 2019
PI, with Co-PI Laura Balzano

NSF CyberSEES Grant (Type 1) & REU Supplement **$416k**
Data-Driven Approaches to Managing Uncertain Load Control in Sustainable Power Systems
Sep 2014 - Aug 2017
PI, with Co-PIs Siqian Shen and Ian Hiskens

UM Energy Institute PISET Grant & Renewal **$80k**
Assessing the Environmental Impacts of Providing Power System Reserves with Demand Response and Distributed Energy Storage
Sep 2014 - Dec 2016
Collaboration with Jeremiah Johnson

Talks

- (Upcoming) NREL Workshop on Resilient Autonomous Energy Systems (virtual), *Impact of Market Timing on the Profit of a Risk-Averse Load Aggregator*, Sep 8, 2021.
- IEEE PES General Meeting (virtual), Super Session: Grid Edge - Devices, Control, Applications and System Operation, *Establishing Credibility for Load Coordination at Scale*, Aug 28, 2021.
- IEEE PES General Meeting (virtual), Panel: Physics-Informed Machine Learning for Power Systems, *Separating Feeder Demand Into Components Using Diverse Measurements from the Distribution Network, Physics-based Models, and Online Learning*, Aug 26, 2021.
- University of Massachusetts (virtual), *Real-Time Disaggregation of Electric Feeder Demand Using Online Learning*, Apr 16, 2021.
- National Academy of Engineering US Frontiers of Engineering Symposium (virtual), *Enabling the Operation of Future Grids Using New Tools in Control Theory and AI*, Feb 25, 2021.
- Implementing the A^2Zero Carbon Neutrality Plan in Buildings Series (virtual), Panel: Electrification & Decarbonization Strategies, *Leveraging (existing + newly electrified) Flexible Resources to Decarbonize the Grid*, Feb 9, 2021.
- University of Washington (virtual), *Managing Uncertainty in Coupled Power and Water Distribution Networks*, Jan 19, 2021.
- International Workshop on Non-Intrusive Load Monitoring (virtual), *Applications of Non-Intrusive Load Monitoring (NILM) to Power Systems and New NILM-type Problems*, Nov 18, 2020. (Keynote)
- IEEE SmartGridComm (virtual), Special Session: Special Topics @ SmartGridComm 2020, *Coordinating DERs to Provide Ancillary Services Without Hurting the Distribution Network*, Nov 11, 2020.
- Carnegie Mellon University (virtual), *Network-Aware Electric Load Coordination Architectures and Control Strategies*, Oct 9, 2020.
- International Conference on Probabilistic Methods Applied to Power Systems (virtual), Panel: Economic Considerations of Risk and Uncertainty, *Strategies for Network-Safe Load Control by a Third-Party Aggregator*, Aug 20, 2020.
- IEEE PES General Meeting (virtual), Panel: Research and Educational Experiences of NSF CAREER Awardees, *Stochastic Capacity Scheduling and Control of Distributed Energy Storage Enabling Stacked Services*, Aug 5, 2020.
- Iowa State University (virtual), *Network-Aware Electric Load Coordination Architectures and Control Strategies*, Jul 21, 2020.
- Colorado School of Mines (Golden, CO), *Network-Aware Electric Load Coordination Architectures and Control Strategies*, Feb 28, 2020.
- ARPA-E Open 2018 – Grid Projects Kick-off Meeting (New Orleans, LA), *Overcoming the Technical Challenges of Coordinating Distributed Load Resources at Scale*, Feb 19, 2020.
- NSF CPS PI Meeting (Arlington, VA), *Lightning Talk: Scalable and Safe Control Synthesis for Systems with Symmetries*, Nov 22, 2019.
- Georgia Tech Workshop on Electric Energy Systems and Optimization (Atlanta, GA), *The Value of Including Unimodality Information in Distributionally Robust Optimal Power Flow*, Nov 15, 2019.

- IEEE Global Conference on Signal and Image Processing (Ottawa, Canada), Symposium: Machine Learning, Optimization, and Security for Future Energy Delivery Systems, *Learning About Loads to Improve Power System Operation and Control*, Nov 13, 2019. (Keynote)
- North Carolina State University (Raleigh, NC), Panel: Power Shift – The Future of Energy and the Women Shaping It, Nov 5, 2019.
- Michigan Public Services Commission Distribution Planning Stakeholder Meeting (Lansing, MI), *DER Coordination as a Non-wire Solution: Opportunities and Challenges in Michigan*, Oct 16, 2019.
- IEEE PES General Meeting (Atlanta, GA), Panel: The Economics of Battery Storage under Different Market Structures, *Scheduling and Controlling Aggregations of Distributed Energy Storage Devices to Provide Stacked Services*, Aug 8, 2019.
- IEEE PES General Meeting (Atlanta, GA), Panel: Distributed Demand Response Dilemma: Defect or Engage, *Coordinating Loads to Provide Ancillary Services While Keeping Consumers Happy*, Aug 6, 2019.
- Ford Motor Company Research and Innovation Center (Dearborn, MI), *Coordinating Uncertain Electric Vehicles for Grid Services*, Jun 5, 2019.
- Isaac Newton Institute (Cambridge, UK), The Mathematics of Energy Systems Closing Workshop: Looking forward to 2050, *Optimal Power Flow with Stochastic Reserves*, Apr 30, 2019.
- Ceres and UM Energy Institute Electric Vehicle Open Forum and Policy Roundtable (Ann Arbor, MI), Panel: Michigan's Grid and Charging Infrastructure: Empirical Analysis and Outlook, Apr 3, 2019.
- UM SEAS Climate + Energy Theme Lightning Talks (Ann Arbor, MI), *Supporting Renewable Energy Integration with Flexible Loads and Storage*, Mar 21, 2019.
- UM SEAS Cities + Mobility + Built Environment Theme Lightning Talks (Ann Arbor, MI), *Using Appliances and University of Michigan Buildings as Batteries to Support Renewable Energy Integration*, Feb 27, 2019.
- Indian Institute of Technology Bombay – NSF – Japan Science and Technology Agency – Research Council of Norway Workshop on Distributed Energy Management and Data Sciences for Smart Grids (Mumbai, India), *Network-Aware Cost-Effective Coordination of Distributed Energy Resources*, Jan 15, 2019.
- Michigan State University (East Lansing, MI), *An Optimal Power Flow Approach to Improve Power System Voltage Stability Using Demand Response*, Oct 11, 2018.
- University of Vermont Future of Energy Workshop (Burlington, VT), *Coordinating Distributed Energy Resources Without Breaking the Bank, or the Grid*, Sep 27, 2018. (Keynote)
- IEEE PES General Meeting (Portland, OR), Panel: The Role of DERs in the Transmission-Distribution Coordination, *Using DERs in the Distribution System to Improve Transmission System Voltage and Rotor Angle Stability*, Aug 9, 2018.
- University of Michigan Energy Institute UROP Lunchbox Discussion (Ann Arbor, MI), *Coordinating Electric Loads to Improve Power System Sustainability, Reliability, and Economics*, Jul 24, 2018.
- University of Illinois Urbana Champaign (Urbana, IL), *Real-Time Energy Disaggregation of a Distribution Feeder's Demand Using Online Learning*, Apr 23, 2018.
- Stanford Smart Grid Seminar (Palo Alto, CA), *A Multiperiod Optimal Power Flow Approach to Improve Power System Voltage Stability Using Demand Response*, Mar 1, 2018.
- Technical University of Denmark (Lyngby, Denmark), *Demand Response Algorithms to Improve Electric Power System Stability Margins*, Jun 26, 2017.
- Commonwealth Scientific and Industrial Research Organisation (CSIRO) Energy Centre (Newcastle, Australia), *Overview of Load Control Research*, Nov 10, 2016.
- IEEE SmartGridComm (Sydney, Australia), Workshop: Smart Buildings As Enablers for a Smarter Grid, *Engaging Distributed Flexible Electric Loads in Power System Operation*, Nov 6, 2016.

- UM Control Seminar (Ann Arbor, MI), *Optimal Scheduling and Control of Distributed Energy Storage to Provide Power Grid Support*, Sep 23, 2016.
- IEEE PES General Meeting (Boston, MA), Panel: Modeling the End-User in CPS-based Simulation Studies, *Scheduling and Controlling Building Power Consumption to Provide Ancillary Services*, Jul 20, 2016.
- NSF Workshop on Cyber-Physical Systems Applications to the Power Grid (Boston, MA), *Scheduling, Inference, and Coordination of Distributed Energy Resources: Overview of 3 NSF-funded projects*, Jul 16, 2016.
- Göran Andersson's Farewell Event at ETH Zurich (Zurich, Switzerland), *Managing Communication Delays and Model Error in Demand Response*, Jun 10, 2016.
- Institute for Mathematics and its Applications (Minneapolis, MN), Workshop: Control at Large Scales – Energy Markets and Responsive Grids, *Inferring the Behavior of Distributed Flexible Electric Loads*, May 12, 2016.
- University of California at San Diego Seminars in Energy Research (San Diego, CA), *Inference and Control of Electric Loads Given Sparse Measurements and Communications Delays*, Apr 20, 2016.
- MIT Department of Mechanical Engineering (Cambridge, MA), *Inference and Control of Electric Loads Given Sparse Measurements and Communications Delays*, Apr 8, 2016.
- University of Toronto Centre for Power and Information Seminar (Toronto, Canada), *Inference and Control of Distributed Energy Resources with Sparse Measurements and Communications Delays*, Dec 4, 2015.
- LBNL/UC Berkeley DR/Renewables/ISO Meeting (Berkeley, CA), *Scheduling and Coordinating Uncertain Electric Loads to Provide Power System Reserves*, Mar 6, 2015.
- Cornell University Information, Systems, and Networks Seminar Series (Ithaca, NY), *Uncertain Power System Reserves from Electric Loads*, Nov 14, 2014.
- Schloss Dagstuhl (Wadern, Germany), Seminar: Modeling, Verification, and Control of Complex Systems for Energy Networks, *Uncertain Power System Reserves from Loads*, Oct 30, 2014.
- UM ECE Administrative Staff Lecture (Ann Arbor, MI), *How Your Refrigerator Can Help Get More Renewable Energy on the Power Grid*, Oct 17, 2014.
- IEEE Transportation Electrification Conference and Expo (Dearborn, MI), Panel: Transportation Technologies of Vehicle to Infrastructure Interaction: Current Status and Challenges, *Coordinating Uncertain Electric Vehicles for Demand Response*, Jun 16, 2014.
- Los Alamos National Laboratory Center for Nonlinear Studies (Los Alamos, NM), *Planning and Control of Uncertain Electric Loads to Help out the Power Grid*, Apr 29, 2014.
- University of New Mexico Department of Mechanical Engineering (Albuquerque, NM), *How Your Refrigerator Can Help Get More Renewable Energy on the Power Grid*, Apr 11, 2014.
- IEEE UM Student Branch – Professor Speaker Series (Ann Arbor, MI), *How Your Refrigerator Can Help Get More Renewable Energy on the Power Grid*, Mar 12, 2014.
- UM Control Seminar (Ann Arbor, MI), *Planning and Control of Uncertain Electric Loads to Help Out the Power Grid*, Feb 14, 2014.
- IEEE Conference on Decision and Control (Florence, Italy), Workshop: Ancillary Services from Flexible Loads to Help the Electric Grid of the Future, *Demand Response Today* and *Thermostatic Loads for Ancillary Services*, Dec 9, 2013.
- University College Dublin Electricity Research Centre, (Dublin, Ireland), *Planning and Control of Demand Response Resources Given Partial Information and Uncertainty,* Nov 26, 2013.
- IEEE PES General Meeting (Vancouver, Canada), Panel: Grid Integration of Energy Efficient Buildings, *Theoretical, Practical and Market-related Issues Associated with the Challenges of Making Buildings Responsive to Real-Time Power System Conditions,* Jul 24, 2013.
- IEEE PES General Meeting (Vancouver, Canada), Transaction Paper Presentation, *State Estimation and Control of Electric Loads to Manage Real-Time Energy Imbalance,* Jul 24, 2013.

- University of Washington Departments of Electrical and Mechanical Engineering (Seattle, WA), *Harnessing Distributed Flexible Resources for Sustainable Electric Energy Systems,* Apr 23, 2013.
- INRIA – National Institute for Research in Computer Science and Control (Paris, France), *Controlling Electric Loads to Manage Energy Imbalances in Power Systems,* Apr 17, 2013.
- Dartmouth College Thayer School of Engineering (Hanover, NH), *Harnessing Distributed Flexible Resources for Sustainable Electric Energy Systems,* Apr 4, 2013.
- UM Department of Electrical Engineering and Computer Science (Ann Arbor, MI), *Harnessing Distributed Flexible Resources for Sustainable Electric Energy Systems,* Mar 25, 2013.
- University of Vermont School of Engineering (Burlington, VT), *Harnessing Distributed Flexible Resources for Sustainable Electric Energy Systems,* Mar 21, 2013.
- York University Lassonde School of Engineering (Toronto, Canada), *Harnessing Distributed Flexible Resources for Sustainable Electric Energy Systems*, Feb 28, 2013.
- University of California at Santa Barbara Department of Mechanical Engineering (Santa Barbara, CA), *Harnessing Distributed Flexible Resources for Sustainable Electric Energy Systems,* Feb 4, 2013.
- University of Florida Laboratory for Cognition and Control in Complex Systems Interdisciplinary Workshop on Smart Grid Design and Implementation (Gainesville, FL), *Harnessing Residential Loads for Demand Response: Engineering and Economic Considerations,* Dec 8, 2012.
- Lucerne University of Applied Science and Arts (Lucerne, Switzerland), *Residential Loads for Demand Response,* Nov 26, 2012. (with Evangelos Vrettos)
- Austrian Institute of Technology Energy Department (Vienna, Austria), *Understanding the Capabilities of Electric Loads in Traditional and Emerging Demand Response Programs,* Nov 6, 2012.
- EPFL – Swiss Federal Institute of Technology (Lausanne, Switzerland), *Managing Energy Imbalances in Power Systems using Residential Appliances,* Oct 30, 2012.
- ETH Zurich – Swiss Federal Institute of Technology (Zurich, Switzerland), *Modeling, Analysis, and Control of Electric Loads for Traditional and Emerging Demand Response Programs,* Sept 28, 2012.
- Pacific Northwest National Laboratory Smart Grid Controls, Optimization, and Economics Workshop (Richland, WA), *Moving from Open-loop to Closed-loop Control of Demand Response Resources,* Jun 15, 2012.
- LBNL Environmental Energy Technologies Division Seminar (Berkeley, CA), *Modeling, Analysis, and Control of Demand Response Resources,* Apr 27, 2012.
- UC Berkeley Department of Mechanical Engineering (Berkeley, CA), *Modeling, Analysis, and Control of Demand Response Resources,* Apr 19, 2012.
- UC Berkeley Expert System Technologies Lab Seminar (Berkeley, CA), *How your refrigerator can help the smart grid: understanding the size of the resource in California, potential revenues, and costs,* Apr 4, 2012.
- Carnegie Mellon University Conference on the Electricity Industry (Pittsburgh, PA), *The Value of Real-Time Data in Controlling Electric Loads for Demand Response,* Mar 13, 2012.
- UC Berkeley Center for the Built Environment Building Science Group Seminar (Berkeley, CA), *Estimating What Didn't Happen: Demand Response Baseline Models and their Errors,* Nov 30, 2011.
- LBNL/UC Berkeley DR/Renewables/ISO Meeting (Berkeley, CA), *Modeling, State Estimation, and Control of Aggregated Heterogeneous Appliances for Load Following,* Oct 17, 2011.
- UC Berkeley Variaya Energy Group (Berkeley, CA), *Modeling, State Estimation, and Control of Aggregated Heterogeneous Appliances for Power Systems Services,* Jul 21, 2011.
- LBNL/UC Berkeley DR/Renewables/ISO Meeting (Berkeley, CA), *Examining Uncertainty in Demand Response Baseline Models and Variability in Automated Responses to Dynamic Pricing,* Apr 7, 2011.
- LBNL Environmental Energy Technologies Division Seminar (Berkeley, CA), *Methods for Analyzing Electric Load Shape,* Jun 17, 2010. (with Phillip Price)

- UC Berkeley Blum Center Safe Water and Sanitation Symposium (Berkeley, CA), *Recent Fieldwork, Preliminary Prototype, and Preliminary Survey Results for ARUBA in Bangladesh,* Apr 10, 2009.
- UC Berkeley Blum Center Safe Water and Sanitation Symposium (Berkeley, CA), *Design for Sustainable Communities: Removing Arsenic from Drinking Water in Rural Bangladesh,* Feb 13, 2008.
- Engineers for a Sustainable World (ESW) Annual Conference (San Francisco, CA), *Design for Sustainable Communities: Removing Arsenic from Drinking Water in Rural Bangladesh,* Feb 5, 2008.
- Aquatic Nuisance Species Task Force Spring Meeting (Hyannis, MA), *MIT Sea Grant Multilingual Aquatic Invasive Species Outreach Campaign,* May 25, 2006.

Workshop Participation

- NSF Cyber-Physical Systems PI Meeting (virtual), Jun 2021.
- ARPA-E Energy Innovation Summit (virtual), May 2021.
- NSF Workshop: Next Big Research Challenges in Cyber-Physical Systems (virtual), Apr 2021.
- NSF Workshop: Grid at the Edge, From Unresolved Problems to Research Questions and Directions (virtual), Mar 2021.
- ARPA-E Engineering Microgrids with Control Co-Design Workshop (virtual), Oct 2020.
- NSF I-Corps (virtual), Apr-Jun 2020.
- NSF Workshop on Forging Connections between Machine Learning, Data Science, & Power Systems Research, Alexandria, VA, Mar 2020.
- NREL Workshop and Demo on Real-time Optimization and Control of Next-Generation Distribution Infrastructure, Golden, CO, Jan 2020.
- NSF Cyber-Physical Systems PI Meeting, Arlington, VA, Nov 2019.
- ARPA-E Energy Innovation Summit, Denver, CO, Jul 2019.
- Indian Institute of Technology Bombay – NSF – Japan Science and Technology Agency – Research Council of Norway Workshop on Distributed Energy Management and Data Sciences for Smart Grids, Mumbai, India, Jan 2019.
- NSF Cyber-Physical Systems PI Meeting, Alexandria, VA, Nov 2018.
- National Renewable Energy Laboratory Autonomous Energy Grids Workshop, Golden, CO, Sep 2017.
- IEEE PES Power and Energy Education Committee Workshop: Cyber-Physical Systems Applications to the Power Grid, Boston MA, Jul 2016.
- Institute for Mathematics and its Applications Workshop: "Control at Large Scales: Energy Markets and Responsive Grid," Minneapolis, MN, May 2016.
- Big Ten Women's Workshop, Milwaukee, WI, Mar 2016.
- Michigan Road Scholars, May 2015.
- NSF CAREER Proposal Writing Workshop, Boston, MA, Apr 2015.
- Dagstuhl Seminar: "Modeling, Verification, and Control of Complex Systems for Energy Networks," Schloss Dagstuhl, Wadern, Germany, Oct 2014.
- ARPA-E Grid of the Future Workshop: From Vertical to Flat, Washington, DC, Jul 2014.
- IEEE PES Power and Energy Education Committee Workshop: Transforming Cyber-Physical Systems Education with Emphasis on the Power Grid, Washington, DC, Jul 2014.
- Dissertations Initiative for the Advancement of Climate Change Research (DISCCRS) Symposium, Colorado Springs, CO, Oct 2013.
- University of Florida Laboratory for Cognition and Control in Complex Systems Interdisciplinary Workshop on Smart Grid Design and Implementation, Gainesville, FL, Dec 2012.

- PSERC Future Grid Initiative Workshop, University of California, Berkeley, CA, Dec 2011.
- International Development Design Summit, MIT, Cambridge, MA, Jul-Aug 2008.
- National Collegiate Inventors and Innovators Alliance (NCIIA) Advanced Innovation to Venture Workshop, MIT, Cambridge, MA, Mar 2008.
- Engineers for a Sustainable World Business/Engineering Sustainability Workshop, University of Maryland, College Park, MD, Feb 2007.

In the News

- "Energy equity depends on data, and experts say there isn't enough of it." *Utility Dive*, Jul 8, 2021.
- "U-M, community partners tackle energy insecurity in three Detroit neighborhoods." *Michigan News*, Nov 23, 2020.
- "Student Energy Club hosts all-female panel: discusses women in STEM and the future of energy." *NC State University Technician*, Nov 7, 2019.
- "The National Academy of Engineering invites Prof. Johanna Mathieu to symposium to advance the engineering frontier." *The Michigan Engineer News Center*, Jul 16, 2019.
- "New research for the future of sustainable power and energy." UM ECE News and Awards Website, Feb 20, 2019.
- "Battery economics could power the future of energy." *The Michigan Engineer News Center*, Feb 19, 2019.
- "Innovative project tests the boundaries of HVAC demand response systems." *Electric Light and Power*, Feb 15, 2019.
- "How air conditioners could advance a renewable power grid." *The Michigan Engineer News Center & The University Record*, Feb 6, 2019.
- "Johanna Mathieu receives NSF CAREER Award to help build a smarter, more sustainable grid." UM ECE News and Awards Website, Feb 1, 2019.
- "What this week's natural gas crisis tells us about Michigan's energy infrastructure needs." *Michigan Radio Stateside*, Feb 1, 2019.
- "Using University of Michigan buildings as batteries." *The Michigan Engineer News Center*, Sep 21, 2017.
- 'The Hidden Systems that our Society Relies on are Stupid: Power." *The Michigan Engineer Magazine*, Spring 2015.
- "EmPOWERing Homeowners: For those with smart meters, energy knowledge is power. And money." *Consumers Energy Re: Energize Publication*, 2014.
- "Prof. Johanna Mathieu Working to Bring Power from Sustainable Sources to Your Home." UM ECE News and Awards Website, 2014.

Students, Postdocs, and Visitors

Ph.D. Students

- Bowen Li, Jan 2014 - Dec 2018, now a postdoc at Argonne National Laboratory
- Gregory Ledva, Sep 2014 - Dec 2018, now at Virtual Peaker
- Stephanie Crocker Ross, Sep 2014 - Dec 2019, now at The Brattle Group
  NSF Graduate Research Fellow
  Rackham Predoctoral Fellow
- Mengqi (Molly) Yao, Sep 2016 - Aug 2020, now a postdoc at UC Berkeley
- Anna Stuhlmacher, Sep 2017 - Present
  NSF Graduate Research Fellow
- Oluwagbemileke Oyefeso, Sep 2019 - Present, co-advised by I. Hiskens

- Ioannis Granitsas, Sep 2019 - Present, co-advised by I. Hiskens
- Jing Peng, Sep 2019 - Present
- Sunho Jang, Sep 2019 - Present, co-advised by N. Ozay
- Hannah Moring, Sep 2020 - Present
- Sunny Chen, Sep 2020 - Present, co-advised by P. Seiler
- Austin Lin, Sep 2020 - Present, co-advised by A. Avestruz
- Joshua Brooks, Sep 2021 - Present
- Xavier Farrell, Sep 2021 - Present

Postdocs

- Yashen Lin, Sep 2014 - May 2016, co-advised by J. Johnson, now at NREL
  UM Energy Institute Partnerships for Innovation in Sustainable Energy Technologies Fellow
  Dow Sustainability Postdoctoral Fellow
- Sina Afshari, Sep 2016 - Jul 2017, co-advised by J. Johnson and I. Hiskens, now at Ecosense Lighting
- Anulekha Dhara, Oct 2018 - Mar 2019, now at TCS Research and Innovation Labs
- Gregory Ledva, Jan 2019 - Feb 2021, now at Virtual Peaker
- Shunbo Lei, Apr 2019 - Jun 2021, co-advised by I. Hiskens, now at CUHK-Shenzhen
- Sebastian Nugroho, starting Jun 2021, co-advised by I. Hiskens

Master's Students

- Anthoula Panagou (ETH Zurich), Master's thesis, May - Nov 2013, co-advised by M. Vrakopoulou and M. Zima, examined by G. Andersson
- Gregory Ledva (ETH Zurich), Master's thesis, Sep 2013 - Mar 2014, co-advised by E. Vrettos and S. Mastellone, examined by G. Andersson
- William Gourlay, Energy Systems Engineering project, May - Aug 2014
- Pragya Agrawal, Research, Jun - Aug 2014, co-advised by L. Balzano and D. Molzahn
- Priya Thyagarajan, Energy Systems Engineering project, May - Aug 2015
- Mengqi Yao, Research, Sep 2015 - Aug 2016
- Abigail Kern, Research, Jan 2017 - Jun 2018, co-advised by J. Johnson
- Aditya Keskar, Research + Master's thesis, May 2017 - Apr 2018, co-advised by J. Johnson and I. Hiskens
  Rackham Summer Awardee
- Han Pyo Lee, Research, Jan 2019 - Jun 2020
- Han Lee, Research + Energy Systems Engineering project, Jun 2019 - Apr 2020
- Ruikai Xu, Research, Sep 2019 - Apr 2020
- Yaoyu Fan, Research, Jul 2021 - Present
- Sehwan Joo, Research, Sep 2021 - Present

Undergraduate Students

- Kristin Kowolik (UC Berkeley), Sep 2007 - Aug 2008, co-advised by A. Gadgil
- Shefah Qazi (UC Berkeley), Jan - Aug 2008, co-advised by A. Gadgil
- Mads Sørensen (DTU), Bachelor's Thesis, Feb - Jun 2013, co-advised by H. Jóhannsson
- Theis Bo Rasmussen (DTU), Bachelor's Thesis, Feb - Jun 2013, co-advised by H. Jóhannsson
- Gabrielle Vuylsteke, Jun - Dec 2014 & Sep 2016 - Apr 2017
  UM Energy Institute Undergraduate Research Opportunities Program (UROP) Student

- Spencer Maroukis, Jun 2015 - Jun 2016
  NSF Research Experiences for Undergraduates (REU) Student
- Sarah Peterson, May 2016 - Apr 2017
  Summer Undergraduate Research in Engineering (SURE) Student
  NSF Research Experiences for Undergraduates (REU) Student
- John Wolfe, May - Nov 2016
  Summer Undergraduate Research in Engineering (SURE) Student
- Anna Stuhlmacher (Boston University), Jun - Jul 2016
  UM Summer Research Opportunity Program (SROP) Student
- Paul Giessner, Jun - Aug 2017, co-advised by I. Hiskens and J. Johnson
  UM Energy Institute Undergraduate Research Opportunities Program (UROP) Student
- Maggie Chen, May 2018 - Apr 2019
- Jordan Dongmo Nzangue, May 2018 - Apr 2019
- Catherine Bertcher, Sep 2018 - May 2021
  NSF Research Experiences for Undergraduates (REU) Student
- Bruce Hicks (Mississippi State University), Jun - Jul 2019
  UM Summer Research Opportunity Program (SROP) Student
- Miguel Siller (Universidad de Monterrey, Mexico), Jun - Aug 2019
  UM Summer Undergraduate Research in Engineering (SURE) Student
- Brendan Mathews, Jul 2020 - May 2021, co-advised by P. Seiler
  NSF Research Experiences for Undergraduates (REU) Student
- Joshua Brooks, Feb - Aug 2021
- Bereket Barma (Addis Ababa Institute of Technology), Jun 2021 - Present
  African Undergraduate Research Adventure (AURA) Student
- Amanuel Solomon (Addis Ababa Institute of Technology), Jun 2021 - Present
  African Undergraduate Research Adventure (AURA) Student

Visiting Ph.D. Students

- Martin Wittrock (DTU), Feb - Jul 2015
- Lars Herre (KTH), May - Oct 2017

Ph.D. Committees

- Sina Sadeghi Baghsorkhi (EE:S), 2015, Advisor: Ian Hiskens
- Kan Zhou (EE:S), 2015, Advisor: Heath Hoffman
- Ian Beil (EE:S), 2015, Advisor: Ian Hiskens
- Elizabeth Ratnam (U Newcastle AU, EECS), 2016, Advisor: Steven Weller
- Chanaka Keerthisinghe (U Sydney AU, EIE), 2016, Advisors: Gregor Verbič, Archie Chapman
- Shankar Mohan (EE:S), 2017, Advisor: Anna Stefanopoulou
- Jonathan Martin (EE:S), 2017, Advisor: Ian Hiskens
- Olivier Mégel (ETH, ITET), 2017, Advisor: Göran Andersson
- Daniel Esteban Morales Bondy (DTU, EE), 2017, Advisor: Henrik Bindner
- Jennifer Marley (EE:S), 2017, Advisor: Ian Hiskens
- Jun Hou (EE:S), 2017, Advisors: Jing Sun, Heath Hofmann
- Erik Miehling (EE:S), 2018, Advisor: Demosthenis Teneketzis
- Yiling Zhang (IOE), 2019, Advisor: Siqian Shen

- Yuanyuan Guo (IOE), 2019, Advisor: Ruiwei Jiang
- Md Salman Nazir (EE:S), 2019, Advisor: Ian Hiskens
- Jonas Kersulis (ECE), 2019, Advisor: Ian Hiskens
- Geunyeong Byeon (IOE), 2020, Advisor: Pascal Van Hentenryck
- Yejun (Wayne) Lao (CEE), 2020, Advisor: Jeffrey Scruggs
- Youngchan Jang (IOE), 2021, Advisor: Eunshin Byon
- Sijia Geng (ECE), Advisor: Ian Hiskens
- Aditya Keskar (NCSU CCEE), Advisor: Jeremiah Johnson

Service

Society Memberships

- Institute of Electrical and Electronics Engineers (IEEE)
  - Power and Energy Society (PES)
  - Control Systems Society (CSS)
- International Institute for Research and Education in Power Systems (IREP)
- (*Intermittently*) Institute for Operations Research and the Management Sciences (INFORMS)

Technical Committees

- IEEE PES Smart Buildings, Loads, and Customer Systems (SBLC) Technical Committee
  - Chair, starting Jul 2021
  - Vice Chair, Jul 2019 - Jul 2021
  - Secretary, Sep 2018 - Aug 2019
  - Technical Committee Paper Coordinator, Sep 2016 - Sep 2018
- IEEE CSS Technical Committee on Smart Grids
- INFORMS ENRE Section Student Best Paper Award Committee, 2018

Editorships & Technical Program Committees

- Associate Editor, IEEE Transactions on Control of Network Systems, starting Jan 2022
- Associate Editor, IEEE Transactions on Power Systems, Jan 2018 - Present
- Associate Editor, IEEE Power Engineering Letters, Jan 2018 - Present
- Editorial Board, Sustainable Energy, Grids and Networks, Oct 2020 - Present
- Conference Editorial Board, IEEE Control Systems Society, Jul 2019 - Present
- Chair, Technical Program Committee (SBLC papers), IEEE PES General Meeting, 2017, 2018
- Chair, Technical Program Committee (SBLC papers), IEEE PES T&D Conference, 2018
- Technical Program Committee, Power System Computation Conference, 2018, 2020, 2022
- Technical Committee, IEEE Communications Society Best Readings in Smart Grid Communications, 2014
- Technical Program Committee, IEEE Conference on Smart Grid Communications, 2013, 2017, 2018
- Reviewer Committee, Conference on Probabilistic Methods Applied to Power Systems, 2020

Conferences, Workshops, and Tutorials

- Invited Session Organizer, IEEE Conference on Decision and Control, 2021:
  "Advanced Strategies to Control Distributed Energy Resources",
  "Machine Learning for Control of Power Systems"

- Panel Session Organizer and Chair, IEEE PES General Meeting, 2021:
  "The Interplay Between Energy Efficiency and Demand Response for Smart Buildings: Implications for Power Systems - Parts I & II"
- Invited Session Organizer and Chair, INFORMS Annual Meeting, 2018:
  "Managing Uncertainty in Electric Power Networks"
- Tutorial Co-Organizer, INFORMS Annual Meeting, 2015:
  "Uncertainty in Demand Response – Identification, Estimation, and Learning"
- Invited Session Organizer and Chair, American Control Conference, 2015:
  "Load Coordination and Control in Electric Power Systems"
- Workshop Co-Organizer, IEEE Conference on Decision and Control, 2013:
  "Ancillary Services from Flexible Loads to Help the Electric Grid of the Future"
- Session Chair, IEEE Conference on Decision and Control, 2013, 2016, 2018
- Session Chair, IEEE Conference on Smart Grid Communications, 2020
- Session Chair, IEEE PES General Meeting, 2017, 2019
- Session Chair, IEEE PES PowerTech Conference, 2019
- Session Chair, North American Power Symposium, 2015
- Session Chair, Power System Computation Conference, 2014, 2018, 2020

Reviewing

- *Journals:* Annual Reviews in Control; Applied Energy; ASME Journal of Dynamic Systems, Measurement, and Control; Automatica; Complexity; Energy; Energy and Buildings; Energy Policy; Energy Systems; Environmental Science and Technology; IEEE Control Systems Letters; IEEE Journal on Selected Areas in Communications: Smart Grid Communications Series; IEEE Power Engineering Letters; IEEE Transactions on Automatic Control; IEEE Transactions on Control of Network Systems; IEEE Transactions on Control Systems Technology; IEEE Transactions on Energy Conversion; IEEE Transactions on Power Systems; IEEE Transactions on Smart Grid; IEEE Transactions on Sustainable Energy; International Journal of Control; International Journal of Electrical Power and Energy Systems; Journal of Energy Storage; Plos One; Proceedings of the IEEE; Sustainable Cities and Society; Sustainable Energy, Grids, and Networks; Utilities Policy
- *Conferences:* American Control Conference; Conference on Probabilistic Methods Applied to Power Systems; European Control Conference; First International Workshop on Smart Grid Modeling and Simulation; Hawaii International Conference on Systems Science; IEEE Conference on Control Technology and Application; IEEE Conference on Decision and Control; IEEE Conference on Smart Grid Communications; IEEE PES General Meeting; IEEE PES PowerTech Conference; IEEE PES T&D Conference; IEEE Photovoltaics Specialists Conference; Mediterranean Conference on Control and Automation; North American Power Symposium; Power Systems Computation Conference
- *Proposals:* ARPA-E; Ohio State University Sustainable and Resilient Economy Program; National Science Foundation; Sloan Foundation; State of Utah Science, Technology, and Research Initiative

Advisory Boards

- Technical Advisory Group, LBNL/DOE project: A framework to characterize the performance of building components in providing flexible loads and building services using a hardware-in-the-loop approach, 2020 - Present

Internal Service

- ECE Faculty Search Committee, Sep 2014 - Aug 2020
- ECE Power/Energy Graduate Student Advisor, Sep 2014 - Dec 2016, Sep 2019 - Aug 2020
- Power System Seminar Series Organizer, Sep 2016 - Apr 2018

- CoE Dow Sustainability Selection Committee, 2017
- Energy Institute Visioning & Director Search Committee, Dec 2017 - Jul 2018
- School for Environment and Sustainability Faculty Search Committee, Sep - Dec 2018
- CoE Nominating Committee, Fall 2019
- ECE Faculty Workload Task Force, Sep 2021 - Present
- PhD Admissions Committee, Sep 2021 - Present

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