West Point Treatment Plant Independent Assessment

Final Report
July 18, 2017

King County Council
516 Third Avenue
Seattle, Washington 98104

Contract #5935175

AECOM

EXECUTIVE SUMMARY

Introduction

On February 9, 2017 during heavy rainfall in the Seattle area, West Point Treatment Plant (WPTP) was operating at peak hydraulic capacity, when a partial interruption of power supply occurred. The ensuing cascade of events caused several elements of the treatment plant to fail, culminating in flooding of WPTP and the bypass of an estimated 180 million gallons of stormwater mixed with untreated sewage into Puget Sound.

In the aftermath of this incident, the King County (County) Council commissioned AECOM on April 24, 2017, to perform an independent assessment. The primary objectives of the study were to perform an independent review of the incident; assess the causes and consequences of failure; review response actions taken by WTD; and recommend next steps for developing preventive strategies, practices, and infrastructure upgrades to avoid a recurrence of a similar incident in the future. This report summarizes the results of the independent assessment.

Study Approach

To address the objectives of the scope of work and maintain the objectivity of the independent assessment study while meeting the project's time constraints, AECOM developed a systematic approach based on experience from similar work, customized to the specific needs of this project. The approach consisted of the following steps:

1. Data collection
    a. Collection of existing documents
    b. Field visits and interviews
2. Data review and analyses
    a. Data Analyses and initial assessment of failure mechanisms
    b. Hazard and operability (HAZOP) workshop
    c. Refinement of failure mechanisms and development of recommendations
3. Preparation of the independent assessment study report

Findings of the Independent Assessment

As with failure of any complex infrastructure of this magnitude, several contributing factors led to the eventual flooding of WPTP. The HAZOP workshop and analysis identified other potential failure mechanisms and risk factors that should be addressed. The major contributing factors include the following:

1. **West Point Treatment Plant has many constraints, and the strain on the plant is likely to worsen.**

    WPTP is located on the shores of Puget Sound in Discovery Park which creates a unique set of challenges to ensure that plant operations do not interfere with the aesthetic, environmental, and recreational value of the setting. The site is very small for a plant of this capacity (440 mgd), and there is little area for expansion. The plant's upgrade in 1995 to include secondary treatment and other improvements used much of the remaining available space. Consequently this limits the peak-flow capacity of the treatment plant.

    In addition, several factors can increase the volume and frequency of flows into the plant. As urbanization continues in the regional watershed upstream of WPTP, the amount of impervious surface areas (pavement and buildings) will increase, while pervious surface areas will be decrease. Rain that previously would have filtered into the soil or run off into streams will instead be conveyed to the combined sewer that leads to the plant, thus tending to increase the amount of peak flows to the plant during storm events. Seattle's population has been growing substantially, which will lead to an increase in sanitary flows to the combined sewer system. Climate change may also lead to more frequent and/or more intense rain events, resulting in increased volumes and frequency of high flows to the plant.

While some of these factors are being compensated by improvements in technology and planned system improvements, the net effect of these factors has the potential to increase the magnitude, frequency, and duration of maximum flows to WPTP, which is a system that is already facing constraints.

2. **West Point Treatment Plant does not have sufficient redundancy.**

When the largest unit or piece of equipment in a system is out of service, the remaining capacity of the plant may be referred to as the reliable or firm capacity. In order to meet the firm capacity, a system must provide redundancy in terms of extra pumps, additional basins, diversion channels or alternative systems.

WPTP is rated by the Washington Department of Ecology to treat a maximum-month design flow of 215 million gallons per day (mgd) (DOE 2014). WPTP can receive up to 440 mgd of instantaneous flows. CSO-related bypasses of the secondary treatment portion of WPTP are authorized when the instantaneous flow rate exceeds 300 mgd as a result of precipitation events.

The firm capacity of WPTP is significantly less than the hydraulic capacity of 440 mgd. Therefore, when the plant operates at a peak capacity of 440 mgd, almost all key units and equipment must be fully operational to pass this flow. For example, if one of the RSPs were out of service, the remaining capacity is 330 mgd. Peak flow at WPTP during the February 9, 2017 event exceeded 440 mgd, requiring the primary treatment system to operate at maximum capacity without backup systems

Firm Capacity

Firm capacity is based on plant operations with one component out of service for each unit in operation. For example, the firm capacity of the EPS, which has four pumps, would be the capacity of three pumps, the fourth being out of service.

Lack of redundancy combined with the complexity of the system gives plant operators very little time to react during peak-flow events. The incident of February 9, 2017, showed that failure in one area of the plant during high flows can quickly lead to a cascade of events at other locations in the plant.

3. **West Point Treatment Plant needs a higher level of operational integration to manage interdependencies.**

Starting in 1911 when it was designated as a favorable location for a wastewater outfall, WPTP has expanded and continuously improved to protect water quality and meet changing regulatory requirements. WPTP is now a Class IV facility that uses three major pumping stations within the plant and numerous other complex mechanical, chemical, biological and electrical systems. The functional complexity of the plant was complemented by a significant expansion of the management and operations team.

The challenge with large, complex plants like WPTP is that the impact of single elements of the plant (e.g., high level floats) on the overall operability and capacity is not readily apparent. In addition, during high flow events, interdependency between various operating elements and seamless communication across operating teams becomes more critical. These issues tend to surface during an unusual event such as the February 9, 2017, event.

To address increasing complexity and hazards, the petrochemical industry created a rigorous Process Safety Management (PSM) System that chemical plants are now required by federal law to institute. This formal process enhances communication and structures the decision-making process to increase focus on life safety for the workers and the public, achieve better operating efficiency, reduce environment impact and reduce financial risk (**Appendix Q**).

The industry standard for wastewater treatment plants in the United States is to use the PSM system only in the hazardous areas of the plant where utilities are legally required to implement it (chemical and gas systems). At WPTP, a PSM System is implemented in the areas of the plant that generate methane and handle hazardous chemicals.

This assessment revealed that due to the size of WPTP, its complexity, limited redundancy, and environmental conditions, the operations procedures should be elevated from industry standard to include elements of PSM across the entire plant.

4. **Emergency response training did not anticipate this type of emergency.**

   The failure event on February 9, 2017 was unprecedented. The systems failures occurred during a period of peak flows, and the plant operators had very little time to respond. Operators were experienced and trained in many safety procedures, and they understood the importance of rapidly returning systems to operation; however, they were not adequately trained for this particular type of emergency. Based on a review of the WTD training/exercise records that were provided, the emergency training and emergency exercises being conducted by WTD, additional training and exercises focussed on using the lessons learned from the February 9, 2017 incident are needed.

   The results of the incident also show that there was a lack of clarity among crew members in identifying the threshold for initiating and implementing emergency bypass procedures. It is important that WPTP management and crew work closely with regulatory agencies to clearly define scenarios when emergency bypass procedures can be initiated while accounting for life safety and protecting infrastructure.

5. **The capital upgrades to the plant should be optimized to improve reliability during high-flow events.**

   WPTP has been upgraded several times over the years, but not all upgrades improved the plant's firm capacity or were fully developed to improve operational efficiency during emergencies. For example, the recently commissioned Ovation plant control system conveyed a rapid series of alarms to Main Control that were not yet fully prioritized. The shift supervisor was faced with more than 2,100 alarms in less than 1 hour, and it was not clear which were critical and which were of lesser significance. The lack of prioritization in the system configuration made it difficult for the shift supervisor to make informed decisions efficiently.

   Moreover, several elements of the plant, such as the raw sewage pumps, still need manual operator intervention, posing a life safety risk during emergency situations. All components of the plant system should be integrated with plant controls.

Recommendations

Based on these conclusions, AECOM proposes several recommendations to reduce the likelihood of future issues at WPTP. Potential strategies that were designed to help meet the overall goals of the recommendations listed below are presented in **Section 6**. Those strategies were discussed in many meetings and were vetted in the HAZOP workshop. AECOM recognizes that the Wastewater Treatment Division (WTD) is currently acting to implement some of those strategies.

1. **Implement a Life Safety Management system.**

   The County should develop and implement an approach to other critical areas of the plant, similar to the Process Safety Management (PSM) system that is currently used where regulatory requirements demand its use. The most effective elements of PSM should be leveraged into a new system which will be called, Life Safety Management (LSM).

   This approach needs to commence with a thorough systematic evaluation of plant systems in terms of function, performance and safety. This approach will improve vertical and horizontal communications regarding plant risks, provide better documentation of decisions, and result in stricter levels of maintenance.

The goal of Life Safety Management is to support the team to keep all the critical elements of the plant in optimum working order. An approach like Life Safety Management may have proactively identified and remediated some of the sources of failure that caused the February 9 event, as well as the risks inherent with using the underground tunnel system.

Most serious incidents are preceded by a series of less-serious incidents – a pattern known as the Incident Pyramid. Recognizing minor incidents early and taking appropriate actions will help to prevent major system failures. Implementing Life Safety Management will also help to avoid what is known as the normalization of deviation (Vaughan 1997), wherein personnel become accustomed to the poor performance of a piece of equipment.

Under Life Safety Management, operations and maintenance procedures are more strictly applied, and operators, maintenance works, engineers, safety managers, asset managers, administrators and manager and policy makers work together to achieve the best possible outcomes. One of the key tenants of Life Safety Management is to work toward continuous improvement and to avoid blaming or scapegoating.

Keeping the PSM and the Life Safety Management systems separate will simplify federal audits, leverage the best parts of PSM across the plant and greatly raise the bar regarding how the utility conducts the business of treating wastewater at WPTP. It will also reduce the serious risk to life safety, risk of release of untreated sewage into the sound and financial risks to the utility.

This innovation of implementing a Life Safety Management System as part of WPTP's policy development, management decisions, and operations, and maintenance will advance the utility and allow WPTP to be function to its highest ability.

2. **Conduct comprehensive emergency response training.**

   Given the limited capacity and complexity of WPTP, it is important that the operators have a well-defined emergency response plan that they are trained. AECOM recommends that WTD formulate and adopt a formal emergency training and emergency exercise program compliant with the Homeland Security Exercise and Evaluation Program. Training can help employees maintain competency for completing their specific tasks during an emergency, as the roles they assume in an emergency could differ from their normal duties. Training is particularly critical for tasks that employees do not perform regularly, such as those related to emergency bypass procedures.

   In concert with the emergency training program, a progressive exercise program provides opportunities to validate plans and procedures and identify and correct potential weaknesses and deficiencies. Exercises may include smaller scale drills and tabletop exercises, and larger coordinated simulations with other levels of the County's emergency organization, such as local and regional emergency operations centers.

   A comprehensive program of emergency training and emergency exercises promotes sharing of ideas, leads to documentation of important decisions, helps increase staff comfort levels regarding unusual emergency-only activities through discussion and practice, and ensures that proper protocols are followed. Please refer to **Section 6** for specific recommendations for emergency training and emergency exercises.

3. **Conduct an integrated evaluation to address plant constraints and improve redundancy.**

   To maximize the capacity of WPTP within the existing footprint and increase system reliability, WTD should implement a strategic plan that considers short-term and longer term improvements. The 50-year Look Ahead being considered by the County would be an excellent opportunity to focus on methodologies and develop integrated solutions that will be reliable and economical for addressing constraints and capacity issues.

It is important to address the lack of passive systems which would allow the plant to handle flows through the facility in the event of loss of automation, lack of power or delayed decision-making. One of the most critical points of failure at WPTP is the emergency bypass gate. If the gate fails to open, the facility can be flooded, posing a serious life-safety risk. It is recommended that passive overflows be evaluated.

This plan should incorporate upstream features in the collection system as well and lay the groundwork for developing a protocol for upstream combined sewer overflows (CSOs) and downstream treatment plant operations during high-flow events. This planning should also consider addressing WPTP's firm-capacity limitations and the extent that it is allowable from a regulatory standpoint to distribute peak flows across the CSO system, and the ability to use the emergency bypasses during peak-flow events.

4. **Optimize a capital improvement plan to maximize redundancy.**

The longer term planning processes should consider capital improvements that have immediate and significant impacts on plant capacity. Some improvements that can have immediate impacts on operations during a peak flow involve configuring the Ovation system to prioritize alarms and integrating pump stations and emergency bypass gates with plant controls.

The HAZOP methodology helped to identify a number of concepts to improve the firm capacity of WPTP. These concepts can be further grouped, refined, modified, augmented, and evaluated for cost effectiveness during the planning process.

Some of the capital improvement costs for improving redundancy and addressing the identified potential failure mechanisms can be significant. These can be implemented optimally over a longer period of time considering the overall impact on the plant by considering the Life Safety Management system approach.

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Abbreviations

AAR	After Action Review
ACC	area control center
ATS	automatic control switch
BOD_5	biochemical oxygen demand
CCTV	closed-circuit television
CMMS	computerized maintenace management system
cfu	colony-forming units
County	King County
CSO	combined sewer overflow
DHS	U.S. Department of Homeland Security
DOE	Washington Department of Ecology
DWO	dry-weather overflow
EB	Emergency Bypass
EBO	Emergency Bypass Outfall
EMO	Emergency Marine Outfall
EP	effluent pump
EPA	U.S. Environmental Protection Agency
EPS	effluent pump station
ERP	Emergency Response Plan
FDS	Flow Diversion Structure
FE	functional exercise
FEMA	Federal Emergency Management Agency
FSE	full-scale exercise
HAZOP	hazard and operability
HSEEP	Homeland Security Exercise and Evaluation Program
HVAC	heating, ventilation, and air conditioning
I&C	instrumentation and control
ICS	influent control structure
IEC	International Electro-technical Commission
IPS	Intermediate Pump Station
kV	kilovolt
MC	Main Control
MCC	motor control center
MG	million gallons
mgd	million gallons per day
mL	milliliters
MLSS	mixed liquor suspended solids
MOV	metal oxide varister
NPDES	National Pollutant Discharge Elimination System
O&M	operations and maintenance
PE	primary effluent
PM	preventive maintenance
PSM	Process Safety Management
RSP	raw-sewage pump
SCADA	supervisory control and data acquisition
SMoC	Safety Management of Change
SOP	standard operating procedure
SSO	sanitary sewer overflow
T^2OPS	Technical Training for Operations
TSS	total suspended solids
TTX	tabletop exercise

UPS	uninterruptible power supply
V	volt
W2E	waste-to-energy
WPTP	West Point Treatment Plant
WTD	Wastewater Treatment Division

1. Objective, Scope, and Approach

1.1 Authorization

On April 24, 2017 the King County (County) Council commissioned AECOM to perform an independent review of the West Point Treatment Plant (WPTP) failure. The goal of this study was to assess the causes and consequences of failure; review response actions; and provide for strategies, practices, and infrastructure upgrades to help prevent a similar event from occurring in the future.

1.2 Objectives and Scope of Services

The scope of services that were included in the contract consisted of performing an independent study and preparing a report that addresses the following general objectives as defined by the County:

- Review prior occasions at WPTP involving shutdowns of effluent discharge pumps or operational interruptions.
- Evaluate the flooding that occurred at WPTP during the event.
- Describe the environmental impacts of the discharge of untreated or minimally treated wastewater and stormwater during the event.
- Describe the event's public health impacts.
- Describe and evaluate the Wastewater Treatment Division's (WTD's) immediate and subsequent responses to the event.
- Evaluate the event's causes or contributing factors, and how flooding of the plant could have been averted.
- Evaluate WPTP's power systems.
- Recommend appropriate preventive approaches, strategies, practices, or systems to avoid a recurrence of extended suspensions of full operation of wastewater treatment at WPTP.
- Evaluate methods to relieve flow volumes at the plant during future heavy storm periods.
- Describe and evaluate WTD's lessons learned from the event.
- Provide any other findings or analysis the consultant deems relevant or necessary for the County Council and the public to understand the event's causes and the effectiveness of the response and determine how to prevent a similar event in the future.

1.3 Approach to the Independent Assessment

To address the objectives of the scope of work and maintain the objectivity of the independent assessment study while meeting the time constraints, AECOM developed a systematic approach based on experience from similar work, and customized it to the specific needs of this project. The approach consisted of the following key steps:

1. Data collection
    a. Collection of existing documents
    b. Field visits and staff interviews
2. Data review and analyses
    a. Data Analyses and initial assessment failure mechanisms
    b. Hazard and operability (HAZOP) workshop
    c. Refinement of failure mechanisms and development of recommendations
3. Preparation of the independent assessment study report

1.3.1 Data Collection

One of the key initial steps of this study involved collecting all readily available data. The primary sources of data were previous studies and reports requested by AECOM and provided by WTD. This information was supplemented by staff interviews and field visits to WPTP.

The County Council requested that WTD cooperate fully with AECOM during the independent assessment. WTD fully cooperated and provided timely access to more than 4,900 documents: design drawings, manuals, reports and records, and external communications. Documents were logged, indexed, and stored on a central server to accommodate easy and timely access to the AECOM team. **Appendix A** presents a summary of the documents received.

WTD also participated in daily meetings with AECOM and the County Council's project manager to convey data requests, track progress in obtaining data, and discuss new information that was received. Multiple site visits to WPTP were conducted to better understand the facility, obtain updates on recovery operations, and review procedures with management and operations and maintenance (O&M) personnel. **Appendix A** presents a list of the site visits conducted during this process.

1.3.2 Data Review and Analyses

To determine where the potential may exist for other catastrophic failures at WPTP, AECOM discipline leads were instructed to evaluate each critical unit operation or process based on several considerations:

- Function
- How the unit or process operates
- What controls the flow, level, or operations sequence
- Failure modes
- Consequences of failure
- Current WTD activities to resolve/prevent future failures
- Areas for further investigation

After the initial assessment of the data, a HAZOP workshop was conducted on May 24–25, 2017 in order to clarify system processes and to evaluate potential failure modes of plant components. This workshop included representatives of the County Council's staff; WTD's management, plant supervisors, operators, maintenance and engineering staff; and AECOM technical team leaders and technical advisors. The HAZOP process is recognized internationally, and is a standard analysis technique sanctioned by the International Electro-technical Commission (IEC). The workshop used a formal customized HAZOP methodology to review each component at WPTP that failed during the plant's flooding event, and to identify other potential hazards and operability problems in the system. Several potential failure modes were identified, along with recommendations of potential mitigation strategies, which will be discussed later in this report.

1.3.3 Preparation of Independent Assessment Report

This independent assessment report summarizes the data collected, the assessment approach, findings, and recommendations. The report is organized into the following sections:

- Section 1, "Objective, Scope, and Approach"
- Section 2, "King County Wastewater Treatment System"
- Section 3, "Overview of the February 9, 2017, Event"
- Section 4, "Response and Recovery Actions"
- Section 5, "Hazard and Operability Process"
- Section 6, "System Evaluation"
- Section 7, "Summary and Recommendations"

Section 2 provides a brief history of WPTP to provide context to the plant's limitations, and describes the wastewater collection system and the historical context of its operation. **Section 3** reviews the incident and its direct impacts, while **Section 4** evaluates WTD's response and the recovery actions taken after the event. The HAZOP methodology used for the assessment is summarized in **Section 5**. **Section 6** provides an overview of the WPTP treatment processes and a more detailed analysis of each critical component identified in the HAZOP workshop. **Section 7** summarizes the lessons learned and provides recommendations of potential mitigation strategies.

1.4 WTD Investigative Reports

AECOM recognizes that several other investigations regarding the event have been performed. WTD commissioned CH2M to perform a root-cause evaluation of the February 9, 2017, incident. The *West Point Flooding Investigation Preliminary Findings Report* was issued April 20, 2017 (CH2M 2017). That report is an important document for the root-cause analysis. The root cause of the initial power failure has not yet been identified.

Additionally, WTD initiated an internal review of the flooding event that was performed by WTD staff who spent several weeks at WPTP conducting the review. This *After Action Self-Assessment Report* (WTD 2017j) is in draft form but was provided to AECOM to be examined as part of this evaluation. The report was developed to provide a tool to incorporate lessons learned and best practices in planning for future activities and plant improvements.

The WTD Operations Manager also the *Memorandum: February 9, 2017 West Point Flood Recovery—Resiliency Action Plan* (WTD 2017f) on May 31, 2017.

This independent assessment report revisits the damage to the plant, the root-cause analysis, and the self-assessment, and then proceeds to document actions that already have been taken or will be taken to eliminate the risk of future flood events at WPTP.

These assessments are evidence that since the February 9 event, WTD has recognized the need for changes and has been actively implementing several of them to deal with similar wet-weather events in the future. The AECOM team has reviewed these documents and utilized the information where applicable.

1.5 Statement of Limitations

AECOM represents that services are performed within the limits of, and in a manner consistent with the level of care and skill ordinarily exercised by other professional consultants under similar circumstances. No other representation, expressed or implied, and no warranty or guarantee are included or intended.

Data used in the preparation of this report are time-sensitive in that they apply only to locations and conditions existing at the time of the observation or preparation of this report. Data should not be applied to any other projects in or near the areas of these studies, nor should they be applied at a future time without appropriate verification by qualified individuals.

AECOM has relied on third-party information and interviews with knowledgeable persons for the purpose of preparing this document and is neither responsible for, nor has independently verified the accuracy of this information. AECOM has not performed independent validation or verification of data by others and does not assume any liability for errors or misrepresentations of this third-party information obtained during performance of this work.

This study was performed in a relatively short period of time with the primary goal of providing an independent assessment and should not be construed as proffering design concepts or making design recommendations.

The scope of services performed during this independent assessment is intended for the sole use of King County and may not be appropriate to satisfy the needs of other users, and any use or reuse of this document, or of the findings, conclusions, or recommendations presented herein is at the sole risk of said user.

Conclusions presented in this report are professional opinions of AECOM team based on available data and information by others.

2. King County Wastewater Treatment System

King County provides wholesale wastewater conveyance and treatment of flows from 17 cities, 16 local sewer utilities, and one tribal government (WTD 2016). WTD's service area occupies 114 square miles, and WPTP serves a current population of about 700,000 people. WPTP is part of the County's regional system that collects and treats wastewater from homes, businesses, and industries (sanitary flows) in the Seattle area and the west side of the Lake Washington. The system also collects and treats stormwater in a combined sewer system (where one pipe carries both sewage and stormwater from source to treatment plant). The County's wastewater service area is divided into the East and West Sections; wastewater from the East Section is conveyed to the South Treatment Plant and Brightwater, and combined wastewater and stormwater from the West Section flows to WPTP.

WTD owns and operates WPTP, which is located on Puget Sound at the western tip of Discovery (WTD 2014) (**Figure 1**). The plant is located between the beach and the forested hill behind the plant, which results in a unique set of challenges to ensure that plant operations do not interfere with the aesthetic value of the setting, where many hikers, beachgoers, and bicyclists come for recreation. The available area of the site is very small for a plant of this capacity, and there is not a lot of additional space to expand the plant, which could constrain potential improvement options.

When large storms occur and flows exceed the capacity of County combined sewer collection system, combined sewer overflows (CSOs) within the conveyance system may occur. CSOs discharge a mix of 10% untreated sewage and 90% stormwater during periods of heavy precipitation to Lake Washington, Lake Union, the Lake Washington Ship Canal, the Duwamish River, Elliott Bay, and Puget Sound (WTD 2017m). CSOs are a recognized source of water pollution that can result in temporary increases in bacterial counts, aesthetic degradation of shorelines, long-term adverse effects on sediment quality at discharge points, and increased public health concerns in areas where the potential exists for public contact (WTD 2017n). CSOs may occur at any of the 38 County CSO locations. They may also occur at the City of Seattle's 87 CSO locations in its local sewer system, for which Seattle is responsible for managing and reporting.

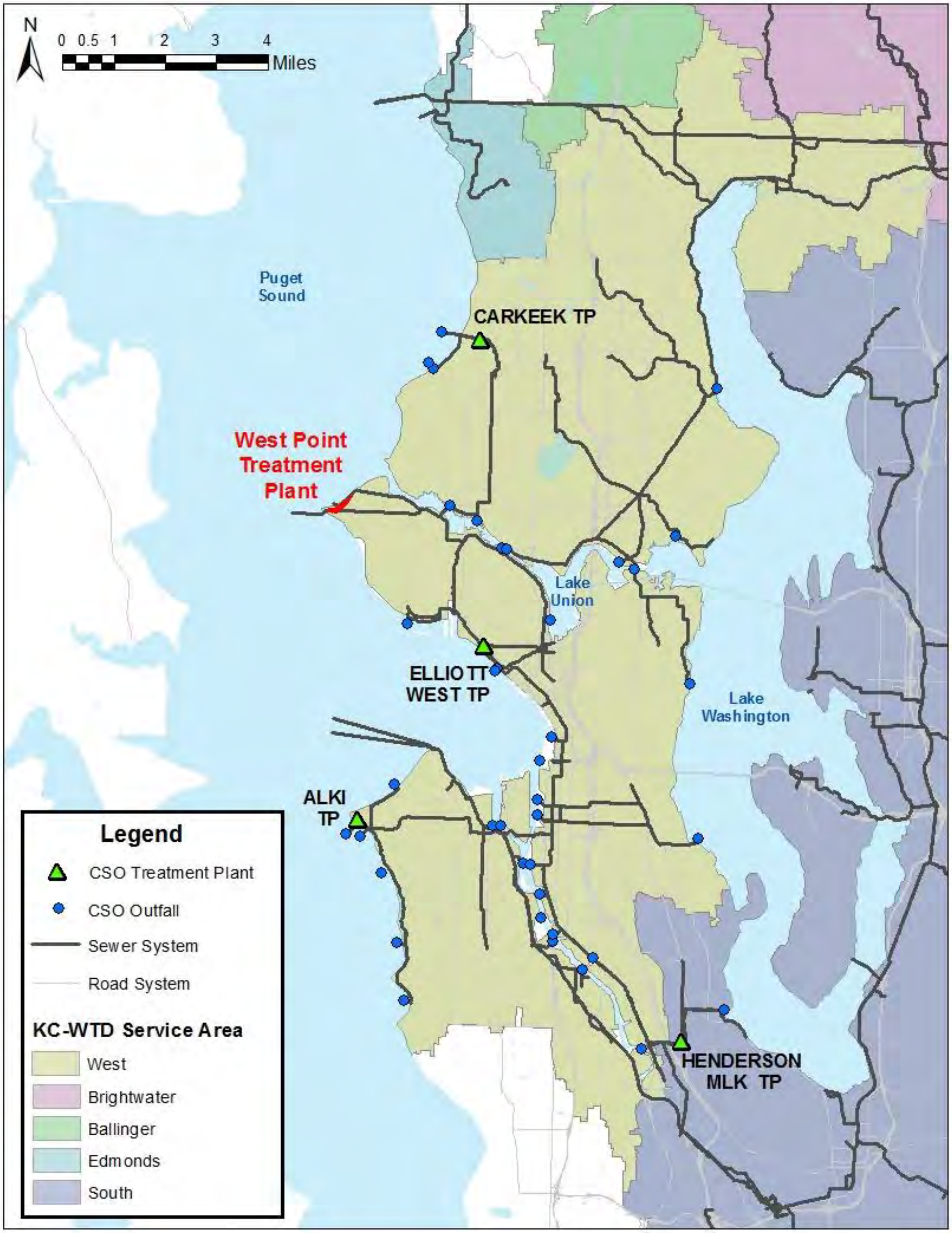
The County's regional system also includes four CSO treatment plants (Alki, Carkeek, Denny/Elliott West, and Henderson/MLK) that operate during heavy rainfall and provide primary treatment, chlorine disinfection, and dechlorination before discharging to a water body.

WPTP and the West collection system have many constraints, and the strain on the system is likely to worsen. The population of the County is growing rapidly, which will increase the amount of base sanitary flows that will need to be treated by WPTP. Also, as urbanization of the regional watershed upstream of the plant continues, more areas with vegetation will be replaced by impervious surfaces (pavement and buildings). Rain that previously would have filtered into the soils or run off into the streams will instead be conveyed to the combined sewer system that leads to the plant. This will increase the volume of the peak flows to the plant during storm events. Climate change may also result in more frequent and/or more intense rain events, which impact the volume and timing of flows to the plant. The net effect of these factors is that the magnitude, frequency and duration of peak flows to WPTP are likely to increase over time.

2.1 Historical Background

In the late 1800s, discharges of raw sewage were contaminating Lake Union and Lake Washington. The City of Seattle recognized this as a problem and began searching for a site to discharge raw sewage to reduce freshwater contamination. In 1904, a study of currents identified a short section of the beach at Fort Lawton (now Discovery Park) as the best site to ensure that raw sewage was carried by currents north into Puget Sound away from the shore (Magnolia 2012). In 1911, a sewer outfall was constructed to discharge raw sewage at a depth of 45 feet at high tide. In 1918, the North Trunk Sewer was completed and ran under Fort Lawton through a 144-inch-diameter tunnel.

Figure 1. West Point and King County West Combined Sewer Overflow Treatment Facilities and Outfalls



(Source: King County 2017)

Even at this carefully chosen location, discharges of raw sewage still led to periodic contamination of the beaches. With the sewer outfall already at Discovery Park, a primary treatment plant was planned for the same site. Primary treatment is a physical treatment process that typically removes 50% to 70% of total suspended solids (TSS) and 25% to 50% of biochemical oxygen demand (BOD_5), or the amount of oxygen that microorganisms must utilize to break down organic material present in wastewater (Pescod 1992).

The primary treatment facility at WPTP began operations in 1966, which represented the first major step in protecting Puget Sound. In 1972, Congress passed the federal Clean Water Act, requiring secondary treatment at all municipal wastewater treatment plants (Magnolia 2012). Secondary treatment is a biological process that further reduces TSS and BOD_5 from wastewater prior to being discharged to the receiving waters.

WPTP operated under a waiver to allow primary treatment only until secondary treatment was constructed. WPTP was upgraded by 1995 to include secondary treatment for flows up to 300 million gallons per day (mgd). Primary treatment is provided for flows up to 440 MGD.

The National Pollutant Discharge Elimination System (NPDES), which prohibits unpermitted discharge of pollution into U.S. surface waters, was also created by the 1972 Clean Water Act. NPDES permits apply to point sources and contain effluent limits, monitoring and reporting requirements, operation and maintenance (O&M) requirements, and other stipulations designed to protect water quality. WPTP operates under NPDES Permit WA0029181 (DOE 2014; WTD 2014). The flows or waste loads for the permitted WPTP must not exceed the following design criteria:

- Maximum Month Design Flow (MMDF) 215 MGD
- Average Wet Weather Flow (non-storm) 133 MGD
- Instantaneous Peak Flow 440 MGD
- BOD_5 Influent Loading for Maximum Month 201,000 lbs/day
- TSS Influent Loading for Maximum Month 218,000 lbs/day

From a review of annual reports since the implementation of the consent decree in 2013 (January 2013-December 2015) only one violation of its NPDES permit has occurred at WPTP prior to the February 2017 event. This was a secondary diversion violation on February 10, 2014.

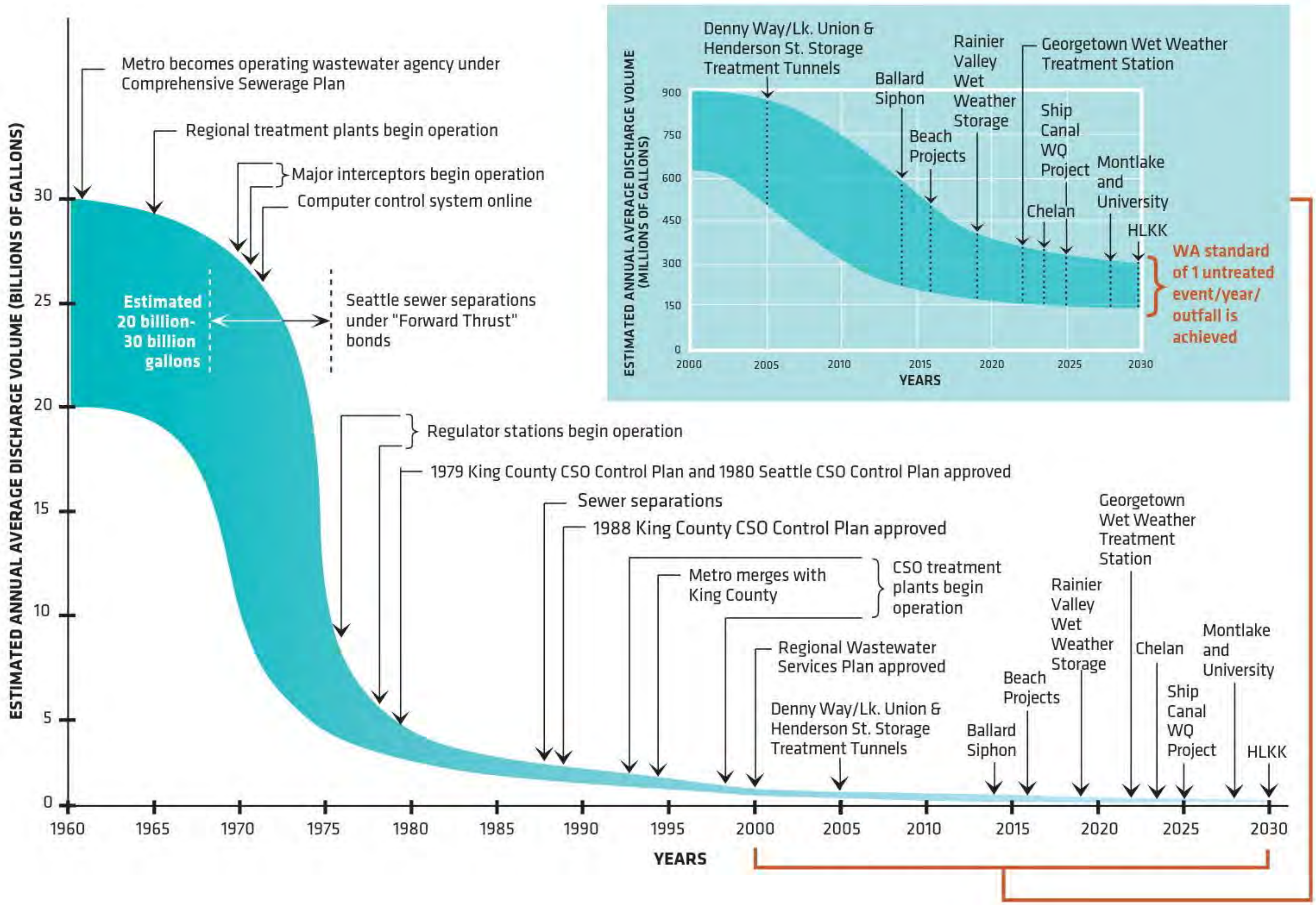
The NPDES permit, which is issued for WPTP and the CSO treatment plants (Alki, Carkeek, Denny/Elliott West, and Henderson/MLK), currently allows for some overflows that are caused by rainfall. The County monitors the frequencies and volumes of both untreated and treated CSOs at all of its CSO discharge sites (WTD 2017i). Since the 1970s when the basic regional wastewater system infrastructure was in place, the Municipality of Metropolitan Seattle (Metro), and its successor, King County, have been implementing CSO control projects to improve water quality in the Seattle area (WTD 2016).

The collection system, as configured in 1983, discharged nearly 2.3 billion gallons per year of untreated sewage and stormwater from a total of 431 overflow events (WTD 2014). Based on data from 2006–2012, the County's average annual untreated CSO volume has been approximately 811 million gallons per year (WTD 2014).

In 2013, King County, the U.S. Department of Justice, and the U.S. Environmental Protection Agency (EPA) signed a federal consent decree (an agreed-upon settlement to a civil enforcement case) that requires the Country to complete its CSO control plan by 2030 (WTD 2016). The implementation of the CSO control plan will reduce pollution, stormwater runoff, and discharges of sewage.

The County is committed to meeting all the milestones and actions outlined in the consent decree (WTD 2016). To support this, the County is providing its staff with ongoing training, briefings, and division-wide communication on the consent decree to ensure everyone works together to achieve these priorities (WTD 2016). As a result, all projects and plans outlined in the consent decree are on schedule to achieve their critical milestones (WTD 2016). The CSO projects that the County has already completed and the CSO projects that the County is planning for is shown in **Figure 2**.

Figure 2. CSO Reductions and Planned CSO Control Projects in King County



(Source: WTD 2017n)

2.2 West Point Treatment Plant

Firm Capacity
Firm capacity is based on plant operations with one component out of service for each unit in operation. For example, the firm capacity of the EPS, which has four pumps, would be the capacity of three pumps, the fourth being out of service.

WPTP can receive up to 440 mgd of instantaneous flows. However, this is only an instantaneous capacity with all units in service; it is not the plant's firm capacity. Firm capacity, which will be discussed in **Section 6.1**, is based on plant operations with one component (basin or pump, for example) out of service for each unit in operation.

Two influent tunnels—Fort Lawton, 144 inches in diameter, and Old Fort Lawton Tunnel, 84 inches in diameter—convey combined sewer flows by gravity to WPTP. Flow from both tunnels enters the plant at the influent control structure (ICS). The ICS distributes the flow evenly to four influent lines that gravity flow through bar screens to the raw sewage pump (RSP) wet well. The bar screens remove large debris like rags, paper, and leaves from the wastewater (influent). The RSPs lift the flow to the preaeration tanks. The preaeration tanks are aerated grit channels that collect grit at the bottom and convey the wastewater to the primary sedimentation tanks where fats, oils, and greases are skimmed from the surface.

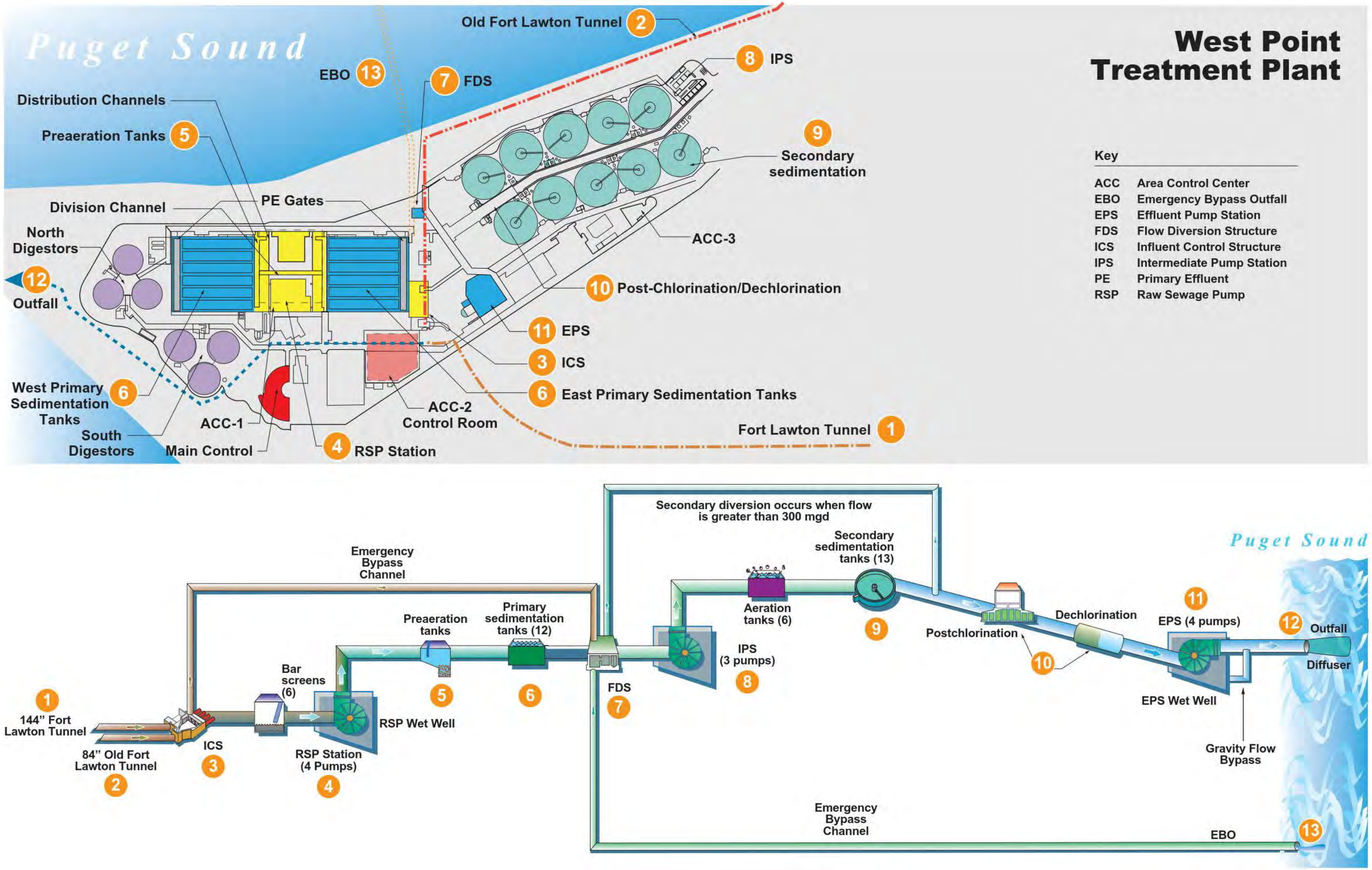
From the primary sedimentation tanks, effluent wastewater flows via gravity to a flow diversion structure (FDS) and then to the intermediate pump station (IPS). The IPS lifts primary effluent to the secondary treatment process from where it flows via gravity through aeration tanks and secondary sedimentation tanks.

The effluent is then chlorinated to inactivate potential pathogens, and dechlorinated to protect aquatic life against the impacts of chlorine residual. The treated effluent is collected at the effluent pump station (EPS), where the plant discharges treated effluent to Puget Sound by gravity or pumping, depending on tide conditions (WTD 2014). At low tide, 150–160 mgd of treated effluent can be conveyed by gravity to the outfall diffuser; however, during high tide, the water must be pumped.

The disinfected effluent discharges to Puget Sound through a 600-foot multiport diffuser located 3,652 feet offshore at a depth of 240 feet below mean low tide (Bendiner 1976; Evans-Hamilton 1975). The diffuser ensures proper mixing into the waters of Puget Sound, so that the effluent poses no public health threat to persons using the beaches or fishing in the waters. The diffuser creates rapid mixing of effluent with seawater such that by the time the effluent reaches the surface, the mixture is about 1 part effluent to 99 parts seawater (or 100:1 dilution). As the plume moves with each tidal cycle, the plume with initial 100:1 diluted plume is further mixed by an additional factor of five- to 10-fold (i.e., diluted to ratios of 500:1 to 1,000:1).

The schematic in **Figure 3** summarizes the treatment process steps at WPTP. For more details on the treatment plant processes, please see the King County Wastewater Treatment Process diagram factsheet (**Appendix B**).

Figure 3. West Point Treatment Plant Plan View and Simplified Schematic of Plant Hydraulics



(Source: Adapted from WTD 2017j)

2.3 Operating Conditions

The operational differences of WPTP during dry weather and wet weather flows are shown in **Figure 4**.

2.3.1 Dry Weather Operations

During dry weather, WPTP treats approximately 90 mgd of wastewater (WTD 20171). The plant follows the treatment process listed in the section above and treats all flows less than 300 mgd to a secondary treatment level. The effluent is discharged via the outfall.

2.3.2 Wet Weather Operations

The secondary treatment process was only designed to treat flows below 300 mgd. During rain events, flows above 300 mgd up and to 440 mgd arriving at WPTP are diverted from the secondary treatment processes and receive only primary treatment. CSO-related bypass of the secondary treatment portion of the WPTP is authorized when the instantaneous flow rate to the WPTP exceeds 300 MGD as a result of precipitation events (DOE 2014).

After primary treatment, up to 300 mgd is conveyed to the secondary treatment processes, whereas excess flows (greater than 300 mgd) are blended with secondary effluent before they go through disinfection and dechlorination (**Figure 4**). The combined flows are then discharged by the EPS from the outfall (WTD 2016). The final discharge must at all times meet the effluent limits of their NPDES permit (DOE 2014) which allow for a small reduction in the monthly removal requirements —80% instead of 85%— during the typical wet-season months of November through April (WTD 2016). WTD submitted, and DOE accepted, documentation that there are no feasible alternatives to this practice as it is a fundamental component of the County's CSO control strategy (WTD 2016).

2.3.3 Combined Sewer Overflows

WPTP can receive up to 440 mgd of instantaneous flows. Flows greater than the plant's hydraulic capacity of 440 mgd are either stored in the upstream collection system, treated to primary treatment levels at a CSO treatment facility, or discharged as untreated CSOs to rivers, lakes, or Puget Sound. Flows through the conveyance system are monitored and controlled using WTD's supervisory control and data acquisition (SCADA) computer system (WTD 2014). The SCADA system minimizes surges, maximizes flow to the plant, and maximizes the use of collection system storage to limit combined sewer overflows (WTD 2014).

2.3.4 Emergency Bypass Event

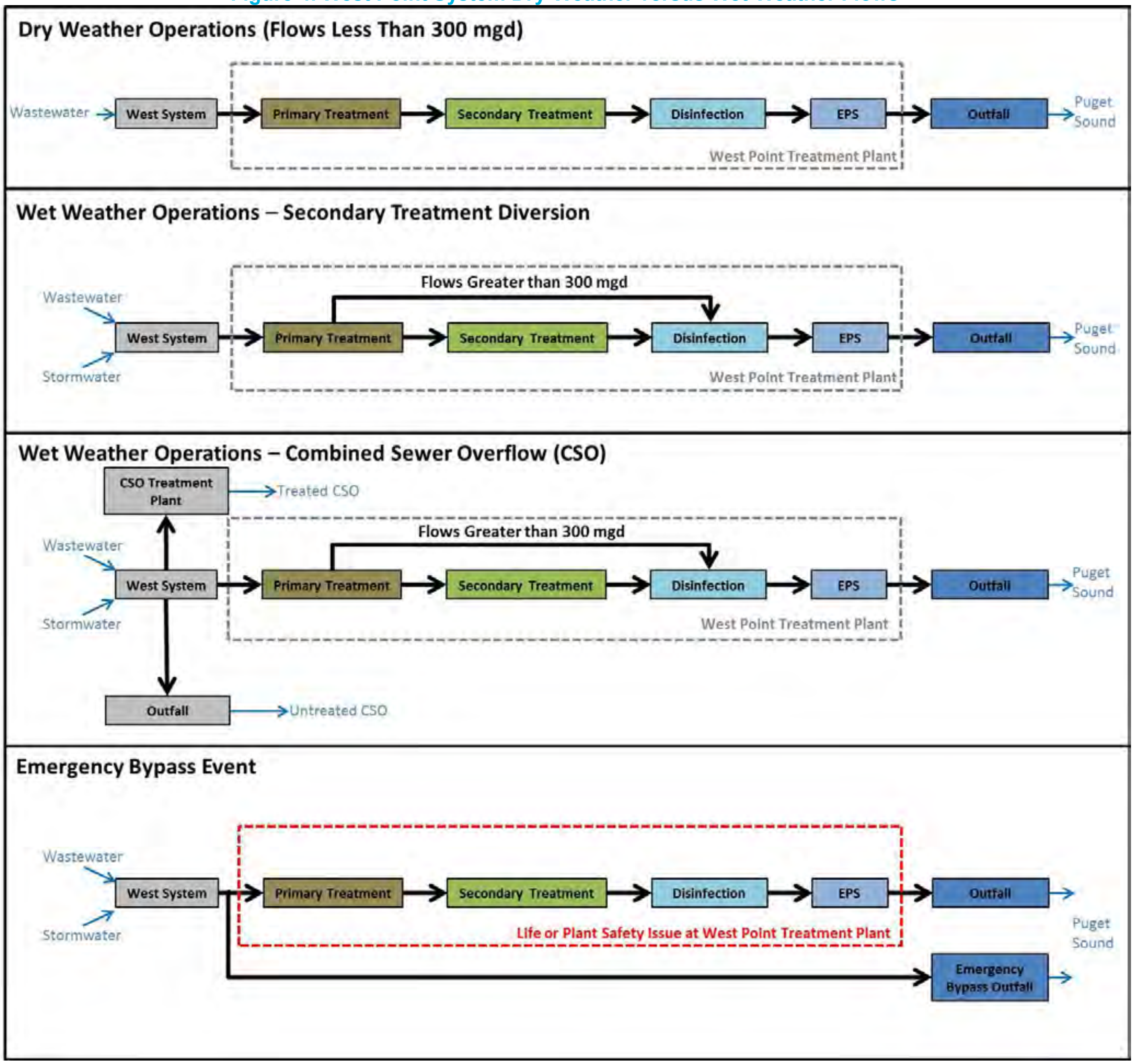
Bypasses, or intentional diversion of waste streams, are prohibited by the NPDES permit, except in the following two scenarios (DOE 2014):

1. Essential maintenance or construction requires a bypass that will not cause a violation of any permit limits.
2. A bypass will prevent loss of life, personal injury, or severe damage to property, the treatment facility, or natural resources, or there are no alternatives to the bypass (e.g., auxiliary facilities, retention of untreated wastes).

While discharge of untreated wastewater is a reportable event, it is understood that this protects the plant so that it can continue to fulfill its mission once the short-term emergency or extreme-flow event passes. Such emergency discharges are reported to Ecology, and the beach is then monitored to detect any contamination.

The plant was designed to bypass for life safety and to protect the facility. In the event that flows exceed the ability of the plant to receive and treat effluent, or should a major failure occur at the plant, the design includes an emergency bypass gate that can convey the entire flow from the plant to the emergency bypass outfall (EBO) (**Figure 4**). The EBO is shorter and shallower than the outfall from the EPS. Its primary purpose is to quickly convey flows exceeding the plant's operational capacity to Puget Sound in an emergency.

Figure 4. West Point System Dry-Weather versus Wet-Weather Flows



2.4 WPTP Corrective Upgrades and Improvements

WPTP has initiated or experienced five emergency bypass events since 2000. Three of these events, in 2000, 2006, and 2009, were similarly associated with plant failure as was the 2017 event. **Table 1** provides an overview of each event and summarizes the corrective actions and upgrades that were taken in response to each bypass.

In response to this event, WTD took a closer look at these past events as part of their *After Action Self-Assessment Report* (WTD 2017j). The detailed WTD summary of the previous bypass events from **Table 1** are available in **Appendix C.** WTD also reviewed previous reports that were developed after these bypass events and reviewed the recommendations and actions taken. If no action was taken, an explanation for the inaction is provided if it is known. **Appendix C** lists the 51 recommendations and actions taken.

WTD has also regularly made improvements and upgrades to WPTP. An overview of plant improvements is available in **Appendix D**. One of the largest improvements was the addition of a new supervisory control system standard for all wastewater facilities.

In 2003, WTD decided to use Ovation by Emerson Process Management as the standard for the new districtwide control system. The Ovation control system utilizes Ovation controllers located at key areas of the plant. The controllers consist of redundant central processing units and power supplies, and network and input/output interfaces to enhance system uptime and reliability. By the time of the 2017 incident, most facilities, including WPTP and the large CSO facilities, had been fully upgraded to Ovation controls.

Because of the size, complexity, and costs of the Ovation upgrades, WTD decided that the replacement of the old supervisory control system would be a SCADA system upgrade, with minimal instrumentation and control (I&C) enhancements included with the upgrade (other than upgrades in hardware and software components being used). The Ovation system has some prioritization of alarms, but these were carried over from the old control system and did not include a dedicated screen for the highest priority (life safety/plant failure) alarms. Alarm management needs to be revisited. **Section 6.4** presents specific recommendations for the Ovation system.

Table 1. Corrective Actions in Response to Previous Bypass Events

Date	Description of the Event	Untreated Discharge Released (MG)	Corrective Actions
January 4, 2000	A storm event increased flow rate from 196 mgd to 367 mgd in 1 hour.	18	Installed separate power units for east and west PE gates.
			Installed separate power units on ICS and FDS.
			Monitoring of EP3.
			New EP/discharge valve algorithm to reduce vibration at startup.
			PM for weekly cleaning of floats and stilling wells implemented.
June 19, 2002	Staff discovered that one of the emergency bypass gates was open 0.5 inch and untreated sewage was leaking through to the emergency marine outfall. The opening was so slight that it did not trigger an alarm.	23.3[1]	Scheduled replacement of both cylinder isolation valves and line to lower side of EB gate cylinder.
			Scheduled routine checks of EB gate position.
December 14, 2006	The region experienced a huge windstorm along with heavy rains. A total of 43 power sags (momentary decreases in voltage magnitude) occurred during the day.	66	Began Operator's Workbook but not completed.
			Added float switches interlock switch bypass status to SCADA.
March 28, 2008	The emergency bypass gate opened and untreated sewage flowed through the emergency marine outfall.	0.4	New SOPs implemented.
			Modified open command button.
			Plan to add alarm feedback when control button activated.
December 14, 2009	An electrical short caused a solenoid to open the emergency bypass gate prematurely.	8.7	Instrument technician called in to repair.
			Added indicators in ACC-1 that there is power to valve that initiates opening the EB gate.

ACC = area control center; EB = Emergency Bypass; EP = effluent pump; FDS = flow diversion structure; ICS = influent control structure; MG = million gallons; mgd = million gallons per day; PE = primary effluent; PM = preventive maintenance; SCADA = supervisory control and data acquisition; SOP = standard operating procedure

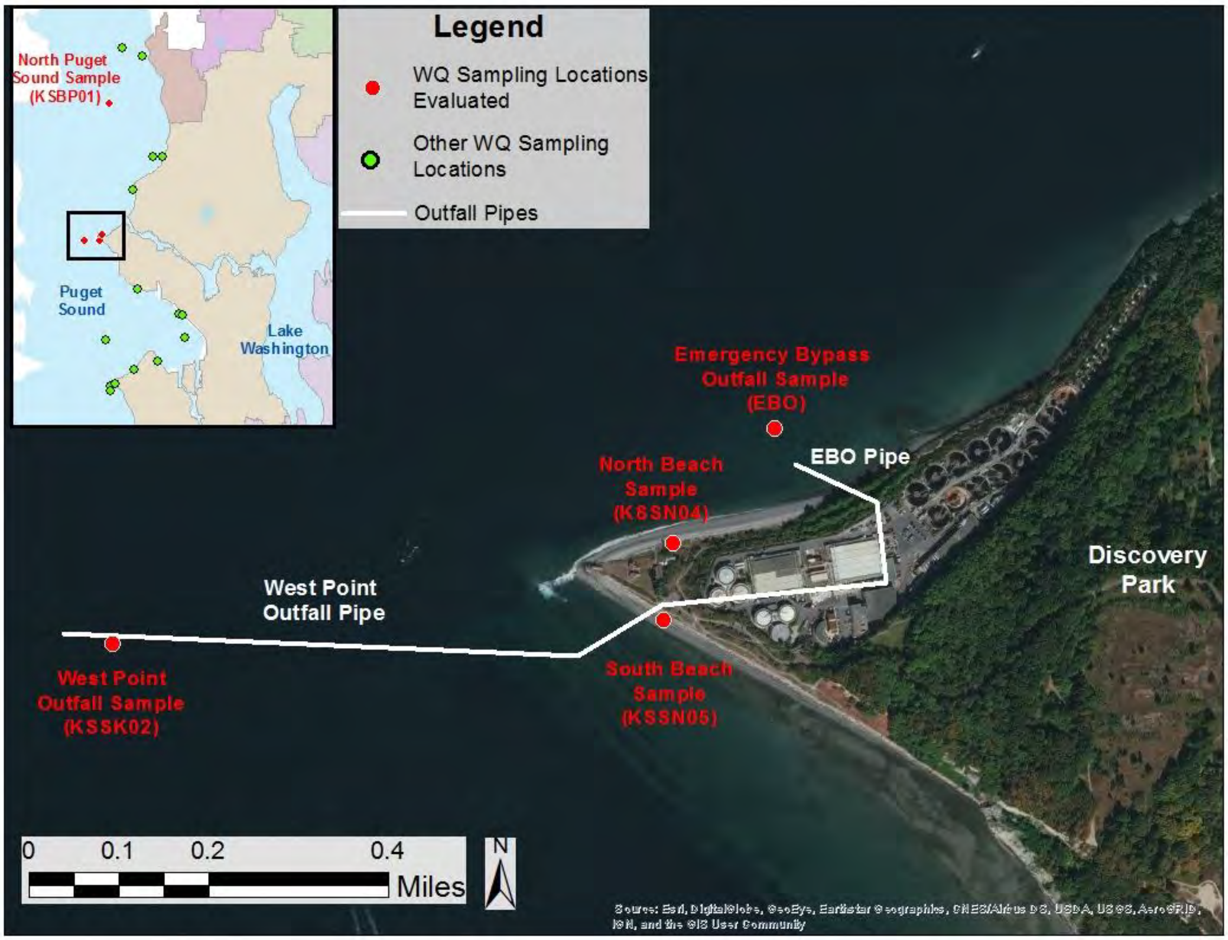
(Source: Adapted from WTD 2016 and WTD 2017j)

[1] Estimated from a maximum discharge rate of 1,800 gallons per minute for 9 days.

2.5 Water Quality Monitoring Program

To provide an understanding of water quality in Puget Sound, King County has maintained a long-term water quality monitoring program that monitors water quality at 12 offshore stations and 20 beach locations (**Figure 5**). The monitoring locations near WPTP, which include offshore sites at the West Point Outfall (KSSK02), in the North Central Puget Sound (KSBP01), and at the Emergency Bypass Outfall (EBO),[1] and beach locations at North Beach West Point (KSSN05) and South Beach West Point (KSSN04).

Figure 5. Water Quality Monitoring Locations



(Source: Keaum, pers. comm., 2017)

The monitoring program forms the basis for assessing water quality conditions. **Table 2** shows the parameters tested and the frequency of regular, ongoing testing.

[1] Added to monitoring after incident.

Table 2. King County Marine Water Quality Monitoring Program

Water Quality Parameter	Offshore Sampling Stations[1]	Beach Locations
Dissolved oxygen	Every 2 Weeks	
Temperature	Every 2 Weeks	Monthly
Salinity	Every 2 Weeks	Monthly
Density (calculated)	Every 2 Weeks	
Chlorophyll	Every 2 Weeks	
Light intensity and transmission	Every 2 Weeks	
Nutrients[2]	Every 2 Weeks[3]	Monthly
Fecal indicator bacteria	Every 2 Weeks[3]	Monthly
Suspended solids	Every 2 Weeks[3]	
Phytoplankton composition and abundance	Every 2 Weeks[4]	

(Source: WTD 2017o)

[1] Measured at entire water column from surface to bottom, unless specified otherwise.

[2] Monitored nutrients include ammonia, nitrate, orthophosphate, and silica.

[3] Measured at specific depths at each site.

[4] Assessed only at a subset of sites.

The marine monitoring program is conducted in accordance with scientific protocols of the regionwide Puget Sound Estuary Program. More information about the existing water quality of Puget Sound can be found in the *NPDES Receiving Water Characterization Study* (King County 2013). The study was designed to provide DOE with a combination of data from the County's ongoing water quality monitoring programs for conventional parameters and bacteria, along with a new, focused data gathering effort for trace metals, pH, cyanide, and alkalinity (King County 2013).

3. OVERVIEW OF THE FEBRUARY 9, 2017, INCIDENT

3.1 Narrative of the Event

On the night of the event, WPTP was operating at its peak hydraulic capacity of 440 mgd. At 2:12 a.m., there was an interruption to part of the power system, which set a complex series of events into motion that, in turn, backed up the flow in the plant.

During the night shift at WPTP on February 9, 2017, one supervisor and eight operators were on duty. The supervisor and one operator were seated in the Main Control (MC) room, while seven other operators were on the ground of the plant. Three staff members were at area control center (ACC)-1, one was at ACC-2, and the other three were at ACC-3. Eight of the nine crew members on duty that night were licensed, trained professionals and there was also a licensed operator-in-training on duty that night who was shadowing one of the operators at ACC-1.

Before the incident occurred, three of four effluent pumps were running at the EPS. The effluent pumps move treated water from the plant to the outlet in Puget Sound. It takes three pumps to manage peak hydraulic capacity, so Pumps 2, 3, and 4 were running at full speed while Pump 1 was in standby mode. Electrical Switchgear A provides power to EPS Pumps 1 and 2, so when Electrical Switchgear A failed at 2:12 a.m., Pump 2 stopped automatically. Subsequent investigation has been unable to determine whether there was an electrical ground fault that caused the switchgear to fail, or where the electrical ground fault may have occurred.

Electrical Switchgear A is also the only power source to a common hydraulic system that opens the control valves downstream of all four effluent pumps. With power to the hydraulic system down, all four control valves shut, which prevented treated water from flowing out through the outlet, and started to back up the flow in the plant. Effluent Pumps 3 and 4 stopped 2 minutes after the power interruption because of vibration as they pumped against closed valves.

The MC dispatched operators at ACC-3 to restart the EPS pumps. MC then began the procedures for managing and storing wastewater in the conveyance system and the plant’s secondary process area. The aim was to use available capacity and provide additional time for restarting the effluent pumps and restoring normal plant flow (CH2M 2017). The MC operator also started to slow down the RSPs to reduce the inflow to the plant.

With all four control valves at EPS shut, and because of the timing of the high tide, only minimal effluent could be released from the EPS, and tank levels in the plant began to rise in sequence. Rising water levels tripped the high-level float switch in the EPS, which through a relay shut the two primary effluent (PE) gates at the primary sedimentation basins (one gate each for the east and west tanks). The intent of the closing the PE gates is to stop the release of flows from the primary treatment area to the secondary area to prevent flooding of the secondary treatment system (the biological secondary system is sensitive to overloading). With the PE gates closed, water levels in the primary tanks began to rise.

MC saw that the PE gates had closed and dispatched operators at ACC-1 to manually reopen the PE gates. However, the operators were not aware that the PE gates had been closed by an interlock system, and continued their efforts until MC saw that the EPS wet well’s high-high interlock had engaged, which prevents the PE gates from opening. The shift supervisor then instructed the operators to return to ACC-1.

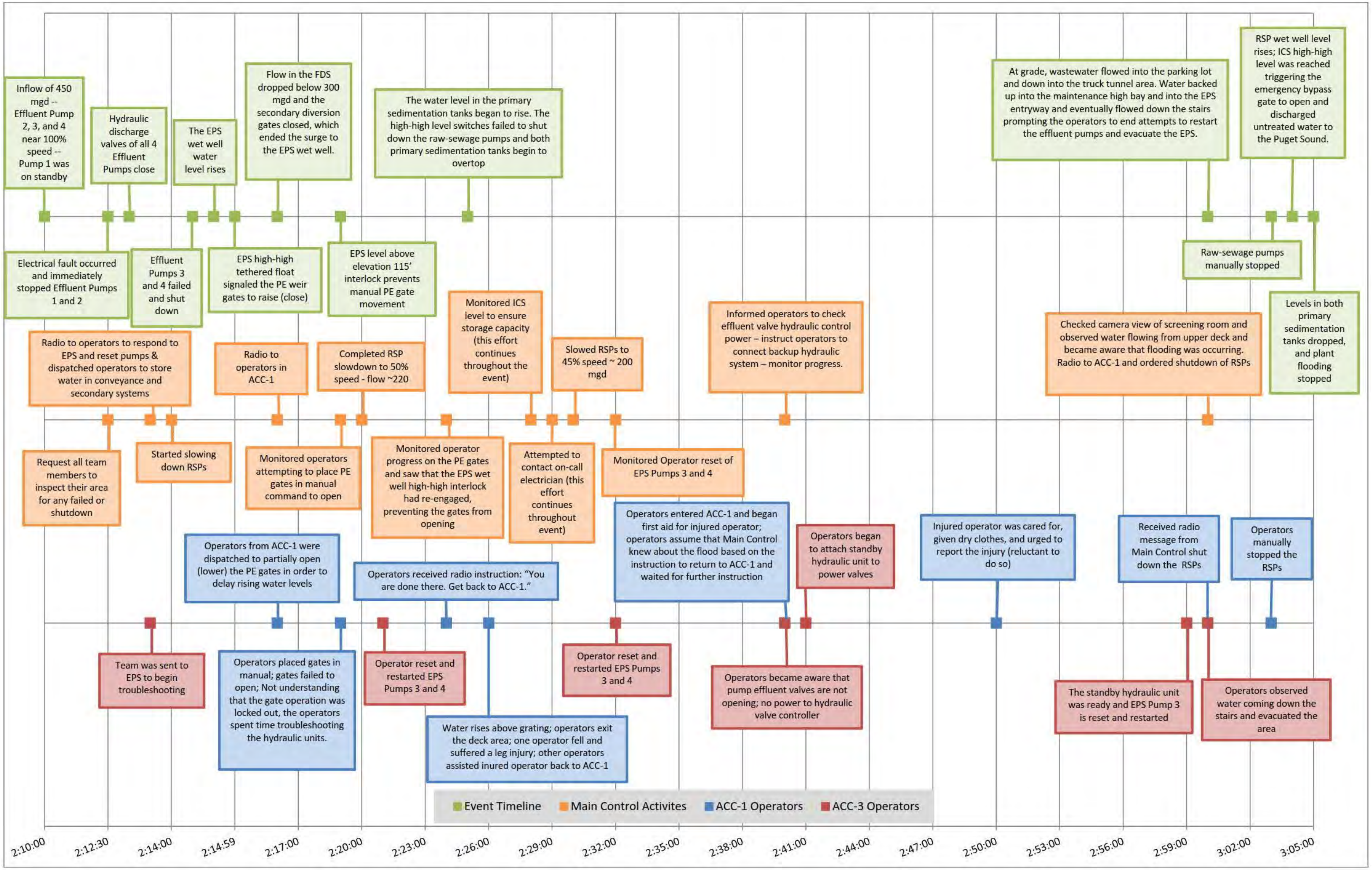
Because the RSPs continued to pump water into the primary treatment area, the primary sedimentation tanks overtopped at 2:25 a.m., just as the operators received the radio transmission to return to ACC-1. The operators noticed that the primary tanks had begun to overtop before receiving the radio transmission from MC, and they started to run for the exits. The covers on the primary tanks were lifted and the water overtopped into the pipe and equipment galleries below. The water in the tunnels was rising quickly, and the operators were running on the primary deck through water deep enough that they could not see the deck. The operator-in-training who was shadowing an experienced operator fell through a hole that was created when a section of grating was pushed up from the waters rising below it. The two other operators assisted the injured operator-in-training back to ACC-1, provided first aid and dry clothes, and explained the procedure for reporting the injury (WTD 2017j). The operators assumed that the MC operator was aware of the flooding, which was why they made no radio transmission to alert MC.

Throughout the flood event, the MC operator was directing operators at the EPS as they attempted to restart the pumps. After several unsuccessful attempts to restart the EPS pumps, the crew discovered that the discharge control valves were closed, and that the hydraulic system that opens the control valves was out of operation. The operators then attempted to connect the “mule” (a portable hydraulic system) to open the control valves to restart Pumps 3 and 4. They were eventually successful, but then noticed water coming down the EPS stairs and the operators evacuated that facility. Water had begun pouring into the parking lot surrounding the EPS building because flows to the EPS from the secondary treatment area had pressurized the EPS wet well which blew out the wet well access panels at ground level.

At 3:00 a.m., the MC supervisor turned to the camera view from the screenings room and saw the water cascading in from the primary sedimentation tanks and issued the request to manually shut down the RSPs. At 3:03 a.m., operators manually stopped the RSPs and the level in the ICS upstream of the pumps began to rise. At 3:15 a.m., the ICS float switches performed their intended function and caused the EB gate to open, which allowed flow to bypass the plant to the EBO. The level in the primary tanks then began to subside and fall below the overflow point, which stopped the flooding of the facility.

WTD has provided a timeline of activities in the MC, EPS, and primary treatment areas (WTD 2017j). The timeline, which describes operator activities at WPTP during the time between loss of power to the EPS and the start of the emergency bypass of flows, is reproduced in its entirety in **Appendix E**. **Figure 6** shows a timeline of key activities of the operators and key events at the plant during the event. WTD also provided a figure of the operations team’s movements during the event, which is reproduced in **Appendix F**.

Figure 6. Timeline of the Event and Actions of Main Control and Operators



(Source: Adapted from WTD 2017j)

3.1.1 Critical Failures during the Event

This section identifies the key critical failures that occurred during the event.

3.1.1.1 Power Outage to Half of the Effluent Pumps

The failure of the EPS was the start of a series of events that resulted in flooding of WPTP. There were no mechanical problems with the pumps; rather, it was the electrical power and pump station support systems that failed.

3.1.1.2 Hydraulic Controls for all Effluent Pump Control Valves had no backup power

One side of the power supply was controlling all of the hydraulic systems that open the control valves downstream of all four effluent pumps at the EPS. With power to the hydraulic system down, all four control valves shut, which prevented treated water from flowing out through the outlet, and started to back up the flow in the plant.

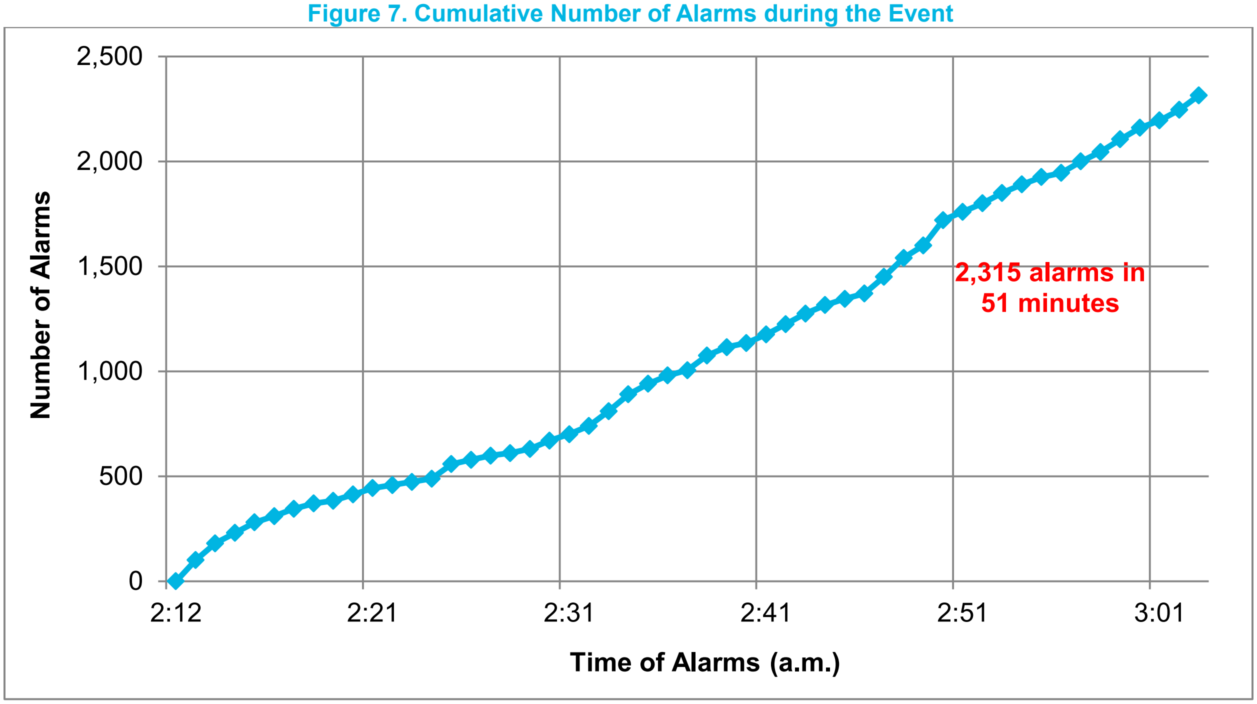
3.1.1.3 High Level Float Switches in Primary Tanks did not activate

As waters in the primary treatment area were rising, they should have triggered a high-level Mercoid float switch that sends an alarm to the SCADA system and reduce the RSPs (which pump wastewater into the plant) to go to idle (minimum) speed. They should have also triggered the high-high float switches (also Mercoid), which should have activated a relay that stops the RSPs. If the high-high float switches in the primary treatment area had signaled the RSPs to stop, then the water in the ICS would have risen as designed. The high water level in the ICS would have triggered float switches to activate the hydraulic system that opens the emergency bypass (EB) gate, and release untreated wastewater through the EBO, which protects the plant from flooding. However, the protective systems did not activate. The high-level float switches in the primary treatment area did not trigger a high-level alarm.

3.1.1.4 Control System Alarms were not prioritized

Also, as the emergency progressed, the number of alarms increased rapidly. More than 120 alarms per minute were coming into the plant control system. **Figure 7** shows the increasing number of alarms that were coming in during the event. The MC operator attempted to view the alarms, but with so many alarms and no critical alarm screen to show the highest priority (life safety/plant failure) alarms, it was difficult to make any decisions.

Figure 7. Cumulative Number of Alarms during the Event



(Source: WTD 2017j)

3.1.1.5 No automated indication of flooding conditions

MC was not aware of the flooding in the primary treatment area until they viewed the flooding from the camera view in the screening room. If there had been automatic indication available, MC would have been made aware of the flooding much sooner and been able to initiate plant shut down operations before the flooding was exacerbated.

3.1.1.6 Manual operation required to shut off Raw Sewage Pumps

The RSPs are critical pieces of equipment in the plant cannot currently be fully controlled from the Ovation control system. They can only be started/stopped from the Local Control Panel located near the pumps.

3.1.2 Root-Cause Analysis

While working to restore WPTP to full operation, WTD commissioned CH2M to perform a root-cause evaluation of the February 9 incident. The *West Point Flooding Investigation Preliminary Findings Report* was issued April 20, 2017 (CH2M 2017). This report found that an abnormal current flow occurred in the main switchgear 50GS relay in the circuit that feeds the A side equipment. This cut off power to Pump 1 at the EPS, but because the hydraulic system that operates the discharge-side control valves was only fed from the A side, these valves closed, leading Pumps 3 and 4 to stop because of vibration. WTD tests and data analysis have been unable to confirm the reason for this ground fault. Additional tests will be performed on the in-plant feed when flows are low enough to allow taking facilities off-line for the test.

The February 9 incident occurred during an evening with lightning activity, but Seattle City Light could not provide any data for the main power feed from the Canal Street substation. However, Seattle City Light data for the other power feed from the Broad Street substation to the plant showed that power on that line was unstable. Several plant operators noticed lights flickering, a common indication of a power "bump" that can lead to equipment shutdown.

Regarding the Mercoid high-high float switches (see **Figure 27** in **Section 6**) in the primary sedimentation basins, the investigation in April 2017 was inconclusive (CH2M 2017). While the float switches were suspected of failing to trigger, the exact cause of this failure was not certain. WTD has since performed tests and evidence indicates a high likelihood that bent rods on the float switches prevented their proper operation. The rods likely were bent during weekly cleaning performed to prevent their fouling.

The high-level (Mercoid) float switches in the preaeration tanks formerly had a relay to turn the RSP (which pump wastewater into the plant) to idle (minimum) speed, but they had been modified to only send an alarm to the MC SCADA. It is not clear when this operational sequence was changed, but WTD staff report that it was changed to only send an alarm signal to the SCADA system, not a control signal to the pumps. However, even these float switches also failed to send a high-level alarm to the Ovation system.

It is also worth noting that the high-high float switches (also Mercoid) which should have activated a relay that stops the RSPs, had been reconfigured at some time in the past to require *two* switches in either the east or west primary sedimentation basins to activate before triggering an alarm to stop the RSPs. WTD staff reported this was done to avoid false alarms from the float switches that would unnecessarily stop the RSPs. Thus, the failure of only one float switch in each tank would be sufficient to prevent the relay from activating. The Ovation system has no record of high-high level alarms from these float switches, so it can be concluded that at least two high-high level switches failed, one in each sedimentation basin.

3.2 Safety, Facility, and Environmental Impacts

Flooding of WPTP resulted in bypasses of untreated stormwater and wastewater into Puget Sound and reduced the level of wastewater treatment while repairs were being made. WPTP repairs were underway and the plant operated under a reduced level of treatment until May 10.

3.2.1 Life Safety

The February 9, 2017, incident represented a major life safety risk. The operators sent to engage the PE gates were on the primary sedimentation basin deck when flows backed up and began flooding the deck and lifting panels. The operator-in-training suffered an injury as the two operators evacuated this area, and the injury could have been much worse than that sustained.

Another operator was in one of the tunnels and discovered water entering the area. This operator went to the locker room to change into taller boots for the high-water condition, but then discovered the water level in the tunnel was rapidly increasing, and made the correct decision to leave immediately. This operator was exposed to a potential risk of engulfment, as well as electrical shock as equipment became submerged.

The injury and the near-miss both highlight safety challenges that may not have been fully recognized: the fact that the primary sedimentation basins can flood very quickly, and actually lift panels and grates; and the fact that the tunnels subject operators to potential entrapment/engulfment and electrocution hazards.

If this flood had occurred during the daytime, when many operators and contractors are normally present in the tunnels and locker room, the consequences could have been much worse.

3.2.2 Facility Damage

Damage occurred when the primary sedimentation tanks overflowed, flooding equipment and pipe gallery tunnels with stormwater, raw sewage, and sludge, while the RSP continued pumping wastewater into the flooding plant. The flooding contaminated and damaged or destroyed millions of dollars of plant equipment including pumps, motors, electrical panels, wiring, transformers, lighting, switches, and motor control centers (WTD 2017j). The flood also contaminated the entire surface area of the mile of gallery tunnels and 2 miles of pipe insulation, and destroyed the plant's staff locker and shower facilities (WTD 2017j). **Table 3** lists the facilities to be replaced as part of the plant recovery effort (WTD 2017g).

The digesters lost power to mixing and gas recovery systems, but the pumps that feed sludge to the first tank, though submerged, were still operating until power completely failed in this area. As mixing and digester gas flow ceased, sludge began to produce gases and foam that forced the lids and belched liquid out of the digesters onto the surrounding plant site. Other than the flooded mechanical and electrical equipment in the tunnels, the primary impacts included the lengthy effort to restore the digesters' biological processes back to normal operation and clean up the area.

Table 3. Summary of Equipment to Be Replaced as a Result of Flood Damage

Equipment to be Replaced	Quantity	Comments
Transformers	14	Eight other transformers were tested satisfactorily.
Motor control centers	8	Total of 120 buckets.
Electric panels	54	Includes breaker panels, field panels, UPSs, environmental control panels, lighting contactors; does not include junction boxes or pull boxes.
Electric motors	101	Additional 70 motors refurbished.
Variable-speed drives	11	
Instrumentation	135	Includes solenoids and Ovation control cabinets.
Mechanical equipment	29	Includes blowers, pumps, water heaters, and mechanical roll-up doors.
Boilers	3	Plant heat and digestion operating systems.
HVAC	22	
Light fixtures	450	Approximate—does not include locker room area, etc.

HVAC = heating, ventilation, and air conditioning; UPS = uninterruptible power supply
(Source: WTD 2017g)

Effluent from the secondary treatment system also flooded the EPS. WTD reported on May 19, 2017, that the resulting damage is estimated at $49 million to $57 million (WTD 2017h).

3.2.3 Environmental Impacts

As discussed in **Section 2**, King County has an existing monitoring program in Puget Sound consistent with its NPDES permit (DOE 2014) and consent decree requirements (EPA 2013). After the event, the County increased the sampling frequency at a subset of four existing offshore monitoring stations from biweekly to weekly. In addition, a new site was added at the emergency bypass outfall and sampled weekly. The County also monitors the West Point wastewater coming into the plant (influent) and the discharge to Puget Sound (effluent) daily for multiple parameters that can affect water quality. The County released regular water quality reports throughout the recovery period that summarized these monitoring data. **Table 4** presents a summary of the water quality reports. The following sections summarize the environmental impacts, which were based on the post incident monitoring data. Additionally, key water quality parameters from monitoring locations were analyzed against the available historic record of data, and are available in **Appendix G.**

3.2.3.1 Upland Area Impacts

The upland area includes the surface area of WPTP and the beaches adjacent to the plant. Flooding of the untreated stormwater/sewage from the treatment plant has the potential to contaminate these upland areas and cause environmental impacts.

The WPTP is composed largely of paved surfaces. The WPTP stormwater conveyance system discharges surface flows to various marine and upland receiving areas (WTD 2005). **Appendix H** presents a map showing WPTP stormwater drainages from the 2005 King County Drainage System Manual. Flooding occurred immediately around the primary settling tanks and nearby areas to the south and east where the stormwater system drains to raw-sewage pipelines that are sent through the WPTP. Wastewaters were not conveyed to upland areas outside of the immediate area of flooding.

Based on the evaluation of the potential pathways for flooded wastewater within the facility to travel, no significant upland impacts (beyond significant damage to facilities and short-term impacts before clean-up) have resulted from the wastewater flooding during this event. Flooded upland areas received a thorough cleaning after the wastewater receded.

3.2.3.2 Marine Impacts

There are two outfalls from WPTP to Puget Sound: the WPTP outfall during normal operations, and the EBO, which is used only in emergencies. Bypasses have the potential to result in local effects at the outfalls and in receiving waters, including biological and chemical hazards. Biological hazards relate to harmful microorganisms that could be present in the discharge and can affect human health. These hazards may affect marine wildlife as well. Chemical hazards relate to potentially harmful chemicals in the discharge and nutrients that could feed algal blooms and disrupt marine ecology. Additionally, nutrients like ammonia and nitrate, which are essential elements for aquatic plants, should not reach high levels. Excess nutrients can cause a sudden increase in aquatic plants that can lead to unfavourable conditions. High ammonia concentrations can be toxic to aquatic organisms, including fish.

WTD estimated that 200 million gallons of stormwater and wastewater were discharged through the EBO during the 18 hours that WPTP was offline on February 9 (WTD 2017b). An estimated 50 million gallons were discharged upstream within the collection system, including marine CSO outfalls upstream of Interbay (WTD 2017b). In the days after partial wastewater treatment resumed, heavy rains prompted two additional emergency bypasses via the EBO on February 15–16 that discharged an estimated 58.3 million gallons of stormwater and wastewater over 20 hours (WTD 2017c). WTD has since performed a closer analysis of the discharges, including hydraulic modeling, and has revised the estimates of discharges from the WPTP as 180 million gallons on February 9, and 55 million gallons on February 15–16, for a total of 235 million gallons.

There have been no reports of additional bypasses occurring since February 16. **Appendix I** provides the letters that were sent to DOE about the bypass events.

Table 4. Water Quality Monitoring and Analysis of Effluent and Marine Monitoring in Puget Sound

	Reporting Dates (2-Week Delay from Monitoring Date)					
	17-Mar	31-Mar	14-Apr	28-Apr	12-May	26-May
Marine Monitoring (13 locations)						
Nutrients						
Dissolved Oxygen						
Fecal Coliform						
Beach Monitoring (20 locations)						
Fecal Coliform						
Effluent Monitoring						
Total Suspended Solids[1]					*	
Biochemical Oxygen Demand[1]					*	
Chlorine[1]					*	
Fecal Coliform[1]						
Metals and Organics	X	X		X	X	X
Whole Effluent Toxicity—Acute Test[1,2]						
Whole Effluent Toxicity—Chronic Test[1,3]						
Additional Monitoring and Analysis						
Sediment at West Point Main Outfall[1]	Sampling planned for August/September					
Mixing Discharge Analysis[4]						
Loading Analysis[5]						X[6]
Dispersion Analysis	Historical analysis (completed)					

Key:

Green = normal value or meeting standards

Orange = abnormal value or not meeting standards

Yellow = within water quality standards, but variable results

Pink = concern or fluctuating results

* = Effluent limitations for biochemical oxygen demand, total suspended solids, and residual chlorine were exceeded in April. However, the secondary treatment process was restored by the end of April, and other processes at West Point and the ability to comply with these effluent limits resumed on May 10.

X = Tested; analysis not available from Summary.

(Source: Adapted from WTD 2017i)

1 Permit-required monitoring.

2 Test conducted on March 21, 2017 (no toxicity). The acute toxicity test is conducted to observe for potential adverse effects of exposing sensitive aquatic organisms to effluent over short test periods (2–4 days depending on the test organism used).

3 Test conducted during April 4–9, 2017 (no toxicity). The chronic toxicity test is used to observe for potential adverse effects on organisms over a longer period of 7 days.

4 Effects of effluent on metals, ammonia, and chlorine in Puget Sound at the outfall.

5 Characterizes the loadings during the period of reduced treatment.

6 In preparation.

After the event, the plant operated at a limited hydraulic capacity and treated effluent only to primary treatment standards. Through most of April, effluent was not meeting the NPDES permit limits for BOD_5 and TSS. The chlorine residual met all but two daily limits in April, but exceeded the monthly limit. The plant was returned to full hydraulic capacity through both primary and secondary treatment systems by April 26, and achieved 100% compliance with all effluent limits specified in the WPTP NPDES permit by May 10.

Table 4 summarizes the data from the County monitoring reports (WTD 2017i). To date, the monitoring data indicate there are normal levels of bacteria, trace metals, and nutrients in Puget Sound.

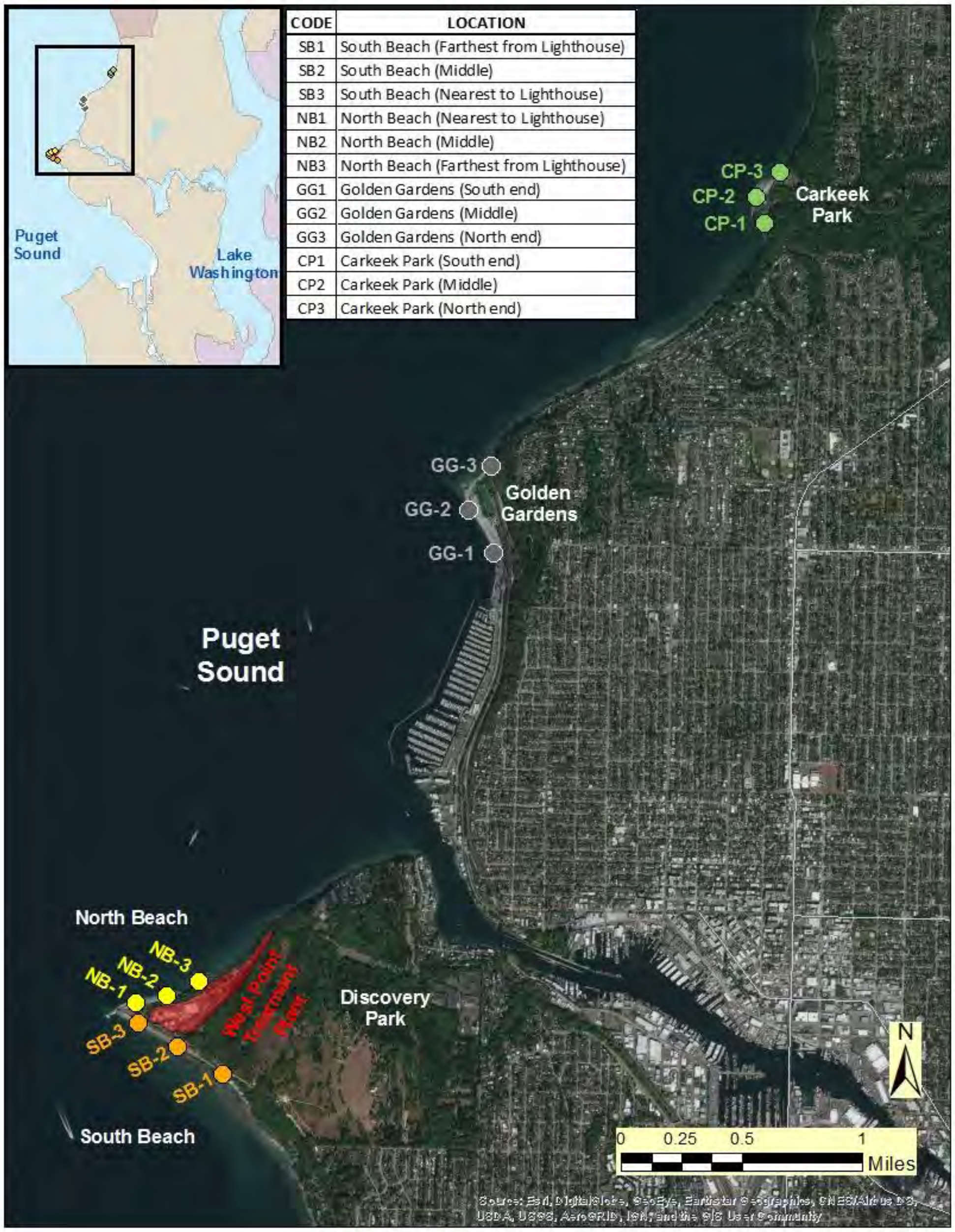
There have been no available records of harm to fish and wildlife after the bypasses on February 9 and February 15–16, nor during the recovery period until May 10. County marine scientists report that the relatively short duration of the discharge, the dilution of sewage from a large volume of stormwater (90% of flow was stormwater, 10% wastewater), and the large tidal exchange and currents in the vicinity of the outfall resulted in rapid dispersion of the flow (WTD 2017d).

For both the acute (Environmental Lab 2017a) and chronic toxicity tests (Environmental Lab 2017b), which test the potential adverse effects of exposing sensitive aquatic organisms to effluent, the data show that the test results have been normal, with no substantial toxicity observed in the effluent. County marine scientists do not expect the discharge of additional solids and organic matter to result in long-term harmful effects on aquatic organisms (WTD 2017d). The County will continue to monitor and look for impacts on both waters and sediments around the WPTP outfall.

3.2.4 Public Health

The County's Environmental Lab sampled waters and tested for bacterial contamination at the nearby public beaches at Discovery Park, Golden Gardens, and Carkeek Park (**Figure 8**). Two types of fecal bacteria (fecal coliform and Enterococcus) are used for evaluating the suitability of water for human water contact recreation such as swimming and scuba diving, and shellfish consumption. The bacteria and other pathogens that go into marine waters after an overflow event do not thrive well in a cold, salty marine environment and die off within about 48 hours (WTD 2017d).

Figure 8. Public Health Sampling Locations at West Point, Golden Gardens, and Carkeek Park



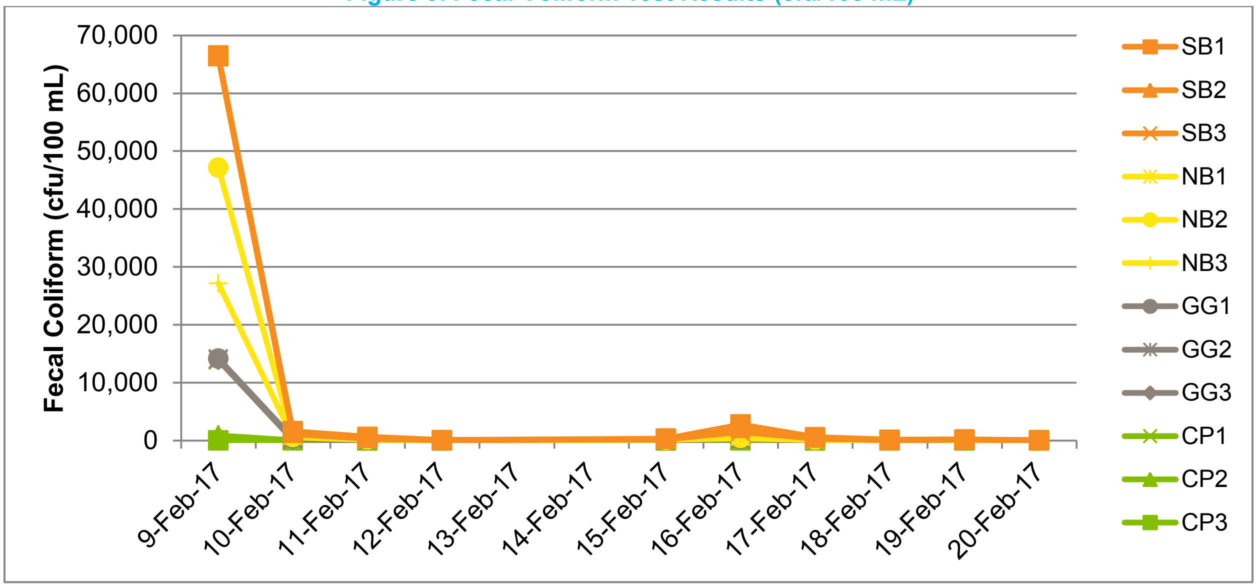
(Sources: Adapted from WTD 2017b; WTD 2017c)

In the event of a sewage overflow or emergency bypass, the County notifies health and regulatory agencies and posts warnings to avoid contact with water at public beaches and access points. Immediately after the event, fecal bacteria concentrations were more than 60,000 colony-forming units per 100 milliliters (cfu/100 mL) in beach samples at West Point, Golden Gardens, and Carkeek Park (**Figure 9** and **Figure 10**).

Fecal coliform levels are considered safe if they are below 43 cfu/mL.[2] Notices were posted at these beaches for closure to water contact recreation. Bacteria levels quickly declined over several days, and were less than 10 cfu/mL by February 20. All beaches were reopened on February 21, and have been open since then.

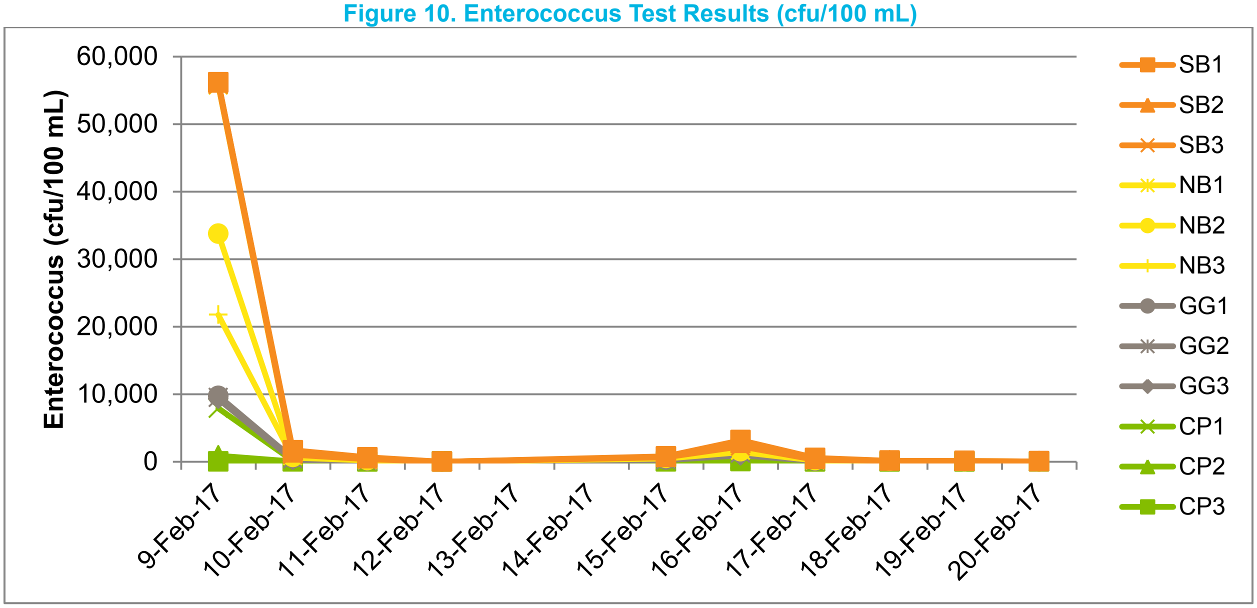
[2] The State of Washington has a two-part standard to protect human primary contact recreation and shellfish consumption in marine waters. The standard includes a 14 cfu/100 mL geometric mean average and a 43 cfu/100 mL peak concentration (the peak concentration is not to be exceeded in greater than 10% of samples). These standards are used for comparing data from multiple samples at a station rather than a single sample. (Source: WTD 2017e.)

Figure 9. Fecal Coliform Test Results (cfu/100 mL)



(Sources: WTD 2017b, 2017c)

Figure 10. Enterococcus Test Results (cfu/100 mL)



(Sources: WTD 2017b, 2017c)

Based on the review of available records, WPTP is now meeting NPDES requirements. No additional reports are available regarding public health.

4. RESPONSE AND RECOVERY ACTIONS

The loss of equipment in the flood led to an immediate and complete shutdown of WPTP. Within 18 hours, plant staff returned the plant to half its hydraulic capacity and limited treatment with screenings, partial primary treatment, and final effluent disinfection and dechlorination (WTD 2017j). Through most of April, the effluent was not meeting the NPDES permit limits for BOD_5 and TSS. The chlorine residual met all but two daily limits but exceeded the monthly limit. However, a significant repair and replacement effort by plant staff and contracted support returned WPTP to its full hydraulic capacity for both primary and secondary treatment systems in 80 days, and the plant achieved 100% compliance with all limits specified in the WPTP NPDES permit after 90 days (by May 10). Additional recovery efforts continue as temporary power systems are replaced with new permanent installations.

4.1 WTD Emergency Response

In January 2017 WTD issued an updated emergency response plan (ERP), the *West Section Emergency Response Plan* (WTD 2017a). Chapter 11 of the West Section ERP specifically addresses hazards of flooding inside the plant. This document is utility-wide and therefore not custom-tailored to WPTP, but it does provide insight into procedures to follow during and after flooding at the plant. This plan outlines the standard safe-workplace policies and procedures required for employee protection during an emergency:

- initial response procedures, including notification, roll call and evacuation, and use of alarms, beacons, and emergency communications systems;
- operations of the Division Incident Response and Emergency Coordination Team and Incident Command System;
- specific hazards and procedures for dealing with various types of emergencies, focusing on the types that have the greatest potential to occur at treatment plants;
- potential emergencies that could affect WTD facilities, including medical emergencies, chemical releases, fires, explosions, technology and infrastructure failures, natural disasters, activities of unauthorized people, and workplace violence; and
- a description of how incident investigations are conducted.

WTD reported the incident to DOE immediately and continued to update the agency about operational conditions and permit compliance. DOE is a regulatory agency responsible for enforcing the permit conditions under which WPTP operates.

4.1.1 Public Health Response

Following protocol from its NPDES permit, King County notified health and regulatory agencies and posted warnings to avoid contact with the water at public beaches and access points when an overflow event occurs. The County's Environmental Lab sampled waters and tested for bacterial contamination (WTD 2017b, 2017c).

Warning signs were posted at beaches and docks until Public Health–Seattle and the County reviewed lab results and approved their removal. WTD also posted incident updates on its webpage to give people choices about recreating in waters where an overflow occurred.

4.1.2 Communication with Stakeholders

King County was committed to keeping people informed as it worked and continues to work to restore WPTP. The County has created a webpage (http://www.kingcounty.gov/depts/dnrp/wtd/system/west/west-point-restoration.aspx) dedicated to progress updates and notices about the event and restoration efforts. The County continuously reported facts as soon as they were available and informed agencies or groups that might have been affected as soon as possible, such as tribes, local agency health and parks departments, and beachgoers.

The webpage also includes links to marine and environmental monitoring reports.

4.1.3 Water Quality Monitoring

WTD conducted permit-required and voluntary supplemental monitoring at WPTP after the plant failure. During repairs to restore operations at WPTP, the frequency of water quality and environmental monitoring was increased to assess the effects of plant operations on Puget Sound while a reduced level of treatment was provided.

4.2 Recovery Actions

Faced with this unique emergency, WTD initiated a series of actions to restore operations. Immediately after the event, WTD mobilized crews and equipment for around-the-clock response to the incident. Protecting employee safety was paramount during this period. WTD obtained a waiver of standard procurement rules so that it could procure emergency engineering, equipment purchases, and installation services. WTD implemented a plan to use the east primary tanks (basins) and provide as much treatment as possible while carefully avoiding bypasses during recovery.

WTD also brought staff in from elsewhere in the organization to assist on an emergency basis in restoring operations. WTD implemented comprehensive restoration actions at WPTP after the overflow event. At the time of this report, restoration work is still ongoing. The plant was restored to its full operational capacity by April 27 and was back to full treatment compliance by May 10.

These incident response recovery actions were documented and posted on the county's website (http://www.kingcounty.gov/depts/dnrp/wtd/response/incident-response.aspx) and are available in **Appendix J.**

4.2.1 Timeline of Recovery Milestones

Table 5 is a timeline of recovery milestones as reported by WTD (WTD 2017k).

Table 5. Timeline of Recovery Milestones

Milestone	Date	Duration
Failure and flooding at West Point Treatment Plant	February 9, 2017	0 days
Primary sedimentation basins and chlorine disinfection system partially online	February 9, 2017	18 hours
Pump-out of galleries	February 13, 2017	4 days
Temporary minimum light and ventilation to galleries	February 15, 2017	6 days
Temporary MCCs delivered/installed/online	February 27, 2017	18 days
Hot water boiler online, heat loop running	March 8, 2017	27 days
Dewatering and thickening processes online	March 28, 2017	47 days
Primary preaeration tanks online	April 3, 2017	53 days
All six digesters operational	April 24, 2017	74 days
MLSS recovery	April 25, 2017	75 days
Secondary treatment online—restart to 300 mgd	April 27, 2017	77 days
Primary clarifiers available for high flows	April 28, 2017	78 days
NPDES permit compliance achieved	May 9, 2017	89 days

MCC = motor control center; mgd = million gallons per day; MLSS = mixed liquor suspended solids; NPDES = National Pollutant Discharge Elimination System
(Source: WTD 2017k)

4.2.2 Internal Review of Plant Failure

As mentioned in **Section 1**, other assessments of the event and operations at WPTP were conducted in parallel with this investigation.

4.2.2.1 After Action Self-Assessment

In April and May 2017, WTD staff conducted investigations at WPTP to gather information from plant staff, records, and systems to determine what occurred during both the February 9 event and other events that resulted in emergency bypass of untreated wastewater from the plant (WTD 2017j). This effort culminated in the *After Action Self-Assessment Report* (WTD 2017j).

The recommendations from the self-assessment report draw not just from the assessment team, but also from the plant's O&M staff. **Table 6** provides actionable recommendations from the self-assessment. These are reproduced in their entirety from the WTD report.

Table 6. Recommendations from the *After Action Self-Assessment Report*

Item	Actionable Recommendation
1	Replace all Mercoid 301 Series liquid level controllers across the division with tethered float switches similar to the new design being used in WPTP's primary treatment area.[1]
2	Update WPTP's hydraulic safety system.
3	Evaluate all hydraulic system life-safety/interlocks and components.
4	Ensure that hydraulic system testing is compliant with the SOP.
5	Functionally test float switches by manipulating the float, not just the switches.
6	Perform CCTV inspection of the Old Fort Lawton Tunnel to verify no damage from a possible surge resulting from the event (delayed opening of the EMO gate).
7	Evaluate the EPS wet-well structure for damage that may have occurred during surcharging.
8	Provide unique labels identifying life-safety equipment.
9	Provide an automated calling service in Main Control for contacting staff.
10	Design/install a transfer switch to provide electrical power automatically to all effluent pumps and Pratt (control) valves in the event of a power interruption on either the A or B electrical feed.
11	Develop an Ovation simulator to train operators on all critical plant operations under normal and unusual scenarios.
12	Evaluate systems for component failure tolerance (single point of failure not causing larger system failure).
13	Evaluate the cause of unexplained alarms originating from liquid level controllers in the preaeration basins.

CCTV = closed-circuit television; EMO = Emergency Marine Outfall; EPS = effluent pump station; OP = standard operating procedure; WPTP = West Point Treatment Plant

(Source: WTD 2017j)

[1] Note: Action complete.

Part of this assessment was an After Action Review (AAR) meeting. An AAR is a discussion of an event that focuses on performance standards and enables colleagues to discover for themselves what happened, why it happened, and how to sustain strengths and improve on weaknesses. On April 10, the Operations crew on duty and other O&M staff and management met to participate in the AAR. That AAR meeting serves as the basis for learning from successes and failures. This AAR will provide benefits when its results are applied to future situations. Future AAR meetings are scheduled with the Electrical and I&C groups, and with the Mechanical group that worked on the treatment plant restoration.

4.2.2.2 Resiliency Action Plan

The WTD Operations Manager issued the document *Memorandum: February 9, 2017 West Point Flood Recovery—Resiliency Action Plan* (WTD 2017f) on May 31, 2017. This memorandum revisits the damage to the plant, the root-cause analysis, and the self-assessment, and then proceeds to document actions that have been or will be taken to eliminate the risk of future flood events at WPTP. The list contains both structural and nonstructural actions to be implemented to reduce both the probability and consequences of failure. The summary table from this document is presented below in its entirety as **Table 7**, organized in order of expected completion date. For explanations of the items listed, please refer to **Appendix K** (WTD 2017f).

Table 7. West Point Treatment Plant Flood Recovery—Resiliency Action Plan

Device/System to Improve	Corrective Action	Specific Corrective Action	Corrective Action Start Date	Corrective Action Completion Date
Raw-Sewage Pump—Primary Sedimentation Level Interlock	Replace existing system	New float design and installation	February 2017	May 2017
Effluent Pump Station Power Supply	Redundant power	Automatic control switch	February 2017	May 2017
Influent Control Structure Gate–Wet Well Level Interlock	Replace existing system	New float design and installation	April 2017	June 15, 2017
Operator Training	Formal shift ops training	New Shift Sup-Trainer to enhance: • shift sup continuity • ops training	May 2017	June 2017
Plant Hydraulic Simulator Program	Develop complete model	Ovation user interface hydraulic model	January 2016	August 2017
EPS Pratt Valve Operations	Redundant control	Design, construct, and install redundant valve hydraulic system	February 2017	January 2018
Life Safety Report and implementation	Review control systems	Contract with CH2M to conduct study	May 2017	January 2018
SCADA Alarm Management	Prioritize critical alarms	Program Ovation to display critical alarms until acknowledged	June 2017	January 2018
Tunnel Access Protocols	Administrative controls	Limit tunnel access during high flows	February 2017	Ongoing
Life Safety Management	Develop LSM-specific maintenance and testing procedures	Apply LSM-specific procedures to all identified Life-Safety issues identified in #8	January 2018	Ongoing

EPS = effluent pump station; LSM = Life Safety Management; ops = operations; SCADA = supervisory control and data acquisition
(Source: WTD 2017f)

5. HAZOP Analysis

The County requested that the independent assessment include recommendations to ensure that catastrophic failures like the event of February 9, 2017, will not occur again at WPTP. To develop a forward-looking evaluation, AECOM conducted a HAZOP (hazard and operability) analysis. This analysis evaluated critical unit operations and processes at WPTP to determine where the potential may exist for other failures that could lead to similar flooding or facility damage. The procedure was modified for the independent assessment effort in this study.

HAZOP is recognized internationally and is a standard analysis technique sanctioned by the International Electro-technical Commission (IEC). The IEC is a worldwide organization for standardization comprising all national electro-technical committees (IEC National Committees). The HAZOP process also has been adopted by the British Standards Institute as a standard for systems evaluation. Although it has not been formerly adopted in the United States, many communities are implementing this process for design reviews and risk management studies.

The HAZOP process was initially developed in the 1960s to analyze major chemical process systems but has since been extended to other areas. HAZOP analyses are conducted to review design and engineering issues that otherwise may not have been found. It identifies and evaluates problems that may represent risks to personnel or equipment. Such analyses are generally performed at the latter stages of detailed design to limit construction issues and contract changes, or modifications required after construction. It was determined that this formal process could be modified for the existing WPTP, and would create a structure for analysis of failure mechanisms.

The analysis is a structured and systematic examination of a complex planned or existing process or operation. A HAZOP analysis is conducted with the objective of identifying the following potential problems within the system:

- hazards, whether essentially relevant only to the immediate area of the system or with a much wider sphere of influence, such as some environmental hazards; and
- operability problems, particularly the causes of operational disturbances and production deviations that are likely to lead to nonconforming products or substandard results.

An important benefit of HAZOP analyses is that the knowledge obtained by identifying potential hazards and operability problems in a structured and systematic manner is of great assistance in determining appropriate remedial measures.

The HAZOP technique breaks down a complex system with multiple interdependent components into individual processes or sub-elements for detailed study. Within these individual process areas, further sub-elements or “nodes” can be evaluated. For example, at the RSP station, nodes would include the pumps, engines, level and flow instruments, fuel supply, electrical service, and instrumentation/control elements.

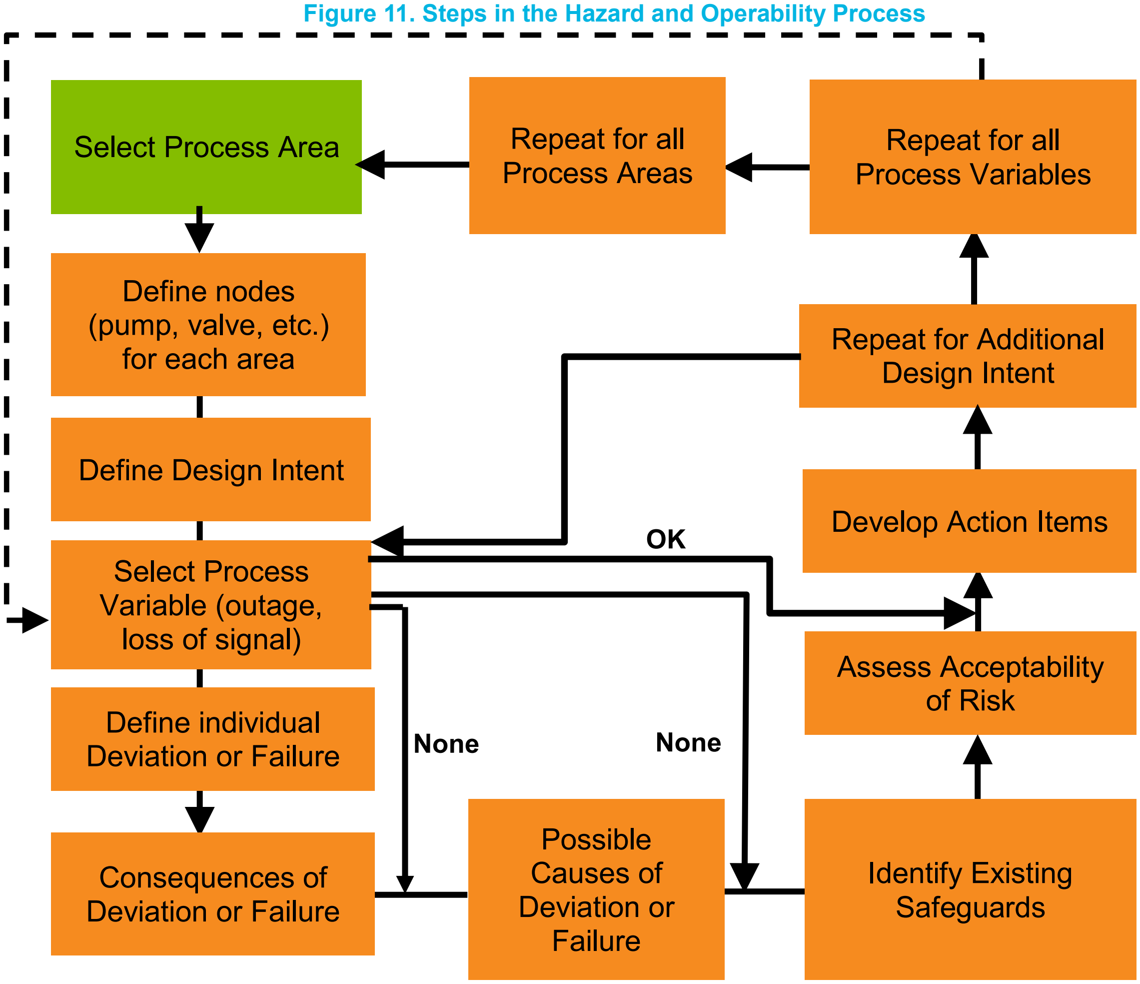
The HAZOP technique is qualitative, calling on the experience of design professionals and other participants to identify potential hazards and operability problems. To provide structure and direction for the review process, standardized guide-word prompts are applied to the review of each node. The technique aims to stimulate participants’ imagination in a systematic way to identify hazards and operability problems. HAZOP should be seen as an enhancement to sound design using experience-based approaches such as codes of practice, rather than as a substitute for such approaches.

These studies require an experienced multidisciplinary team to participate in team discussions or HAZOP workshops. A characteristic feature of a HAZOP analysis is the workshop or “examination session,” when a multidisciplinary team guided by a study leader systematically examines all relevant parts of a design or system. The relevant international standard calls for team members to display “intuition and good judgment” and for the meetings to be held in “a climate of positive thinking and frank discussion.”

Many tools and techniques are available to identify potential hazards and operability problems: use of checklists, fault modes and effects analysis, fault tree analysis, and HAZOP. Some techniques, such as use of checklists and what-if analyses, can be used early in the system's life cycle when little information is available, or in later phases if a less detailed analysis is needed. HAZOP studies require more details regarding the systems under consideration, but produce more comprehensive information regarding hazards and errors in the system design.

The process can be represented by the flow chart in **Figure 11**, which shows the steps required to identify each node in the selected process and explains how they are evaluated.

Figure 11. Steps in the Hazard and Operability Process



For this evaluation at WPTP, AECOM limited the HAZOP analysis to process-critical components that would cause a flood at the plant if operational failure were to occur. The following components of the plant were considered critical unit operations and processes:

- Plant hydraulics
- Influent control structure
- Preliminary treatment
- Raw-sewage pumps
- Preaeration and primary sedimentation
- Flow diversion structure
- Effluent pump station

AECOM discipline leads were instructed to evaluate each unit operation or process based on several considerations:

- Function

- How the unit or process operates
- What controls the flow, level, or operations sequence
- Failure modes
- Consequences of failure
- Current WTD activities to resolve/prevent future failures
- Areas for further investigation

A customized HAZOP workshop was held as part of the analysis. Participants included the County Council's project manager and staff; key staff from WTD management operations, maintenance, and engineering; and AECOM team leaders and technical advisors. The group conducted a roundtable review of each main component of WPTP that failed on February 9, 2017, and of the plant's other critical components. This approach allowed the County to vet a long list of potential failure modes which are discussed in **Section 6**.

6. SYSTEM EVALUATION

This section reviews WPTP processes as a system, and then evaluates the areas reviewed by the HAZOP process. The following discussion first examines the hydraulics, process and mechanical systems, then evaluates electrical and system instrumentation, and then the O&M processes.

6.1 Plant Hydraulics

WPTP is rated by the Washington Department of Ecology to treat a maximum-month design flow of 215 mgd (DOE 2014). The overall plant hydraulic capacity is 440 mgd. CSO-related bypasses of the secondary treatment portion of the WPTP are authorized when the instantaneous flow rate exceeds 300 mgd as a result of precipitation events.

An important concept is the firm capacity of each component at WPTP. This concept, promoted by EPA (2005), is that the firm capacity for each unit operation corresponds to the capacity of that unit operation with one basin or piece of equipment out of service. For example, the firm capacity of the EPS, which has four pumps, would be the capacity of three pumps, with the fourth being out of service.

Firm Capacity

Firm capacity is based on plant operations with one component out of service for each unit in operation. For example, the firm capacity of the EPS, which has four pumps, would be the capacity of three pumps, the fourth being out of service.

Table 8 shows the firm capacity of each unit operation, as estimated by AECOM based on evaluation of information obtained from WTD.

Table 8. Firm Capacity of Key Unit Operations

Process	Component	Quantity	Flow (mgd)		
			Per Unit Capacity	Instantaneous Capacity	Firm Capacity (Quantity - 1)
ICS	ICS Sluice Gate	4	118	472	354
	Bar Screen	6	88	528	440
RSP	Raw-Sewage Pump	4	120	480	360
Primary Treatment	Preaeration Tank	4	110	440	330
	Primary Sedimentation Tank	12	37	444	407
	Primary Weir Gate	2	220	440	220
IPS	IPS Pumps*	3	164	492	328
Secondary Treatment	Contact Channel	4	110	440	330
EPS	EPS Pumps	4	144	576	432

EPS = effluent pump station; ICS = influent control structure; IPS = Intermediate Pump Station; mgd = million gallons per day; RSP = raw-sewage pump

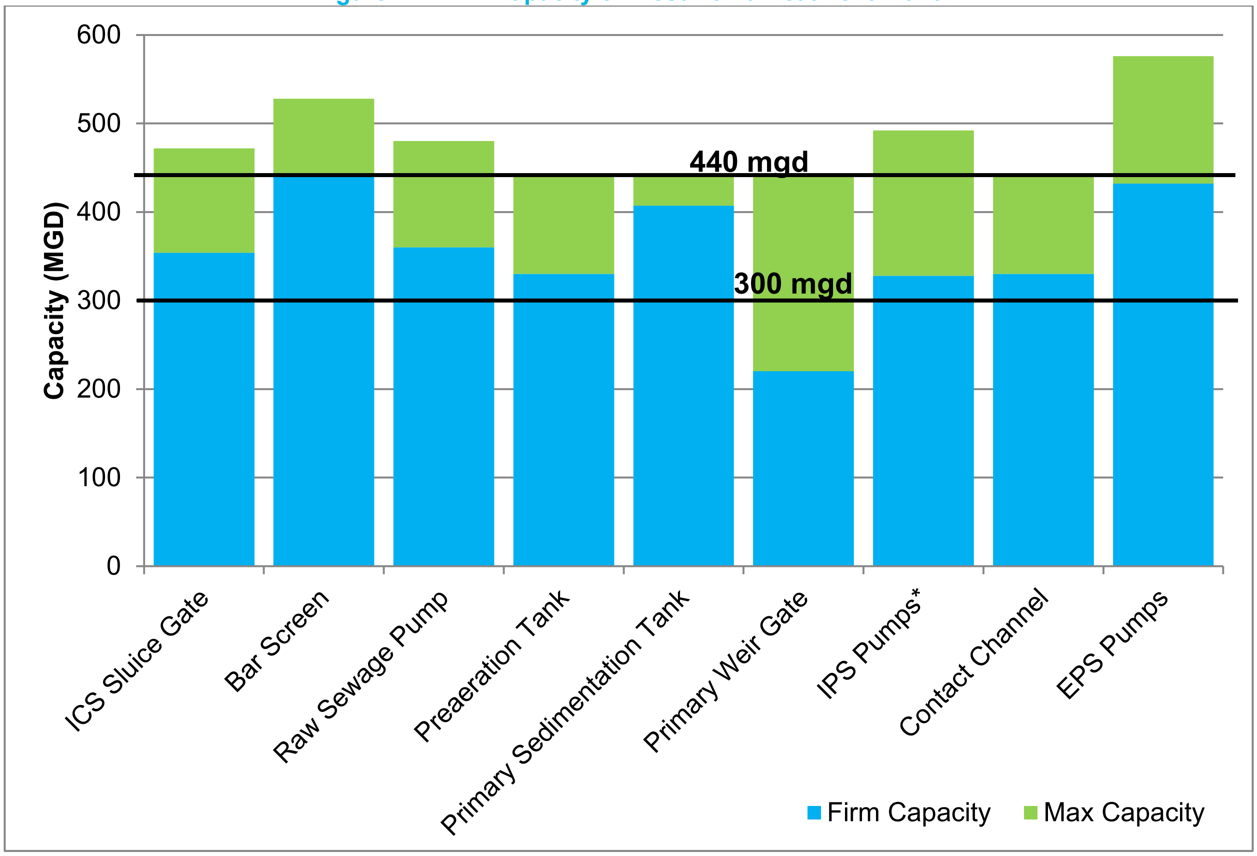
** The IPS pumps do not need to meet the rated plant capacity of 440 MGD as any flows greater than 300 MGD will be diverted around the secondary process via gravity.*

The firm capacity of WPTP is significantly less than the hydraulic capacity of 440 mgd. Therefore, when the plant operates at a peak capacity of 440 mgd, almost all key units and equipment must be fully operational to pass this flow. Although some of the plant's systems (e.g., the bar screens) have sufficient redundancy, most of the system does not. For example, if one of the RSPs were out of service, the remaining capacity is 360 mgd.

Lack of redundancy combined with several interdependencies in the complex system gives plant operators very little time to react during peak-flow events. The incident of February 9, 2017, showed that failure in one area of the plant during high flows can quickly lead to a cascade of events at other locations in the plant. In order to meet the firm capacity, a system must provide redundancy in terms of extra pumps or additional basins.

The firm capacity of each component at WPTP is illustrated in **Figure 12**, compared with the plant's instantaneous maximum hydraulic capacity of 440 mgd and the primary treatment capacity of 300 mgd.

Figure 12. Firm Capacity of West Point Treatment Plant



** The IPS pumps do not need to meet the rated plant capacity of 440 mgd, as any flows greater than 300 mgd will be diverted around the secondary process via gravity.*

Design standards for CSO control systems do not normally require redundant units because the frequency of operation is intermittent (DOE 2008). However, if flow conditions are such that all the pumps are required to operate several times per year, then redundancy is needed. **Table 9** shows that the secondary treatment portion of the WPTP has been used 16-46 times per year over the past 8 years. Therefore, the recommended firm capacity of the plant should meet the peak hydraulic capacity of the plant of 440 mgd.

Table 9. Annual Number Days per Year that Peak Daily Flow Exceeds 300 mgd (2009-2016)

Year	# of Days Peak Daily Flow Exceeds CSO Related Bypass Limits
2009	34
2010	34
2011	30
2012	44
2013	16
2014	46
2015	32
2016	43

Additionally, CSO-related bypass flows must receive solids and floatables removal, primary clarification, and disinfection (DOE 2014). Therefore the firm capacity for components that provide primary treatment must be able to meet the peak hydraulic capacity of the plant of 440 mgd.

6.1.1 Design and Operation

The design and operation of WPTP was described in **Section 2.2.** This section discusses the design and operation of the plant hydraulics system.

Many treatment plants rely on influent pumping to lift the water at the head of the plant, and then operate by gravity flow through the rest of the plant. However, WPTP's hydraulic profile differs from that of typical wastewater treatment plants, as flow through WPTP is lifted three times through a series of pump stations (**Appendix L**). Pump stations lift water to the primary sedimentation tanks, then up to 300 mgd to the secondary treatment trains, and then pump the treated effluent to the outfall when the combination of flows and Puget Sound tide levels exceed the ability for effluent to flow via gravity.

WPTP has a cascading hydraulic control system based on levels in the various hydraulic structures. A high level alarm at the EPS wet well, which is at the end of the WPTP processes, signals the primary effluent gates in the primary tanks to close. This causes the water level in the primary tanks to rise, and when the high level is reached, it triggers the RSPs to stop pumping. When the RSPs shut down, the water level in the RSP wet well raises until it triggers a high level alarm, which signals the influent gate to close at the ICS. Once the ICS high level is reached, it signals the emergency bypass gate to open. **Figure 13** shows a simplified schematic of the current cascading hydraulic control system.

6.1.2 Performance Evaluation

After the EPS pumps failed, the water level in the EPS wet well rose rapidly. The high water level caused the primary effluent gates to close, as designed with hardwired interlocks. The water level in the primary tanks started rising, but the float switches designed to detect high and high-high water levels failed. These switches are designed to shut off the RSP, which pumps water into the primary tanks. Instead, the RSPs continued to pump wastewater into the primary tanks, causing the primary tanks to overflow.

When the RSPs were manually stopped, the level in the ICS upstream of the pumps began to rise. At 3:15 a.m., the ICS float switches performed their intended function and caused the EB gate to open, which allowed flow to automatically bypass the plant and divert into the EBO.

Instantaneous flows exceeding the plants peak capacity of 440 mgd were measured during the February 9, 2017 event. Influent flows from the collection system are managed via Ovation control and operations manipulation to target flows for the hydraulic capacity. Occasionally flows, which are measured downstream of the EPS, may exceed hydraulic capacity (for short durations) without a bypass event. WTD staff members have reported that the flowmeter has an error of up to 10%.

WPTP does not have adequate storage capacity to allow time for responding to emergency situations involving high flow. An evaluation of the collection system is recommended to identify ways to improve flow management in the collection system and the potential for additional storage to reduce the strain of high flows/higher-than-rated capacity flows to WPTP. An improved control strategy could be implemented, such as by using real-time controls or control strategies based on historical flow, rainfall, and system response information. The evaluation should focus on maximizing the use of the existing infrastructure. For example, there is potential to use the Old Fort Lawson Tunnel for storage past the Diversion Structure. The evaluation should also consider primary treatment technologies such as High Rate Clarification for future implementation in the collection system.

One of the most critical points of failure at WPTP is the EB gate. If the gate fails to open, the facility can be flooded, posing a serious life-safety risk. Passive overflows that do not rely on equipment and controls provide the most fail-safe mechanism to protect the plant and workforce. It is recommended that passive overflows be evaluated to replace the EB and EMO gates. These can include reconfiguring the ICS and flow diversion structure (FDS) with a weir wall and/or multiple gates to reduce the risk of failure. This would require a discussion with Ecology, as a bypass could occur without any human intervention. However, passive systems do not require any power supply and could help prevent a future incident from occurring.

Another potential strategy that could help prevent a future incident from occurring would be to permit WPTP as a CSO outfall. Although King County has 38 CSO outfalls in the Seattle area, WPTP is not permitted as a CSO outfall. This would require coordination with the permitting authority, Ecology to regulate WPTP a CSO outfall.

6.1.3 Potential Failure Mechanisms and Mitigation Strategies

Table 10 summarizes the potential failure mechanisms and potential mitigation strategies for plant hydraulics.

Figure 13. Schematic of West Point Treatment Plant Hydraulic Control Philosophy

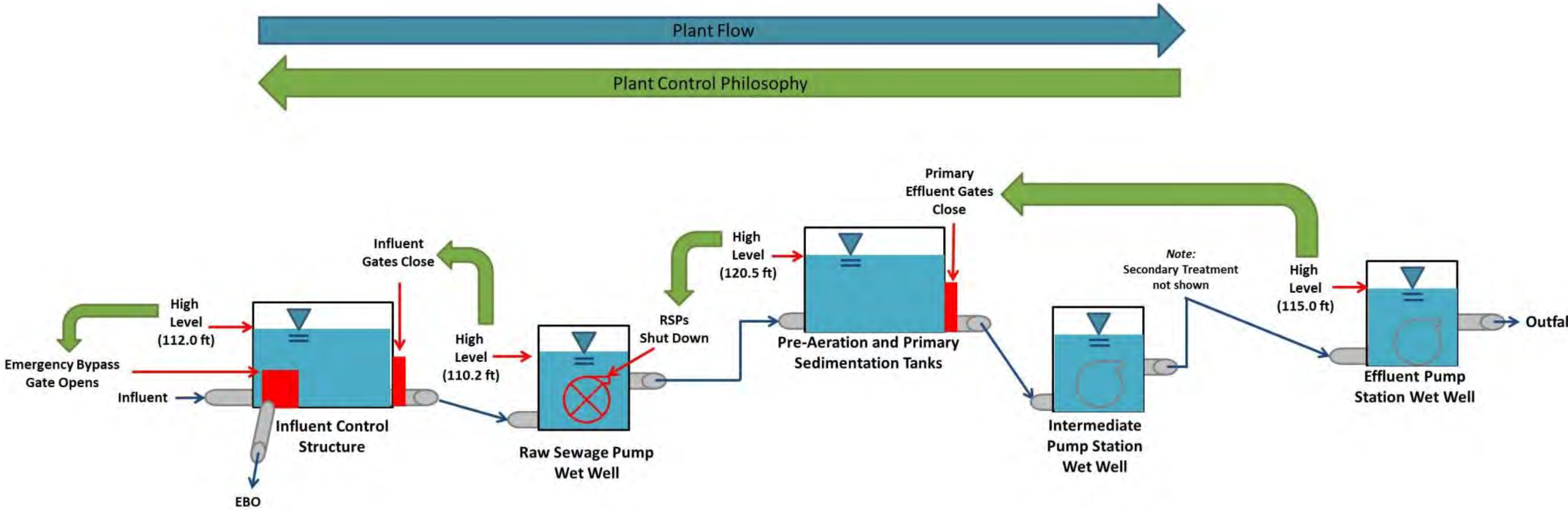


Table 10. Potential Failure Mechanisms and Mitigation Strategies—Plant Hydraulics

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
WPTP has limited storage capacity and receives instantaneous flows exceeding its capacity.	Limited time to respond to emergency situations; high strain on equipment; potential to flood the plant.	Evaluate ways to improve control strategies and flow management within the collection system.	Help delay peak flows to WPTP.
		Evaluate the collection system to identify new areas for storage.	For example, the Old Fort Lawton Tunnel.
		Add primary treatment technologies to the collection system.	Relieve WPTP during high flows.
		Consider implementing passive overflows at key locations.	Passive overflows that do not rely on equipment and controls provide the most failsafe mechanism to protect the plant and workforce.
		Request that WPTP be regulated as a CSO outfall.	Currently able to discharge to outfalls at other locations.
			This would require coordination with DOE.
		Evaluate maximizing flow through the overflow weir by allowing head to build in the ICS.	There is some freeboard above the weir, but flow is limited because of the elevation of the high-high level alarm, triggering the EB gate to open.
			Increasing the water level in the ICS can negatively influence downstream (bar screens) and upstream (Ballard weir) systems.

CSO = combined sewer overflow; DOE = Washington Department of Ecology; EB = Emergency Bypass; ICS = influent control structure; WPTP = West Point Treatment Plant

6.2 Process and Mechanical

To determine whether there are particular risks for which mitigation should be investigated further, an evaluation was performed for the following process and mechanical unit operations or components:

- Influent control structure (ICS)
- Preliminary treatment
- Raw-sewage pumps (RSP)
- Preaeration tanks
- Primary sedimentation tanks
- Flow diversion structure (FDS)
- Effluent pump station (EPS)

The IPS, which pumps primary effluent to the secondary treatment system, was not considered a process-critical component in this evaluation, which focused on the primary treatment systems and components. Further analysis of all plant components, including secondary treatment areas, is recommended.

6.2.1 Influent Control Structure

6.2.1.1 Design and Operation

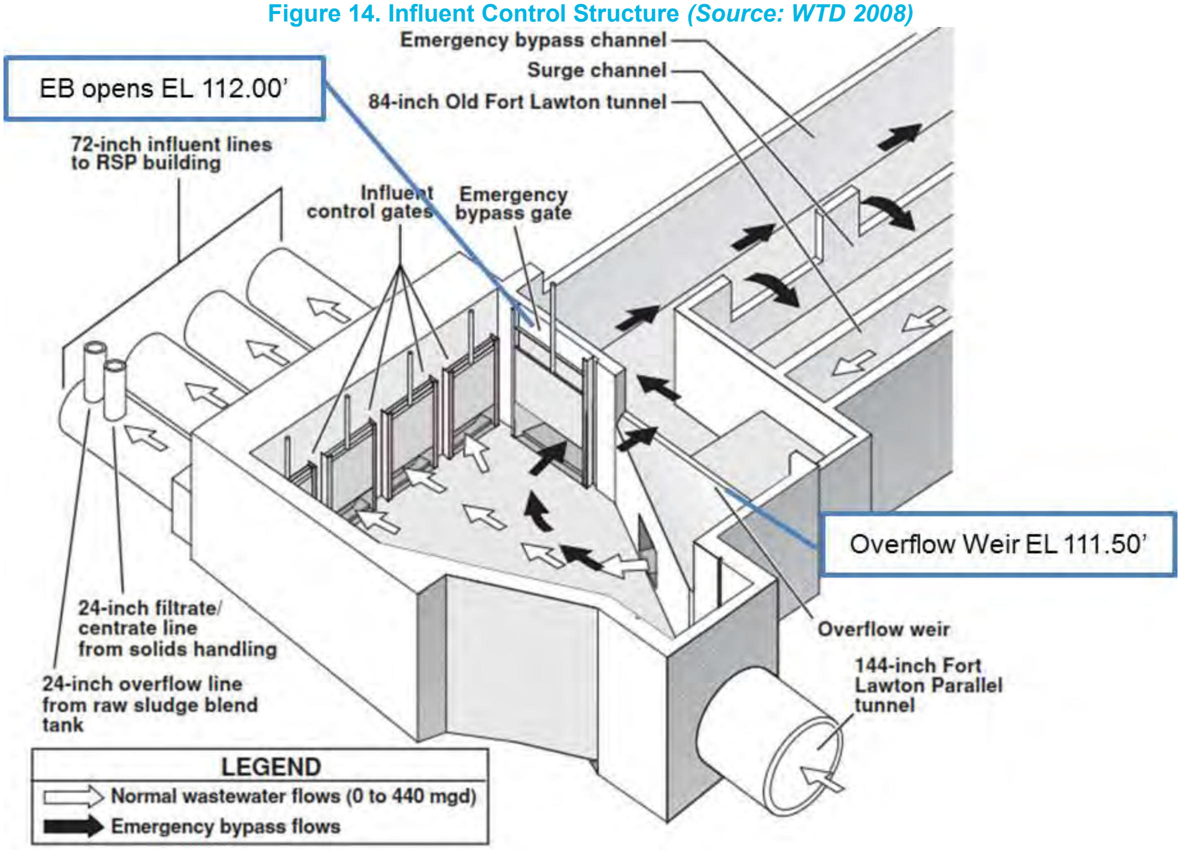
The ICS is a hydraulic control structure that receives plant influent from the 144-inch Fort Lawton Tunnel and the 84-inch Old Fort Lawton Tunnel. See **Figure 14** for an overview of this structure.

The ICS has two major functions. During normal operation, it distributes flow evenly to the downstream preliminary treatment process. During emergencies, it allows the flow to be bypassed through an overflow weir and emergency bypass gate. The ICS is equipped with four influent control gates and one 12-foot by 12-foot EB gate and level instruments including float switches and a level element.

If the water surface elevation in the ICS rises above the overflow weir elevation of 111.50 feet, the weir provides some passive hydraulic control. However, the weir's capacity is limited to approximately 30 mgd. The EB gate opens if the water surface elevation rises to 112.00 feet and has the capacity to bypass 440 mgd. The EB gate is a single gate with no redundancy or a backup. The lack of redundancy or additional passive overflow is a critical failure mode at WPTP that has flooding and life-safety implications.

Bypassed flow over the weir and/or through the EB gate flows by gravity to the EB channel that is connected to the EBO through the FDS. A surge channel parallels the EB channel and empties back into the EB channel through flap gates (duck bills) at the bottom.

Figure 14. Influent Control Structure *(Source: WTD 2008)*



6.2.1.2 Performance Evaluation

After the RSPs were manually stopped, the ICS float switches performed their intended function and caused the EB gate to open, which allowed flow to automatically bypass the plant and divert to the EBO.

6.2.1.3 Potential Failure Mechanisms and Mitigation Strategies

Table 11 summarizes the potential failure mechanisms and potential mitigation strategies for the ICS.

Table 11. Potential Failure Mechanisms and Mitigation Strategies—Influent Control Structure

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
EB gate fails to open at ICS	Flooding of plant if influent gates are open; also backup into Fort Lawton tunnels and North Interceptor	Evaluate adding a passive bypass weir.	Possibility of using the 84-inch Old Fort Lawton Tunnel to back flow to the Marine Outfall Gate at the Flow Diversion Structure. Utilize upstream storage, if any.
Controls of the EB gate are overridden to keep the gate manually closed	Life-safety risk	Avoid overriding controls of the EB gate to keep the gate manually closed.	None.
EB gate fails to close at ICS	Unintentional bypass	Add automated EB gate control at ICS.	Consider adding a second solenoid valve for redundancy and switching from hardwired interlock controls to control from the Ovation system.
EB gate cannot be operated remotely from Main Control	Delay in responding to emergencies; flooding/life-safety issues	Add ability to remotely operate EB gate from Main Control.	Provides rapid response without putting operators in harm's way.
Influent gates are not currently configured to close when EB gate is opened	Flooding of downstream processes	Add ability to control influent gates from Main Control.	Clogged bar screens could cause water to back up in the ICS and trigger the EB gate to open but would not close the influent gates.
		Add control system programming that closes influent gates automatically when EB gate is opened.	
Level readings not correlated to influent flow	Delayed response to high influent flows	Install flow meters on influent lines.	Provide an instantaneous direct flow reading that can be utilized for overall plant control.
		Add real-time collection system controls.	Incorporate historical collection system and watershed data into control strategies.

EB = Emergency Bypass; ICS = influent control structure; mgd = million gallons per day; WPTP = West Point Treatment Plant

6.2.2 Preliminary Treatment

6.2.2.1 Design and Operation

Preliminary treatment at WPTP consists of raw wastewater screening and grit removal.

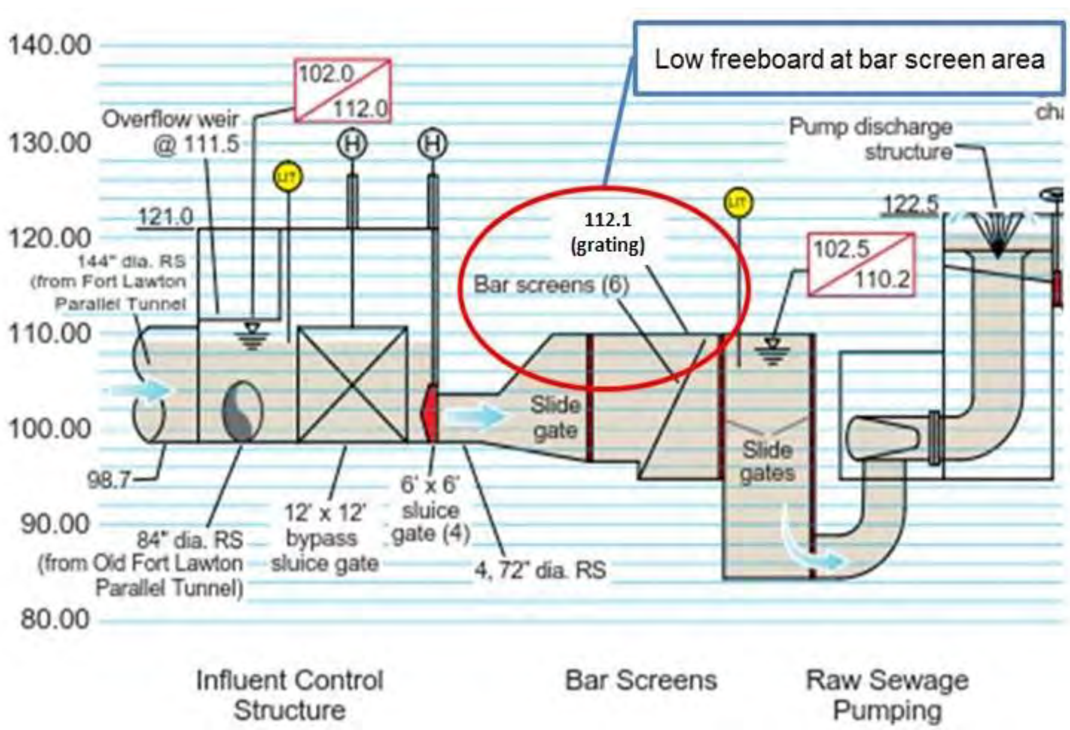
There are four 72-inch conduits from the ICS to the bar screen facility. They join in a common header supplying the total plant flow to six bar screens. The two inside screens have ¼-inch bar spacing and are used during normal operations. The outside four screens have ⅜-inch bar spacing and are used during high flow operations. The screens are a traveling rake type. The different screen sizes are rated for difference capacities, and the flow is paced by variable-frequency drives. Each screen is isolated with a motorized inlet gate. The screenings deposit onto belt conveyors and are conveyed to an adjoining building where they are cleaned, dried, and compacted.

The number and speed of operating screens and processing equipment can be controlled manually or automatically via bubbler-type level transmitters. The bubblers maintain a constant wet-well level to maintain stable operation of the RSPs.

Five duty screens (screens that are in use) can handle the peak flow of 440 mgd, with the sixth unit providing redundancy. The screenings' raking mechanism is controlled through a differential level between the upstream and downstream sides of the bar screens. As debris and screenings accumulate on the flow-facing side of the screen, the available open area for the flow to pass through decreases, causing higher headloss across the screen and increasing the water level in the screen channel. At a preset differential level, the raking mechanism is triggered to remove the screenings, which reduces the upstream water level in the screening channel.

During wet weather, it is typical for bar screens in wastewater treatment facilities to become overwhelmed by high screening loads. A high debris/screening load can cause blinding of the bar screen, which causes a rapid rise in the water level at the bar screens. The bar screen/RSP building at WPTP sits at a low elevation, with the top of the screen channel at 112.1 feet with low freeboard between the high-water elevation and the grating (**Figure 15**). This makes the bar screen area and building susceptible to flooding during flow surges.

Figure 15. Hydraulic Profile through Preliminary Treatment to Raw-Sewage Pumps



(Source: WTD 2008)

6.2.2.2 Performance Evaluation

During the February 9, 2017, event, the preliminary treatment process performed as designed. There were no direct failures in the preliminary treatment area; however, the area did flood from the overtopped primary sedimentation tanks.

Also, the water level in the bar screen channels rose when the RSPs were manually shut down. The level switches in the RSP wet well failed and did not close the influent gates, so wastewater kept flowing from the ICS to the bar screen area until the EB gate finally opened. The water level reached 112.1 feet in the screen area when the RSPs shut down.

6.2.2.3 Potential Failure Mechanisms and Mitigation Strategies

Table 12 summarizes the potential failure mechanisms and potential mitigation strategies for preliminary treatment.

Table 12. Potential Failure Mechanisms and Mitigation Strategies—Preliminary Treatment

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
Bar screens overwhelmed by high screening/debris load	Flooding of bar screen area and ICS	Continuously rake bar screen area during wet-weather events.	This is opposed to using a differential-level trigger.
			WTD has made this change.
Flow surge	Flooding of bar screen area	Raise the channel height at the bar screen area.	Provides surge protection and increased head in the ICS for flow over the passive bypass weir.

ICS = influent control structure; WTD = Wastewater Treatment Division

6.2.3 Raw-Sewage Pump Station

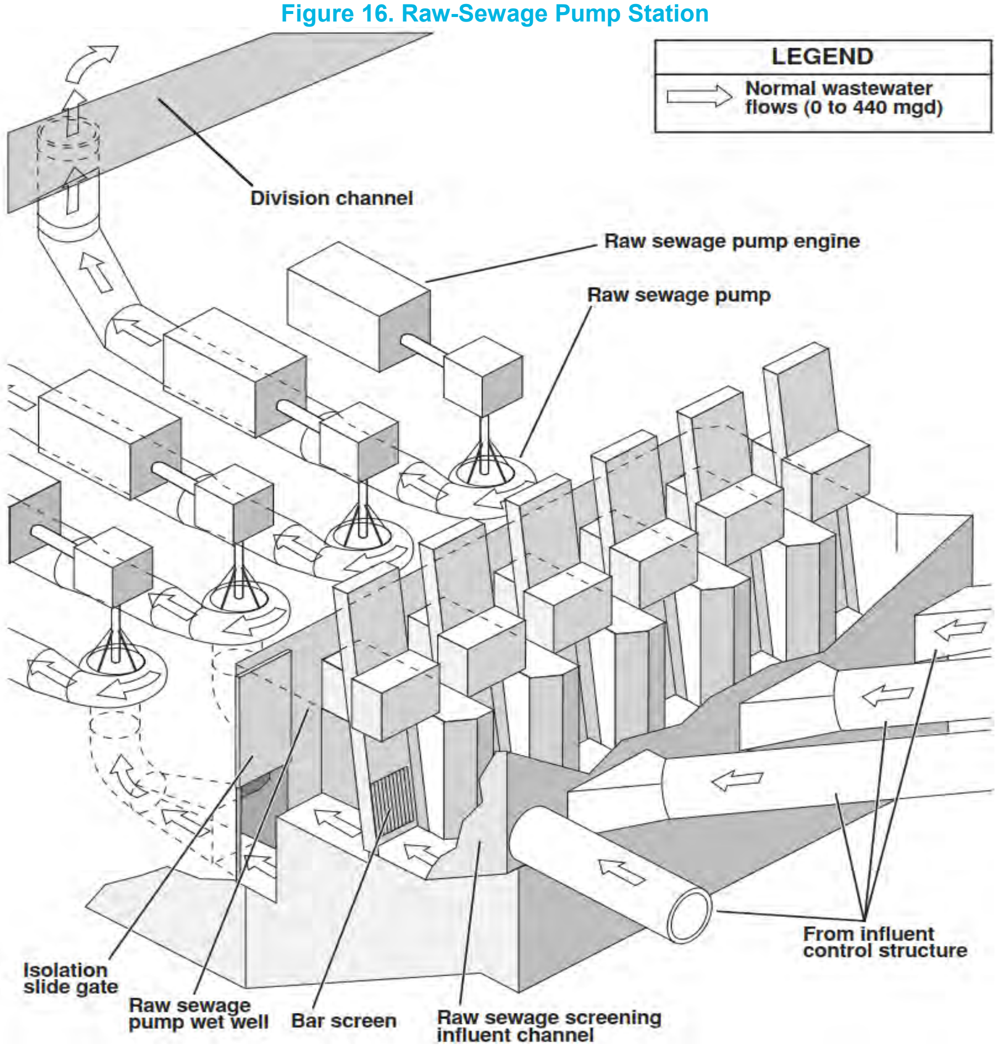
6.2.3.1 Design and Operation

RSPs lift wastewater from the ICS to the primary clarifier division channel. There are four RSPs. Each pump has a 450-horsepower engine with a right-angle gearbox. Pump speed and flow are controlled to maintain water-level set points in the wet well.

With the exception of an emergency bypass event, the pump station operates continuously. The 50-year-old pumps/engines have been well maintained and appear to be in reasonable operating condition. Pump station equipment is located on three levels of the building. **Figure 16** is a schematic diagram of the pump station.

Each RSP has a nominal flow capacity of 110 mgd. At influent flow rates exceeding 330 mgd, all four pumps must operate and there is no standby pump available. The lack of a 440 mgd firm pumping capacity is a significant challenge.

Figure 16. Raw-Sewage Pump Station



(Source: WTD 2008)

Figure 17 is a photograph of the pump engines and right-angle gearboxes at WPTP.

Figure 17. Raw-Sewage Pumps

6.2.3.2 Performance Evaluation

The pumps performed as designed. However, after the plant was already flooded by the primaries, the level switches in the RSP wet well failed to engage and did not close the wet well's isolation gates. The interlocks for influent gates are on a 6-second delay and wastewater kept flowing from the ICS to the bar screen area until the EB gate finally opened.

6.2.3.3 Potential Failure Mechanisms and Mitigation Strategies

Table 13 summarizes the potential failure mechanisms and potential mitigation strategies for the RSP station.

Table 13. Potential Failure Mechanisms and Mitigation Strategies—Raw-Sewage Pump Station

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
Failure of one RSP when influent flow rate is greater than 330 mgd	Water level will rise in the RSP wet well and ICS.	Evaluate options to provide 440 mgd firm pumping capacity at RSP.	Options and study items could include: 1. Adding a new pump. 2. Replacing existing pumps with new/larger capacity pumps. 3. Increasing the speed of the existing pumps. 4. Changing impellers to provide more flow. This may require a larger engine and modifications to the right-angle gear box. 5. Controlling and limiting collection system flow to the plant at 330 mgd. 6. Considering providing more on-site and/or off-site CSO storage volume.
		Develop a detailed plan to operate at 330 mgd in preparation for losing a pump.	Not enough firm capacity at RSP.
		Install flow meters on influent lines.	Provides instantaneous influent flow for faster reaction times during high-flow events (compared to calculating influent flows from the effluent discharge).
		Evaluate incorporating automatic controls through a SCADA.	Automatically stop pumps based on critical plant high-high water level set points to help prevent flooding.
		Provide additional staff training on operating RSP.	During peak-flow events and various failure events, more training is needed.
		Update safety procedures on operating the RSP during peak-flow conditions.	Not enough firm capacity at RSP.
Pump engine failure	Pump fails with a 110 mgd reduction in pump station flow capacity.	Replace RSP engines with electric motors.	Electric motors are more reliable and less expensive to maintain (high initial cost).
Pump/engine support system failure (e.g., lubrication oil, seal water, heat exchanger, starting air system, solenoid valves)	Pump/engine will not operate.	Evaluate current condition of RSPs and determine expected life span.	Plan/budget for equipment maintenance, updates, and replacements.
		Provide backup systems to increase redundancy.	Redundancy reduces opportunity for failure.
Piping system failures of RSPs	Leaks occur, with potential for flooding/equipment damage.	Evaluate current condition and determine expected life span.	Estimate pressure capacity, and incorporate corrosion inspections and durability to withstand earthquakes.
Failure of RSP instrumentation to close the wet well's isolation gates.	Flooding/life-safety issues	Modify control strategy to include secondary instruments.	Redundancy reduces opportunity for failure.

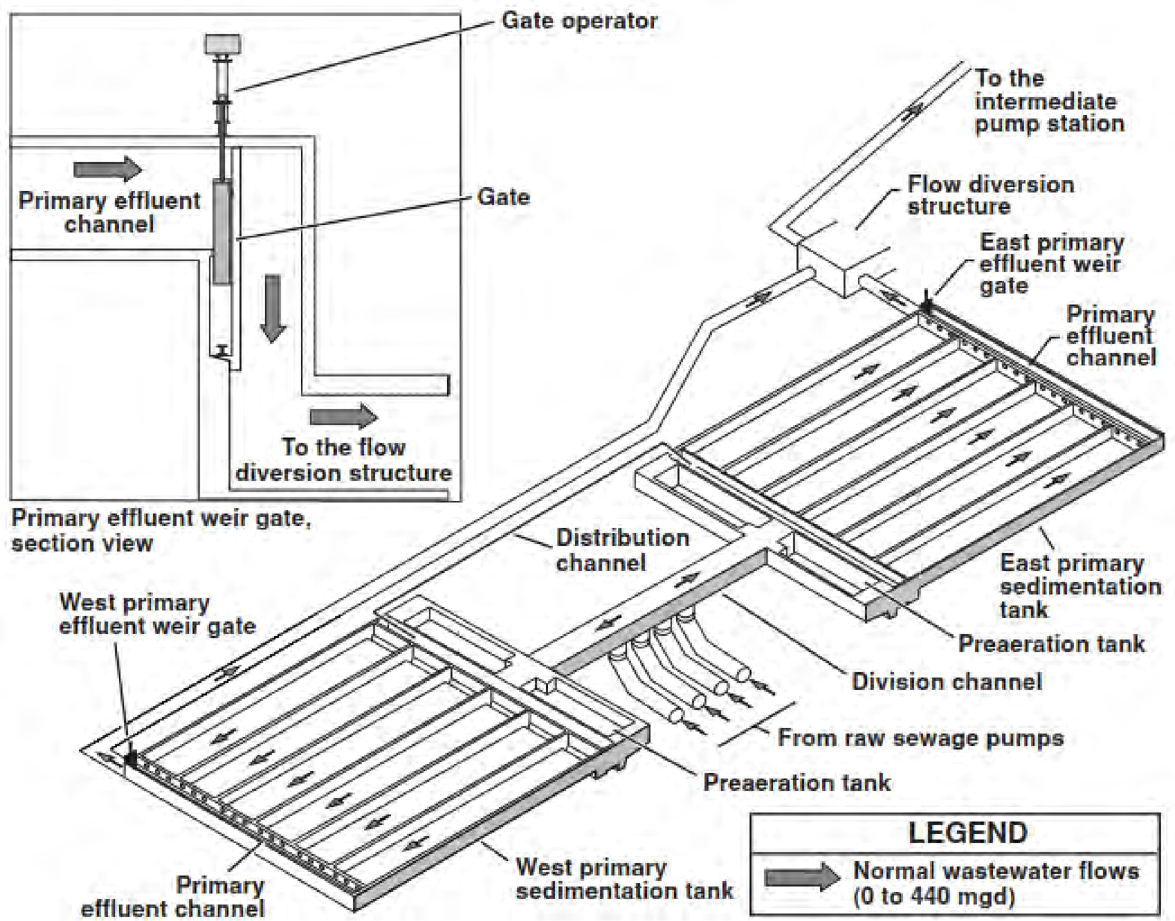
CSO = combined sewer overflow; ICS = influent control structure; mgd = million gallons per day; RSP = raw-sewage pump; SCADA = supervisory control and data acquisition

6.2.4 Preaeration and Primary Sedimentation Tanks

6.2.4.1 Design and Operation

WPTP has two banks of preaeration and primary sedimentation tanks, split into eastside and westside facilities. **Figure 18** shows the location and configuration of these processes with the preaeration tanks adjacent to a bank of primary sedimentation tanks. Flow from the RSPs is lifted to a division channel and split between the east and west sides through two sets of distribution channels.

Figure 18. Preaeration and Primary Sedimentation Tanks



(Source: WTD 2008)

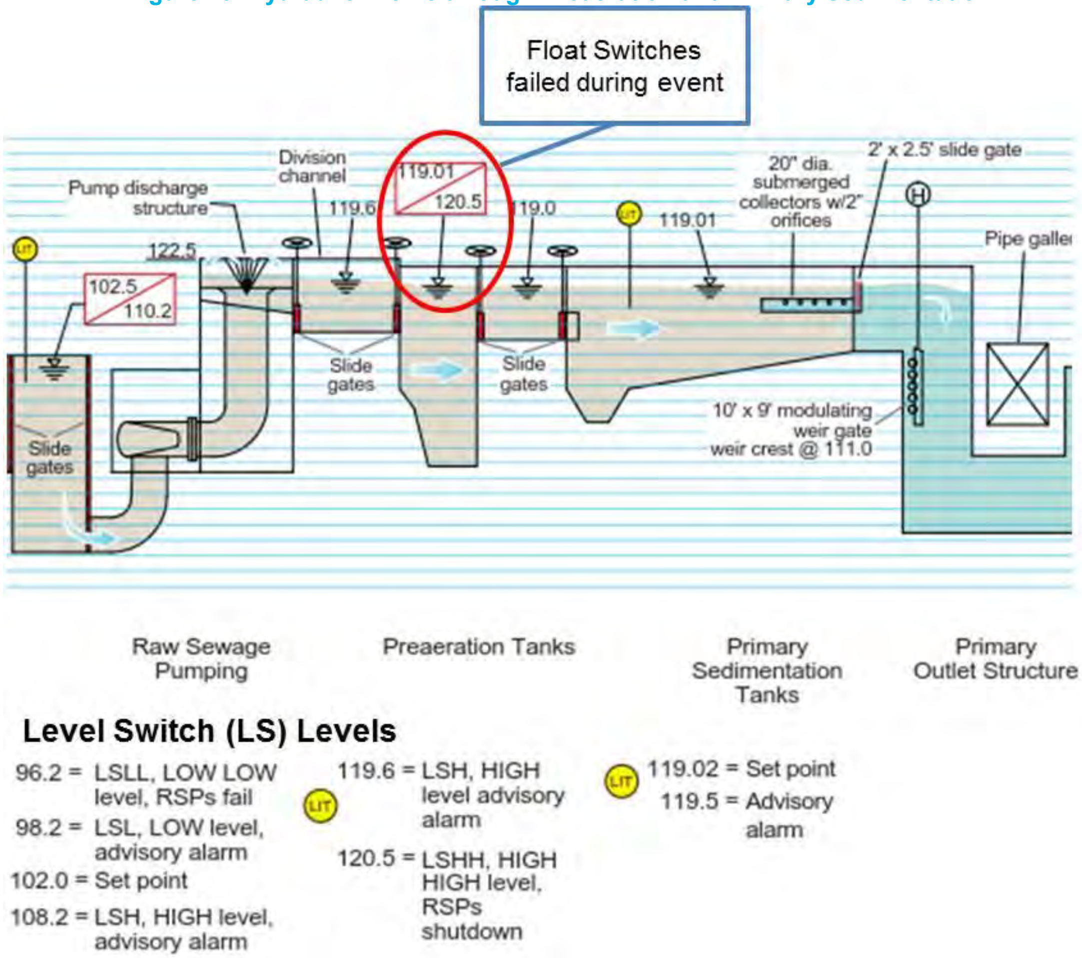
Preaeration Tanks

The preaeration tanks remove grit through settling while lighter organic solids are moved to the primary sedimentation process downstream. WPTP has a total of four preaeration tanks with sloping bottoms. The four preaeration tanks can handle a total of 440 mgd of flow. Each tank has an inlet and outlet gate and can therefore be individually isolated. With one unit out of service, the rated capacity is decreased to 330 mgd. However, a higher flow can be channeled through the tanks, but there would be a decrease in grit removal performance.

The RSPs are controlled by the level in the preaeration tanks (**Figure 19**). In the original design, when the level in any preaeration tank reached the High level, elevation 119.0, the RSP wet-well controls were overridden and the pump engines were to reduce speed to idle. This process has since been changed. The High level float switches, installed in stilling wells at the preaeration basins, now only activate an alarm in the SCADA system.

As the level continues to rise, the high-high level alarm should activate at elevation 120.5 and shut down the RSPs. The high-high level alarm and interlock are activated by float switches installed above the preaeration basins. In the original design, the high-high level float switches were installed in stilling wells, but the wells were later cut short to reduce fouling issues.

Figure 19. Hydraulic Profile through Preaeration and Primary Sedimentation



(Source: WTD 2008)

Primary Sedimentation Tanks

The primary sedimentation tanks are used for settling the solids in wastewater and TSS reduction. The sedimentation tanks contain equipment to collect the solids that settle on the bottom of the tank and the scum that floats to the surface.

Each bank of primaries (east and west) consists of six rectangular sedimentation tanks measuring 254 feet long by 38 feet wide. The west and east bank of primaries can each handle a flow rate of 220 mgd. Primary effluent leaves the sedimentation tanks through six 20-inch-diameter, submerged, fiberglass effluent launders. The launders are located between the sludge layer on the bottom of the tank and the scum layer on the surface of the tank (**Figure 20**).

Flow from launders collects into an effluent channel on the east and west sides of the primary sedimentation tanks. Because the launders in the sedimentation tanks are submerged between the sludge layer on the bottom of the tank and the scum layer on the surface of the tank, the levels in the tanks are maintained by a primary effluent (PE) weir gate at the end of each primary effluent channel.

Figure 20. Effluent Launders at the Primary Sedimentation Basins

Figure 18 shows the plan view of the east and west primary areas and a section view of the PE gate that is used to control the water level in the primaries. The PE gate is modulated using the level instruments (bubbler and ultrasonic) installed in each bank of primary sedimentation tanks. The PE gate is also used to isolate the east or west primary sedimentation and preaeration tank system. The PE gates can also be closed in an emergency to protect the downstream facilities from flooding. For example, if the IPS fails, the water level in the IPS wet well rises and triggers the PE gates to close.

Should one of the PE gates fail in a closed position, flow can still pass through a single bank of primary sedimentation tanks, reducing the capacity of the process to 220 mgd.

There is also a 2-foot gap above the PE gate in the effluent channel that allows primary effluent flow to pass to the downstream process when the PE gate is closed.

6.2.4.2 Performance Evaluation

During the event of February 9, 2017, the float switches in the preaeration basin failed to trigger an alarm at the High level and high-high level. As a result, the RSP pumps continued to pump wastewater into the primary treatment area, which eventually caused the level to overtop the tank walls and flood the primary galleries below the tanks.

In addition, the two PE gates (for the east and west tanks) were closed by an interlock system upon failure of the EPS. The PE gates can be operated via the Ovation system, but the can only be rest via a local panel at the gates. MC dispatched operators to engage the hydraulic gate control to open the PE gates. The operators continued their efforts until MC saw that the EPS wet well's high-high interlock had engaged, which prevents the PE gates from opening.

6.2.4.3 Potential Failure Mechanisms and Mitigation Strategies

Table 14 summarizes the potential failure mechanisms and potential mitigation strategies for the preaeration and sedimentation tanks.

Table 14. Potential Failure Mechanisms and Mitigation Strategies—Preaeration and Sedimentation Tanks

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
Level switches stick inside stilling well.	Flooding of plant; frequent tripping/idle mode of RSPs	Replace level switches with modern tethered switches that do not require a stilling well and are less likely to fail.	WTD has already done this.
Level switches fail to record high level.	Flooding/life-safety issues	Modify control strategy to include secondary instruments.	Redundancy decreases opportunity for failure.
Level switch in primary tanks interlock fails.	Flooding/life-safety issues	Incorporate automatic controls through a SCADA.	Multilayered control system is not limited to a single interlock control.
Effluent weir gate fails to close.	Flooding/life-safety issues	Evaluate feasibility of a passive bypass.	Effluent can be diverted to the EBO within the FDS.
One primary effluent gate fails to close.	Treatment capacity reduced by about 50%	Evaluate feasibility of connecting east and west primary effluent channels.	If one gate fails, near-full utilization of both primary sedimentation basins can continue.
Primary effluent overtops closed weir gates.	Flooding of FDS	Evaluate feasibility of a passive bypass.	Effluent can be diverted to the EBO and 3x3 vent within the FDS.
Cascading control strategy fails (EPS level, RSP level, ICS level).	Flooding	Reevaluate control strategy.	The control strategy can be based primarily on influent flow measurement, not a series of cascading system levels.

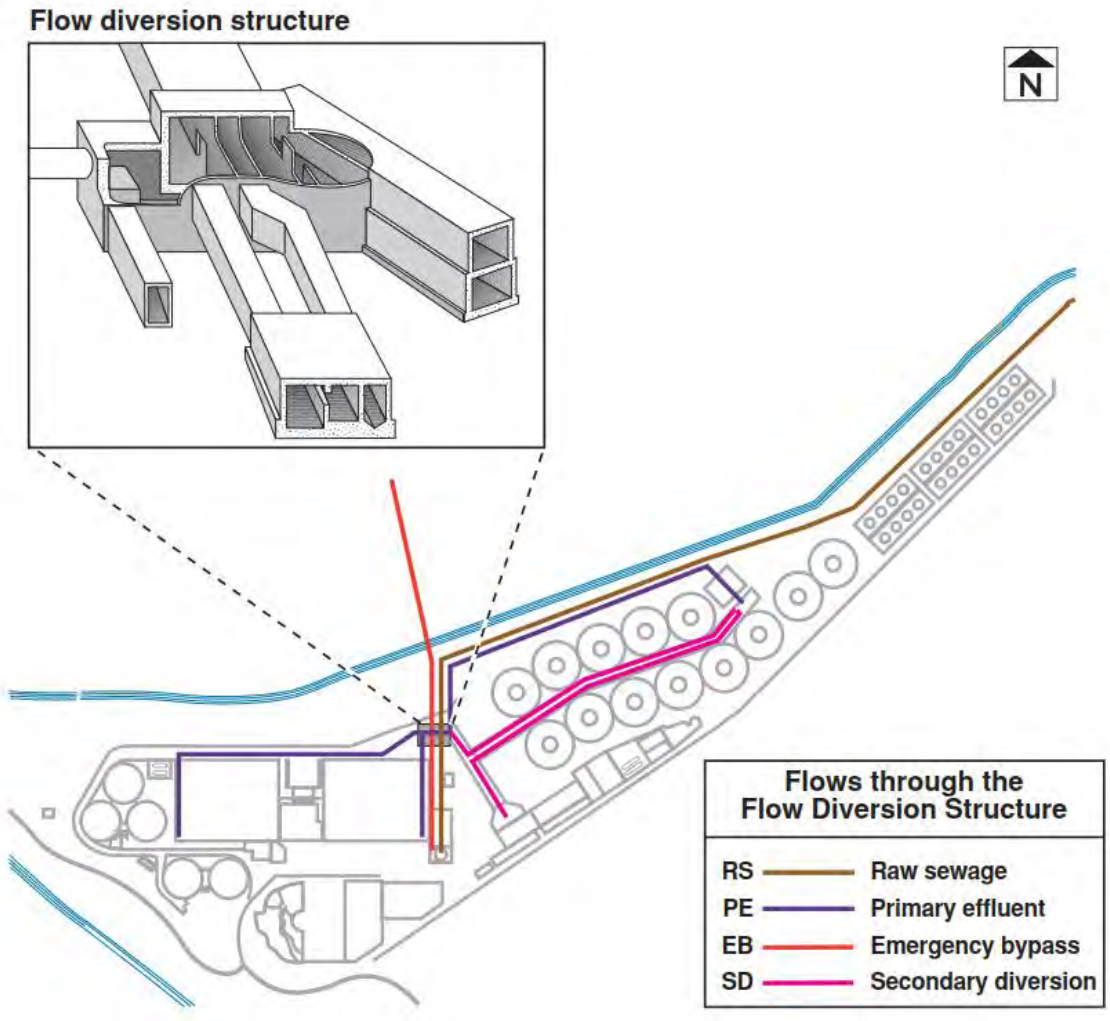
EBO = Emergency Bypass Outfall; EPS = effluent pump station; FDS = flow diversion structure; ICS = influent control structure; RSP = raw-sewage pump; SCADA = supervisory control and data acquisition; WTD = Wastewater Treatment Division

6.2.5 Flow Diversion Structure

6.2.5.1 Design and Operation

The FDS is a hydraulic structure that has multiple functions. The 84-inch Old Fort Lawton Tunnel passes through the FDS before it enters the ICS, and it controls flow and distribution during normal, secondary bypass, and emergency operations. The FDS is located below grade between the primary and secondary processes (**Figure 21**).

Figure 21. Location of Flow Diversion Structure



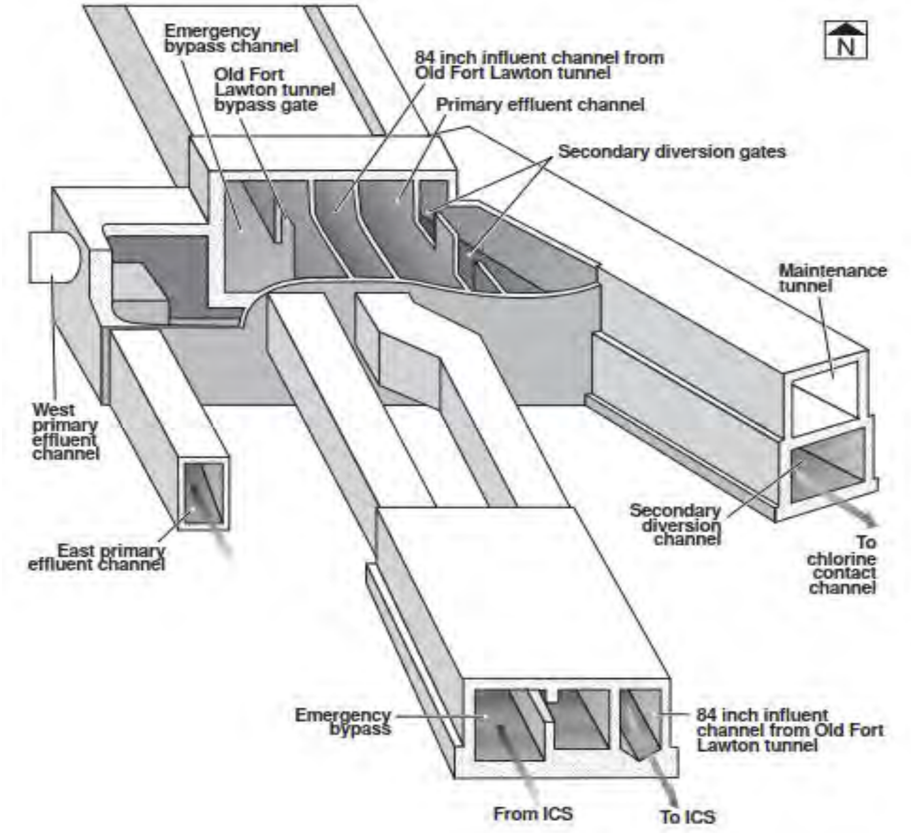
(Source: WTD 2008)

The FDS consists of three gates and various channels and pipelines that carry effluent to and from the primary treatment area, and to the emergency bypass outfall (**Figure 22**). The east and west primary effluent flows enter the FDS and are distributed to the downstream secondary process during normal operations.

During an emergency bypass, wastewater from the tunnel can be diverted by opening the EMO gate and connecting the Old Fort Lawton Tunnel directly to the outfall, rather than sending the flow to the ICS and then back through the EB gate and bypass channel.

At flows higher than 300 mgd, the FDS regulates the flow to the secondary treatment process, with flow exceeding 300 mgd diverted to the chlorine contact channels through the secondary diversion channel.

Figure 22. Flow Diversion Structure



(Source: WTD 2008)

6.2.5.2 Performance Evaluation

The EMO gate at the FDS, which could relieve flows coming in from the Old Fort Lawton Tunnel and send these directly to the EBO (and bypass the plant), was not valved-in properly at the time of the event, so it failed to open when the EB gate opened. This flow relief option would have most likely been minimal during the event however due to high tide levels. Also, this would not have prevented flooding of the plant, but it would have reduced the flow into the plant, and possibly have slightly reduced the volume of flooding in the primary treatment area.

6.2.5.3 Potential Failure Mechanisms and Mitigation Strategies

Table 15 summarizes the potential failure mechanisms and potential mitigation strategies for the FDS.

Table 15. Potential Failure Mechanisms and Mitigation Strategies—Flow Diversion Structure

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
EMO gate fails to open at FDS.	Surge in Old Fort Lawson Tunnel	Evaluate feasibility of a passive bypass.	Options include creating a bypass from the Old Fort Lawton Tunnel or directing primary effluent to the EBO pipe.
EMO gate opens unintentionally.	Unintentional bypass	Add automated EMO gate control at FDS.	Previous practice was to manually override controls at low flow (<250 MGD). The EB gate is now always valved in.
EMO gate cannot be operated remotely from Main Control.	Delay in responding to emergencies; flooding/life-safety issues	Add ability to remotely operate EMO gate at FDS from Main Control.	Provides rapid response without putting operators in harm's way.

EB = Emergency Bypass; EBO = Emergency Bypass Outfall; FDS = flow diversion structure; mgd = million gallons per day

6.2.6 Effluent Pump Station

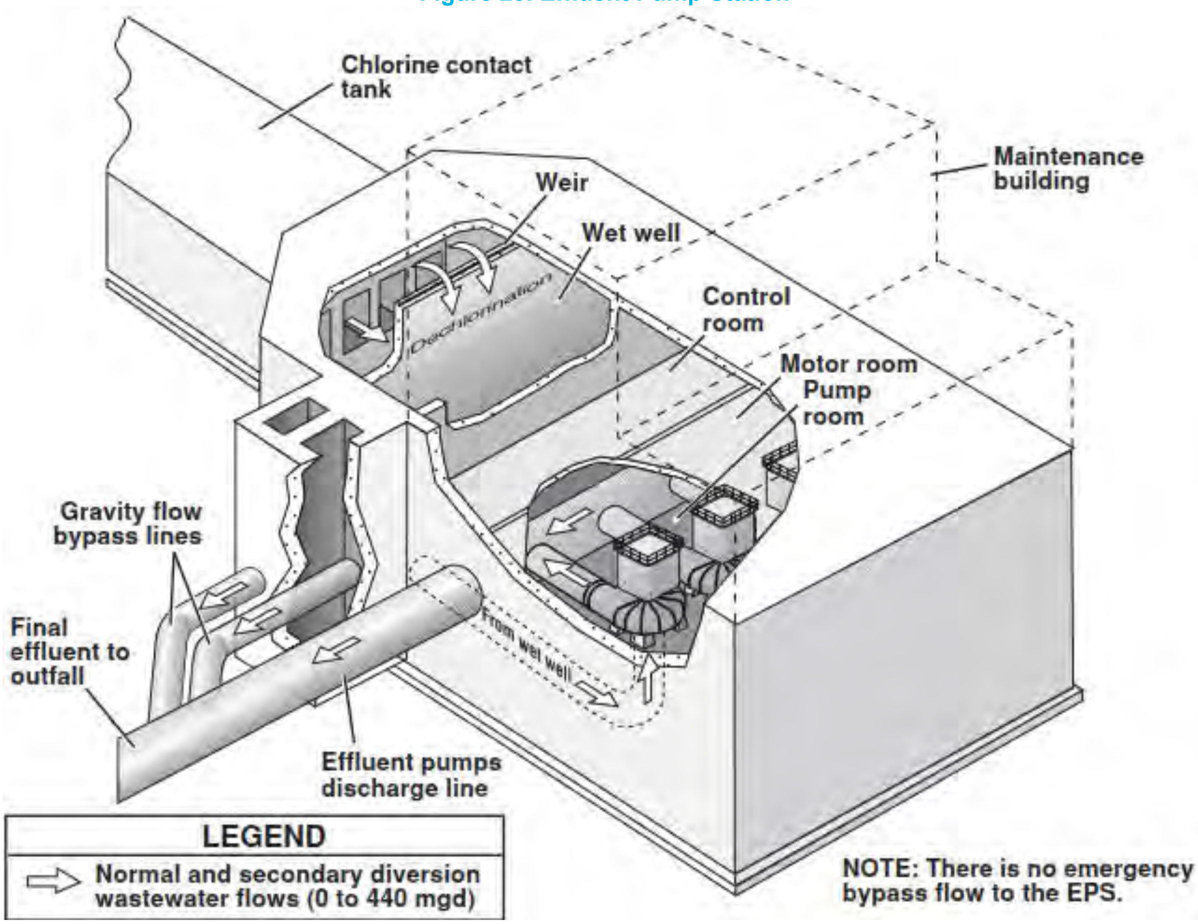
6.2.6.1 Design and Operation

The EPS delivers treated plant effluent to Puget Sound via a 96-inch outfall pipe. Depending on the plant's flow rate and Puget Sound tide water levels, effluent either will be pumped or will flow by gravity to the outfall. During low tide an estimated 160 mgd can be discharged by gravity. Pump speed/flow is controlled to maintain the pump station's wet-well water level.

There are four effluent pumps: three duty and one standby. The EPS's firm pumping capacity is 432 mgd. Each pump has a 2,250-horsepower electrical motor and variable-frequency drive. **Figure 23** is a schematic diagram of the pump station.

The pump station is relatively new and appears to be in good operating condition. Pump station operation is complicated by the various discharge conditions (gravity or pump), variable-speed pump drives, and flow control/check valve operating conditions. Equipment is located on three levels of the building.

Figure 23. Effluent Pump Station



(Source: WTD 2008)

Figure 24 is a photograph of pump electric motors. **Figure 25** is a photograph of the pumps at the lower building level.

Figure 24. Electric Motors at Effluent Pump Station

Figure 25. Pump at Effluent Pump Station

6.2.6.2 Performance Evaluation

Failure of the EPS's electrical power supply, control valve hydraulic system, and plant instrumentation systems are described in detail in **Section 3** of this document. The failure of the EPS was the start of a series of events that resulted in flooding of WPTP. There were no mechanical problems with the pumps; rather, the electrical power and pump station support systems failed.

6.2.6.3 Potential Failure Mechanisms and Mitigation Strategies

Table 16 summarizes the potential failure mechanisms and potential mitigation strategies for the EPS.

Table 16. Potential Failure Mechanisms and Mitigation Strategies—Effluent Pump Station

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
Failure of control valve/hydraulic operator system	If control valve closes and will not open, the pump will try to start, but with no flow to the system, it will shake and be shut off by the vibration monitor. If the control valve stays open, it will not operate as a check valve to prevent reverse flow.	Provide a spare hydraulic unit that can operate with any pump control valve.	Redundancy reduces opportunity for failure.
		Provide redundant electrical power supply to all hydraulic power units.	Redundancy reduces opportunity for failure.
		Add pressure relief valves at pump discharge lines.	Prevents pump from operating at zero flow/shut-off head conditions if control valve is closed while pump is operating. Discharge flow from pressure relief valves to gravity or pump discharge pipeline.
		Provide portable ladder platform and handwheel to manually operate the butterfly control valve.	
Failure of EPS pump vibration monitor	Pump will stop.	Routinely examine data from vibration monitors to determine trends to help forecast pump maintenance and repairs.	None.
		Update vibration monitors.	None.
Failure of pump support system (e.g., seal water, oil lube)	Damage to pumps will occur, resulting in increased pump maintenance and failures. Low-lubrication oil flow will stop pump.	Evaluate the current condition of the EPS and determine its expected life span.	Plan/budget for spare parts and equipment maintenance, updates, and replacements.
		Provide backup systems to increase redundancy.	Redundancy reduces opportunity for failure.
		Provide good maintenance, closely monitor systems, and stock critical spare parts.	
Failure of effluent flow meter	There will be no flow signal to chemical feed and other plant systems.	Use a differential pressure sensor across the pump to estimate flow rate.	An algorithm would be developed that considers pump head/flow curve, pump speed, and pump differential pressure reading. The algorithm can be calibrated using information from the existing effluent flow meter.
Failure of variable-frequency drive at EPS	Pump will not operate.	Provide controls that allow the EPS to operate at constant speed.	As a backup, provide controls that allow the pump to operate at constant speed while using the control valve to throttle discharge flow and maintain the wet-well water level set points.
			This would require adding single-speed starters.

EPS = effluent pump station

6.3 Electrical

6.3.1 Design and Operation

Electrical service to WPTP consists of two 26.4-kilovolt (kV) Seattle City Light services from separate and independent substations: Canal and Broad Street. Normally all plant power is fed from Canal; however, the Broad Street service is automatically switched to power the entire plant if Canal service fails. The services are interlocked so that only one of the two services will power the plant at any time.

WPTP energy is reduced from 26.4 kV to 13.8 kV through a pair of transformers that then feed the facility. The two 13.8 kV services are then fed to the main 15 kV switchgear, which has a main breaker for each service, distribution breakers to other plant switchgears, and a tie breaker separating the switchgear into two halves: A-side bus and B-side bus. All process facilities at WPTP are fed from both the A bus and the B bus with a tie breaker. **Appendix M** shows a schematic one-line diagram of the power plant at WPTP.

All tie breakers at the main 15 kV switchgear and the individual process 15 kV switchgears and individual process 480-volt (V) switchgears are manually operated and require an electrician to operate. In general, half of the process loads are powered from the A side and half from the B side, so that upon a power outage to one side of the switchgear, only half the plant is lost until the failed side is isolated and the tie breaker closed. This is a very common electrical distribution design. Nonetheless, the following factors must be taken into account with this type of distribution system:

1. **An electrician is required to make the manual transfer.** The reason for the power loss must be determined by an electrician is so that equipment is not damaged or life safety is not compromised while the tie breaker is closed into what may be a short circuit. In addition, arc flash requirements (industry practice and County code requirements) dictate that proper personal protective equipment be worn while closing the tie breaker and that the person closing the breaker be familiar with the equipment and the dangers involved.

2. **There must be sufficient time to make the manual transfer (open failed source main breaker and close tie breaker) without violating discharge requirements or life-safety requirements**. For example, if a pump station with two pumps on the A side and two on the B side were to lose power on one of the sides during peak-flow condition when three pumps are required, the pump station's wet well should have sufficient capacity to allow an electrician to be contacted, travel to the switchgear, evaluate the situation, and make the manual transfer.

3. **Manual transfers may be required at each substation switchgear.** Loss of a main switchgear on the A or B side that feeds numerous substations will involve manual transfers at each substation switchgear if there is a fault in the main switchgear bus. Therefore, the time constraint identified above may increase significantly.

An alternative distribution system design uses automatic transfer switches at each side of each substation or automatic operation of the main breaker and tie breaker operation. This allows for immediate reconnection of the failed side of the distribution system to be reenergized from the remaining source. This adds cost and complexity, but may be required to keep the plant in operation after a power outage.

The existing distribution system is protected to a certain degree from power line voltage spikes caused by lightning or switching transients. This is accomplished with the use of surge arresters connected to the incoming side of each switchgear. These surge arresters are simple metal oxide varisters (MOVs) that provide reasonable protection.

Critical facilities in lightning-prone areas include medium-voltage transient surge suppressors to provide superior protection against power line voltage spikes caused by lightning or switching transients. These surge suppressors include phase-to-phase and phase-to-ground MOVs and line-to-ground surge capacitors.

The electrical distribution system also includes feeders to individual 480 V motor control centers, some with main-tie-main configurations, and then to 480 V–208/120 V transformers to power panelboards for I&Cs. Critical instrumentation and interlock systems, such as the Ovation equipment or the emergency outfall gate interlock system, are powered from uninterruptible power supplies or battery systems. In general, this distribution system continues with the A-side and B-side configuration, with half the loads being on each of the two sides.

6.3.2 Performance Evaluation

6.3.2.1 EPS Switchgears

During the event of February 9, 2017, the electrical distribution system performed as designed. The breaker in the main 15 kV switchgear that feeds the EPS A-side switchgear tripped on ground fault. Even though extensive testing and research has been conducted, the actual cause of the ground fault has not yet been determined; however, the ground-fault relay was tested and determined to be functioning properly.

Following the breaker trip in the 15 kV main switchgear, EPS Pump 2 de-energized, leaving only Pumps 3 and 4 to handle the incoming flow. Because this occurred at night, no electricians were on duty to make the manual transfer to power the EPS A-side switchgear from the B-side power source. Therefore, the result would still have been an eventual bypass event because three EPS pumps were required to pump the incoming flow at the time of the incident. With only two of the three EPS pumps available, the EPS wet well would have reached its high level, which would have triggered the cascading hydraulic control philosophy, and eventually opened the EB gates.

6.3.2.2 EPS Discharge Valves

All EPS discharge valves are controlled from a single hydraulic power unit powered for the A-side switchgear. A standby portable hydraulic power unit was available; however, sufficient time was not available to connect the unit before sewage overflow occurred.

During the recovery period, an automatic transfer switch was installed so that the hydraulic power unit would be powered from either the A side or the B side, with automatic switching upon loss of the preferred power source. Maintenance staff plans to install an additional permanently connected hydraulic power unit on the B side and remove the automatic transfer switch. Either hydraulic power unit will be able to power any of the four valves. This redundancy will greatly reduce the risk that became evident during the event.

6.3.3 Potential Failure Mechanisms and Mitigation Strategies

Table 17 summarizes the potential failure mechanisms and potential mitigation strategies for the electrical system.

Table 17. Potential Failure Mechanisms and Mitigation Strategies—Electrical

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
Loss of A-side or B-side switchgear	Plant capacity reduced. Extent of capacity reduction dependent on number of standby equipment and whether any standby is out of service for maintenance. If incoming flow exceeds reduced capacity of plant, eventual emergency bypass may result.	Incorporate automatic transfer of switchgear main and tie breakers upon power loss.	Provides rapid response for substations that require faster response time than what personnel can provide.
		Staff at least two electricians during high-flow events.	Two electricians are required for life-safety reasons.
Loss of power to EPS discharge valves hydraulic power unit	All EPS valves close, shutting down all EPS pumps, and eventual EBO discharge may result.	Provide additional permanently connected hydraulic power unit on the B side.	Include provisions for either unit to power all discharge valves.
		Power EPS discharge valve controls from individual variable-frequency drives.	This is rather than powering from the hydraulic power units.
Loss of power that would affect all associated equipment	Entire process lost.	Analyze single points of failure for all components.	For example, a breaker that would feed control power to all EPS pump controllers or both primary and backup Ovation system controllers.
Lightning strikes and power line switching	Surge of electricity to critical equipment at the plant.	Add surge suppressors.	Medium-voltage transient surge suppressors on both sides of the main 15 kV switchgear.
Power system voltage and current transients	Not knowing what caused a breaker to trip or equipment to fail.	Install power line monitors with transient waveform capture feature on each substation's main breaker.	A maintenance tool to help analyze power system health and forensic analysis of failures.
Ground fault 52-3 trip at EPS	Power loss.	Conduct the remainder of testing related to the main switchgear 722-MSG01 circuit breaker ground fault 52-3 trip.	As soon as a plant shutdown is feasible.
	SOP does not include all of the recommended steps.	Update SOP for EPS restart after ground fault.	Locally reset EPS vibration panels, variable-frequency drives, and pump local control panels upon a fault.

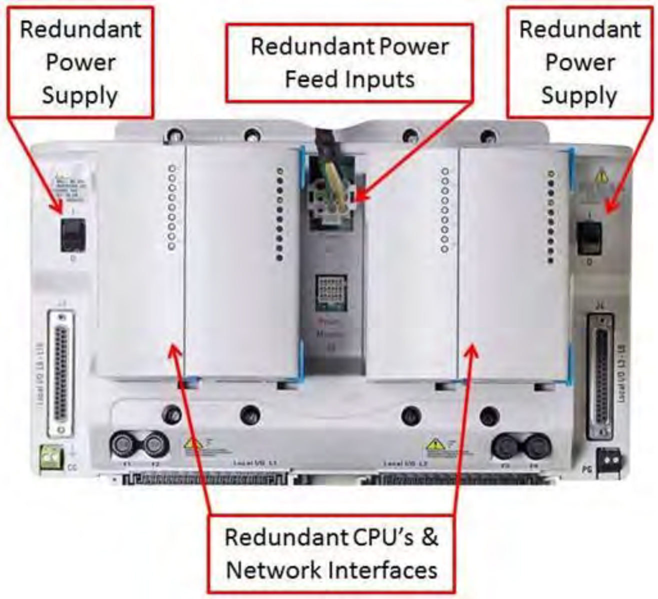
EBO = Emergency Bypass Outfall; EMO = Emergency Marine Outfall; EPS = effluent pump station; kV = kilovolt; SOP = standard operating procedure

6.4 Instrumentation and Control/Supervisory Control and Data Acquisition

6.4.1 Design and Operation

The Ovation control system utilizes Ovation controllers located at key areas of the plant. The controllers consist of redundant central processing units (CPUs) and power supplies, and network and input/output interfaces to enhance system uptime and reliability (**Figure 26**).

Figure 26. Ovation Controller with Redundant CPUs and Power Supply



WPTP's current I&C system consists of a state-of-the-art Ovation system that is deemed to meet current design standards for wastewater treatment plant control systems, based on AECOM experience, with the following exceptions:

1. WTD recently completed upgrades to the WPTP control system to Emerson Process Management's Ovation control system. This system controls the majority of plant equipment remotely through Ovation controllers. However, several critical pieces of equipment in the plant cannot currently be fully controlled from the Ovation control system:
    a. RSPs can be manually started/stopped only from the Local Control Panel located near the pumps.
    b. The EB gate can be opened/closed only from the Local Control Panel located near the gate inside the ICS building and from ACC-1.
    c. There is no local control for the EMO gate. It can be manually opened/closed only from the ICS.
    d. PE gates cannot be opened when high-level interlocks are activated.
    e. Effluent pumps can be reset/restarted only from the Local Control Panel near the pumps after a pump fault condition.

    Current control-system design standards for wastewater treatment plants typically require that all major process equipment be capable of being fully controlled remotely by the plant's control system. This includes the capability of the plant supervisor to override any interlocks or automatic control conditions remotely through the control system on any equipment, should it be deemed necessary.

2. WTD design philosophy to date has been that control of critical flood/life-safety systems be accomplished through hardwired interlocks from instrumentation directly to the equipment that is to be placed into a safe state—in other words, *not* utilizing the supervisory control system.

   Table 18 shows some examples of this approach to flood control at WPTP.

Table 18. Examples of Hardwired Interlocks for Flood Control

Location	Instrument Used	Hardwired Interlock
Influent control structure	High-high level float switches	Opens emergency bypass gate if two of three switches show high-high level.
Raw-sewage wet well	High and high-high level float switches	Closes influent gates when a High and a high-high switch from the same well are activated.
Preaeration tanks	High-high level float switches	Stops all RSPs if both switches from the same tank show high-high level.
Flow diversion structure	High level float switch	Opens secondary treatment diversion (CSO) gates when switch shows High level.
	High-high level float switches	Closes both PE weir gates when switch shows high-high level.
EPS wet well	High-high level float switch	Closes both PE weir gates.

CSO = combined sewer overflow; EPS = effluent pump station; PE = primary effluent; RSP = raw-sewage pump

   Current control system design standards for wastewater treatment plants typically require that all major process equipment be controlled first and foremost by the plant's control system, and only upon failure of the control system should any hardwired interlocks be activated. For the items listed in **Table 18** above, this means that the Ovation control system should first attempt to control the equipment at a slightly lower level set point than the switches noted above, with the switches and their associated hardwired interlocks being activated only if the control system fails to resolve the process upset.

3. The WPTP control system's alarm handling currently consists of:

   a. A mimic panel (a computer monitor tied to Ovation) that shows critical systems and control areas in individual boxes on the screen. If an alarm occurs in the named area, the box and text change color to alert operators to alarms in a general area or with a specific piece of equipment.

   b. An Ovation system historical alarm page that shows approximately the last 40 alarms registered on the system. The alarms appear at the top of this page as they come into the system and scroll down the page, eventually disappearing off the bottom of the page, as newer alarms come in. Operators can scroll through the alarm page to view older alarms, but the page is updated continuously as new alarms come into the system. The system contains a criticality rating field that can be used to assign a numeric value for every alarm, with 1 being the most critical alarm rating. However, WPTP has not completed the extensive exercise of determining the appropriate rating for each alarm.

   Current control system design standards for wastewater treatment plants typically require that all SCADA alarms go through a rigorous alarm management process during the design or implementation phase. This process reviews every SCADA alarm and determines:

   i. Validity of the alarm: Should this alarm be used? Is it useful information to the operator?
   ii. Alarm conditioning: Is this alarm always valid, or only when other process or equipment conditions are satisfied?
   iii. Should operators/supervisors be given the capability to disable the alarm?
   iv. Criticality rating of the alarm.

   Following the alarm management process, a separate Critical Alarm page is typically developed. This page shows only the alarms that have been determined to have the highest criticality rating, allowing operators to concentrate on only these critical alarms during a major event.

6.4.2 Performance Evaluation

The fundamental cause of the plant flooding on February 9, 2017, has been determined to be the failure of the preaeration tanks' Mercoid high-high level float switches, which are hardwire interlocked (controlled via relays and wiring; not controlled by the Ovation control system), to shut down the RSPs. Additionally, the preaeration tanks' Mercoid high-high and High level float switches failed to activate any alarms on the Ovation control system. Issues were also found with the PE gates and the SCADA alarms.

6.4.2.1 Float Switches

If the float switches had functioned as intended, the RSPs would have been automatically shut down from the tripping of the high-high level float switches, or manually when the operators received multiple preaeration tank high-level alarms.

Four interconnected preaeration tanks are located immediately upstream of the east and west primary tanks. Each preaeration tank has both a High level and a high-high level float switch, for a total of eight separate float switches. When any one of the four High level float switches activates, operators receive a SCADA alarm on the Ovation control system.

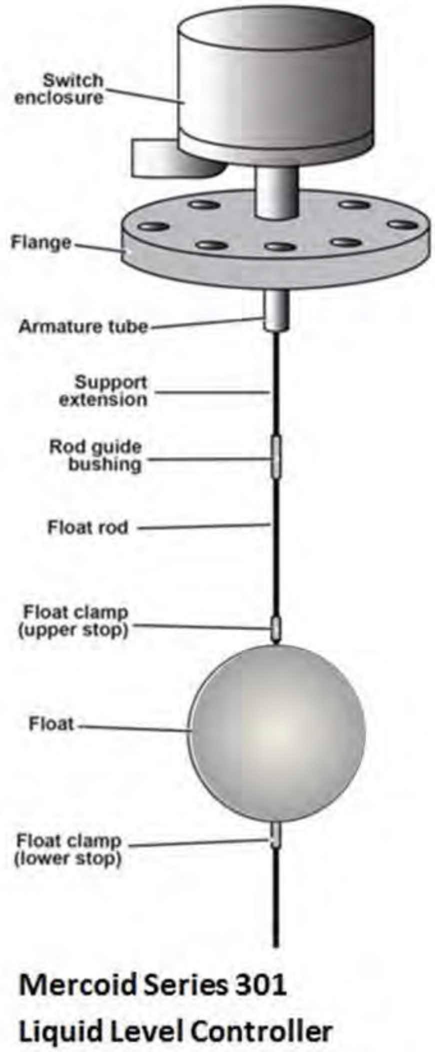
There are four high-high level float switches, one pair in each east and west preaeration basin. Both switches in either basin must be trigered to send an alarm and activate the interlock. This also means that if only one switch in each basin fails, then the alarms and the interlock that would shut down the RSPs would not be activated.

No alarm was received from any of the eight float switches, nor did the switches activate the RSP shutdown circuit at any time during the incident on February 9, 2017.

Previous analysis attributed the failure of the float switches to the bending of the float support rods that travel up through an armature tube to the switch enclosure, as shown in **Figure 27**. The armature tube has a plate at the bottom of the tube with a small aperture, just large enough to allow the float rod to move up and down inside the armature tube.

Additionally, an interlock bypass selector switch located at ACC-1 has been included in the circuit to allow operations to perform preventive maintenance (PM) on the float switches without running the risk of an inadvertent RSP shutdown. This switch is also wired into the Ovation control system as an alarm point, alerting operations if the RSP interlock is accidentally left in bypass following PM. The wiring/circuitry for the SCADA alarm signals and the interlock to shut down the RSPs are independent.

Figure 27. Mercoid Float Switch



(Source: WTD 2017j)

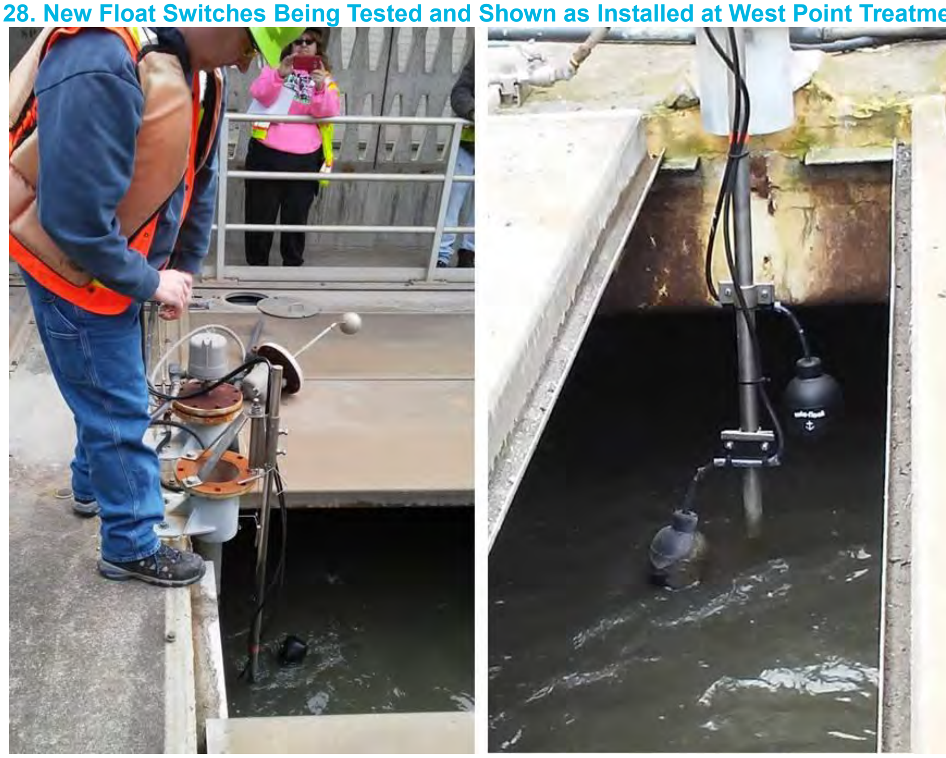
6.4.2.2 Level Float Switches that Are Hardwire Interlocked to Equipment

For the failure modes involving level float switches that are hardwire interlocked to equipment, adding primary control of this equipment through the Ovation control system should be considered further.

It was understandable that the hardwired-only approach was used when the old supervisory control system was in operation, given its lack of redundancy. However, with the recent Ovation system upgrades, this control strategy should be reviewed and possibly revised. As stated in **Section 2**, the new Ovation controllers in use throughout WTD facilities have multiple forms of redundancy, making Ovation a reliable control source for a first line of defense against plant flooding.

Since the incident, new float switches have been installed for the preaeration tank High and high-high levels based on Roto-Float direct-acting tethered float switches by Anchor Scientific Inc. These floats are mounted on a pipe assembly that can be lowered into the sewage for full hydraulic functionality testing on a regular schedule. **Figure 28** shows the new float switches being tested and in their installed position.

Figure 28. New Float Switches Being Tested and Shown as Installed at West Point Treatment Plant



Because these float switches are not intrinsically safe (electrical spark/ignition limiting) and the area in which the float switches are located has been identified as hazardous, an intrinsically safe relay was also added for each float contact before interfacing with the Ovation control system or the RSP interlock circuit. These new float switches have been successfully tested at WPTP and the County has now adopted them as its new standard for float-level switches at all plants.

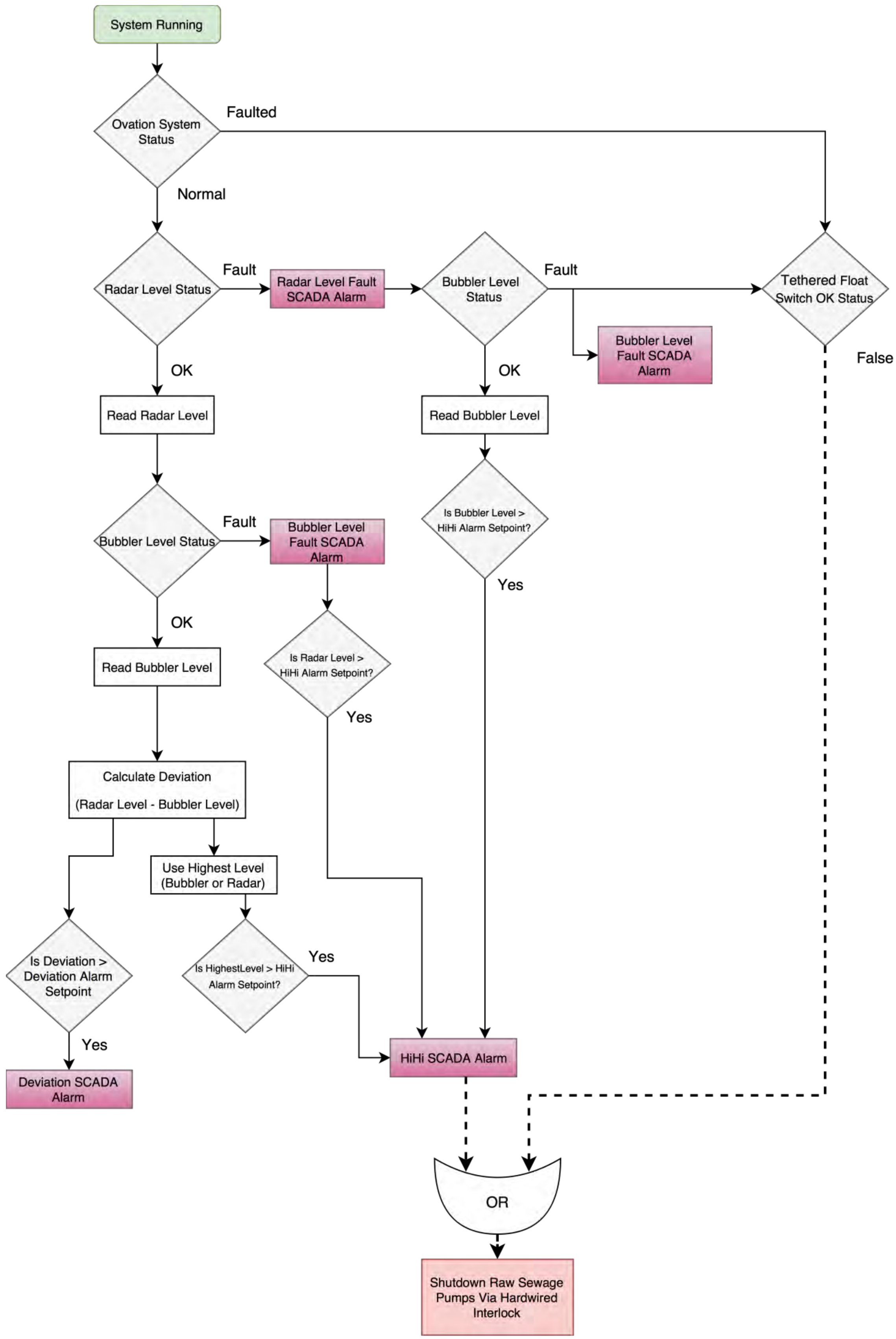
One potential future approach would be to use the existing level transmitters in the primary sedimentation tanks as the first level of defense against plant flooding. These existing transmitters would consist of different instrumentation/sensing technologies: a bubbler and a radar-level transmitter, respectively. Other level sensing technologies could also be evaluated and possibly used. The high-high level alarm shutdown set point for this first line of defense would be set at a level lower than the new backup tethered float-level switches. Typical flood control would be normally controlled through the Ovation system, with the backup float-level switches being used only in the rare event that both level transmitters and/or the Ovation system have faulted out or are unavailable. **Figure 29** shows a potential control system logic diagram for this proposed alternate flood control method.

6.4.2.3 Primary Effluent Weir Gates

Another control issue during the event was the operation of the PE weir gates. Two PE weir gates are located at the discharge of the east and west primary sedimentation tanks, respectively. The normal function of these PE gates is to maintain the proper level in the sedimentation tanks for optimal performance of the tanks to remove sedimentation and scum. During high EPS/FDS levels, the PE gates are commanded to close via a hardwired interlock between the level float switches and the hydraulic controls for the PE gates.

During the event, the PE gates received this signal to close. MC saw that the PE gates had closed, and dispatched operators to the PE gates to try to open them. Operators were unsuccessful in opening the gates because of the hardwired interlock override, leading Operations to spend time and resources that could have been used elsewhere. Also, it was one of these operators who was injured during the evacuation of this area as it flooded.

Figure 29. Potential Control System Logic Diagram for West Point Treatment Plant



6.4.2.4 SCADA Alarms

A final controls issue was the large number of SCADA alarms coming in to the system during the event. The alarms came in at such a high rate (up to 120 alarms per minute at its peak) that it was difficult for the operator to obtain useful information from the SCADA alarms page.

Because this is the primary interface for the operations supervisor and therefore the single most important operations tool, the Ovation system should be configured to better prioritize alarms and assist in making critical decisions during emergencies, not just during normal operations with occasional alarm signals.

6.4.3 Potential Failure Mechanisms and Mitigation Strategies

Table 19 summarizes the potential failure mechanisms and potential mitigation strategies for the I&C system.

Table 19. Potential Failure Mechanisms and Mitigation Strategies—Instrumentation and Control System

Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
Primary effluent weir gate interlocked closed during high-EPS- or FDS-level event.	Operations cannot open the gates by bypassing the interlock.	Add an "Interlock Active" indication light to the local control panels.	Alert the operators when the interlock is engaged (help with troubleshooting).
		Add a SCADA bypass switch to bypass the interlock.	This should be available only to the supervisors.
		Prevent interlock from being activated during high-plant-flow scenarios.	High-flow events pose a life-safety risk.
Preaeration tanks' level float switches (high-high level) did not activate interlock or trigger a SCADA alarm.	Primary tanks overflow, flooding the plant.	Remove the requirement to use both the High and high-high switches to activate the interlock.	Only the high-high switch would be required.
		Add an Ovation-level high-high signal to the hardwired interlock.	The Ovation signal should be set to activate before the float switches.
RSPs cannot be remotely started/stopped from the Main Control room.	Operations must send operators to the RSP area to locally start/stop the pumps, taking time and potentially placing operators in harm's way.	Add remote start/stop pump controls to the Main Control room through the Ovation system.	Provides rapid response without putting operators in harm's way.
		Add a hard-wired emergency stop push button not controlled through Ovation.	Provides rapid response without putting operators in harm's way.
RSPs' influent gates cannot be remotely opened/closed from the Main Control room.	Operations must send operators to the screen room or influent conduits to locally open/close the gates, taking time and potentially placing operators in harm's way.	Add remote start/stop pump controls to the Main Control room through the Ovation system.	Operations must send operators to the raw-sewage wet-well area to locally open/close the gates, taking time and potentially placing operators in harm's way.
Raw-sewage wet-well level float switches (High and high-high level) did not activate interlock or trigger a SCADA alarm.	The raw-sewage wet well overflows, potentially flooding the plant.	Remove the requirement to use both the High and high-high switches to activate the interlock.	Only the high-high switch would be required.
		Add an Ovation-level high-high signal to the hardwired interlock.	The Ovation signal should be set to activate before the float switches.
The emergency bypass gate cannot be remotely opened/closed from the Main Control room or ACC-1.	Operations must send operators to the EB gate area to locally open/close the gate, taking time and potentially placing operators in harm's way.	Add remote open/close gate controls to the Main Control room through the Ovation system.	Make these controls highly visible to respond in emergencies.
The Ovation system receives a large number of incoming alarms as an emergency develops.	The Main Control operator may be distracted or unable to process large amounts of information and make mission-critical decisions.	Conduct an alarm management review workshop to properly prioritize alarms and remove or condition alarms.	The system is not optimized to prioritize alarms.

ACC = Area Control Center; EB = Emergency Bypass; EPS = effluent pump station; FDS = flow diversion structure; RSP = raw-sewage pump; SCADA = supervisory control and data acquisition

6.5 Operations

Analysis of failure mechanisms and effects should include human and organizational aspects as well as equipment and electrical and instrumentation systems (Creedy 2011). An attribute of industries with major accident potential is that they have a high degree of technological and organizational complexity (Perrow 1984). Human behavior is increasingly recognized as one of the most important factors in major accidents (Creedy 2011). In this section, O&M practices are evaluated using the HAZOP methodology.

Challenges in the following areas in an organization could lead to a failure event (Creedy 2011):

- **Knowledge—**Never realized that a problem could occur (benchmarking error).
- **Policy—**Thought the situation would be acceptable but did not realize the full implications until the problem happened.
- **System design—**Even if everything had been done as intended, the problem would still have occurred.
- **System execution (management system error)**—The problem occurred because someone or something did not perform as intended.

6.5.1 Staffing

6.5.1.1 Design and Operation

Several groups at WPTP—Engineering, Administration, Operations, Asset Management, Maintenance, and Health and Safety—have clear-cut roles and responsibilities.

WPTP employs 32 operators in four crews (A, B, C, and D). Each crew is led by a shift supervisor, who reports to the wastewater plant operations Assistant manager. In addition, teams of mechanical and instrumentation and electrical technicians perform routine operation and maintenance. Crew C was on duty during the event on February 9, 2017.

King County operations supervisors, senior-in-charge operators, senior operators, operators, and operators-in-training are all DOE Wastewater Treatment Operator Certified.

There is a general shortage of qualified wastewater operators. Staff retention at WPTP has been an ongoing issue. The plant is not in an easy location for commuting, and the cost of living in the surrounding area is high. Since 2007, 121 employees have been hired (including six new staff members since the February 9, 2017, event). **Table 20** provides a critical review of how staff retention has particularly suffered at WPTP. Between November 1, 2010, and November 19, 2013, WPTP had a significant number of new hires compared to the South Plant and Brightwater Treatment Plants. Some of this was because of retirements, resignations, and terminations, but there has been a large number of transfers from WPTP to one of the County's other treatment plants.

Table 20. Staff Retention (November 1, 2010–November 19, 2013)

Crew	West Point		South Plant		Brightwater	
Increase/decrease	+	-	+	-	+	-
New hires	40		7		3	
Retirements + terminations		20		11		6
Plant transfers	3	23	18	6	9	1

Loss of corporate memory is a potential problem with a lack of staff retention. New employees receive training to understand the way a task is done, but not necessarily to understand why the task is done that way, the potential consequences of doing it differently, and how to detect and recover from undesired actions (Creedy 2011).

WTD is taking an innovative approach to address the issue of hiring experienced, trained, and qualified wastewater treatment plant operators and ensuring proper succession planning. WTD is developing a pool of trained, qualified operators with a 2-year Operator-in-Training Program. This program has produced employees who are motivated and has created a very competitive workforce that will be used to bridge WTD's hiring gap. These new staff members are energized by their mission to protect public health and the environment. Aspects of this program should be extended to existing staff members with only a few years of experience. The County should also look at incentive programs to retain existing staff.

6.5.1.2 Evaluation

During the night shift at WPTP on February 9, 2017, one supervisor and eight operators were on duty. The supervisor and one operator were seated in the Main Control (MC) room, while seven other operators were on the ground of the plant. Three staff members were at area control center (ACC)-1, one was at ACC-2, and the other three were at ACC-3. Eight of the nine crew members on duty that night were licensed, trained professionals and there was also a licensed operator-in-training on duty that night who was shadowing one of the operators at ACC-1 (WTD 2017j). With the exception of the operator-in-training, all staff members on duty during the event had between 3 and 32 years of experience.

6.5.1.3 Potential Failure Mechanisms and Mitigation Strategies

Table 21 summarizes the potential failure mechanisms and potential mitigation strategies for staffing at WPTP.

Table 21. Potential Failure Mechanisms and Mitigation Strategies—Staffing

Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
Staff retention	Loss of corporate memory	Develop incentive programs to retain staff at WPTP.	It is difficult to retain employees at WPTP.
Inconsistent levels of staff system knowledge	Operators who are unable to perform their jobs	Extend aspects of the Operator-in-Training program to existing staff.	Currently the Operator-in-Training Program is only for new hires with no previous wastewater treatment plant experience.

WPTP = West Point Treatment Plant

6.5.2 Operator Performance

After careful review of the events and the operators' response to the events, it is clear that the operators on shift did what could reasonably be expected under these difficult circumstances, and in many cases went above what could reasonably be expected to keep the plant operational.

There is a need to recognize the seriousness of consequences and mechanisms of causation. A Life Safety Management system focuses on the process rather than the individual worker and can identify the mechanisms and consequences of failure.

6.5.2.1 Design and Operation

The Operations Supervisor, serving as MC, monitors operator activity and equipment status, manages flows in the plant and conveyance system, and contacts on-call staff if needed. WPTP's MC monitors all pump stations, regulator and outfall stations, and storage facilities and checks their trends frequently throughout a normal shift. During rain events, the conveyance system needs closer monitoring, and flows entering WPTP may need to be managed to avoid exceeding the plant's capacity. MC also monitors off-site facilities for proper operation and notifies the off-site operators when problems happen. The normal daily duties and responsibilities for the operator with MC responsibility are listed in **Appendix N**.

Operators carry out the orders assigned to them from MC and manage on-the-ground tasks as needed. They depend on automatic functions to help manage most events efficiently.

WPTP standard operating procedures (SOPs) guide operators on how to execute the plant's various operations. They provide specific step-by-step instructions for how to operate, isolate, start, and stop specific components of the plant. The operator can access SOPs online when receiving a PM work order, or when directed by the shift supervisor to prepare for a certain operation. A list of the WPTP SOPs was provided in the *After Action Self-Assessment Report* (WTD 2017j) and is reproduced in its entirety in **Appendix O**. WTD has developed SOPs and the WPTP staff has been trained on them, but the SOPs may not always be strictly followed.

6.5.2.2 Evaluation

The following operational actions occurred at each of the three active locations at WPTP. More information regarding operator activities can be found in **Section 3,** which includes a timeline of activities in the MC, EPS, and primary treatment areas during the time between loss of power to the EPS and the start of the emergency bypass of flows. WTD also provided a figure of the operations team's movements during the event, which is reproduced in **Appendix F**.

Main Control:

- Received indications and alarms that the effluent pumps are not operational.
- Dispatched operators in ACC-3 to restart the effluent pumps.
- Began the procedures to manage and store wastewater in the conveyance system and the plant's secondary process area. The aim was to use available capacity and provide additional time for restarting the effluent pumps and restoring normal plant flow (CH2M 2017). If the conveyance system pumps are slowed to reduce flow to the treatment plant, more flow is then diverted to CSO outfalls and CSO treatment facilities.
- Slowed the RSPs to reduce inflow to the plant.
- Dispatched operators in ACC-1 to manually reopen the PE gates.
- Scrolled through the multiple alarms in the control system, although they were off the screen too fast for the operator to catch the significance of each alarm. The Ovation system was not ready for use in an emergency event because alarms had not been prioritized.
- Monitored operator progress on the PE gates and saw that the EPS wet-well high-high interlock had reengaged, which prevented the gates from opening. Ordered the operators to return to ACC-1.
- Monitored water levels at the ICS wet well to ensure storage capacity.
- Initiated contact for an on-call electrician.

- Monitored the operator reset attempts at the EPS pumps. Detected that the EPS pump effluent valves were closed after the two attempted restarts and instructed operators to check valve operation. Informed operators to check effluent valve hydraulic valve control power and to connect the backup hydraulic system.
- Checked camera view of screening room and observed water flowing from the upper deck, and became aware that flooding was occurring. Dispatched operators from ACC-1 to shut down the RSPs.

The operators were trying to prevent flow from being diverted if at all possible. No SOP was in place for when to make a bypass decision, and the operators were not comfortable making this decision without clear instruction. The operators' day-to-day priority was to prevent a bypass.

MC also slowed the RSPs down to decrease the inflow to the plant. If the conveyance system pumps are slowed to reduce flow to the treatment plant, this backs up flow in the collection system upstream and results in more diversion of flow to CSO outfalls and CSO treatment facilities. The operators were trying to prevent flow from being diverted if at all possible.

MC has a significant number of responsibilities: monitoring the plant and alarms, monitoring and controlling flows upstream and into the plant, managing and communicating with operators, and contacting on-call staff, among other responsibilities. This requires considerable effort for two operators. Streamlining automation of the system controls and installing an automatic bypass control override button would help with operation. Contacting on-call assistance is a significant effort that diverts attention from the reason that assistance is being called. An improved method of contacting on-call staff should be considered. Making additional operators available during wet-weather events to focus on management of the upstream system would also be beneficial.

ACC-1:

- Worked to troubleshoot the hydraulic system to manually open the PE gates.
- Evacuated the primary basin area when flooding occurred. An operator-in-training was injured during the evacuation.
- Assisted the injured operator-in-training.
- Shut down the RSPs.

Operators did not radio and confirm that MC was aware of the flooding. Such a confirming communication should have occurred when the operators reached a safe location.

ACC-3:

- Attempted to restart the EPS pumps.
- Attempted to hook up the portable hydraulic system skid (mule) to operate the closed valves.
- Evacuated the EPS area when water was seen coming down the stairs.

Operators in ACC-3 were initially unaware of the power outage of the main hydraulic skid. This was listed as a step to be checked on the SOP for EPS restart. Recent issues with EPS pumps have been related to vibration, and based on this previous experience, the operators did not expect power to the valves to be an issue. In addition, the hydraulic skid is in the lower pump room and takes additional time to check.

6.5.2.3 Potential Failure Mechanisms and Mitigation Strategies

Table 22 summarizes the potential failure mechanisms and potential mitigation strategies for WPTP operators.

Table 22. Potential Failure Mechanisms and Mitigation Strategies—Operators

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
No SOP exists for emergency bypass.	Operators were not comfortable making the emergency bypass decision.	Create an Emergency Bypass SOP.	If a standardized process is in place, the operators could operate the plant as it is designed.
Operators were too focused on preventing an emergency bypass from occurring.	Operators were not comfortable making the emergency bypass decision.	Change the “no bypass” philosophy.	This is important to protect life safety and equipment and to reduce the amount of time the plant is in bypass mode.
			Important to keep the environmental protection mission of the organization.
Operators were not able to quickly make a bypass decision.	Flooding/life-safety issues occurred.	Add an Emergency Bypass override button at the Main Control room.	Currently this is embedded in the control strategy.
Operators were not comfortable making decisions during the event.	Operators were not able to perform their jobs and flooding/life-safety issues occurred.	Provide hands-on Emergency Response Plan training.	None.
		Run the hydraulic simulation model so operators know narrow time margins and potential consequences.	None.
		Implement a Life Safety Management system.	An aspect of this type of process is that it focuses on the process rather than the individual worker to avoid scapegoating and to effectively reduce risk.
Main Control has too many responsibilities.	The Main Control operator may be distracted while making mission-critical decisions.	Add an automated call program to contact on-call personnel.	None.
		Increase the number of staff on duty in MC during wet-weather events.	None.
The Ovation system receives a large number of incoming alarms as an emergency develops.	The Main Control operator may be unable to process large amounts of information and make mission-critical decisions.	Conduct an alarm management review workshop to properly prioritize alarms and remove or condition alarms.	The system is not optimized to prioritize alarms.
Main Control was not aware of flooding in the plant.	Flooding/life-safety issues occurred.	Add a visual beacon/strobe-type alarm in the control room.	To warn the operators in the control room that flooding was imminent unless action is taken.
		Provide Emergency Communications training.	Should be part of Emergency Response Plan training.
Operators did not check for a power outage of the main hydraulic skid.	Operators spent time on a process that was not going to work,	Practice SOPs for EPS restart.	This was listed as a step to be checked on the SOP for EPS restart. Recent issues with EPS pumps have been related to vibration, and based on this previous experience, the operators did not expect power to the valves to be an issue.

EPS = effluent pump station; SOP = standard operating procedure

6.5.3 Operator Training

6.5.3.1 Design and Operation

WTD has developed many different training tools for its staff. The operational technical training tools and certification training workbooks and manuals are continuously updated and enhanced. The tools are integral components for achieving WTD's mission to protect public health and enhance the environment by collecting and treating wastewater, while recycling valuable resources for the Puget Sound region.

Safety Training

WTD has an extensive employee safety program in place and keeps records of all training for compliance with NPDES and with Federal Emergency Management Agency (FEMA) requirements. Employees are trained in safety issues related to their position and apply them in their daily work activities. The program's most-used tools are the online and classroom training sessions for operators and all other WTD staff members.

On-the-Job Training

Throughout the years WPTP operations staff have always been provided with on-the-job training, where senior staff train junior or new staff members in all tasks associated with running the plant's equipment and process systems. This on-the-job training is done while on shift and includes hydraulic reviews and testing, plant-wide emergency drills, practice at starting and stopping equipment or process systems, and debriefing discussions.

Formalized Training Program

WTD also uses a formalized training program called the Technical Training for Operations (T^2OPS) program. The goal of the T^2OPS program is to increase employee understanding of the plant and off-site systems to effectively and safely operate WTD facilities under normal or emergency conditions. Consistent trainings are typically held during the summer and fall (the dry seasons).

The technical training program includes:

- ***Plant Hydraulics Training***—This training allows for additional conversations regarding "what-if" case scenarios, management of high flows during wet weather, restart procedures after a power outage, critical elevations, and set points, and discussions of emergency response and overflows.
- ***Wet-Weather Training***—This training includes daylong tabletop training involving staff members from throughout WTD, working as a team to respond to ever-changing event challenges. The training gets participants thinking about all possible effects of an event and the need to provide good responses. This is generally an informal event, with minimal pre-training preparation of materials or official post-training documentation. Participants can suggest scenarios for discussion. This program does not extend to all plant operators and on-duty employees.
- ***Operator-in-Training Program***—WTD is developing a pool of trained, qualified operators. This program includes a 6-week WTD Wastewater Boot Camp and 3-month rotation assignments at each treatment facility including shift operation, offsite and day operations.

Providing a casual forum for discussing emergency scenarios, such as the wet-weather training, can be very helpful and productive for staff who may be required to respond to emergencies. However, it would be beneficial to enhance the current training with a more formalized and extensive training and exercise program in accordance with U.S. Department of Homeland Security (DHS) directives.

6.5.3.2 Evaluation

Safety Training

A few employees who were interviewed after the flooding event (CH2M 2017) recommended designating a specific emergency evacuation path. Such a designation would have helped operators know where to step and potentially avoid paths that could be flooded. Operators should practice this route regularly.

Another employee recommended developing an SOP for tunnel entry during wet weather. Past a certain high flow, staff members should not enter tunnels under any circumstances. This SOP already exists, so it should be re-evaluated and trained on more often.

After the event, all employees were made aware of employee services that are always available if needed, such as additional health and safety training and counseling.

On-the-Job Training

The number of operators on duty at WPTP has varied over the years as the plant has become more automated. Although enough operators may be available to operate the plant in most situations, there is not additional capacity to complete daily duties and additional on-the-job training. On-the-job training and experience are necessary to eventually become a shift supervisor and work in MC. They also improve understanding of plant operations as a whole, an uncalculatable benefit for employees.

Formalized Training Program

Only two operators stated that they were comfortable during the event (CH2M 2017). Many crew members who were interviewed after the event expressed interest in receiving additional emergency response training.

Operator training was reviewed to assess the appropriateness and amount of training provided. **Appendix P** presents a complete list of courses taken by operators at WPTP from 2014 through 2017. A review of the number of training courses for the past 3 years for all operators reveals that all employees complete extensive training. **Table 23** summarizes the total number of training courses completed by each crew since 2014.

Table 23. Total Number of Training Courses per Operator Crew per Year (2014–2017)

Crew	2014	2015	2016	2017	Total
A	154	198	133	82	**567**
B	80	164	93	9	**346**
C	207	156	109	31	**503**
D	99	94	113	31	**337**
Total	**540**	**612**	**448**	**153**	**1753**

(Source: WTD 2017h)

A review of the titles of courses completed by operators (**Appendix P**) revealed that only a few training courses focused on emergency response, communications, wet-weather training, or other specific issues identified by staff members in post-event interviews as areas for which they would like additional training (CH2M 2017). **Table 24** lists these applicable courses.

Table 24. Number of Key Courses Completed by Crew C (2014–2017)

Course Name	Number of Crew C Staff Members Who Completed Course
ACC-2 Restart Procedures After a Power Outage	
Emergency Action Plans for Plant Operation and Maintenance Personnel	
Emergency Communication	
Emergency Communications Methods and Protocols	

Course Name	Number of Crew C Staff Members Who Completed Course
Emergency Evacuation/Alarms and Beacons/NFPA Classifications	
Emergency Response—Awareness and Operations Level	
Emergency Response Plan	
Emergency Response Plan Tailgate (2015)	7
Emergency Response Procedures—Operation Level	
Event Debrief—Primary Effluent Valve Failure Aeration (Close Due to Communications Loss at High Flows)	
Hazard Communication Standard, Chemical Safety and Physical Safety	
High-Flow Event and EPS (Effluent Pumping) Failure Debrief	
How to Use the Hydraulic Skid at EPS	
HRD Safety and Claims Management	
Peaking Pump—Reset	4
Wet-Weather Meeting—2015	2
WTD Incident Response and Emergency Coordination—2014	1
WTD Wet-Weather Exercise–Annual—2016	2
Total Crew C courses completed	**16**

ACC = area control center; EPS = effluent pump station; NFPA = National Fire Protection Association; WTD = Wastewater Treatment Division
(Source: WTD 2017h)

Although Crew C has completed a combined total of 503 courses relating to the plant and off-site systems and effectively and safely operating WTD facilities under normal or emergency conditions, many courses have not been completed in the past 3 years.

Operator training should be reviewed further to assess the appropriateness and amount of training provided. Further analysis should occur to assess the consistency of training between instructors and the ability of the operators to understand and use the information.

Practical training should be provided on actual equipment, with timed drills to verify whether the tasks can be completed in the time available during normal and unusual circumstances.

Emergency Training

A formal emergency training program can help employees maintain competency for completing their specific tasks during an emergency, as the roles they assume in an emergency could differ from their normal duties. Training is particularly critical where employees do not face the particular type of scenario regularly. A formal emergency training program may include (but not limited to) the following components:

- **Incident Command System and National Incident Management System Training**. This training should be consistent with FEMA requirements. It may be beneficial to provide live in-person training that can be customized and more effective than standardized, generic online course materials.
- **Disaster Service Worker Training**. This training is important to clarify the responsibilities and obligations of being a King County employee. This may be particularly important for new employees and/or staff members who have been reassigned.
- **Emergency Response Plan Training**. WTD maintains various ERPs specific to the division and its facilities. To the extent possible and appropriate, ERP training should be integrated with emergency training courses to maintain familiarity with the contents and expectations specifically set forth in WTD ERPs.

Emergency Exercises

Emergency exercises allow emergency response personnel to become familiar with the procedures, facilities, and systems used during actual emergencies. It may be beneficial to implement a formal and progressive exercise program, with periodic exercises conducted each year. A primary purpose of periodic exercises would be to train staff and formally evaluate the effectiveness of WTD emergency plans and procedures. Additional smaller scale drills and exercises may be required periodically to correct any weaknesses or deficiencies. The small-scale exercises may be completed by specific WTD crews. When appropriate, exercises can be coordinated with other levels of the County's emergency organization, such as local and regional emergency operations centers.

The exercises should include staff at various levels of experience so that participants can gain valuable insight into the thought processes between managers and direct reports, and can discuss and agree on strategies for abnormal operational activities. This may help enhance employees' confidence so that staff members at all levels feel comfortable initiating alternate operations during emergencies.

Documentation of these exercises should be compliant with the Homeland Security Exercise and Evaluation Program (HSEEP). The documentation should include preparation materials, participant handouts, situation manuals, master scenario events lists, controller/evaluator handbooks, exercise evaluation guides, post-exercise debrief summaries, after-action reports, and improvement plans, as appropriate.

The WTD ERPs and WTD's overall capability to respond to emergencies could be tested using a combination of the following DHS-compliant exercise types:

- **Tabletop Exercise (TTX):** These discussion-based exercises involve key personnel and are generally held in an informal setting intended to generate discussion of various issues regarding a hypothetical, simulated emergency incident. TTXs can enhance awareness, validate plans and procedures, and assess the types of systems needed to guide prevention of, protection from, response to, and recovery from a defined incident. Generally, TTXs are aimed at facilitating conceptual understanding, identifying strengths and weaknesses, and achieving changes in the approach to a particular type of emergency. Participants are encouraged to discuss issues in depth. The low-stress environment allows them to develop decisions through slow-paced problem solving rather than the rapid, spontaneous decision-making that occurs under actual incident conditions. A TTX is effective when participants are energetically involved and they assess recommended revisions to current policies, procedures, and plans.
- **Wet-Weather Training:** The County already conducts wet-weather training consisting of daylong TTX-type activities. To enhance these activities and reap their full benefits, TTXs should be supported with HSEEP-type documentation to properly identify and acknowledge needs, deficiencies, and corrective actions and ensure that responsibilities are delegated to maintain accountability. It can also be beneficial to limit participation in specifically focused TTXs to a core group of 15–20 participants. A small, controlled group may enable those attending to make more active contributions, and may contribute to an atmosphere that promotes honest information-sharing.
- **Functional Exercise (FE):** FEs are operational exercises designed to validate and evaluate capabilities and activities within a function or interdependent groups of functions. FEs focus on exercise plans, policies, procedures, and staff involved in management, direction, command, and control functions. An exercise scenario projects events and provides event updates that drive activity at the management level. An FE is conducted in a realistic, real-time environment; however, movement of personnel and equipment is simulated.
- **Full-Scale Exercise (FSE):** FSEs are operational exercises and typically the most complex and resource-intensive type of exercise. They are multi-agency, multi-jurisdictional, and multi-organizational exercises that validate many facets of preparedness. An FSE focuses on implementing and analyzing the plans, policies, and procedures developed in discussion-based exercises such as TTXs, and honed during previous, smaller operational exercises such as FEs. Events are projected through an exercise scenario with event updates that drive activity at the operational level. The FSE is conducted in a real-

time, stressful environment that closely mirrors a real incident. Personnel and resources are mobilized and deployed to the scene where actions would be conducted as if a real incident had occurred. The FSE simulates reality by presenting complex and realistic problems involving operations in multiple functional areas that require critical thinking, rapid problem-solving, and effective response by trained personnel.

Upon completion of an exercise, an evaluation should be completed within 30 days. This evaluation will include a summary of the lessons learned, an after-action report, and an improvement plan. This information should be distributed to County training coordinators and emergency managers. Additional training, preparedness, mitigation, plans/procedures, and other improvements should be identified from the weaknesses identified during the exercises and become part of the after-action activities. Exercise documentation should comply with the HSEEP.

6.5.3.3 Potential Failure Mechanisms and Mitigation Strategies

Table 25 summarizes the potential failure mechanisms and potential mitigation strategies for training.

Table 25. Potential Failure Mechanisms and Mitigation Strategies—Training

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
No designated emergency evacuation path	Life-safety issue	Create a designated emergency evacuation path.	Train often on designated emergency evacuation path.
No high-flow SOP for tunnel entry	Life-safety issue	Develop SOP for tunnel entry.	Develop a SOP for tunnel entry, particularly to avoid entering at high flows.
Lack of consistent training for operators	Operators not able to perform jobs	Review operator training program.	Need to assess the appropriateness and amount of training provided.
Fewer operators on duty	Lack of familiarity with system as a whole	Increase number of operators on duty.	Operators need time on nonemergency shifts to gain on-the-job training across the plant.
Operators uncomfortable making decisions during event	Operators not able to perform jobs/flooding/life-safety issues	Provide hands-on Emergency Response Plan training.	

SOP = standard operating procedure

6.5.4 Equipment and Systems Testing Procedures

6.5.4.1 Design and Operation

The failure mechanisms for each system component have been identified in previous sections of this report. This section focuses on the procedures used to operate and test WPTP as a system, and on the systems in place to protect operators and the plant.

WTD has developed the following resources to operate and test the components of WPTP and to test the system as a whole:

- **WPTP—Restart Procedures after a Power Outage**
- **Critical Elevations and Set Points Document**
- **Wet- and Dry-Weather System Checks**—Wet-weather system checks are planning and training sessions held at the plants before the start of the wet season and during the season.
- **Annual Dry-Weather Emergency Hydraulic Control Test**—During the fall season, a shift crew conducts the Dry-Weather Emergency Hydraulic Control Test. The SOP for annual testing directs the staff to trip the switches using the actual high-water level. However, the testing is done by removing the covers and activating the mercury switches manually without physically moving the floats

6.5.4.2 Evaluation

The dynamic hydraulics of WPTP requires operators to react quickly to unexpected changes in flow. Operators need to have a good understanding of the timing and hydraulics of the plant. The use of a dynamic computer model to simulate plant conditions, both normal and abnormal, is becoming more common in the industry. After the 2000 bypass event, development of an operator training tool that incorporates this technology was recommended. Such a tool was not developed at the time because of the high cost.

During the HAZOP workshop, County staff referenced existing plans to acquire a simulator by January 2018 for operator training purposes. It may be beneficial to integrate simulator training with the emergency training and exercise program to routinely test the hydraulic protection equipment under actual conditions.

On the night of the event, multiple components of the system failed:

- More than 2,000 alarms were displayed in the Ovation system. Alarm criticality ratings should be reviewed, and only life-safety/hydraulic protection–related alarms should be classified as criticality level 1. These alarms should remain visible until cleared.
- There was no visual beacon/strobe-type alarm to warn the operators in the control room that flooding was imminent. Adding an alarm system would provide increased life-safety/hydraulic protection.
- The PE gate interlock is designed to turn on an indicator light in ACC-1 when the gate is hydraulically interlocked. This indicator light was not illuminated until after the event had occurred. Alarm systems such as this should undergo routine testing.
- The lighting in the basement went out when the power went out. The basement lighting should have backup and be waterproof.
- The operators in ACC-3 tried to reset the EPS pumps several times during the event. The EPS restart SOP should specify how long the operators should try to reset the EPS before giving up.
- The hydraulic skid system, which is sometimes needed to restart the EPS, is on a different level and hooking it up is time-consuming. Two emergency skids should be hooked up at all times (not online but connected).
- An operator-in-training was injured when he fell through a cover that popped off as a result of hydraulic pressure. All covers should be properly secured.

A Life Safety Management system should be developed and implemented to reduce risk and improve safety for plant staff members, protect the equipment, and reduce the duration of bypass events.

6.5.4.3 Potential Failure Mechanisms and Mitigation Strategies

Table 26 summarizes the potential failure mechanisms and potential mitigation strategies for equipment and systems testing procedures.

Table 26. Potential Failure Mechanisms and Mitigation Strategies—Equipment and Systems Testing Procedures

Potential Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
Failure of lights in tunnel of gallery	Life-safety issue	Add waterproof lighting in the basement.	
Inability to hook up emergency skids quickly	Inability to restart EPS	Have two permanent skids hooked up at all times.	Have online but connected.
Release of walkway covers during flooding	Life-safety issue	Secure walkway covers.	Fixed.
Annual testing done by removing covers and activating mercury switches manually without physically moving floats	Lack of testing of hydraulic protection equipment under actual conditions	Revise SOP for annual plant hydraulic safety.	It was done this way because of multiple tank leaks experienced when water levels are above normal. This has been fixed.
No process to make sure system is functioning as a whole	Increased risks	Implement a Life Safety Management system.	A Life Safety Management system should be developed and implemented to reduce risks and improve safety for the staff at the plant, protect the equipment, and reduce the duration of bypass events.
			Scheduled to be completed by January 2018.
		Develop a dynamic computer model to simulate plant hydraulic conditions.	Scheduled to be completed by January 2018.
No routine testing of the PE gate interlock indicator in ACC-1	Failure of PE gate interlock indicator in ACC-1 to work during an event	Implement routine testing of the PE gate interlock indicator in ACC-1.	
Large number of incoming alarms received by Ovation system during developing emergency	Distracted Main Control operator or potential inability to process large amounts of information and make mission-critical decisions	Conduct an alarm management review workshop to properly prioritize alarms and remove or condition alarms.	Alarm criticality ratings should be reviewed. Only life-safety/hydraulic protection–related alarms should be classified as criticality level 1. These alarms should remain visible until cleared.
Too much time spent by operators trying to restart EPS	Flooding of plant	Revise SOP for EPS reset.	Need to specify the amount of time operators have during different flow conditions.
			SOP specifies 2 attempts for restart.

ACC = area control center; EPS = effluent pump station; PE = primary effluent; SOP = standard operating procedure

6.5.5 Maintenance Procedures

6.5.5.1 Design and Operation

Computerized Maintenance Management System

WTD's CMMS tracks assets and assigns their criticality. The criticality of an asset is calculated based on the asset's function in the system. Experienced operators calculate criticality, taking into account the likelihood and the consequence of failure. Criticality level 1 is the highest level and criticality level 5 is the lowest.

The maintenance of an asset is directly related to its assigned criticality level. Criticality level 1 and level 2 assets are managed at a high level of preventive and predictive maintenance, including forecasting end-of-life refurbishment or replacement. Assets at criticality levels 3, 4, and 5 receive minor PM all the way down to run-to-fail or no maintenance. Criticality level 3 is the default and is automatically assigned to all assets when they are initially loaded into the CMMS, unless adjusted up or down by operations staff.

Preventive Maintenance

Work orders are assigned to operators for preventative maintenance (PM) on a weekly basis and for annual testing of the total plant's hydraulic safety system. The PM SOP is written in the "work requested" field on the PM work order.

Corrective Maintenance

Corrective maintenance work orders have been reviewed for compliance with adopted business practices originating as far back as the 2008 Genesis Solutions Maintenance Best Practice initiative project. One primary objective of the Maintenance Best Practice project is to show the risk to which WTD is being exposed by individual assets. The proper, consistent documentation of work orders is a major driver of WTD's key performance indicators, life-cycle management, and ability to ascertain risk exposure.

6.5.5.2 Evaluation

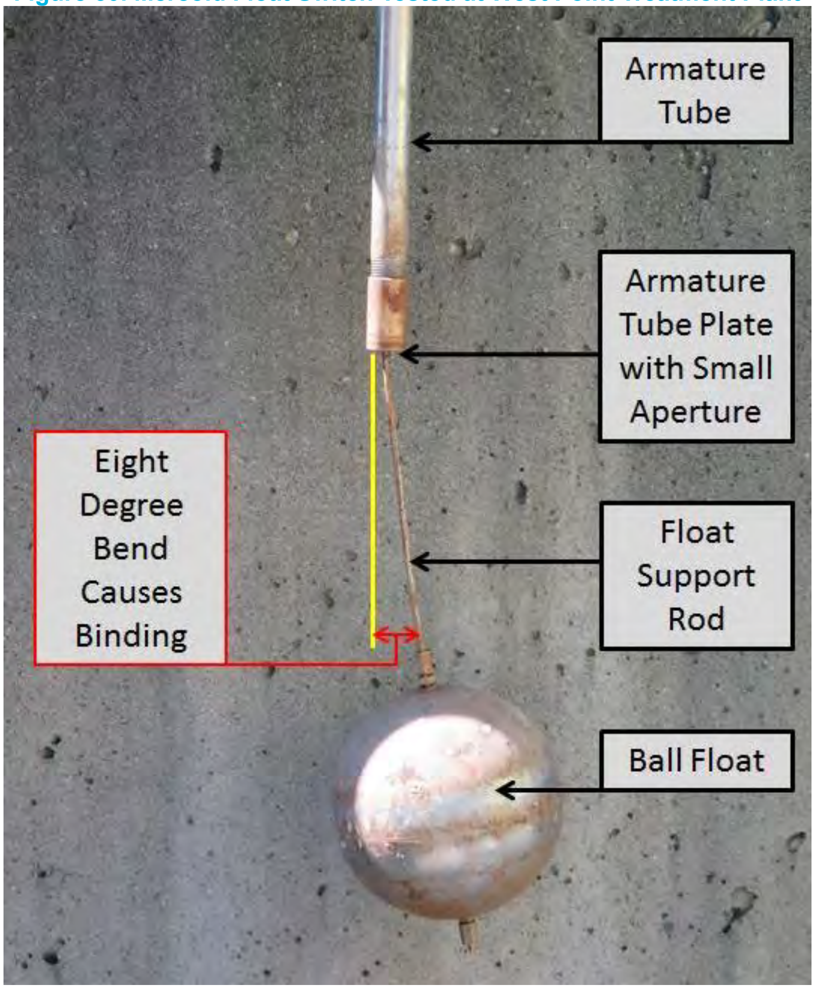
Float Switch Preventative Maintenance

Following an extensive review, AECOM agrees with the conclusion of the *After Action Self-Assessment Report* (WTD 2017j) that the float rods were bent as a result of the weekly PM cleaning, and that this bending caused the failure of the switches to function properly. Additional background that AECOM observed that supports this conclusion is as follows:

1. With one person reinserting the float switch into the stilling well after cleaning, it is very difficult to lower the float without the float touching the stilling well walls. There is only a ¾-inch clearance from the float ball to the stilling well wall. If the float hits the flange at the top of the stilling well or if it is lowered into the well at a slight angle from vertical, the rod will bend.

   During a demonstration of the cleaning, an operator successfully inserted the float into the well without any bending of the rod. However, when the float was lowered, the assembly was moved several inches off center. This does not seem significant; however, it was observed in a test performed by AECOM that bending the float rod only 8 degrees created enough of a bend in the rod that it would not slide into the armature tube without considerable force. **Figure 30** illustrates the eight degree bend of the Mercoid float system at WPTP.

Figure 30. Mercoid Float Switch Tested at West Point Treatment Plant



In addition, the bent support rods would most likely cause the float ball to rub up against the inside wall of the stilling wells, creating additional friction and requiring even more force for the rod to move up.

2. During an interview on May 11, 2017, an operator stated that all the rods appeared to be bent to some extent. If the operator observed that the rods were excessively bent, the operator would notify maintenance. However, a slight bend in the rod would not cause the operator to notify maintenance.
3. In some past instances, PM cleaning was performed by a single person. This would require the person to lay the float switch assembly horizontally on the concrete deck to wash out the stilling well and the float.

   AECOM tested a high-high level float switch assembly after the incident by gently laying it on the pavement with the flange of the switch assembly and the float both in contact with the pavement. This caused the float rod to bend enough that it would not slide into the armature tube without force when returned to a vertical position.
4. During weekly PM of the float switches, the floats were not normally exercised up and down into the switch enclosure to physically verify if the rod was binding.
5. During annual maintenance testing of the float system, the electrical switch was activated by removing the cover on the switch enclosure and activating the internal contact without physically moving the float. Therefore, the full functionality of the float operation was not verified during annual maintenance testing.
6. These floats have had a history of malfunction:

a. During the bypass event on January 4, 2000, no entries for High or high-high RSP wet well levels or preaeration tanks were recorded in the alarm log, suggesting that the floats failed.

b. During the bypass event on December 14, 2006, it was believed that the control interlock—which should have shut down the RSPs because of high water levels in the primary sedimentation tank—did not function because the high-high interlock bypass switch for the RSP was in bypass mode. However, it is also likely that the floats did not operate and caused this event.

c. Computerized maintenance management system (CMMS) records show that since 1998, six corrective maintenance work orders have been written against the eight preaeration basin float assemblies because of bent float rods.

In conclusion, AECOM believes that the binding of the slightly bent rods at the armature tube aperture, together with the additional friction of the float rubbing against the inside wall of the stilling well, was adequate to prevent the floats from activating.

General Maintenance Procedures

Post event analysis of maintenance records and SOPs in use at WPTP shows the need for consistent application of asset management and Maintenance Best Practices standards.

More frequent and more effective communications among the people who are—Engineers, Administrators, Operators, Asset Managers, Maintenance workers, and Health and Safety experts—would lead to a higher level of integration within the utility on an ongoing basis Roles and responsibilities and communication responsibilities of WTD staff need to be well defined. The Life Safety Management system includes a process for looking at the system as a whole: materials, equipment, and individuals and procedures.

Some areas of WPTP (such as methane generation) are subject to Process Safety Management (PSM), a stringent, federally mandated O&M system for industrial facilities with strict reporting and evaluation criteria. The remainder of the plant is subject to standard O&M practices that are normal for wastewater treatment plants. However, it does not appear that standard O&M practices were adequate to recognize the risk of systemic operational flaws (such as failure of the float switches caused by a common flaw) or the lack of redundancy in the hydraulic system.

WTD is already developing an approach similar to the federally mandated PSM used for maintenance of specific high-risk processes (**Appendix Q**). The new approach, referred to as Life Safety Management, would recognize the life-safety and operational implications at WPTP and would require better documentation and stricter maintenance requirements. It would be developed around these main components:

- Development of a program to ensure that staff members adhere to all maintenance best practices that were developed for WTD.
- Recognition of the seriousness of consequences and mechanisms of causation, leading to focus on the process rather than the individual worker.
- Understanding that many of the key decisions influencing safety may be beyond the control of the worker or even the site—they may be made by people at another site, or organization.
- The need to look at the whole—materials, equipment and systems—and consider individuals and procedures as part of the system.
- Management system approach for control.

This approach needs to commence with a thorough systematic evaluation of the function, performance, and safety of systems at WPTP. Such an approach would most likely have proactively identified and remediated the sources of failure during the February 9 event, and the risks inherent in using the underground tunnel system, allowing WTD to mitigate these risks.

O&M procedures are applied more strictly under Life Safety Management. Operators and maintenance personnel would require more thorough training to understand how their activities fit into the larger goals of plant operational safety.

In short, Life Safety Management recognizes that physical changes to the plant to improve operational safety must be accompanied by operational changes.

Computerized Maintenance Management System

The criticality of assets performing like functions across WTD should be confirmed in Ovation. See **Section 6.4** for more discussions on assigning criticality in the Ovation system.

6.5.5.3 Potential Failure Mechanisms and Mitigation Strategies

Table 27 summarizes the potential failure mechanisms and potential mitigation strategies for maintenance procedures.

Table 27. Potential Failure Mechanisms and Mitigation Strategies—Maintenance Procedures

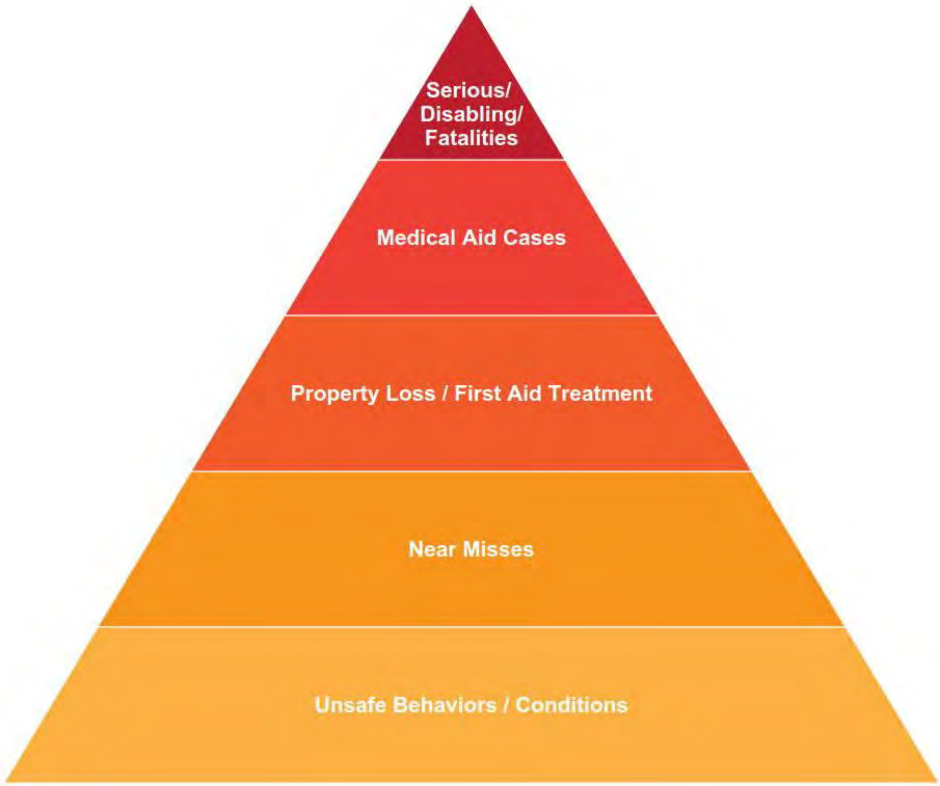
Failure Mechanism	Effects	Potential Mitigation Strategies	Comments
Issues with systems or equipment are not communicated to all groups responsible	Risk to life safety and plant failure	Implement a Life Safety Management approach to all maintenance not included in PSM	Implement a Life Safety Management approach to all maintenance not included in PSM.
Maintenance activities in themselves may also trigger events	Accidents may develop into major accidents		Maintenance may negatively affect component performance if the execution is incorrect, insufficient, delayed, or excessive.
There may be a complicity in maintenance activities because of social normalization of deviance	People in the organization become so accustomed to a deviation that they do not consider it deviant		Implement a Life Safety Management approach to all maintenance not included in PSM.
Communication gaps across organization	Lack of awareness of failure mechanisms		Organized communication is a component of a Life Safety Management system.

PSM = Process Safety Management;

6.6 Summary of Potential Mitigation Strategies

Most serious incidents are preceded by a series of less-serious incidents, in a pattern known as the Incident Pyramid (**Figure 31**) (Creedy 2011). Recognizing minor incidents and taking appropriate action will help to minimize the risk of major system failures by ensuring a culture of prevention.

Figure 31. Incident Pyramid



(Source: Creedy 2011)

“Good” companies can be lulled into a false sense of security by their performance in personal safety and health. They may not realize how vulnerable they are to a major accident until it happens. If a system has performed reliably and safely for many years, they may expect that this will always be the case, without understanding that changes elsewhere may affect this system; that maintenance may lead to unintended consequences; or that a system is gradually deteriorating and may not function reliably (Creedy 2011).

Maintenance activities may negatively affect a component’s performance if the execution is incorrect, insufficient, delayed, or excessive (Okoh and Haugen 2013). From a management perspective, complicity in maintenance activities may occur because of the “social normalization of deviance.” This theory states that people in an organization become so accustomed to a deviation that they do not consider it deviant, even though they far exceed their own rules for elementary safety (Vaughan 1997). There is a natural human tendency to rationalize shortcuts under pressure, especially when nothing bad happens (Wilcutt and Bell 2014). The lack of bad outcomes can reinforce the “rightness” of trusting past success instead of objectively assessing risk (Wilcutt and Bell 2014).

The results of this investigation included the output of the HAZOP workshop and follow-on efforts resulting from these discussions. Several potential mitigation strategies were developed and are summarized in **Appendix R**. Many of the recommendations are repetitive across multiple components and systems. Key recommendations were identified to support the key findings. **Table 28** shows the recommendations from this assessment, along with the corrective actions identified by WTD in its updated Resiliency Action Plan (WTD 2017b).

Table 28. Key Recommendations Compared to Planned WTD Corrective Actions

Recommendation	WTD Corrective Action (WTD 2017f)	WTD Corrective Action Completion Date (WTD 2017f)
Implement a Life Safety Management system.	Life Safety Report and Implementation	January 2018
	Ongoing Life Safety Management System	January 2018 (Start)
	Tunnel Access Protocols	Ongoing
Conduct an integrated evaluation to address plant constraints and limited redundancy.	Redundant EPS Pratt Valve Operations	January 2018
	Plant Hydraulic Simulator Program	August 2017
	EPS Redundant Power Supply	May 2017
Conduct comprehensive emergency response training.	Formal Shift Operators Training	June 2017
Configure the Ovation control system to handle emergencies.	SCADA Alarm Management Prioritization	January 2018

DOE = Washington Department of Ecology; EPS = effluent pump station; SCADA = supervisory control and data acquisition; SOP = standard operating procedure; WTD = Wastewater Treatment Division

7. Summary and Recommendations

7.1 Summary of the Flooding and Bypass Event and Immediate Effects

At approximately 2:00 a.m. on February 9, 2017, WPTP was successfully treating peak sewage flows and the final effluent pumps were operating correctly. At 2:12 a.m., power from Side A of the electrical switchgear was interrupted, which instantly cut off the power to final effluent pumps 1 and 2 and shut all four valves on the four final effluent pumps. This, in turn, set a complex series of events into motion that backed up the flow in the plant. Approximately 13 minutes after the partial power outage, the primary sedimentation tanks overflowed and WPTP began flooding. Less than 1 hour after the partial power outage, the WPTP operators manually stopped the RSPs, thereby stopping the flooding of WPTP.

The key critical failures that occurred during the event were:

- Power outage to half of the effluent pumps
- Hydraulic controls for all effluent pump control valves had no backup power
- High level float switches in primary tanks did not activate
- Control system alarms were not prioritized
- No automated indication of flooding conditions
- Manual operation required to shut off raw-sewage pumps

The flood resulted in an immediate and complete shutdown of WPTP. Flooding of the plant resulted in considerable damage to the plant's infrastructure, including its subterranean facilities. Within 18 hours after the event, WPTP staff returned the plant to half its hydraulic capacity and limited treatment capacity. Heavy rains prompted two additional emergency bypasses on February 15–16 that discharged combined stormwater and wastewater over a 20-hour period. No additional bypasses have been recorded since February 16, 2017.

WTD analyzed the discharges, including through hydraulic modeling, and now estimates the discharges from WPTP as 180 million gallons on February 9 and another 55 million gallons on February 15–16.

From February 9 through most of April, the WPTP effluent was not fully meeting its permit. However, the plant was returned to its full hydraulic and treatment capacity by April 26, 2017, and achieved full compliance with all permit limits by May 10, 2017.

Immediately after the WPTP flooding and bypass, fecal bacteria levels in beach samples were high at West Point, Golden Gardens, and Carkeek Park. These public beaches were all posted for closure to water contact recreation. Concentrations of fecal bacteria declined quickly over several days after the bypass events, and all beaches were reopened on February 21 and have been open since. Between February 9 and May 10, the bypass did not produce any known reports of harm to fish, wildlife, or people.

Recognizing the significant impacts of this event, the County Council contracted with AECOM Technical Services on April 24, 2017, to perform an independent investigation evaluating the causes of failure and providing guidance on remedial actions and practices.

7.2 King County's Assessment of Event Causes

AECOM recognizes that several other investigations regarding the event have been performed. These investigations and reports include the:

- *West Point Flooding Investigation Preliminary Findings Report* (CH2M 2017).
- *After Action Self-Assessment Report* – Draft (WTD 2017j)
- *Memorandum: February 9, 2017 West Point Flood Recovery—Resiliency Action Plan* (WTD 2017f)

These assessments are evidence that since the February 9 event, WTD has recognized the need for changes and has been actively implementing several of them to deal with similar wet-weather events in the future. The AECOM team has reviewed these documents and utilized the information where applicable.

7.3 Project Approach to AECOM's Independent Investigation

To address the objectives of the scope of work and maintain the objectivity of the independent assessment study while meeting the time constraints, AECOM developed a systematic approach based on experience from similar work, and customized it to the specific needs of this project. The approach consisted of the following key steps:

1. Data collection
    a. Collection of existing documents
    b. Field visits and staff interviews
2. Data review and analyses
    a. Data Analyses and initial assessment failure mechanisms
    b. Hazard and operability (HAZOP) workshop
    c. Refinement of failure mechanisms and development of recommendations
3. Preparation of the independent assessment study report

More than 4,900 documents, drawings, reports, and manuals were collected and supplemented by interviews and field visits. To evaluate critical unit operations and processes at WPTP to determine where the potential may exist for other catastrophic failures, AECOM discipline leads were instructed to evaluate each unit operation or process based on several considerations:

- Function
- How the unit or process operates
- What controls the flow, level, or operations sequence
- Failure modes
- Consequences of failure
- Current WTD activities to resolve/prevent future failures
- Areas for further investigation

Technical teams investigated each key area of the plant that could lead to a failure of function. The areas of study included:

1. Hydraulics
2. Process and mechanical, including the following areas of WPTP:
    a. Influent control structure
    b. Preliminary treatment
    c. Raw-sewage pumps
    d. Preaeration and primary sedimentation
    e. Flow diversion structure
    f. Effluent pump station
3. Electrical systems
4. Instrumentation and control systems
5. Operations
6. Maintenance

As part of the evaluation process, a HAZOP analysis was performed, including a HAZOP workshop held May 24–25, 2017. The results of this investigation included the output of the HAZOP workshop and follow-on efforts resulting from these discussions. Detailed summaries of failure mechanisms are provided in **Section 6** of this report.

7.4 Findings of the Independent Assessment

As with failure of any complex infrastructure of this magnitude, several contributing factors led to the eventual flooding of WPTP. The HAZOP workshop and analysis identified other potential failure mechanisms and risk factors that should be addressed. The major contributing factors include the following:

1. **West Point Treatment Plant has many constraints, and the strain on the plant is likely to worsen.**

   WPTP is located on the shores of Puget Sound in Discovery Park which creates a unique set of challenges to ensure that plant operations do not interfere with the aesthetic, environmental, and recreational value of the setting. The site is very small for a plant of this capacity (440 mgd), and there is little area for expansion. The plant's upgrade in 1995 to include secondary treatment and other improvements used much of the remaining available space. Consequently this limits the peak-flow capacity of the treatment plant.

   In addition, several factors can increase the volume and frequency of flows into the plant. As urbanization continues in the regional watershed upstream of WPTP, the amount of impervious surface areas (pavement and buildings) will increase, while pervious surface areas will be decrease. Rain that previously would have filtered into the soil or run off into streams will instead be conveyed to the combined sewer that leads to the plant, thus tending to increase the amount of peak flows to the plant during storm events. Seattle's population has been growing substantially, which will lead to an increase in sanitary flows to the combined sewer system. Climate change may also lead to more frequent and/or more intense rain events, resulting in increased volumes and frequency of high flows to the plant.

   While some of these factors are being compensated by improvements in technology and planned system improvements, the net effect of these factors has the potential to increase the magnitude, frequency, and duration of maximum flows to WPTP, which is a system that is already facing constraints.

2. **West Point Treatment Plant does not have sufficient redundancy.**

   When the largest unit or piece of equipment in a system is out of service, the remaining capacity of the plant may be referred to as the reliable or firm capacity. In order to meet the firm capacity, a system must provide redundancy in terms of extra pumps, additional basins, diversion channels or alternative systems.

   WPTP is rated by the Washington Department of Ecology to treat a maximum-month design flow of 215 million gallons per day (mgd) (DOE 2014). WPTP can receive up to 440 mgd of instantaneous flows. CSO-related bypasses of the secondary treatment portion of WPTP are authorized when the instantaneous flow rate exceeds 300 mgd as a result of precipitation events.

   The firm capacity of WPTP is significantly less than the hydraulic capacity of 440 mgd. Therefore, when the plant operates at a peak capacity of 440 mgd, almost all key units and equipment must be fully operational to pass this flow. For example, if one of the RSPs were out of service, the remaining capacity is 330 mgd. Peak flow at WPTP during the February 9, 2017 event exceeded 440 mgd, requiring the primary treatment system to operate at maximum capacity without backup systems

   Lack of redundancy combined with the complexity of the system gives plant operators very little time to react during peak-flow events. The incident of February 9, 2017, showed that failure in one area of the plant during high flows can quickly lead to a cascade of events at other locations in the plant.

3. **West Point Treatment Plant needs a higher level of operational integration to manage interdependencies.**

   Starting in 1911 when it was designated as a favorable location for a wastewater outfall, WPTP has expanded and continuously improved to protect water quality and meet changing regulatory requirements. WPTP is now a Class IV facility that uses three major pumping stations within the plant and numerous other complex mechanical, chemical, biological and electrical systems. The functional complexity of the plant was complemented by a significant expansion of the management and operations team.

The challenge with large, complex plants like WPTP is that the impact of single elements of the plant (e.g., high level floats) on the overall operability and capacity is not readily apparent. In addition, during high flow events, interdependency between various operating elements and seamless communication across operating teams becomes more critical. These issues tend to surface during an unusual event such as the February 9, 2017, event.

To address increasing complexity and hazards, the petrochemical industry created a rigorous Process Safety Management (PSM) System that chemical plants are now required by federal law to institute. This formal process enhances communication and structures the decision-making process to increase focus on life safety for the workers and the public, achieve better operating efficiency, reduce environment impact and reduce financial risk (**Appendix Q**).

The industry standard for wastewater treatment plants in the United States is to use the PSM system only in the hazardous areas of the plant where utilities are legally required to implement it (chemical and gas systems). At WPTP, a PSM System is implemented in the areas of the plant that generate methane and handle hazardous chemicals.

This assessment revealed that due to the size of WPTP, its complexity, limited redundancy, and environmental conditions, the operations procedures should be elevated from industry standard to include elements of PSM across the entire plant.

4. **Emergency response training did not anticipate this type of emergency.**

The failure event on February 9, 2017 was unprecedented. The systems failures occurred during a period of peak flows, and the plant operators had very little time to respond. Operators were experienced and trained in many safety procedures, and they understood the importance of rapidly returning systems to operation; however, they were not adequately trained for this particular type of emergency. Based on a review of the WTD training/exercise records that were provided, the emergency training and emergency exercises being conducted by WTD, additional training and exercises focussed on using the lessons learned from the February 9, 2017 incident are needed.

The results of the incident also show that there was a lack of clarity among crew members in identifying the threshold for initiating and implementing emergency bypass procedures. It is important that WPTP management and crew work closely with regulatory agencies to clearly define scenarios when emergency bypass procedures can be initiated while accounting for life safety and protecting infrastructure.

5. **The capital upgrades to the plant should be optimized to improve reliability during high-flow events.**

WPTP has been upgraded several times over the years, but not all upgrades improved the plant's firm capacity or were fully developed to improve operational efficiency during emergencies. For example, the recently commissioned Ovation plant control system conveyed a rapid series of alarms to Main Control that were not yet fully prioritized. The shift supervisor was faced with more than 2,100 alarms in less than 1 hour, and it was not clear which were critical and which were of lesser significance. The lack of prioritization in the system configuration made it difficult for the shift supervisor to make informed decisions efficiently.

Moreover, several elements of the plant, such as the raw sewage pumps, still need manual operator intervention, posing a life safety risk during emergency situations. All components of the plant system should be integrated with plant controls.

Recommendations

Based on these conclusions, AECOM proposes several recommendations to reduce the likelihood of future issues at WPTP. Potential strategies that were designed to help meet the overall goals of the recommendations listed below are presented in **Section 6**. Those strategies were discussed in many meetings and were vetted in the HAZOP workshop. AECOM recognizes that the Wastewater Treatment Division (WTD) is currently acting to implement some of those strategies.

1. **Implement a Life Safety Management system.**

   The County should develop and implement an approach to other critical areas of the plant, similar to the Process Safety Management (PSM) system that is currently used where regulatory requirements demand its use. The most effective elements of PSM should be leveraged into a new system which will be called, Life Safety Management (LSM).

   This approach needs to commence with a thorough systematic evaluation of plant systems in terms of function, performance and safety. This approach will improve vertical and horizontal communications regarding plant risks, provide better documentation of decisions, and result in stricter levels of maintenance.

   The goal of Life Safety Management is to support the team to keep all the critical elements of the plant in optimum working order. An approach like Life Safety Management may have proactively identified and remediated some of the sources of failure that caused the February 9 event, as well as the risks inherent with using the underground tunnel system.

   Most serious incidents are preceded by a series of less-serious incidents – a pattern known as the Incident Pyramid. Recognizing minor incidents early and taking appropriate actions will help to prevent major system failures. Implementing Life Safety Management will also help to avoid what is known as the normalization of deviation (Vaughan 1997), wherein personnel become accustomed to the poor performance of a piece of equipment.

   Under Life Safety Management, operations and maintenance procedures are more strictly applied, and operators, maintenance works, engineers, safety managers, asset managers, administrators and manager and policy makers work together to achieve the best possible outcomes. One of the key tenants of Life Safety Management is to work toward continuous improvement and to avoid blaming or scapegoating.

   Keeping the PSM and the Life Safety Management systems separate will simplify federal audits, leverage the best parts of PSM across the plant and greatly raise the bar regarding how the utility conducts the business of treating wastewater at WPTP. It will also reduce the serious risk to life safety, risk of release of untreated sewage into the sound and financial risks to the utility.

   This innovation of implementing a Life Safety Management System as part of WPTP's policy development, management decisions, and operations, and maintenance will advance the utility and allow WPTP to be function to its highest ability.

2. **Conduct comprehensive emergency response training.**

   Given the limited capacity and complexity of WPTP, it is important that the operators have a well-defined emergency response plan that they are trained. AECOM recommends that WTD formulate and adopt a formal emergency training and emergency exercise program compliant with the Homeland Security Exercise and Evaluation Program. Training can help employees maintain competency for completing their specific tasks during an emergency, as the roles they assume in an emergency could differ from their normal duties. Training is particularly critical for tasks that employees do not perform regularly, such as those related to emergency bypass procedures.

   In concert with the emergency training program, a progressive exercise program provides opportunities to validate plans and procedures and identify and correct potential weaknesses and deficiencies.

Exercises may include smaller scale drills and tabletop exercises, and larger coordinated simulations with other levels of the County's emergency organization, such as local and regional emergency operations centers.

A comprehensive program of emergency training and emergency exercises promotes sharing of ideas, leads to documentation of important decisions, helps increase staff comfort levels regarding unusual emergency-only activities through discussion and practice, and ensures that proper protocols are followed. Please refer to **Section 6** for specific recommendations for emergency training and emergency exercises.

3. **Conduct an integrated evaluation to address plant constraints and improve redundancy.**

   To maximize the capacity of WPTP within the existing footprint and increase system reliability, WTD should implement a strategic plan that considers short-term and longer term improvements. The 50-year Look Ahead being considered by the County would be an excellent opportunity to focus on methodologies and develop integrated solutions that will be reliable and economical for addressing constraints and capacity issues.

   It is important to address the lack of passive systems which would allow the plant to handle flows through the facility in the event of loss of automation, lack of power or delayed decision-making. One of the most critical points of failure at WPTP is the emergency bypass gate. If the gate fails to open, the facility can be flooded, posing a serious life-safety risk. It is recommended that passive overflows be evaluated.

   This plan should incorporate upstream features in the collection system as well and lay the groundwork for developing a protocol for upstream combined sewer overflows (CSOs) and downstream treatment plant operations during high-flow events. This planning should also consider addressing WPTP's firm-capacity limitations and the extent that it is allowable from a regulatory standpoint to distribute peak flows across the CSO system, and the ability to use the emergency bypasses during peak-flow events.

4. **Optimize a capital improvement plan to maximize redundancy.**

   The longer term planning processes should consider capital improvements that have immediate and significant impacts on plant capacity. Some improvements that can have immediate impacts on operations during a peak flow involve configuring the Ovation system to prioritize alarms and integrating pump stations and emergency bypass gates with plant controls.

   The HAZOP methodology helped to identify a number of concepts to improve the firm capacity of WPTP. These concepts can be further grouped, refined, modified, augmented, and evaluated for cost effectiveness during the planning process.

   Some of the capital improvement costs for improving redundancy and addressing the identified potential failure mechanisms can be significant. These can be implemented optimally over a longer period of time considering the overall impact on the plant by considering the Life Safety Management system approach.

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