Revised Final Report Submittal

Revised Final Report for Wastewater Salinity Follow-up Study Naval Base Kitsap-Bremerton, Washington

W.O. #s 1642902 and 1690245
Contract N44255-15-D-0011 and N44255-20-D-0001
Delivery Order/Call Nos. N44255-19-F-4491 and N44255-21-F-4324

Submitted to
Naval Facilities Engineering Systems Command Northwest
Bremerton, Washington

Submitted by
WSP USA

Approved for public release: distribution unlimited

3 March 2022

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WASTEWATER SALINITY FOLLOW-UP STUDY
REVISED FINAL REPORT

Naval Facilities Engineering Systems Command Northwest
Public Works Department Kitsap
Naval Base Kitsap-Bremerton, Washington

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1.0 EXECUTIVE SUMMARY[1]

WSP USA Inc. has prepared this preliminary report to document the activities, results, and recommendations of the salinity study conducted at Naval Base Kitsap-Bremerton (NBK-Bremerton). The intent of this report is to identify sources of high salinity (greater than 5 parts per thousand [ppt], or roughly 8 mS/cm at 25 degrees Celsius) that discharge into the sanitary sewer system at NBK-Bremerton, evaluate these sources, and recommend capital improvement projects (CIPs) or operational changes to reduce or eliminate these sources of salinity.

NBK-Bremerton discharges its wastewater to a collection system and wastewater treatment plant (WWTP) owned and operated by the City of Bremerton (City). The City has expressed concerns that elevated levels of salinity in the influent to their WWTP may have caused exceedances of their effluent discharge limits for biochemical oxygen demand (BOD). There were two exceedances in 2015 and none since then. Our current understanding (based on the following report) is that NBK-Bremerton is contributing less than half of the salinity load to the WWTP (between 31 to 40 percent). NBK-Bremerton has undertaken this study to determine the sources of salinity within its facility and understand any negative impact that salinity can potentially cause to the WWTP process or its components. This study evaluates: (1) acceptable levels of salinity at the City's WWTP, (2) the sources of salinity within NBK-Bremerton's own system, (3) how these sources of salinity impact BOD and carbonaceous BOD (CBOD) levels at the City's WWTP, and (4) potential CIPs or operational changes that could reduce or eliminate sources of salinity within NBK-Bremerton's collection system.

Naval Facilities Engineer Systems Command Northwest selected and authorized WSP to perform an engineering study related to high salinity levels in the sanitary sewer system at NBK-Bremerton under Contract N44255-15-D-0011, Delivery Order N44255-19-F-4491, Work Order No. 1642902. A follow-up study was completed under Contract N44255-20-D-0001, Delivery Order N44255-21-F4324, Work Order No. 1690245.

WSP submitted a Sampling and Analysis Plan (SAP) to accomplish the objectives noted above on March 18, 2020, which is further discussed in Section 4.0. The SAP identified specific monitoring locations within NBK-Bremerton sewer system that could be used to identify potential source(s) of high salinity. The SAP included two phases of sampling. The duration of the first phase (referred to as Phase 1 throughout the report) was four weeks (March/April 2020), followed by a second phase (Phase 2) lasting two weeks (June/July 2020). An additional phase (Phase 3) of four weeks of sampling was conducted in September and October of 2021 to assess the impacts that Covid-19 may

[1] The executive summary has been revised heavily to reflect the additional results and conclusions drawn from Phase 3 of the study.

have had on the results from the first two phases of sampling and to verify conclusions drawn from Phase 1 and Phase 2.

This report focuses on identifying locations within the NBK-Bremerton collection system that have either elevated conductivity/salinity concentrations or elevated salinity loading values. Where appropriate, three different analyses were completed to compare any two or more monitoring points that are upstream/downstream of each other. These analyses include the following.

- Salinity Loading Comparisons
- Salinity Concentration Comparisons
- Conductivity Comparisons

Section 1.0 of this report is this Executive Summary, Section 2.0 is an Introduction, and Section 3.0 provides some project background. Section 4.0 includes a discussion of the selection of monitoring locations and brief summaries of tributary areas upstream of each monitoring location.

Section 5.0 presents our data analysis and results of monitoring, as well as preliminary conclusions on the relative sources of salinity. Phase 1 monitoring included various locations within the City's system, and it was determined that of the roughly 47,000 kg/day of salinity that entered the City's WWTP on average, the Navy contributed approximately 19,000 kg/day, City pump station CE-1 also contributed roughly 20,000 kg/day, City pump station CE-4 contributed only 386 kg/day, and other City sources contributed the remaining 7,600 kg/day.

Figure 1 represents the various sources of salinity into the City of Bremerton's WWTP, as percentages, during Phase 1 and Phase 3 of monitoring.

Water quality monitoring during the two 28-day monitoring periods of this study (Phases 1 and 3) indicates that concentrations of salinity in NBK-Bremerton effluent would likely exceed the City's ordinance of 6.0 mS/cm for continuous 30-day average (the ordinance does not mention any temperature, but NBK-Bremerton staff assumes it is 6.0 mS/cm at 25 degrees C). However, water quality monitoring at the WWTP headworks indicates that combined flows influent to the plant would likely be within compliance of the ordinance.

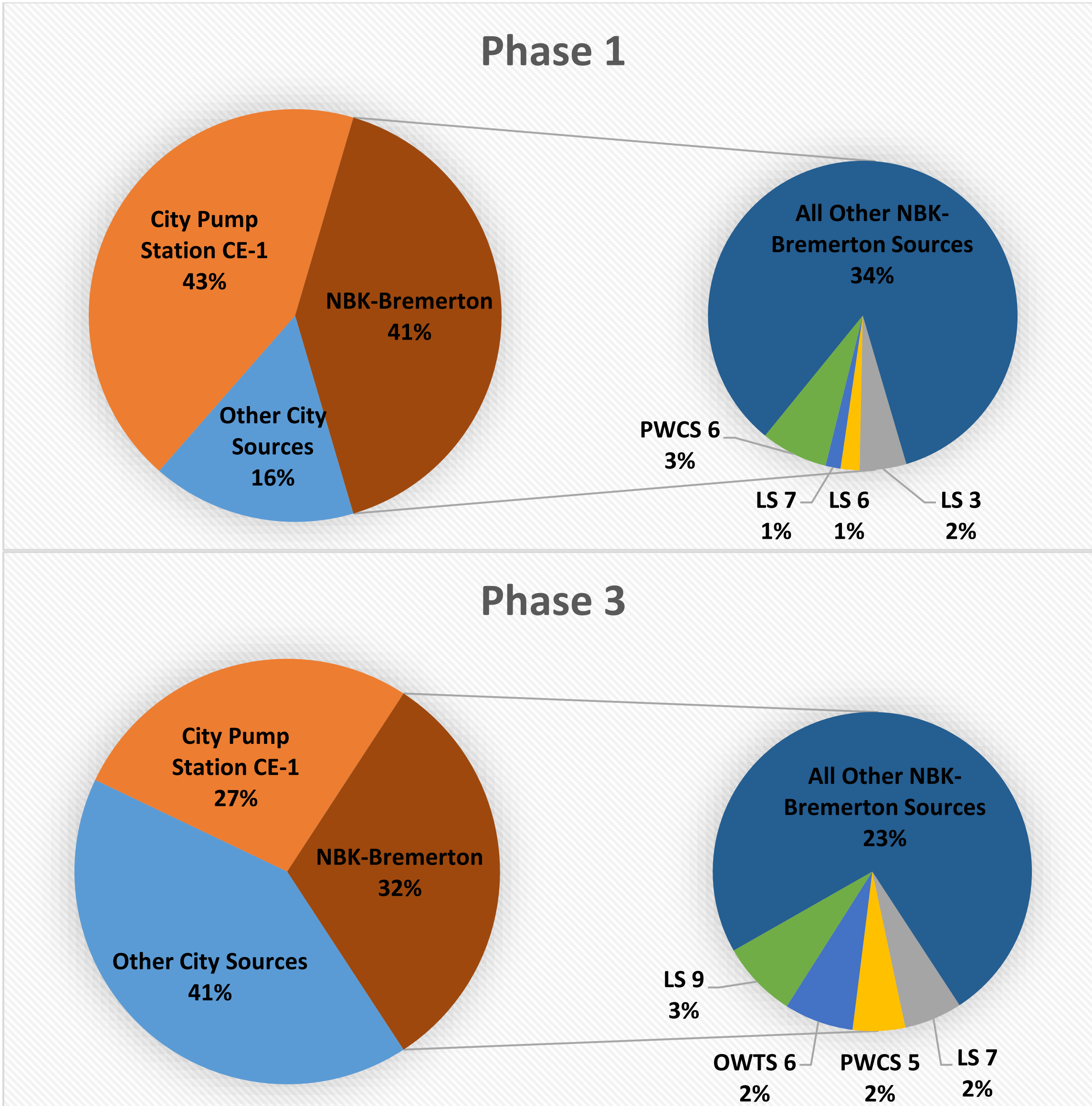

Figure 1: Sources of Salinity Loading to City of Bremerton Wastewater Treatment Plant

Section 6.0 presents a technical analysis of the relationship between the elevated salinity sewer flow at the WWTP headworks and its impact on the treatment of the biochemical oxygen demand (BOD) and carbonaceous biochemical oxygen demand (CBOD) at the City's WWTP. The report presents the efforts made by WSP to correlate BOD and CBOD levels at the WWTP to salinity levels from NBK-Bremerton, and the efforts to establish a maximum salinity level in the WWTP wastewater influent to allow the City to meet its previous BOD discharge limits. Research indicates that 10 ppt (16.4 mS/cm at 25 degrees C) of salinity is the generally acceptable maximum value understood to not cause operational concerns with BOD at a WWTP. Our review of monitoring data of wastewater at the headworks influent to the WWTP indicate that the average salinity concentration between 25 September and 25 October 2021 was 3.8 ppt (5.9 mS/cm), and that the maximum salinity was 14.19 ppt (22.75 mS/cm at 25 degrees C) during a period of approximately 30 minutes where the salinity was elevated above 10 ppt (16.4 mS/cm at 25 degrees C). Using the BOD/CBOD data provided by the City of Bremerton, no correlation between NBK-Bremerton's salinity levels and BOD/CBOD values at the WWTP was found. Section 6.0 also discusses calculations made to establish an average salinity level that would not cause a problem at the WWTP. For this, it was assumed that a 7.5 ppt (12.63 mS/cm at 25 degrees C) average salinity level at the WWTP is acceptable, and it was determined that NBK-Bremerton's discharge could be up to 18 ppt (28.51 mS/cm at 25 degrees C) average for the WWTP to be at an average of 7.5 ppt.

Section 7.0 summarizes the significant locations of sources of salinity within NBK-Bremerton and provides a discussion of the potential categories of activities associated with those sources. Analysis of the data indicates that there are four major categories of high salinity into the wastewater system at NBK-Bremerton: (1) docked ship wastewater, (2) groundwater intrusion into the floor of the dry docks collected by the process water collection systems, (3) saltwater sources such as ship ballast water and bilge water being discharged via the oily water treatment systems, and (4) groundwater infiltration into the sanitary sewer. Table 1 below summarizes the salinity loading associated with these four main categories based on monitoring during this project and from historical data.

Table 1. Salinity Loading from Major Contributor Categories (as a Percentage of the Total Salinity Loading at NBK-Bremerton)

Major Source of Salinity	Phase 1 Average	Phase 3 Average	Maximum Daily During Phase 1 and Phase 3	Range on Any Given Day (includes Historical Data from PSNS & IMF)
Ship Wastewater	12%	1%	31% (10 April 2020)	0 – 69%[3]
Groundwater Intrusion into PWCS	26%	11%	Unknown[2]	11 – 65%[4]
OWTS	3%	7%	32% (16 Oct 2021)	0 – 32%
Groundwater Infiltration to Sanitary Sewer	Unknown[1]	12%[1]	14% (24 & 25 Oct 2021)	0 – 14%

[1] Phase 1 monitoring did not directly estimate groundwater infiltration to the sanitary sewer. Phase 3 indicated that groundwater intrusion near LS 1 and LS 9 contributed roughly 12% of NBK-Bremerton's total salinity load.

[2] Salinity loading from groundwater intrusion into PWCS for Phase 1 and Phase 3 was calculated based on average flowrate and conductivity values. Daily levels were not calculated, but are expected to be relatively consistent.

[3] Per NBK-Bremerton staff, on days when sanitary sewer groundwater infiltration is 0%, OWTS is 0%, PWCS is 31%, then carrier wastewater will be up to 69%.

[4] The upper range of 65% comes from 2019 investigations into PWCS discharges by PSNS & IMF staff.

Ship wastewater is high in salinity because many ships' domestic wastewater systems use saltwater for certain processes like flushing toilets. When ships are docked at NBK-Bremerton, all of their sewage, including the saltwater, is discharged to NBK-Bremerton's sanitary sewer. The process water collection systems (PWCS) are a major source of salinity because each of the six dry docks (DDs) have groundwater intrusion/leakage through the floor and most DDs have a small amount of leakage at the caisson seat seals that makes its way into the PWCS. Each DD also has an oily water treatment systems (OWTS) plant that treats bilge water and ballast water discharged from vessels in that DD, and also treats some wastewater from the PWCS in certain rain events. It should be noted that groundwater infiltration into the sanitary sewer could not be monitored entirely. Section 7.0 discusses the salinity loading from groundwater infiltration in more detail. Understanding of these types of sources is useful in evaluating potential projects or activities to reduce salinity and informed the analysis in Section 8.0. Section 8.0 presents potential projects to reduce or eliminate some of the most significant sources of salinity from NBK-Bremerton. Eleven potential projects are identified. Of these projects, nine are recommended for consideration and two were evaluated but not recommended. A few projects considered that could potentially have a significant impact on salinity levels are mentioned below.

As is shown in Table 1, ship wastewater has historically contributed up to 69 percent of the total salinity load from NBK-Bremerton. Potential Project 7 evaluated options to treat discharge from docked vessels but determined that this was infeasible due to the large footprint required to install treatment facilities capable of removing salinity from the discharge water. Potential Project 8 evaluated conversion of sanitary flush water from saltwater to freshwater on docked vessels. This was also determined to not be feasible, as the conversion would either require full replacement of all vessel saltwater flow requirements, or special piping that can be temporarily installed on docked vessels to deliver freshwater to all flushing stations.

Potential Projects 2 to 4 involve installation of groundwater relief wells at various DDs. These projects are feasible and could potentially eliminate groundwater intrusion into PWCS, which historically have contributed up to 65 percent of the salinity load from NBK-Bremerton, per Table 1. Potential Project 9 involves additional treatment of OWTS flows that could allow the OWTS to discharge back into the Sinclair Inlet. Potential Project 1 involves repairing sanitary sewer pipes and structures near LS 1 and LS 9.

The projects could reduce up to 65 percent of the total salinity load discharged from NBK-Bremerton. A cost analysis of these potential projects is provided under separate cover. The various feasible projects involve CIPs to reduce infiltration of high salinity groundwater into the sewer system and dry docks, treatment of certain sewer sources at NBK-Bremerton to discharge back to the Sinclair Inlet rather than to the City's sewer collection system, and operational changes that will reduce the use of salty water at NBK-Bremerton.

2.0 INTRODUCTION

Naval Base Kitsap-Bremerton (NBK-Bremerton, see Figure 2) and the City of Bremerton (City) have worked together for decades to properly treat wastewater from NBK-Bremerton at the City's Wastewater Treatment Plant (WWTP). The City's WWTP experienced upsets in 2015, and claimed the upsets were due to high salinity in effluent from NBK-Bremerton. It should be noted that elevated salinity concentrations have also been documented in the City's sewer system influent to the WWTP, and the majority of salinity load influent to the WWTP is from the City's sewer system, and not NBK-Bremerton. In addition to the potential to cause upsets in the treatment process, high salinity in wastewater can cause other economic impacts to the wastewater system, such as corrosion and the resulting increased maintenance needs. For these reasons, NBK-Bremerton and the City are both interested in determining the source of salinity in the wastewater system.

This study characterizes the various sources of salinity in NBK-Bremerton's wastewater system via analysis of sampling results prepared by WSP, sampling data provided by NBK-Bremerton, and other existing data sources. While these sources do not appear to be the cause of any biochemical oxygen demand (BOD)/carbonaceous biochemical oxygen demand (CBOD) exceedances at the WWTP, this study provides both operational and capital improvement project (CIP) recommendations to mitigate these salinity sources.

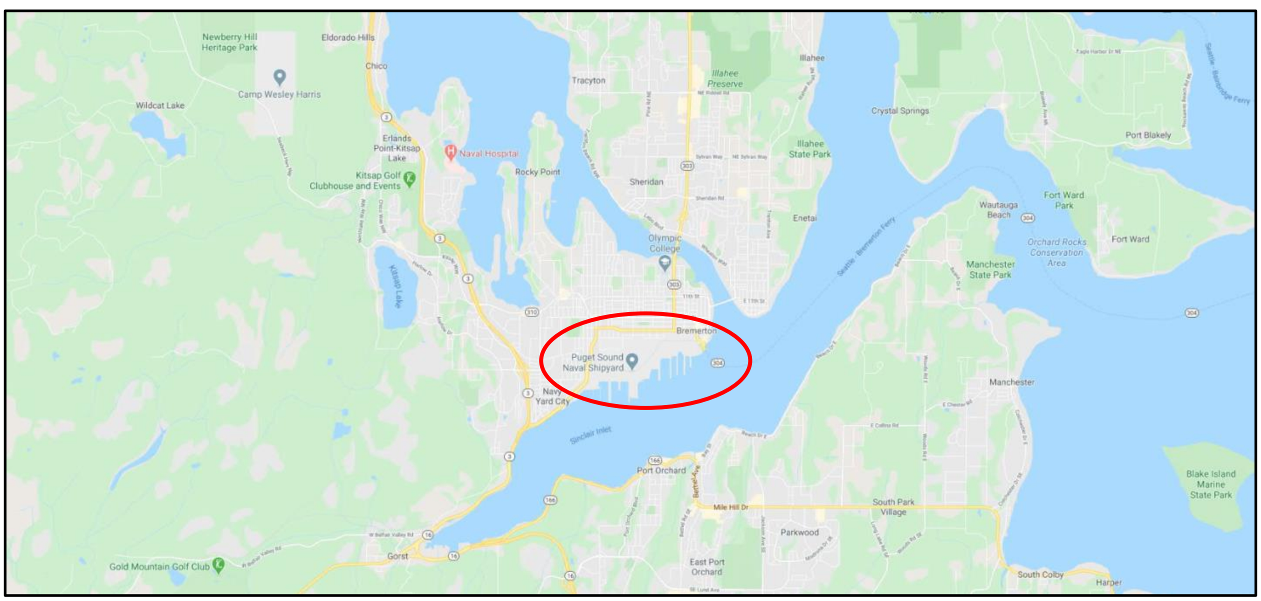

Figure 2. Vicinity Map - Naval Base Kitsap-Bremerton

3.0 PROJECT BACKGROUND

As discussed in project meetings and as is reflected in the City's WWTP discharge monitoring reports (DMRs), the City exceeded their discharge limit for biochemical oxygen demand (BOD) at their West Plant twice in 2015 and believes that high salinity from NBK-Bremerton may be a potential cause for these exceedances. It should be noted that the Fact Sheet for National Pollutant Discharge Elimination System (NPDES) Permit No. WA0029289 states that, for the exceedances, there were possible unknown toxics in the influent that affected the BOD analysis. The official cause of these exceedances was not specifically attributed to high salinity wastewater. The focus of this study is to determine the level and source of salinity at NBK-Bremerton, evaluate how they relate to BOD treatment at the City's WWTP, and provide recommendations and cost estimates for potential CIPs and operational changes that NBK-Bremerton can make to reduce salinity in wastewater effluent.

3.1 Impacts of Salinity on NBK-Bremerton and the City of Bremerton's Wastewater Systems

High salinity in wastewater can have negative impacts on sewer/wastewater collection infrastructure, such as pumps and pipes, due to the intensification of corrosion in the system, as well as on wastewater treatment processes and receiving waters.

High salinity in wastewater treatment processes may negatively impact the various organisms that are used to treat organic pollutants, such as BOD/CBOD, in sewage. In a high salinity environment, these organisms will use more dissolved oxygen to remove organic materials than they would in a low salinity environment. Thus, it can be expected that increases in salinity in the wastewater stream can impact a dischargers ability to maintain BOD levels, or require a discharger to modify certain aspects of their treatment process to otherwise reduce BOD levels. Section 6.0 below discusses the impacts of salinity on BOD in further detail.

In addition to the ability of high salinity to negatively impact the wastewater treatment process, the City is concerned that the salt contents of the biosolids being applied as fertilizer at their tree farm may negatively affect the trees.

3.2 History of Salinity within NBK-Bremerton and the City of Bremerton's Wastewater Systems

Prior to the project's kickoff meeting on February 7, 2020 members of the project team from NBK-Bremerton and WSP met with the City. During this meeting, City representatives explained that their treatment plant historically met BOD limitations, but in late 2014-2015, the City started exceeding the BOD effluent limits. The City also indicated that the increase in effluent BOD was rather sudden, not a gradual increase. Our review of DMRs provided to the Washington State Department of Ecology's (Ecology) Water Permitting and Reporting Information System indicates there were only two exceedances in effluent BOD in early 2015, and there have been no exceedances since that time. See summary of violations for the past 20 years in Section 6.1, Table 10.

The City also stated that they had investigated their own system and could not identify a likely source of salinity. However, our findings in this report indicate there are potential sources of salinity in the City's system. The City believes the source of the increase may be from NBK-Bremerton. A comprehensive study to examine the salinity levels in the NBK-Bremerton wastewater and to substantiate the source of the increased salinity was initiated by NBK-Bremerton. Our study also included monitoring of salinity within the City's sewer system and found levels of salinity similar to levels in NBK-Bremerton.

3.3 Description of NBK-Bremerton's Sewer System

The sewer system at NBK-Bremerton consists of sewer laterals, gravity mains, force mains, lift stations, collection, holding, and transfer (CHT) systems, dry dock (DD) process water collection systems (PWCS), and oily water treatment systems (OWTS). The sewer system collects sewage and industrial wastewaters from residential/commercial, industrial areas, piers, moorings, and DDs.

3.3.1 General Overview of Sewer System

Figure 3 in Section 4.2.1 shows an overview of the project site. The sewage originating between the western boundary of the site and western side of DD 3 (most of the site's sewage) flows to a series of 12 lift stations (Lift Stations 2 – 8 discharge to LS 1 via a shared force main, then LS 1 pumps to a separate force main with LS 10 – 13) along the shoreline that pump sewage into a force main that travels from east to west along the shoreline. This force main is then pumped out of the site at the City's lift station WB-3. There is an additional gravity piping area that drains to WB-3 that collects from restrooms on the west side of Building 900. Sewage originating approximately east of DD 3 is routed towards the eastern project boundary and is pumped out of the site by LS 9 through Manhole 9-32 (MH 9-32) to the City's meter and eventually to the City's pump station CE-4.

3.3.2 Dry Dock and Process Water Collection Systems Description

Any water that hits the floor of a DD is considered process water as it can absorb contaminants from the floor due to vessel work processes ongoing within the DD. Water entering the DD is primarily stormwater (rain), and saline groundwater leaking up through the floor. Fresh water is used in pressure washers to clean the hull of docked vessels, and this water is collected for treatment at the OWTS plants. Fresh water is used to hose down the DD floor and floor trenches for DD cleaning prior to docking events where the DD is flooded and then dewatered. These docking events occur sporadically, approximately one to three times per year, and sometimes up to 12 to 18 months or even longer between docking events. Dewatering discharge is directed back into the Sinclair Inlet via dewatering pumps. After every dewatering event, the floor must be cleaned of bay sediment entering the dock from the Sinclair Inlet through the flooding process. After dewatering is completed and the floor cleaned, all water hitting the floor eventually flows to the floor trenches along the east and west sides of the DD.

The trenches direct the water to the PWCS sump, and PWCS pumps discharge to one of three destinations, (1) the sanitary sewer; (2) the PWCS holding tanks (40,000-gallon capacity each) where it is eventually (after OW processing) processed through the OWTS plants before discharge to the sewer; and (3) the drainage pump wet well, where the Drainage Pumps discharge to the Sinclair Inlet. Destinations are all automated with an industrial programmable logic controller-based control system and all six DDs are monitored to allow no more than 950,000 gallons per day (gpd), from midnight to midnight, to discharge directly to the sanitary sewer per Puget Sound Naval Shipyard and Intermediate Maintenance Facility (PSNS & IMF) State Waste Discharge Permit. Discharge from the OWTS plants is in addition to this allowance. When this direct discharge maximum allowance is reached, the destination is changed to the holding tanks, and when the holding tanks are full, the destination is changed to the Sinclair Inlet through the drainage pump system. Concerning the three destinations to which the PWCS pumps, data for three and a half years (from 2016 to 2019) indicates that 92.2 percent, 4.4 percent, and 3.4 percent of the total pumped volumes went to sanitary sewer, holding tanks for treatment, and drainage pump wet well, respectively.

The sewer is not needed for overflow backup. If a 100-year storm overwhelms the capacity of the PWCS, the PWCS discharges to the Sinclair Inlet via the drainage pump wet well.

Each PWCS serves a single DD, except DD 2 and DD 4 have interconnecting PWCS piping that allows sharing of some storage tanks. The PWCS is a system of DD floor trenches, sand traps, pumps, pipes, and holding tanks that collect process water and stormwater. This water can be diverted to three destinations, the sanitary sewer, the OWTS for treatment, or discharged to Sinclair Inlet. The turbidity of the water (a surrogate for copper) is monitored to determined when it should be sent to the OWTS for treatment. Because the water is very clean in general, 92 percent of the total volume has been sent to the sanitary in the last few years. Sinclair Inlet discharge is the last option that normally only happens during very heavy rainy day (over two-year 24-hour storm events). Any seawater that leaks through the caissons, which generally happens during the period right after a DD dewatering event, is diverted to the DD drainage system to prevent it from entering the DD PWCS. Some DDs have high salinity groundwater intrusion that accumulates on the DD floors and is then collected by the PWCS and then by the sanitary sewer system. This intrusion is further discussed in Section 7.3.

To provide for relief of the pressure produced by groundwater on the sides and bottom of the DDs, the original DD designs provided groundwater relief systems. These are critical pumping systems because failure to relieve the groundwater pressures could result in structural failure of the DD. This is due to the structural design of all DDs (except DD 2) as "Fully Relieved" type foundations. DD 2 is designed as a "Full Hydrostatic" foundation that is intended to stand, even without groundwater pressure relief. DD 1 through DD 5 pump approximately 2 million gpd of relief groundwater to the bay. DD 6 pumps approximately 5 million gpd of relief groundwater to the bay.

There is some groundwater intrusion onto the DD floors, which is a small percentage of the overall relief groundwater that is pumped to the bay. The groundwater intrusion varies by DD. This relatively small amount of groundwater (with high salinity levels) currently enters the sewer system through the PWCS. In 2015 this problem was addressed at DD 4. At DD 4, the underfloor relieving water system was failing to keep water from seeping through the floor and into the PWCS. As described in Section 8.2.1.6, a repair project was completed, which installed high capacity relief wells. These wells directed underfloor relieving water to the side tunnels where the water is directed to the DD 4 drainage pumps that discharge to the Sinclair Inlet through an existing permitted outfall.

The groundwater relief system consists of perforated piping at the DD perimeter walls and under the DD floor. The relieving groundwater drains to the DD drainage system wet well where "drainage pumps" can pump the water to the Sinclair Inlet via a permitted outfall.

3.3.3 OWTS Plants Description

Each OWTS plant serves a single DD. All OWTS plants treat bilge water and ballast water discharged from the vessels in their DD and treat some wastewater from the PWCS depending on the severity of rain events. The OWTS consists of a double walled piping distribution system from all six DDs, Piers 3, 4, 6, B, and D to six OWTS plants located near the south end of each DD. The oily waste is pumped into the OWTS by pumps onboard the in-dock vessels and from vessels berthed at the piers served by the oily water piping distribution system. The onboard oily waste comes from bilge water, compensation water from the fuel tanks (sea water is added to the fuel tanks to maintain ballast when using fuel at sea), and from any other onboard contaminated oily wastes. The compensation water normally has about a 5 percent fuel component mixed with the seawater. The oily water is pumped into multiple 20,000-gallon holding tanks located at each DD and is processed through the six OWTS plants from these dedicated holding tanks. The treated effluent is discharged to the sanitary sewer at a maximum of 200 gallons per minute (gpm) from each of the six plants. OWTS discharge is largely made up of seawater that has been treated to remove the oily contaminants, including diesel fuel, and thus are probable sources of high salinity into the NBK-Bremerton sewer system. OWTS 2, 4, and 6 all discharge directly into the shared force main that flows to LS 1, and OWTS 1, 3, and 5 discharge to various lift stations that also flow to LS 1.

3.3.4 Collection, Holding, and Transfer (CHT) Description

Sewage in CHT holding tanks on-board a docked vessel is pumped to NBK-Bremerton's sanitary sewer system via ship-to-shore hose connections. During the winter season, saltwater is added to the hoses for freeze protection. The amount of salinity added to the sanitary sewer system by this process is very low and is negligible relative to other sources of salinity from docked vessels, such as salt water toilets. CHT hoses are cleaned and hydrotested in Building 875. The hoses are 4 inches in diameter and can be flushed for up to 2 hours. These processes can introduce a few thousand gallons of saltwater into the sewer system, but these processes are infrequent.

4.0 SUMMARY OF SAMPLING AND ANALYSIS [2]

WSP prepared and submitted a Sampling and Analysis Plan (SAP) on 18 March 2020. The SAP included specific monitoring locations within NBK-Bremerton's sewer system to be used to identify potential sources of salinity. Four monitoring stations were also located within the City's sewer system to identify potential sources of salinity outside of NBK-Bremerton. Two phases of sampling were completed in 2020. The first phase had a duration of four weeks with locations selected that would provide data for the entire system. This first phase occurred roughly between 27 March and 24 April 2020, with some meters being installed prior to and removed after these dates. The second phase had a duration of two weeks, and the locations were selected based on initial review of the data received from the first phase. This second phase occurred at various intervals between 17 June and 20 July 2020. Due to problems encountered, certain meters were left in for longer than two weeks, so that a full two-week data set could be used. Another four-week phase of sampling was conducted between 28 September and 26 October 2021 in order to conduct a third analysis and to revise the conclusions drawn from the first two phases of sampling as needed.

Sections 4.1 to 4.3 provide information regarding the monitored wastewater parameters, the proposed monitoring locations, and the existing monitoring locations. Refer to Figure 2 for a map of the project sampling locations.

4.1 Monitored Wastewater Parameters

Parameters that were monitored, as well as established units, are summarized in Table 2 below. It should be noted that both conductivity and salinity concentration were monitored. Conductivity was specifically monitored and reported so that comparisons could be made against existing, historic conductivity values from NBK-Bremerton and the City. Salinity concentration was monitored and reported so that salinity loading could be calculated. See Section 5.0 for a detailed description of conductivity, salinity concentration, and salinity loading, how they relate to each other, and how they apply to this report.

Table 2. List of Monitored Constituents/Parameters

Constituent/Parameter	Units
pH	-
Conductivity	mS/cm
Temperature	°C
Chlorides	mg/L
Salinity	ppt

[2] Section 4 has been revised to reflect the additional Phase 3 monitoring locations. Light changes were made to Sections 4.0 to 4.3 to differentiate between Phases 1, 2, and 3 monitoring locations. Section 4.4 has been added to summarize the Phase 3 monitoring locations.

This four-week duration of the first phase was intended to allow for data collection during any combination of high/low tide, wet/dry weather conditions, and high/low diurnal flows. This way, the impact that these different conditions have on the monitored wastewater parameters could be determined.

According to the National Oceanic and Atmospheric Administration (NOAA) Tide Station in Bremerton, there are approximately 28 high and low tides per four-week period. Approximately two spring tides, or periods of time when high tides are higher than average, and low tides are lower than average, occur over any four-week period.

Based on historic data, the average number of days with precipitation, and the average precipitation depth in the Seattle area are significant during the months of March, April, and May. Average precipitation in March is approximately 3.3 inches per month, with 16 days of precipitation. Average precipitation in April is approximately 1.97 inches per month, with 13 days of precipitation. Average precipitation in May is approximately 1.57 inches per month, with 11 days of precipitation. Thus, it was assumed that there would be an adequate frequency and intensity of rainfall events and dry periods during the first four-week monitoring period.

Section 5.4.2 below presents the actual rainfall that occurred, as well as the impacts that rainfall had on the sewer flow and salinity loading.

4.2 Selected Monitoring Locations (Monitoring Phases 1 and 2)

Most of the data collected is from the continuously monitored locations. These locations were selected to capture flows from the entire site, so that no sources of salinity would potentially bypass any of the installed meters. Additional selected locations were monitored instantaneously at various times and intervals to supplement the continuously monitored data. Section 4.2.1 below presents the continuously monitored locations, and Section 4.2.2 presents the instantaneous sampling locations. Additionally, Section 4.3 presents any areas where either NBK-Bremerton or the City already monitor data that was used in the analysis.

4.2.1 Continuous Monitoring Locations

Through review of project documents, coordination with NBK-Bremerton staff, and coordination with subconsultants, WSP determined the following set of monitoring locations would be responsive to the project scope and are adequate to generally locate the source(s) of salinity in the NBK-Bremerton system.

- Eight monitoring stations on lift station wet wells
- Two monitoring stations on gravity manholes
- One monitoring station in a DD sump
- Three monitoring stations on or near pressurized lines
- One pier sewer monitoring station

An additional four continuously monitored locations within the City's system were selected with input from the City and NBK-Bremerton to compare salinity loading from NBK-Bremerton versus the rest of the City system. It should be noted that the four City monitoring locations were originally planned to be between NBK-Bremerton and the WWTP headworks. However, it was determined during the kickoff meeting, and with input from the City, that the four City locations would be more beneficial to be placed at various areas throughout the City system. (A map of the city monitoring locations can be found in Appendix A, for Meters 16 to 19). Additionally, certain locations were instantaneously sampled, as described further in Section 4.2.2 below. After four weeks of monitoring was completed, each monitoring station was decommissioned and four of the gravity stations were relocated to new gravity manholes. The locations of these four follow-up monitoring locations were selected based on initial review of the first four weeks of data to further pinpoint the source(s) of salinity. Each specific method of monitoring is described below.

1) Eight sensor probes were installed into the wet wells of LS 2 to LS 9
2) Two sensor probes were installed in gravity manholes to monitor flows from DDs 2 and 3
3) One sensor probe was installed in the PWCS sump in the floor of DD 1
4) Three sensor probes were installed on the pressurized PWCS at DDs 4, 5, and 6
5) One sensor probe was installed to monitor flows coming from the sewer line along the west side of Pier D
6) Four sensor probes were installed within the City's system
7) Four sensor probes were relocated to MH 1-68, MH 1-25, MH 1-3, and MH 9-8 gravity manholes within the NBK-Bremerton site for two weeks, after the initial four-week period

Table 3 summarizes the proposed quantities/durations for each method of monitoring. Monitoring Phase 1 occurred between 27 March 2020 and 24 April 2020, and Monitoring Phase 2 occurred between 17 June 2020 and 20 July 2020.

Table 3. Summary of Proposed Monitoring Locations and Durations

Monitoring Method	Quantity	Monitoring Phase 1 (4 weeks)	Monitoring Phase 2 (2 weeks)
Lift station wet well monitoring	8	X	
PWCS DD sump monitoring	1	X	
PWCS gravity manhole monitoring	2	X	
PWCS pressure system monitoring	3	X	
Pier D west monitoring	1	X	
City system manhole monitoring	4	X	
Gravity manhole monitoring	4		X

Table 4 presents number of meters at each monitoring location and a description of the sewer line type, general location, specific monitoring points, and comments. Maps of each location can be found in Appendix A.

Table 4. Monitoring Locations Overview

Meter	Sewer Line Type	Location	Monitoring Points	Comments
1	Gravity	LS 2	LS 2	Monitoring occurred in LS 2 wet well
2	Gravity	LS 3	LS 3	Monitoring occurred in LS 3 wet well
3	Gravity	LS 4	LS 4	Monitoring occurred in LS 4 wet well
4	Gravity	LS 5	LS 5	Monitoring occurred in LS 5 wet well
5	Gravity	LS 6	LS 6	Monitoring occurred in LS 6 wet well
6	Gravity	LS 7	LS 7	Monitoring occurred in LS 7 wet well
7	Gravity	LS 8	LS 8	Monitoring occurred in LS 8 wet well
8	Gravity	LS 9	LS 9	Monitoring occurred in LS 9 wet well
9	Gravity	DD 1	-	Monitoring occurred in PWCS sump on floor of DD 1
10	Gravity	DD 2	MH 6-16	This gravity manhole collects process water from DD 2
11	Gravity	DD 3	MH 8-4B	This gravity manhole collects process water from DD 3
12	Pressure	Pier D West	-	Collects water from Pier D
13	Pressure	DD 4	-	Dry dock line US of LS 5
14	Pressure	DD 5	-	Dry dock line US of force main near LS 4
15	Pressure	DD 6	-	Dry dock line US of force main near LS 3
16	Gravity	WWTP Headworks	-	City of Bremerton Treatment Plant
17	Gravity	WB-3	-	City of Bremerton - western connection to NBK-Bremerton
18	Gravity	CE-4	-	City of Bremerton - eastern connection to NBK-Bremerton
19	Gravity	CE-1	-	City of Bremerton - collects from East Bremerton
20	Gravity	LS 1 Gravity System	MH 1-68	One of three manholes selected to pinpoint salinity source(s) into the gravity system upstream of LS 1
21	Gravity	LS 1 Gravity System	MH 1-25	One of three manholes selected to pinpoint salinity source(s) into the gravity system upstream of LS 1
22	Gravity	LS 1 Gravity System	MH 1-3	One of three manholes selected to pinpoint salinity source(s) into the gravity system upstream of LS 1
23	Gravity	LS 9 Tributary Area	MH 9-8	Manhole was selected to pinpoint the source(s) of salinity into the tributary area of LS 9

At each monitored wet well, the probes were intentionally placed in areas of high mixing within each wet well to ensure that the data is as representative as possible of the flows that pass through the wet well. As the probes were installed in the wet wells, and not the force mains leaving each wet well, calculations in this report assume that the well-mixed areas around each probe is similar (in conductivity and temperature) as the water that is pumped out of the wet well. Note that while data was still being collected and recorded while each wet well was not pumping or receiving any inflows that would mix the water, the data from these time periods is not used in any of the salinity loading calculations.

Figure 3 presents an overall project map of NBK-Bremerton and the locations of all monitoring locations, as well as locations where existing data collection was used. Individual exhibits with detailed maps of each monitoring area can be found in Appendix A. Detailed reasoning and descriptions of each monitoring location are described more in the following sections.

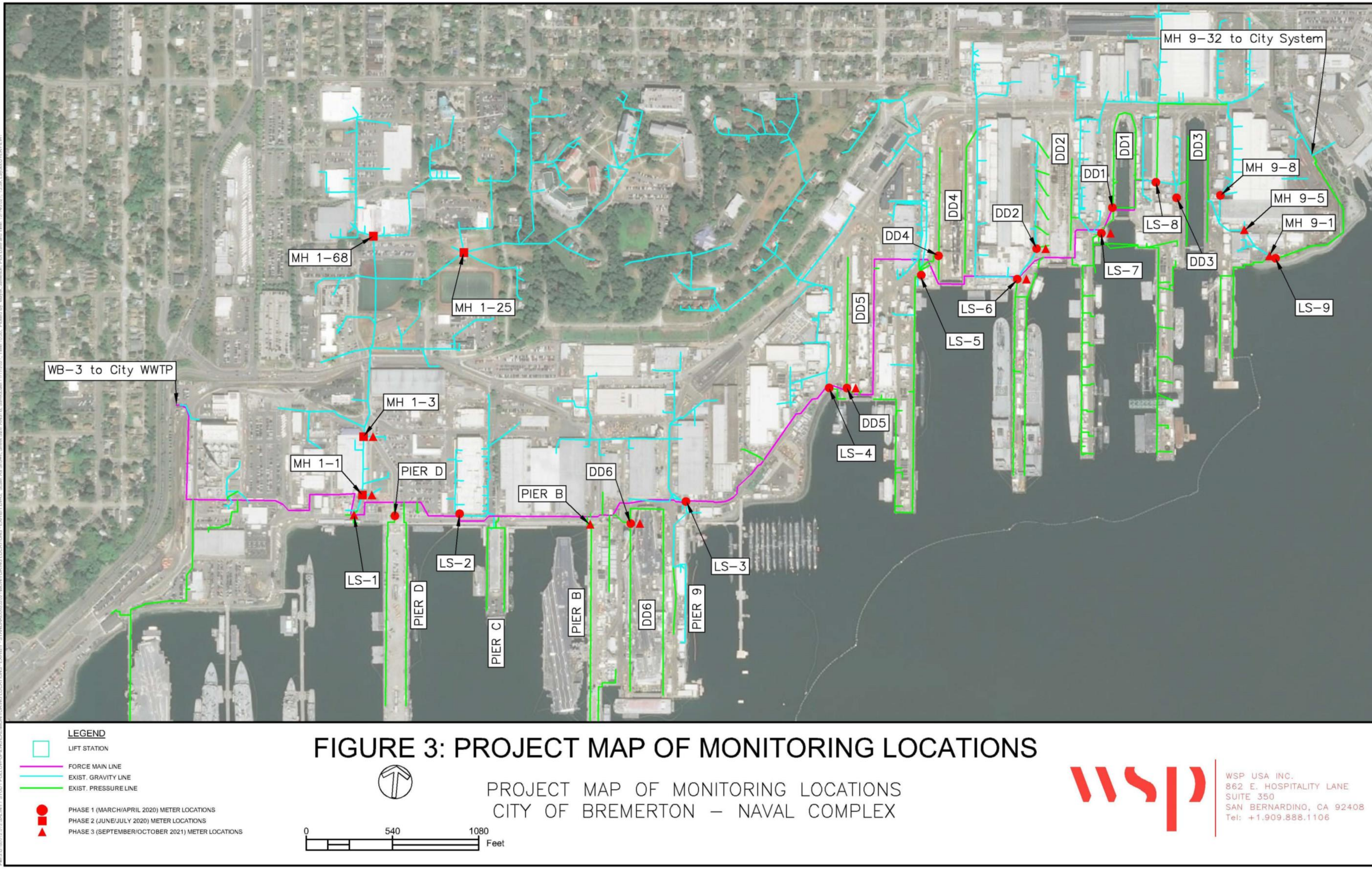

Figure 3. Project Map of Monitoring Locations

4.2.2 Instantaneous Sampling Locations

In addition to the continuously monitored locations described in Section 4.2.1 above, instantaneous samples were collected at various locations throughout the site during Phase 1 and Phase 2 to obtain additional data for analysis, and to validate accuracy of existing data collection points. Instantaneous samples were collected related to three aspects of the site: samples from the OWTS effluent, DD 4 and DD 6 groundwater relief wells, and from LS 1 and WB-3.

OWTS samples were collected by NBK-Bremerton staff and analyzed by WSP. This data was paired with OWTS flow data, also provided by NBK-Bremerton, to estimate salinity loading that can be attributed to the OWTS at each DD. The results of these analyses are further discussed in Sections 5.1.9, 5.2.8, and 5.3.8.

Samples from groundwater relief (GWR) wells in the side tunnels of DDs 4 and 6 were collected to characterize the salinity of groundwater as the data was paired with estimates of groundwater intrusion into each DD. The results of these analyses can be found in Section 5.4.1.

4.3 Existing Monitoring Locations

NBK-Bremerton and the City collect water quality data and sewer flow data in the sewer system historically for other purposes. This data was provided to WSP for use in combination with the project-specific data. Sources of the existing data that was obtained by WSP includes the following.

1) Existing conductivity meter at NBK-Bremerton LS 1: An existing conductivity meter exists at LS 1 and data was used in WSP's analysis. This location receives flow from NBK-Bremerton LS 2 through LS 8, from residential areas to the north in the vicinities of Barclay Street, Dewey Street, and Cole Avenue, OWTS 2, 4, and 6, and from DDs 5 and 6 PWCS, Pier B, Pier C, and Pier D ship discharges.
2) Existing conductivity meter at City's pump station WB-3: Data from an existing conductivity meter located in the City's pump station WB-3 was used in WSP's analysis. Differences in results between the LS 1 and WB-3 conductivity meters can be attributed to certain areas, including the inactive fleet area, Mooring G (which has a sewer connection to LS 12), LS 10 (which has low conductivity steam plant boiler discharge of around 20,000 gpd), and LS 11, LS 12, and LS 13.
3) Existing City pump station flow meters: Data from City flow meters near the two NBK-Bremerton sewer system discharge connection points for the testing period were received (flow data from WB-3, at the western stations CE-1 and CE-4, as well as at the City's WWTP system headworks, was requested to analyze in combination with the conductivity/salinity data that was collected by WSP at these locations).

4) Flow data related to monitoring locations: Data that allowed WSP to determine flowrates at each monitoring location was provided by NBK-Bremerton. This included direct flowrate data, flow volume data, and pump on/off data.

5) Tidal and rainfall information: Data from NOAA Tidal Gauge 9445958 in Bremerton (approximately 1,000 feet east of the site in the Sinclair Inlet) were used for tidal information. Data from NOAA weather station F0240 in Bremerton, provided to WSP by NBK-Bremerton, was used for rainfall information.

4.4 Late-Pandemic Monitoring Locations (Monitoring Phase 3)[3]

A third phase of sampling and analysis was conducted between 28 September and 25 October 2021 (four weeks) in order to conduct a late-pandemic analysis and to revise the conclusions drawn from the first two phases, as needed. The locations for this third phase of monitoring were selected by NBK-Bremerton staff, and are as follows:

1) One meter at the City pump station CE-1, which receives flows from East Bremerton.
2) One meter at the City's WWTP headworks.
3) Two meters at MH 1-1 and 1-3, to determine contribution from groundwater into the sanitary sewer.
4) One meter at Pier B, to measure flowrate and salinity of wastewater discharging from docked vessels.
5) Three meters at LS 1, LS 6, and LS 7.
6) Two meters at MH 9-1 and 9-5.
7) Three meters at the PWCS for DD 2, DD 5, and DD 6.

In addition to the 13 meter locations above:

1) OWTS samples were collected and tested by PSNS & IMF Code 134 Analytical Laboratory and the results were provided to WSP for analysis.

2) Calculations were made at LS 1 and LS 9 based on conductivity and flowrate data provided by NBK-Bremerton staff, and at WB-3 based on data provided by the City of Bremerton

NBK-Bremerton staff collected 24-hour composite samples from all dry dock PWCS (when possible), which were tested by PSNS & IMF Code 134 Analytical Laboratory, and the results were provided to WSP for analysis.

[3] Section 4.4 has been added to summarize the Phase 3 monitoring locations.

5.0 DATA ANALYSIS[4]

This section presents an analysis of data obtained at each of the monitoring locations outlined in Section 4.0. The standard parameters are as follows.

1) Conductivity (in mS/cm), which represents the capacity of water to transmit electricity, and is the standard method for estimating salinity concentrations in water samples.

2) Salinity concentration (in mg/L), which represents the amount of salinity in a given volume of water.

3) Salinity loading (in kg/day), which represents the amount of salinity that flows through any location in a given amount of time.

Salinity concentration can be estimated as a function of conductivity and temperature of water. Conductivity is a measure of water's ability to pass electrical flow, which is directly related to the concentration of ions such as dissolved salts and other inorganic materials. Temperature is also used in the calculation of salinity concentration, as temperature also impacts the conductivity of water. The set of formulas used to calculate salinity concentration were obtained from the manufacturer of one of the meters used to obtain data. This formula was applied to all data sets so that the calculated salinity values would be comparable.

Figure 4 below shows the relationship between conductivity and salinity concentration, at various temperatures. As can be seen, with conductivity held as a constant, a warmer sample will have a lower salinity concentration than a colder sample. This is because conductivity increases as temperature increases.

Salinity loading values (in units of kg/day) for any lift station, manhole, or pipe were calculated as a function of the salinity concentration and volumetric flowrates. The specific formulas can vary depending on the data intervals for salinity concentration and flowrate measurements at each monitoring location. For example, at LS 1, flowrate and salinity concentration data were both available at 1-second intervals. The volume of water pumped at any given second (i.e., 1 liter per second) was multiplied by the salinity concentration at that second (i.e., 10 ppt or 10 grams per liter), to obtain a salinity loading during that second (i.e. 10 grams per second). This calculation was repeated for each second during the monitoring period to obtain total salinity loading values.

[4] The only revisions in Section 5.0 were on Table 5, which has been revised to include the results of Phase 3 monitoring. Section 5.1 and its subsections received further updates.

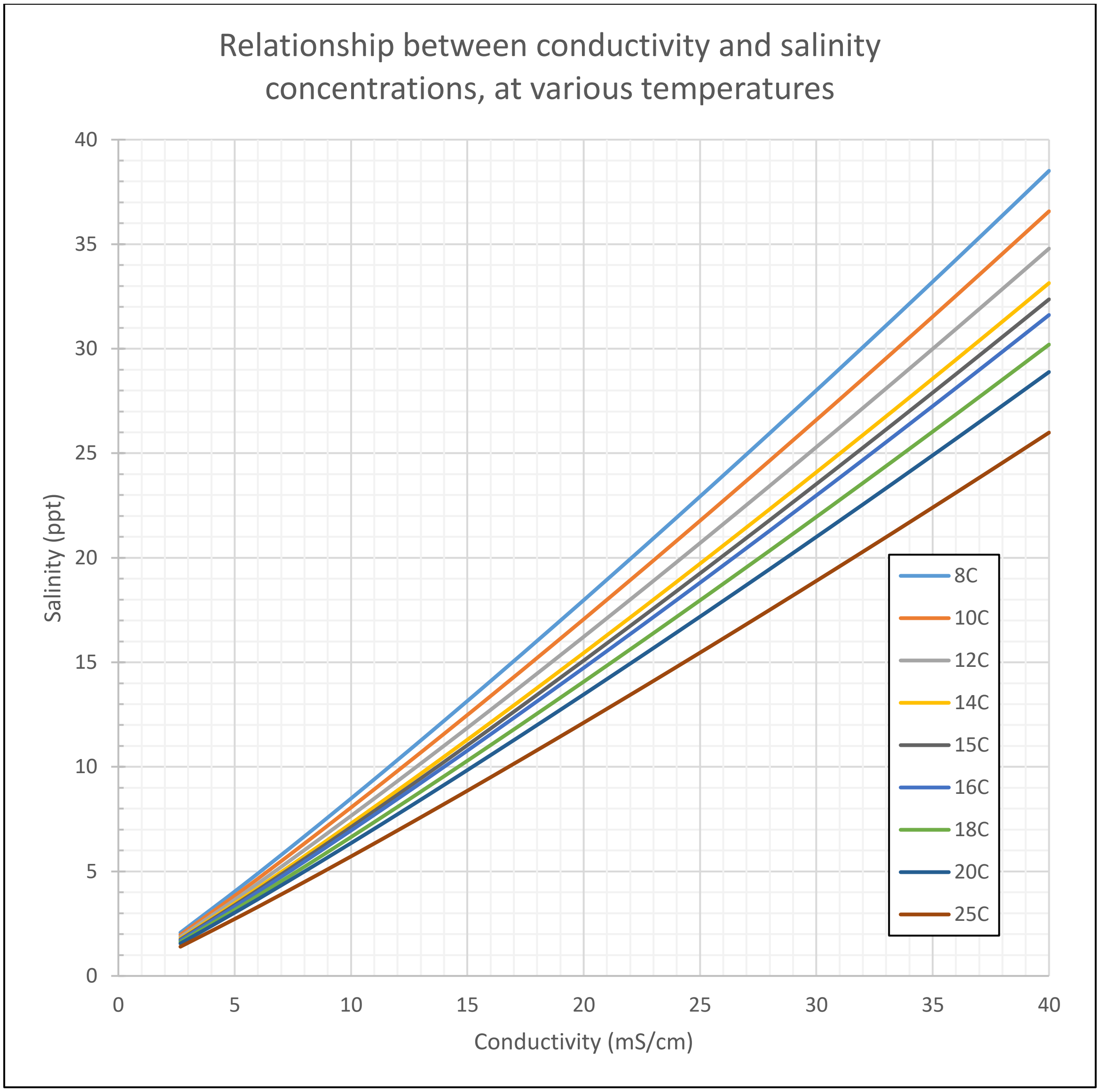

Figure 4. Conductivity/Salinity Concentration Relationships

Salinity concentration and salinity loading values are both important to analyze. Elevated salinity concentrations can indicate specific sources of salinity into the sewer system, and spikes of elevated salinity concentrations can have negative impacts on the biological treatment processes. Sustained high salinity loadings can also have long-term negative impacts on other wastewater infrastructure such as pumps and pipes due to intensified corrosion.

It should be noted that salinity concentration and salinity loading are related, but not always directly correlated. A system with low salinity loading can still have high salinity concentrations, if flowrates are low. Alternatively, a system can have high salinity loadings with low salinity concentrations, if flowrates are high.

Table 5 presents the salinity observations, as well as any correlations that serve as a potential explanation for the salinity values. The data summaries provided in Table 5 below are generalized and full descriptions of the data can be found in Section 5.0 and in the various appendices. Meter 1 through Meter 23 and the existing LS 1 meter data are provided in Appendices B to E.

Table 5. Conductivity Observations, Salinity Concentration Observations, Loading Observations, and Correlations

Lift Station	Conductivity Observations	Salinity Concentration Observation	Salinity Loading Observations	Potential Correlations
LS 1	• Conductivity fluctuates multiples times per day with lows between 2 and 5 and highs generally between 7 and 20 mS/cm (Phase 1 and Phase 3 were roughly the same) • Conductivity spiked above 23 mS/cm for 1-3 hours on 4/12 at 22:00, 4/13 at 19:40, 4/18 at 05:50, 4/18 at 18:30, 4/19 at 08:00, 4/19 at 22:00, 4/20 at 13:00 (Phase 1) and spiked above 20 mS/cm on 9/23 and 9/24 (Phase 3)	• Salinity concentration fluctuates multiple times per day, with highs generally between 10 and 15 ppt, and lows generally between 3 and 7 ppt (Phase 1 and Phase 3 were roughly the same) • Salinity concentration peaked to levels between 18 and 23 ppt roughly eight times during Phase 1, and roughly 21 times during Phase 3	• Average salinity loading was calculated to be 18,975 kg/day during Phase 1 and 17,047 kg/day during Phase 3	There are no clear correlations between LS 1 and any other monitored location, as LS 1 captures the combined flows of many locations. However, due to the high salinity loading values at LS 1 in comparison to salinity loading values from other monitored locations that discharge into LS 1, the manholes in the gravity line upstream of LS 1 were selected to further pinpoint the source(s) of salinity in LS 1 in Phase 3. Phase 3 indicated low salinity loading through the gravity system upstream of LS 1.
LS 2 (Phase 1 only)	• Conductivity fluctuates multiple times per day, generally ranging between 2 and 20 mS/cm • Conductivity spiked above 20 mS/cm on 4/9 between 10:40 and 12:40, 4/12 from 21:25 to 22:10, 4/13 from 19:25 to 22:55 and between 4/24 at 18:25 and 4/26 at 22:50	• Salinity fluctuates multiple times per day, with highs between 5 and 15 ppt, and lows between 2 and 5 ppt • Salinity spikes above 20 ppt for 1 to 2 hours three times (4/9 at 12:05, 4/12 at 21:30, 4/13 at 21:30) • Salinity was found to be continually above 16 ppt for 48 hours starting 4/24 at 18:30 and ending 4/26 at 22:40	• Salinity loading is generally less than 100 kg/day • Salinity loading spiked from 50 kg/day on 4/23 to 550 kg/day on 4/24 and 4/25	The spikes in salinity concentration and salinity loading do not appear to correlate to any external factors, such as time of day, rainfall, or tides.

Table 5. Conductivity Observations, Salinity Concentration Observations, Loading Observations, and Correlations (continued)

Lift Station	Conductivity Observations	Salinity Concentration Observation	Salinity Loading Observations	Potential Correlations
LS 3 (Phase 1 only)	• Conductivity fluctuates multiple times per day, ranging between 1 and 7 mS/cm • Conductivity spiked above 20 mS/cm for approximately four days between 4/3 at 14:50 and 4/7 at 9:05	• Salinity concentration fluctuates multiple times per day, with highs between 3 and 5 ppt, and lows between 0.25 and 1 ppt • Salinity concentrations spiked to levels between 15 and 28 ppt, between roughly 4/3 and 4/7	• Salinity loading was generally less than 100 kg/day • Salinity loading spiked to over 6,000 kg/day on 4/4, 4/5, and 4/6. Through coordination with NBK-Bremerton, it was determined that these dates correspond to the dates when DD 6 was flooded, and that saltwater from the DD 6 pumpwell was pumped to LS 3.	The spike in salinity concentration and loading does not appear to correlate to any external factors, such as time of day, rainfall, or tides.
LS 4 (Phase 1 only)	• Conductivity fluctuates multiple times per day, ranging between 0.2 and 1.5 mS/cm • Conductivity spiked above 2 mS/cm on 4/9 11:15 to 17:40, 4/14 between 13:15 and 15:05, 4/17 between 2:40 and 4:50, 4/19 between 5:10 and 8:05, between 4/19 22:00 and 4/20 2:00, 4/20 between 6:15 and 14:40, 4/21 between 3:50 and 13:45	• Consistently between 0.2 and 1 ppt • Three instances where salinity spiked to above 5 ppt for 2 to 4 hours (4/9 at 12:55, 4/20 at 07:00, and 4/21 at 08:00)	• Loading is generally less than 75 kg/day • Loading spiked to 120 kg on 4/9, 250 kg on 4/20, and 175 kg on 4/21	LS 4 and its tributary area do not likely have any intrusion, or operations, that contribute significantly to overall salinity discharged from NBK-Bremerton. The spikes on 4/9, 4/20, and 4/21 do not appear to correlate to any external factors, such as time of day, rainfall, or tides.

Table 5. Conductivity Observations, Salinity Concentration Observations, Loading Observations, and Correlations (continued)

Lift Station	Conductivity Observations	Salinity Concentration Observation	Salinity Loading Observations	Potential Correlations
LS 5 (Phase 1 only)	• Conductivity fluctuates multiple times per day between 0.5 and 5 mS/cm • Conductivity spiked to approximately 9 mS/cm on 4/2 at 21:10 for approximately 2 hours due to approximately 26,000 gallons of OWTS water discharged upstream	• Salinity is generally below 1 ppt • Salinity spikes for 4 to 6 hours per day, usually reaching a maximum of roughly 3.5 ppt	• Loading is generally between 50 and 100 kg/day • There was a minor spike to 145 kg/day on 4/22, which correlates to a rain event of 0.68 inch on 4/22	LS 5 generally had low salinity concentration and salinity loading values.
LS 6	• Conductivity fluctuates multiple times per day with lows between 0.5 and 3 mS/cm and highs between 4 and 14 mS/cm (Phase 1 and 3 were roughly the same, but the high end of the highs approximately doubled during Phase 3, at around 28 mS/cm) • There were no significant spikes in conductivity	• Salinity concentration fluctuates multiple times per day, with highs between 3 and 12 ppt and lows between 0.5 and 2 ppt (Phase 1 and 3 were roughly the same, but the high end of the highs approximately doubled during Phase 3, at around 13 ppt) • There were no significant spikes in salinity concentration	• During Phase 1, salinity loading fluctuated between 250 and 400 kg/day during Phase 1, with an average salinity loading of 375 kg/day • During Phase 3, salinity loading fluctuated between 200 and 600, with an average salinity loading of 302 kg/day	LS 6 had consistently high salinity loading values during Phase 1 and Phase 3. Certain spikes in salinity correlate to the PWCS salinity; however, other spikes in salinity concentration do not appear to correlate to any external factors, such as time of day, rainfall, or tides.
LS 7	• Conductivity fluctuates multiple times per day by 2 to 4 mS/cm. Lows were between 1 and 4 mS/cm, and highs were between 4 and 10 mS/cm (Phase 1 and 3 were roughly the same) • Conductivity spiked above 20 mS/cm on 10/13 at 13:15, and above 25 mS/cm for 0.5 hours on 10/14 at 17:55	• Salinity concentrations fluctuate multiple times per day, with highs between 2 and 8 ppt, and lows between 0.5 and 3 ppt (Phase 1 and 3 were roughly the same) • Salinity concentration spiked above 15 ppt on 10/13 at 13:15, and above 20 ppt for 0.5 hours on 10/14 at 18:00	• Loading fluctuates between 200 and 400 kg/day during Phase 1, with an average salinity loading of 297 kg/day. • During Phase 3, salinity loading fluctuated between 600 and 3,800 kg/day, with an average salinity loading of 1,269 kg/day.	LS 7 had consistently high salinity loading values during Phase 1, with significantly higher values during Phase 3. During Phase 1, the spikes in salinity concentration appear to directly correlate to the PWCS 1 pump-on times. Phase 3 was mostly due to abnormal discharged from PWCS 1 on 13 and 14 October 2021 (see Section 7.0 for more information)

Table 5. Conductivity Observations, Salinity Concentration Observations, Loading Observations, and Correlations (continued)

Lift Station	Conductivity Observations	Salinity Concentration Observation	Salinity Loading Observations	Potential Correlations
LS 8 (Phase 1 only)	• The data from the meter installed at LS 8 was determined to be inaccurate. Please see Section 5.1.6 for descriptions of follow-up sampling and conclusions drawn about LS 8.	• The data from the meter installed at LS 8 was determined to be inaccurate. Please see Section 5.1.6 for descriptions of follow-up sampling and conclusions drawn about LS 8.	• The data from the meter installed at LS 8 was determined to be inaccurate. Please see Section 5.1.6 for descriptions of follow-up sampling and conclusions drawn about LS 8.	LS 8 only receives water from PWCS 3/DD 3, which was monitored for four weeks, as well as a small gravity network. WSP sampled the gravity network to and found low salinity values. So, it can be assumed that most of the salinity at LS 8 came from PWCS 3/DD 3. See Section 5.1.6.2 for more information.
LS 9	• Conductivity fluctuates multiple times per day with lows between 3 and 7 mS/cm and highs between 10 and 15 mS/cm (Phase 1 and 3 were roughly the same, with slightly higher highs during Phase 3) • Beginning on 4/18 at 5:45 and ending on 4/20 at 10:00, conductivity was sustained over 15 mS/cm	• Salinity concentrations fluctuate between multiple times per day, with highs between 6 and 12 ppt, and lows between 2 and 5 ppt. (Phase 1 and 3 were roughly the same, with slightly higher highs during Phase 3) • There were no distinguishable spikes in salinity concentration outside of the daily fluctuations	• Loading was consistently less than 400 kg/day during Phase 1. • During Phase 3, the salinity loading fluctuated between 900 and 4,000 kg/day, with an average salinity loading of 2,727 kg/day.	LS 9 had relatively high salinity concentrations during Phase 1, and concentrations and salinity loading were significantly higher during Phase 3. It should be noted that the previous 1998 study indicated multiple leaks in the tributary area to LS 9, with 18 gpm of groundwater infiltration to the system. It should be noted that the issues observed in the 1998 study were repaired prior to these observations. During Phase 3, NBK-Bremerton staff indicated that the water looked clear and had high conductivity on weekends and holidays when there was not much traditional sewage to dilute the infiltrated, high salinity water.

5.1 Salinity Loading Observations[5]

Salinity loading represents the amount of salinity (in units of mass) that is added to the sewer system. WSP calculated salinity loading using various data at each of the following locations for the first and/or second phases of monitoring: LS 1 through LS 9, PWCS 1 through 6, OWTS 1, 2, 4, and 6, Pier D, WWTP headworks, CE-4, CE-1, WB-3, MH 1-68, MH 1-25, MH 1-3, and MH 9-8.

In the third phase of monitoring, salinity loading was calculated at LS 1, 6, and 7, MH 1-1, 1-3, 9-1, and 9-5, PWCS 2, 5, and 6, Pier B, OWTS 1 to 6, LS 9, City pump station CE-1, and the City's WWTP headworks.

The results of the salinity loading calculations for the first and third phases of monitoring are summarized in Figure 5, which displays the daily average salinity loading, during the monitoring periods, as a percentage of the daily average salinity loading from the entire NBK-Bremerton system.

For Phase 1, LS 1 was determined to be representative of discharge from the entire base. LS 9 is a separate contributor but contributed an insignificant amount of flow volume and salinity loading. Due to the flow data at LS 1 being inaccurate prior to 9 April 2020, only data after 9 April 2020 was used in the calculations for the figure below. The average salinity loading at LS 1 between 10 April 2020 and 25 April 2020 was 18,975 kg/day.

For Phase 3, the average salinity loading from NBK-Bremerton was calculated as the sum of the salinity loading at WB-3 and LS 9, as LS 9 had higher contributions during Phase 3 than during Phase 1. The average salinity loading from NBK-Bremerton during Phase 3 was 21,583 kg/day. It should be noted that the salinity loading at LS 9 prior to 14 October 2021 is inaccurate, so the average between 14 October and 25 October 2022 of 1,674 kg/day was applied to the entire monitoring period.

[5] The following subsections have been revised heavily to include new monitoring and results: 5.1.1, 5.1.8, 5.1.9 ,5.1.10, and 5.1.11. The remaining sections (5.1.2, 5.1.3, 5.1.4, 5.1.5, 5.1.6, and 5.1.7) only received light revisions to specify monitoring phases.

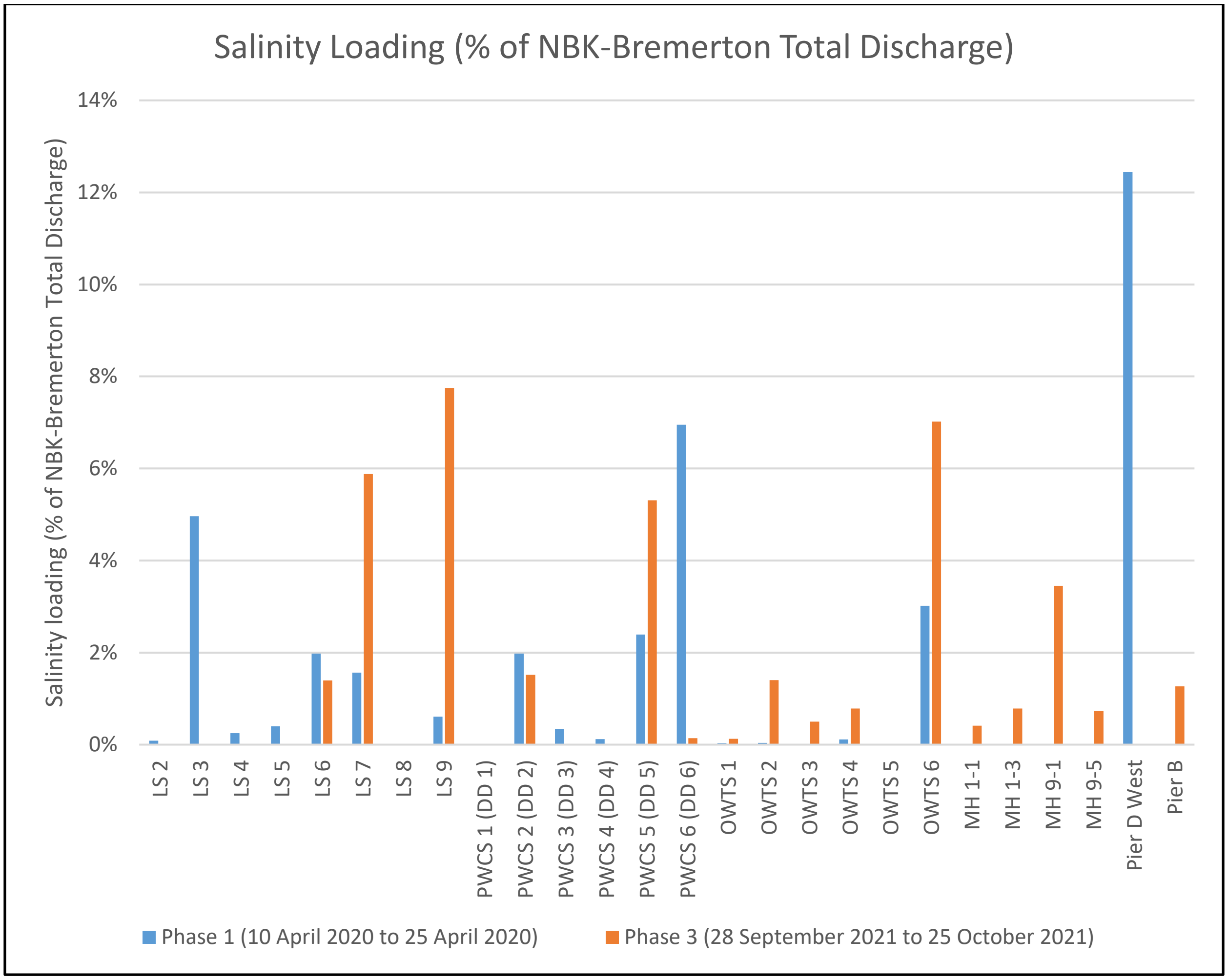

Figure 5. Salinity Loading Summary Chart

As can be seen, there are notable discrepancies between the results from Phase 1 and Phase 3. Discrepancies have been examined at the following locations:

1) MH 1-1 and 1-3: While these manholes were not monitored directly in the first phase of monitoring, it was estimated that the gravity sewer network flowing through these manholes contributes 12,454 kg/day, or 65 percent of the salinity from NBK-Bremerton. As can be seen below, they only contributed 169 kg/day, or less than 1 percent of the salinity loading from NBK-Bremerton during the third phase of monitoring.

2) LS 7: the salinity loading at LS 7 jumped from an average of 297 kg/day during Phase 1 to 1,269 kg/day during Phase 3.

3) LS 9: the salinity loading at LS 9 jumped from an average of 115 kg/day during Phase 1 to 1,674 kg/day during Phase 3.

4) PWCS 5: the salinity loading as a percent of NBK-Bremerton's total at PWCS 5 increased from 2.3 percent in Phase 1 to 5.3 percent in Phase 3. An analysis of

average daily flows during non-rain days completed by NBK-Bremerton staff indicated that the groundwater intrusion flow increased by about 25% between Phase 1 and Phase 3. This indicates that the jump from 2.3 to 5.3 percent was likely caused by specific operations that occurred within DD 5 during Phase 3 that did not occur in Phase 1. However, NBK-Bremerton staff were not aware of any specific operations that could increase salinity loading at PWCS 5.

5) PWCS 6: the salinity loading as a percent of NBK-Bremerton's total at PWCS 6 decreased from 7 percent in Phase 1 to 0.14 percent in Phase 3. During Phase 1, NBK-Bremerton staff estimated that an average of 85,200 gallons per day leaked to the dry dock floor. Per NBK-Bremerton staff, in early 2021 NAVFAC personnel initiated a temporary fix to the groundwater problem at DD 6 by welding metal plates over areas that are leaking onto the dry dock floor, eliminating flow to the sanitary sewer for most days.

6) OWTS 4: the salinity loading as a percent NBK-Bremerton's total at OWTS 4 increased from 0.1 percent in Phase 1 to 0.78 percent in Phase 3. NBK-Bremerton staff have indicated that the cause of this increase is due to increased activities at OWTS 4, including processing DD 2 dry dock cleaning water, which was salt water at the time due to a shortage of backflow preventers that allow the use of fresh water.

7) OWTS 6: the salinity loading as a percent of NBK-Bremerton's total at OWTS 6 increased from 3 percent in Phase 1 to 7 percent in Phase 3.

8) Pier D versus Pier B: WSP understands that docked vessels were present at Pier D during Phase 1 and at Pier B during Phase 3. The salinity loading at Pier B during Phase 3 was calculated to be 273 kg/day, lower than at Pier D during Phase 1 which was 2,360 kg/day.

Additionally, the daily average flowrates during first and third phases of monitoring are summarized in Figure 6 below. Similar to Figure 5, only data after 9 April 2020 was used for Phase 1. The average flowrate from NBK-Bremerton for Phase 1 was 599,340 gpd, and for Phase 3 was 631,028 gpd. The difference is likely due to additional rainwater inflow into the sanitary sewer in Phase 3.

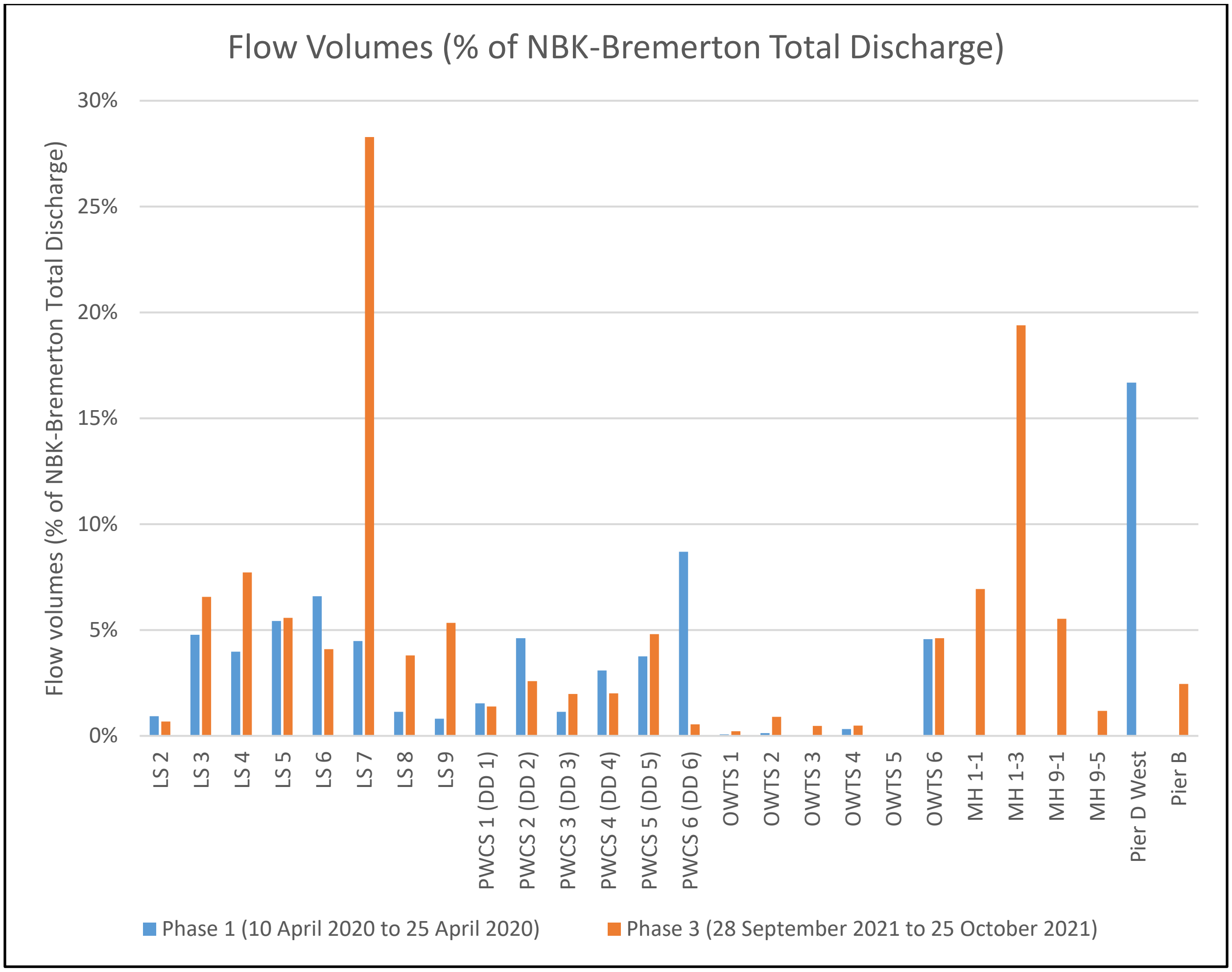

Figure 6. Flowrates Summary Chart

As can be seen on Figure 5 and Figure 6, MH 1-3 had greater salinity loading and flowrates than MH 1-1 during Phase 3 of monitoring although it is upstream of MH 1-1. This is likely due to backflows from LS 1 interfering with the flowmeters installed in these two manholes.

Salinity loading comparisons have been made where salinity is high in any monitoring location that is downstream of another location or downstream of multiple locations, and correlations were made from the data from all locations to establish the source of the high salinity in the downstream location. Salinity loading comparison figures are provided in Appendix C.

The following comparisons have been made.

1) Comparison of LS 1 to LS 2 through LS 9

2) Comparison of LS 1 to the sum of LS 2 to LS 8, PWCS 5, PWCS 6, and Pier D

3) Comparison of LS 5 to PWCS 4

4) Comparison of LS 6 to PWCS 2

5) Comparison of LS 7 to PWCS 1

6) Comparison of LS 8 to PWCS 3

7) Comparison of LS 1 to WB-3

8) Comparison of WWTP vs CE-4, WWTP vs CE-1, and WWTP vs WB-3

9) Comparison of OWTS plants to overall flows

10) Comparison of MH 1-68, MH 1-25, and MH 1-3 to LS 1

11) Comparison of LS 9 to MH 9-8

5.1.1 Comparison of Lift Stations 1 through 9

5.1.1.1 Purpose of Comparison

This comparison was made so that the salinity loading attributed to each lift station can be compared against other lift stations.

5.1.1.2 Methodology/Summary of Results

The following data sources were used to calculate salinity loading values for the comparison of LS 1 to LS 2 through LS 9.

1) LS 1 through LS 9 flow data provided by NBK-Bremerton for both phases of monitoring

2) LS 1 conductivity data provided by NBK-Bremerton for Phase 1, used to calculate salinity

3) LS 1 conductivity collected by WSP's team for Phase 3

4) LS 2 through LS 9 salinity data collected by WSP's team

Figure C1 in Appendix C compares LS 1 through LS 9 for Phase 1 of monitoring (excluding LS 8, due to the data inaccuracies, further explained in Section 5.1.6) salinity loadings. The average daily salinity loading at LS 1 is 18,975 kg/day. The average salinity loading at LS 2 through LS 9 are as follows: 16 kg/day at LS 2, 926 kg/day at LS 3, 47 kg/day at LS 4, 75 kg/day at LS 5, 375 kg/day at LS 6, 297 kg/day at LS 7, and 115 kg/day at LS 9, also shown in Table 6. Due to inaccurate monitoring data, LS 8 salinity loading was not calculated. See Section 5.1.6 for further details regarding LS 8.

For Phase 3 of monitoring, only data at LS 1, LS 6, and LS 7 was collected. These results are also shown in Table 6 below.

Table 6. LS 1 to LS 9 Daily Average Salinity Loading

Lift Station	Average Salinity Loading during First Monitoring Period (kg/day)	Average Salinity Loading during Third Monitoring Period (kg/day)
LS 1	18,975	17,047
LS 2	16	-
LS 3	926	-
LS 4	47	-
LS 5	75	-
LS 6	375	313
LS 7	297	2,042
LS 8	NA	-
LS 9	115	-

NBK-Bremerton staff provided daily flow volume summaries for LS 1 to LS 9 for the Phase 3 monitoring period. An analysis of this data indicated that of the roughly 741,000 gpd average that flowed through LS 1, only 49 percent came from LS 2 to LS 8, indicating that 51 percent of the flows at LS 1 came from sources outside of LS 2 to LS 8, including but not limited to the OWTS, PWCS, and piers with docked vessels. See Section 5.1.2 for more information.

5.1.1.3 Conclusions

Based on the results of Phase 1 and Phase 3 of monitoring, the sum of salinity loading values from contributors to the shared force main (LS 2 to LS 8, PWCS 5, PWCS 6, OWTS 2, OWTS 4, OWTS 6, Pier D, and Pier B) are lower than the salinity loading at LS 1, the conclusion was made that much of the salinity flowing though LS 1 does not come from the shared force main. While Phase 3 only included monitoring at LS 6 and LS 7, an analysis of daily flowrate summaries for LS 1 to LS 8, PWCS 5 and 6, OWTS 2, 4, and 6, and Pier B (discussed further in Section 7.1) indicates that 60 percent of the flow volume pumped out of LS 1 originates from sources outside of LS 2 through LS 8. These can be any connections to the shared force main other than those described above or the wet well structure of LS 1.

5.1.2 Comparison of LS 1 to the sum of LS 2 to LS 8, PWCS 5, PWCS 6, OWTS 2, 4, 6, Pier B, and Pier D

5.1.2.1 Purpose of Comparison

This comparison was completed to determine what percentage of the salinity at LS 1 comes from the force main (LS 2 through LS 8, PWCS 5, PWCS 6, OWTS 2, 4, 6, and Pier D) versus what comes from the gravity sewer collection system to the north of LS 1. By subtracting the total flows from the various sewer sources into the force main from the total flow at LS 1, the flows into LS 1 from the gravity system were estimated. It should be noted that LS 9 was left out of this comparison, as it does not flow through to LS 1, as previously discussed.

5.1.2.2 Methodology/Summary of Results

The following data sources were used to calculate salinity loading values for the comparison of LS 1 to the sum of LS 2 to LS 8, PWCS 5 and 6, OWTS 2, 4, 6, Pier B, and Pier D.

1) LS 1 to LS 8 flow data provided by NBK-Bremerton
2) LS 1 conductivity data provided by NBK-Bremerton
3) LS 2 to LS 8 salinity data collected by WSP's team (for Phase 3, WSP only collected salinity data at LS 1, 6, and 7)
4) PWCS flow data provided by NBK-Bremerton
5) PWCS 4 and 6 salinity data collected by WSP's team
6) Pier D flow estimates provided by NBK-Bremerton for Phase 1
7) Pier B flow data collected by WSP's team for Phase 3
8) Pier B and D salinity data collected by WSP's team (for Phases 1 and 3, respectively)
9) OWTS 2, 4, and 6 salinity data collected by WSP's team, using OWTS samples provided by NBK-Bremerton
10) OWTS flow data provided by NBK-Bremerton

The average salinity load from LS 1 was determined to be 18,975 kg/day during Phase 1. The average salinity load from LS 2 to LS 8, PWCS 5 and 6, OWTS 2, 4, and 6, and Pier D was determined to be 6,415 kg/day. Therefore, approximately 66 percent of the salinity load at LS 1 was from sources outside of LS 2 to LS 8, PWCS 5 and 6, OWTS 2, 4, and 6 and Pier D during Phase 1. It was assumed that nearly all of this 66 percent originates from the upstream gravity sewer collection system to the north of LS 1, as Pier C and other unaccounted flows tributary to the force main were inactive during the monitoring period. Figure C2 presents a comparison of LS 1 salinity load to the sum of LS 2 to LS 8, PWCS 5, PWCS 6, OWTS 2, 4, and 6, and Pier D.

Due to this high salinity load from the gravity system to the north of LS 1, three follow-up locations at MH 1-68, MH 1-25, and MH 1-3 were recommended to further pinpoint the source(s) of salinity to different areas. The results of this follow-up monitoring are presented in Sections 5.1.10, 5.2.9, and 5.3.9 below.

See Figure 7 for a comparison of daily flow volumes for LS 1 versus LS 2 – 8, PWCS 5, PWCS 6, OWTS 2, OWTS 6, and Pier B as measured during Phase 3.

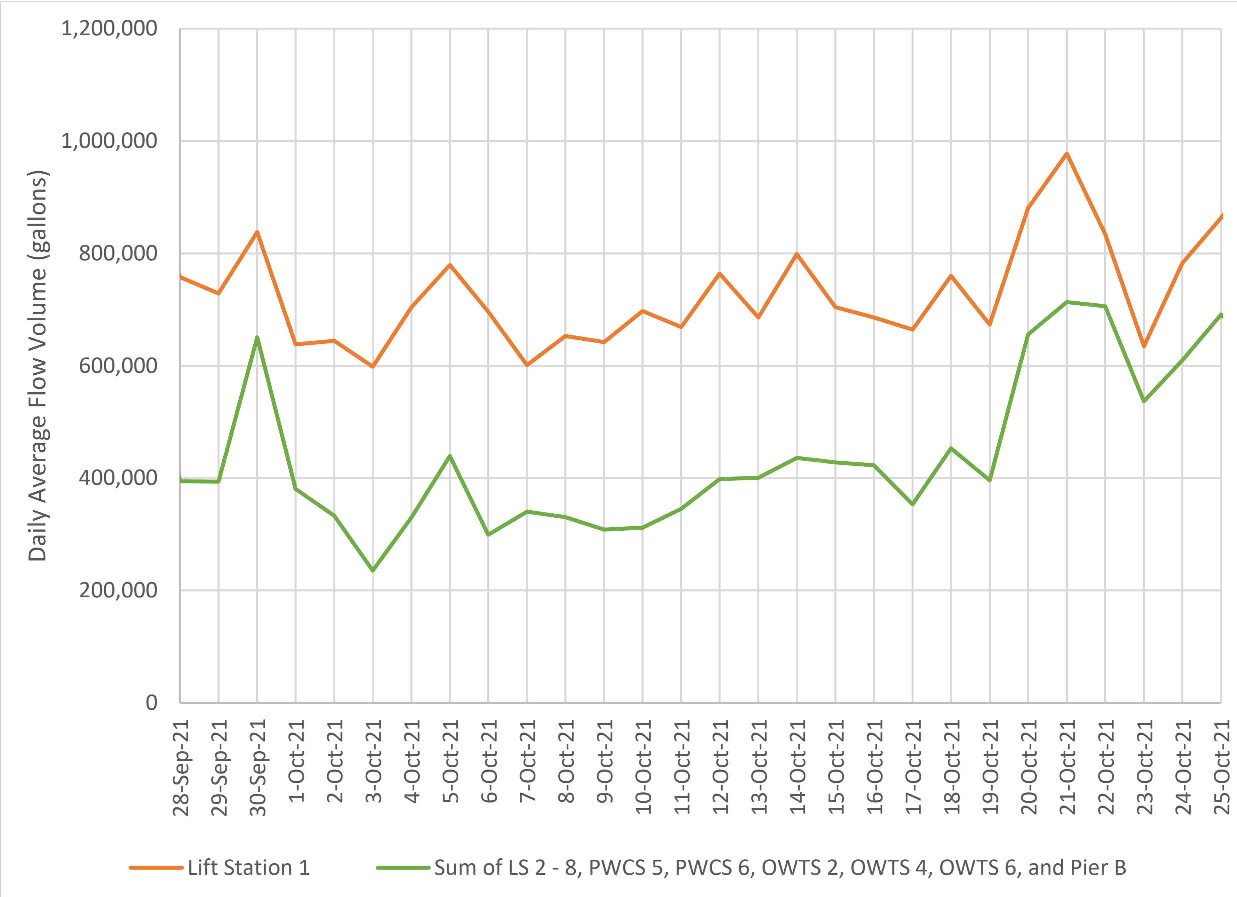

Figure 7. Lift Stations 1 through 9 Daily Flow Volume Analysis for Phase 3

5.1.2.3 Conclusions

During Phase 1, it was determined that approximately 34 percent of the salinity load at LS 1 is from the force main entering LS 1 from the east (LS 2 to LS 8, PWCS 5, PWCS 6, and Pier D). Thus, it was assumed that approximately 66 percent of salinity load originates from the upstream gravity system. Phase 2 and 3 of monitoring provided additional information from the gravity system and indicated that the gravity system contributes low levels of salinity loading.

5.1.3 Comparison of LS 5 to PWCS 4

5.1.3.1 Purpose of Comparison

The purpose of this comparison is to determine the percentage of salinity load at LS 5 from PWCS 4 versus the gravity system tributary to LS 5 based on the results of the first phase of monitoring.

5.1.3.2 *Methodology/Summary of Results*

The following data sources were used to calculate salinity loading values at LS 5 and PWCS 4.

1) LS 5 pump data provided by NBK-Bremerton
2) LS 5 wet well salinity data collected by WSP's team
3) PWCS 4 pump data provided by NBK-Bremerton
4) PWCS 4 salinity data collected by WSP's team

Figure C3 presents a comparison of salinity loads at LS 5 and PWCS 4. The average salinity load at LS 5 was determined to be 75 kg/day, approximately 0.44 percent of the average salinity load at LS 1. The average salinity load at PWCS 4 was determined to be 22 kg/day. Therefore, approximately 53 kg/day of salinity enters LS 5 from the gravity system/other sources outside of PWCS 4.

5.1.3.3 *Conclusions*

At LS 5, approximately 30 percent of the salinity load comes from PWCS 4, and 70 percent of the salinity load comes from the gravity system/other sources upstream of LS 5.

5.1.4 Comparison of LS 6 To PWCS 2

5.1.4.1 *Purpose of Comparison*

The purpose of this comparison is to determine the percentage of the salinity load at LS 6 from PWCS 2 versus the gravity system tributary to LS 6.

5.1.4.2 *Methodology/Summary of Results*

The following data sources were used to calculate salinity loading values at LS 6 and PWCS 2.

1) Pump data for LS 6 and PWCS 2 was provided by NBK-Bremerton
2) Salinity data at the LS 6 wet well and at PWCS 2 was collected by WSP's team

Figure C4 presents a comparison of salinity loads at LS 6 and PWCS 2 during Phase 1. The average salinity load at LS 6 was determined to be 376 kg/day, approximately 2.0 percent of the average salinity load at LS 1. The average salinity load at PWCS 2 was also determined to be 376 kg/day. This indicates that the salinity loading at LS 6 comes from PWCS 2.

However, on a day-to-day basis during Phase 1, the salinity loading at PWCS 2 was either much higher or much lower than at LS 6. This can be the result of either inaccurate conductivity readings or flowrate values used in creating the charts. As shown on Appendix B Figure B11, it appears that the conductivity/salinity data started reading zero, potentially due to the probe being exposed to air during low flow periods.

During Phase 3, LS 6 had an average salinity loading of 302 kg/day, or roughly 1.4 percent of the total salinity loading at NBK-Bremerton. PWCS 2 conductivity data was extremely low and contradictory to what lab reports provided by NBK-Bremerton indicated. WSP used conductivity data provided by NBK-Bremerton staff to determine that there were roughly 327 kg/day of salinity from PWCS 2. This is slightly higher than what was observed at LS 6 (302 kg/day), likely due to error in flowrate or conductivity readings.

5.1.4.3 Conclusions

The conclusion was made that almost 100 percent of salinity loading at LS 6 comes from PWCS 2 during both Phase 1 and Phase 3. See Figure C4 in Appendix C for a comparison of the salinity loading at LS 6 compared to PWCS 2.

5.1.5 Comparison of LS 7 To PWCS 1

5.1.5.1 Purpose of Comparison

The purpose of this comparison is to determine what percentage of the salinity flowing through LS 7 comes from PWCS 1 versus the gravity system tributary to LS 7 based on the results of the first phase monitoring.

5.1.5.2 Methodology/Summary of Results

The following data sources were used to calculate salinity loading values at LS 7 and PWCS 1.

1) LS 7 pump data provided by NBK-Bremerton
2) LS 7 wet well salinity data collected by WSP's team
3) PWCS 1 pump data provided by NBK-Bremerton
4) PWCS 1 salinity data collected by WSP's team

Figure C5 presents a comparison of salinity loads at LS 7 and PWCS 1. The average salinity load at LS 7 was determined to be 297 kg/day, or roughly 1.6 percent of the average salinity load at LS 1. The average salinity load at PWCS 1 was determined to be 253 kg/day. Therefore approximately 44 kg/day of salinity enters LS 7 from the gravity system/other sources outside of PWCS 1.

5.1.5.3 Conclusions

Approximately 85 percent of salinity load at LS 7 comes from PWCS 1 and 15 percent of salinity load originates from the gravity system/other sources outside of PWCS 1.

5.1.6 Comparison of LS 8 To PWCS 3

5.1.6.1 Purpose of Comparison

The purpose of this comparison is to determine what percentage of the salinity flowing through LS 8 comes from PWCS 3 versus the gravity system tributary to LS 8 based on the results of the first phase of monitoring.

5.1.6.2 *Methodology/Summary of Results*

Meter 7 at LS 8 recorded inaccurate salinity/conductivity data. Despite this lack of reliable data at LS 8, steps could still be taken towards conclusions related to the salinity contributions at LS 8. As LS 8 has a very small upstream gravity system, and PWCS 3 has a relatively low salinity loading average of 65 kg/day, it can be assumed that LS 8 does not contribute greatly to the overall salinity loading at NBK-Bremerton. To confirm this assumption, WSP's field engineer took samples at MHs 8-4 and 8-1A (both are just upstream of LS 8) and confirmed that the gravity flows through these manholes have very low salinity.

5.1.6.3 *Conclusions*

LS 8 does not contribute significant amounts of salinity to the sewer system, as results of the instantaneous samples at MHs 8-4 and 8-1A and the continuous monitoring at PWCS 3 both show low salinity. Figure C6 presents a comparison of salinity load at LS 8 and PWCS 3.

5.1.7 Comparison of LS 1 to WB-3

5.1.7.1 *Purpose of Comparison*

The purpose of this comparison is to determine the flow volume and salinity that can be attributed to the areas of NBK-Bremerton that are downstream of LS 1 and upstream of WB-3 based on the results of Phases 1 and 3 of monitoring. Differences in results between the LS 1 and WB-3 conductivity meters can be attributed to certain areas tributary to LS 10, LS 11, LS 12, and LS 13.

5.1.7.2 *Methodology/Summary of Results*

The following data sources were used to calculate salinity loading values at LS 1 and WB-3.

1) Flowrate and conductivity values at WB-3 (that represent the portion of flows at WB-3 that come from NBK-Bremerton) were obtained from the City
2) LS 1 flow and conductivity data provided by NBK-Bremerton
3) Temperature values at WB-3 obtained from WSP's team

Figure C7 presents a comparison of salinity loads at LS 1 and WB-3 during Phase 1. The average salinity load from LS 1 was determined to be 18,975 kg/day. The average salinity load at WB-3 that can be attributed to NBK-Bremerton was determined to be 18,823 kg/day. Theoretically, the salinity loading at LS 1 should be less than or equal to the salinity loading at WB-3. However, the data shows that the salinity loading at LS 1 is roughly 0.8 percent higher than at WB-3. This discrepancy could be the result of inaccurate flowrate, conductivity, or temperature data at the WB-3 or LS 1 metering locations.

It should also be noted that LS 1 conductivity data was unavailable prior to 9 April 2020, so data between 10 April 2020 and 25 April 2020 was used for the LS 1 and WB-3 results discussed in this section.

During Phase 3, the average salinity loading at WB-3 during Phase 3 was 19,910 kg/day, and was 17,047 kg/day at LS 1. However, it should also be noted that the daily average flowrate at LS 1 was 631,000 gallons per day, while WB-3 was calculated at only 597,000 gallons per day. As mentioned above, the flowrate and salinity loading values at WB-3 should both be higher than at LS 1, as it is downstream of LS 1. The fact that WB-3 had a higher salinity loading and lower flowrate than LS indicates that the flowrate readings at WB-3 or LS 1 are inaccurate.

5.1.7.3 *Conclusions*

As the estimated salinity loading at LS 1 was higher than WB-3, it can be assumed that any salinity load that enters the system between LS 1 and WB-3, through LS 10, LS 11, LS 12, or LS 13, is negligible during Phase 1. This matches what NBK-Bremerton expected, as discussed during the kickoff meeting and other correspondences. Phase 3 results were less conclusive due to potentially inaccurate data at LS 1, but the salinity loading at WB-3 and LS 1 are still within 15 percent of each other.

5.1.8 Comparison of WWTP vs CE-4, WWTP vs CE-1, and WWTP vs WB-3

5.1.8.1 *Purpose of Comparison*

The purpose of this comparison is to understand the impacts that salinity loading at CE-4, CE-1, and WB-3 has on the salinity loading at the WWTP system headworks (influent). As discussed above, CE-1 and CE-4 represent sewer pump stations operated by the City. CE-4, CE-1, and WB-3 results were compared against the WWTP during Phase 1. During Phase 3, only CE-1 was monitored and compared against the WWTP.

5.1.8.2 *Methodology/Summary of Results*

The following data sources were used to calculate salinity loading values at WWTP, CE-4, CE-1, and WB-3.

1) Salinity values at CE-1, CE-4, and WWTP were provided by the WSP's team
2) Flowrates at CE-1, CE-4, and WWTP were provided by the City
3) Flowrate and conductivity values at WB-3 (that represent the portion of flows at WB-3 that come from NBK-Bremerton) were obtained from the City

Figure C8 compares salinity loading at the WWTP versus CE-4, CE-1, and WB-3 during Phase 1. Salinity loading at the WWTP fluctuated between 40,000 to 60,000 kg/day, with an average of roughly 47,000 kg/day. Average salinity loading for WB-3 and CE-1 were both roughly 20,000 kg/day; however, the salinity loading at the WWTP appears to correlate very closely with the salinity loading at WB-3, and not very closely, if at all, with CE-1. This could be due to the fact that WB-3 is much closer to the WWTP headworks than CE-1.

See Appendix A Meters 16 to 19 for a map of the tributary areas to the various City lift stations.

During Phase 1, CE-4 had a relatively low average salinity loading of roughly 600 kg/day and had no visible impacts on the salinity loading at the WWTP.

Figure C8 shows that the spikes in salinity loading at the WWTP correlate closely with the spikes at WB-3. WB-3 collects flow from NBK-Bremerton, as well as a small amount of flows from the City's system; however, the sensors at WB-3 only look at the portion of flow that comes from NBK-Bremerton. The average salinity loading at WB-3 was 17,979 kg/day between 24 March 2020 and 25 April 2020.

Figure C8.1 compares the daily average salinity loading at LS 1, the WWTP, and CE-1 during Phase 3 of monitoring. LS 1 and the WWTP appeared to share similar trends, but seem less correlated than what is shown on C8 for Phase 1.

CE-1 pump station collects flow from East Bremerton, through an inverted siphon under the Port Washington Narrows. The average salinity loading at CE-1 was 18,532 kg/day between 28 September and 25 October 2021, compared to the WWTP which had 68,338 kg/day during this period.

CE-4 pump station collects flow from the east side of NBK-Bremerton, which includes flows from LS 9 and a small gravity sewer system east of Building 460, as well as a small amount of flows from the City's system. The average salinity loading at CE-4 was 386 kg/day between 25 March 2020 and 24 April 2020. It should be noted that there are two pumps operating at CE-4. Pump 2 was broken. Because pumps 1 and 2 are alternating pumps, WSP assumed the total flowrate equals to pump 1 times two.

5.1.8.3 Conclusions

The salinity loading at NBK-Bremerton appeared to have a direct correlation to the salinity loading at the WWTP during Phase 1, when looking at daily average values. The correlation was less apparent during Phase 3. The correlation is less clear with CE-1 salinity loading during both Phase 1 and Phase 3, potentially because CE-1 is further away from the WWTP. During Phase 1, CE-4 had very low salinity loading values and had no apparent correlation to the salinity loading at the WWTP.

5.1.9 Comparison of OWTS to Overall Flows

5.1.9.1 Purpose of Comparison

The purpose of this comparison is to evaluate the contribution that each OWTS has to the overall salinity loading at NBK-Bremerton based on the results of the first and third phases of monitoring.

5.1.9.2 *Methodology/Summary of Results*

The following data sources were used to calculate salinity loading values at each OWTS.

1) OWTS discharge pump times, durations, and volumes provided by NBK-Bremerton
2) OWTS samples were provided by NBK-Bremerton, tested by WSP's field engineer to obtain salinity data for the first monitoring period, and tested by PSNS & IMF Code 134 Analytical Laboratory for the third monitoring period

During Phase 1, it was determined that OWTS 1, 2, and 4 had average daily salinity loading values of 6, 8, and 21 kg/day during the first phase of monitoring, respectively. This translates to 0.033 percent, 0.042 percent, and 0.110 percent (respectively) of the total salinity loading that passed through LS 1.

However, OWTS 6 had an average salinity loading of 573 kg/day, or 3.02 percent of the total salinity loading that passes through LS 1 during Phase 1. Figure C9 compares salinity loadings at OWTS 1, 2, 4, and 6 during the first phase of monitoring.

During the third phase of monitoring, it was determined that OWTS 1, 2, 3, 4, 5, and 6 had average salinity loading values of 27, 302, 108, 169, 0, and 1,516 kg/day, respectively. This translates to 0.13 percent, 1.40 percent, 0.50 percent, 0.78 percent, 0 percent, and 7.02 percent of the total salinity loading that passed through LS 1. For three days during Phase 3, OWTS 6 had salinity loading values greater than 3,000 kg/day. On 16 October 2021, OWTS 6 had 4,740 kg of salinity loading (22.8 percent of the total salinity loading from NBK-Bremerton on this day). A review of the OWTS discharge data provided by NBK-Bremerton staff indicates that all of the OWTS 6 discharge on this day occurred between 06:30 and 13:10.

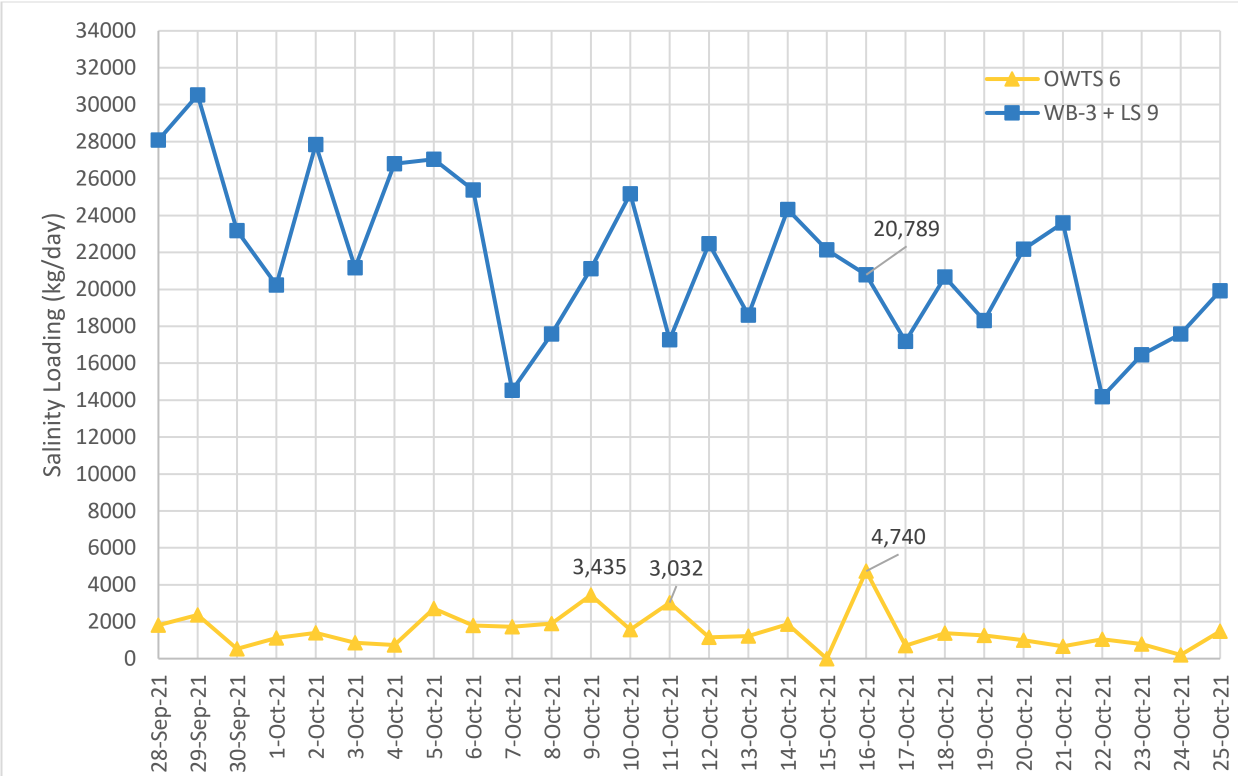

Figure 8. Salinity Loading at NBK-Bremerton and at OWTS 6 during Phase 3 of Monitoring

5.1.9.3 Conclusions

During Phase 1, each OWTS plant had a low contribution to the overall salinity loading discharged by NBK-Bremerton. OWTS 1, 2, 4, and 6 contributed roughly 0.033, 0.042, 0.110, and 3.02 percent, respectively, of the total salinity loading through LS 1 in Phase 1. It should be noted that the salinity loading at each OWTS appears to be lower than they have been historically. NBK-Bremerton staff indicated that the OWTS plants contributed an average of 23 percent of the salinity loading at LS 1, according to conductivity data collected in May 2019 and June 2019.

As discussed above, there were large variations in the salinity loading contribution from each OWTS between the two 28-day monitoring periods. It should be noted that this OWTS data is only representative of the 28-day monitoring periods and may fluctuate greatly due to changes in operations on site. See Section 7.5 for additional discussion on how the OWTS contribution to overall salinity may vary over time.

5.1.10 Comparison of MH 1-68, MH 1-25, MH 1-3, and MH 1-1 to LS 1

5.1.10.1 Purpose of Comparison

As previously discussed, LS 1 shows very high salinity loading, and results of Phase 1 of monitoring indicated that most of the salinity comes from the gravity system upstream and to the north of LS 1. MHs 1-68, 1-25, and 1-3 are all part of this upstream gravity system and were monitored during Phase 2. MH 1-3 and 1-1 were monitored during

Phase 3. By comparing the salinity loading through each of these manholes and at LS 1, source(s) of salinity in this upstream gravity system can be further pinpointed.

5.1.10.2 Methodology/Summary of Results

The following data sources were used to calculate salinity loading values at MHs 1-68, 1-25, 1-3, 1-1, and LS 1.

1) Conductivity, temperature, and flowrate values recorded by WSP's meters installed at MHs 1-68, 1-25, 1-3, and 1-1.
2) Conductivity and flowrate values recorded by NBK-Bremerton's meter at LS 1 during Phases 1 and 2.
3) Flowrate values recorded by NBK-Bremerton's meter, and conductivity and temperature data recorded by WSP's meters at LS 1 during Phase 3.

The results of the monitoring at these locations show that MH 1-3 conveys anywhere between ~250 and 2,000 kg/day of salinity, with an average of 1,018 kg/day during Phase 2. LS 1 conveyed roughly 18,975 kg/day, and roughly 65 percent of that (~12,560 kg/day) comes from the gravity system during Phase 1. That means that, based on Phases 1 and 2 of monitoring, of the 12,560 kg/day that flows through LS 1, an average of 11,560 kg/day enters the system between MH 1-3 and LS 1, isolating the suspected groundwater intrusion into the gravity system directly north of LS 1 for about 225 feet with most of this piping running under Building 997 and serving Building 1027. It is speculated that the ~250 to 2,000 kg/day of salinity entering MH 1-3 likely comes from groundwater intrusion into the sewer piping between MH 1-3 and MH 1-8, including the laterals that feed into that piping segment.

However, monitoring at MH 1-3 and 1-1 during Phase 3 indicated much lower salinity loading, with MH 1-1 and 1-3 contributing less than 2 percent of the total salinity loading at LS 1.

5.1.10.3 Conclusions

Based on the results of Phase 1 and Phase 2 of monitoring, most of the salinity loading into LS 1 comes from the segments of sewer pipe that are upstream of LS 1 and downstream of MH 1-3. This pipe runs under Building 997 and serves Building 1027. See Sections 7.1 and 8.1 for further discussion of this potential salinity source. This conclusion from Phase 1 was not the result of direct monitoring. During Phase 3 of monitoring, MH 1-1 and 1-3 only contributed less than 2 percent of the salinity loading at LS 1, indicating that the unexplained salinity loading at LS 1 may come from areas outside of the MH 1-1 tributary area. This suggests that infiltration may be occurring within the wet well of LS 1.

5.1.11 Comparison of LS 9 to MH 9-8 (Phase 1), and LS 9 to MH 9-1 and MH 9-5 (Phase 3)[6]

5.1.11.1 Purpose of Comparison

As was summarized in Table 5 above, LS 9 had relatively high salinity concentration and loading values during the first phase of monitoring, so MH 9-8 was selected as a follow-up monitoring location for Phase 2 to further pinpoint the sources of salinity into the gravity system upstream of LS 9. The purpose of this comparison between LS 9 and MH 9-8 is to see what portion of the salinity loading at LS 9 came from the areas upstream versus downstream of MH 9-8 based on results of the first and second phases of monitoring.

During Phase 3, additional monitoring was completed at MH 9-1 and 9-5 for comparison against LS 9 data that was provided by NBK-Bremerton staff.

5.1.11.2 Methodology/Summary of Results

As can be seen in Figure C11 in Appendix C, salinity loading at MH 9-8 for Phase 1 appears inaccurate. This is likely due to the meter being exposed due to low flows through the manhole, which interrupts conductivity readings. There are no reliable conductivity/salinity data at MH 9-8.

Figure 9 shows the daily average flowrates recorded at MH 9-8 and LS 9 during Phase 1. As can be seen, LS 9 flows are within the expected range, while MH 9-8 flows are above the expected range, and are above the flows at LS 9 even though MH 9-8 is upstream of LS 9.

Data from Phase 3 was able to provide more insight into the sources of salinity at LS 9. During the third phase of monitoring, MH 9-1 and 9-5 had 745 and 157 kg/day of salinity loading on average, or 3.4 and 0.7 percent of the salinity loading discharged from NBK-Bremerton, respectively. Salinity loading at LS 9 was calculated using conductivity and flowrate data provided by the Navy, and temperatures at MH 9-1 (no temperature data was available at LS 9, so it was assumed that the temperature at LS 9 was roughly equal to the temperature at MH 9-1). NBK-Bremerton staff indicated that the LS 9 conductivity data was unreliable prior to 13 October 2021, so calculations were only completed using conductivity data from 14 October to 25 October 2021. The salinity loading at LS 9 was calculated to be 1,614 kg/day on average, or roughly 7.7 percent of the average salinity loading discharged from NBK-Bremerton for Phase 3, and 8.1 percent of the average salinity loading discharged from NBK-Bremerton between 14 October and 25 October 2021 (19,777 kg/day).

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[6] Discussion comparing MH 9-1 and 9-5 to LS 9 has been added to Section 5.1.11 and subsections based on the results of Phase 3 of monitoring.

As can be seen further on Figure C12 in Appendix C, MH 9-5 had relatively low contributions to LS 9, while the contribution from MH 9-1 to LS 9 varied significantly on a day-to-day basis (for example, on 17 October MH 9-1 salinity loading was only 3 percent of that of LS 9, while on 21 October, MH 9-1 salinity loading was 88 percent of that of LS 9).

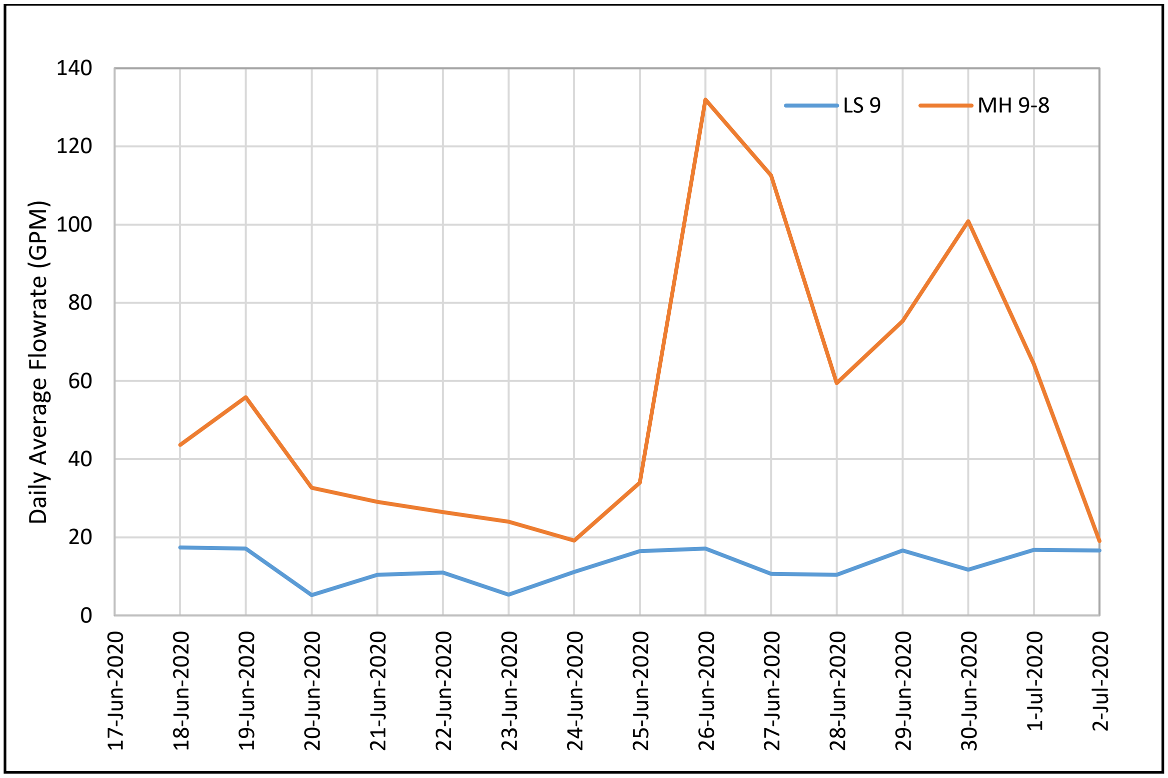

Figure 9. Flowrate Comparison of MH 9-8 to LS 9

5.1.11.3 Conclusions

The inaccurate data at MH 9-8 make it hard to pinpoint the source of salinity into LS 9 during the first and second phases of monitoring. However, the low flows observed in MH 9-8 indicate that a disproportionately high amount of flow enters the system downstream of MH 9-8.

During the third phase of monitoring, MH 9-1 had a salinity loading approximately 48 percent of that at LS 9 and LS 9 had a salinity loading approximately 8.4 percent of that NBK-Bremerton, on days with good LS 9 data. This indicates there are significant sources of salinity in the gravity system upstream of LS 9, with approximately half of the salinity coming from upstream of MH 9-1 and half coming from downstream of MH 9-1. The large salinity loading coming in downstream of MH 9-1 suggests intrusion at the wet well structure of LS 9. Groundwater infiltration was observed visually at MH 9-1 when the sensor was installed for Phase 3, and the pump-on and pump-off levels of the LS 9 wet well were lowered to ensure no wastewater backed up to MH 9-1 and 9-5. This likely increased the rate of groundwater intrusion into the wet well and surrounding pipes. Further discussion is provided in Section 7.2.

5.2 Salinity Concentration Observations[7]

Salinity concentration was measured in units of psu (practical salinity units). Psu is equivalent to parts per thousand (ppt), which refers to the ratio of solutes in the solution (salts in the water). One ppt is equal to 1,000 mg of salt per 1 liter (or 1 gr of salt per 1 liter) of water. Salinity concentration values were taken directly from the various meters installed at NBK-Bremerton. WSP obtained salinity concentration at each of the following locations during Phase 1: LS 1 to LS 9, PWCS 1 to 6, OWTS 1, 2, 4, and 6, Pier D, WWTP, CE-4, CE-1, WB-3, MH 1-68, MH 1-25, MH 1-3, and MH 9-8. During Phase 3, salinity concentrations were obtained at LS 1, 6, 7, and 9, PWCS 2, 5, and 6, OWTS 1 – 6, Pier B, WWTP, WB-3, MH 1-1, 1-3, 9-1, and 9-5. Comparisons have been made where one location is downstream of another location or downstream of multiple locations. Salinity concentration comparison figures are provided in Appendix D.

The following comparisons have been made.

1) Comparison of LS 1 to LS 2 through LS 9 for Phase 1; comparisons for Phase 3 only include LS 1, 6, 7, and 9
2) Comparison of LS 5 to PWCS 4
3) Comparison of LS 6 to PWCS 2 for Phase 1 and Phase 3
4) Comparison of LS 7 to PWCS 1 for Phase 1 and Phase 3
5) Comparison of LS 8 to PWCS 3
6) Comparison of LS 1 to WB-3 and Pier D (Phase 1)/Pier B (Phase 3)
7) Comparison of WWTP vs CE-4 and WWTP vs CE-1 for Phase 1, and WWTP vs WB-3 for Phase 1 and Phase 3
8) Comparison of OWTS for Phase 1 and Phase 3
9) Comparison of MH 1-68, MH 1-25, and MH 1-3 to LS 1 for Phase 1, and of MH 1-1 and 1-3 to LS 1 for Phase 3
10) Comparison of LS 9 to MH 9-8 for Phase 1, and LS 9 to MH 9-1 and 9-5 for Phase 3

[7] The following subsections have been revised heavily to include new monitoring and results: 5.2.1, 5.2.7, 5.2.8, 5.2.9, and 5.2.10. The remaining sections (5.2.2, 5.2.3, 5.2.4, 5.2.5, and 5.2.6) only received light revisions to specify monitoring phases.

5.2.1 Comparison of Lift Stations 1 through 9

5.2.1.1 Purpose of Comparison

This comparison was made so that the salinity concentrations attributed to each lift station can be compared against other lift stations. It should be noted that LS 2 through LS 8 discharge to LS 1.

5.2.1.2 Methodology/Summary of Results

The following data sources were used to compare salinity concentration values at LS 1 to LS 2 through LS 9.

1) LS 2 through LS 9 wet well salinity data collected by WSP's team

2) LS 1 conductivity data provided by NBK-Bremerton

For Phase 1, Figure D1 compares salinity concentration at LS 1 to LS 9. Figure D1 shows that salinity concentration at all lift stations fluctuated multiple times per day. Salinity at LS 1 spiked with highs between 15 to 22 ppt and lows between 5 to 10 ppt; at LS 2 with highs between 5 and 15 ppt, and lows between 2 and 5 ppt; at LS 3 with highs between 3 and 5 ppt, and lows between 0.25 and 1 ppt. Salinity at LS 4 was consistently between 0.2 and 1 ppt. Salinity at LS 5 was generally below 1 ppt.

During Phase 1, salinity at LS 6 fluctuated with highs between 3 and 7.5 ppt and lows between 0.5 and 2 ppt; at LS 7 with highs between 3 and 8 ppt, and lows between 0.5 and 3 ppt; at LS 9 with highs between 6 and 12 ppt, and lows between 2 and 5 ppt. Meter 7 at LS 8 did not measure accurate salinity data. Table 7 below summarizes this data. As is shown, the high range of salinity concentration fluctuations at LS 2 – 8 are all lower than at LS 1, indicating that sources of high salinity concentration into LS 1 must come from sources other than LS 2 – 8 (PWCS 5 and 6, OWTS 2, 4, and 6, and carrier discharge from Pier B and Pier D).

Table 7. Fluctuations in Salinity Concentrations at Lift Stations 1 to 9

Lift Station	Phase 1		Phase 3	
	Salinity Concentration, Range of Fluctuation Lows (ppt)	Salinity Concentration, Range of Fluctuation Highs (ppt)	Salinity Concentration, Range of Fluctuation Lows (ppt)	Salinity Concentration, Range of Fluctuation Highs (ppt)
LS 1	5 - 10	15 - 22	2 - 7	15 - 25
LS 2	2 - 5	5 - 15	-	-
LS 3	0.25 - 1	3 - 5	-	-
LS 4	0.2	1	-	-
LS 5	0	1	-	-
LS 6	0.5 - 2	3 - 7.5	0.5 – 2.5	7 - 13

Lift Station	Phase 1		Phase 3	
	Salinity Concentration, Range of Fluctuation Lows (ppt)	Salinity Concentration, Range of Fluctuation Highs (ppt)	Salinity Concentration, Range of Fluctuation Lows (ppt)	Salinity Concentration, Range of Fluctuation Highs (ppt)
LS 7	0.5 - 3	3 - 8	0.5 - 2	5 - 10
LS 8	NA	NA	-	-
LS 9	2 - 5	6 - 12	2 - 10	15 - 23

For Phase 3, Figure D1.1 compares salinity concentrations at LS 1, 6, 7, and 9. LS 1 fluctuated with highs between 15 and 25 ppt, and with lows between 2 and 7 ppt. LS 6 fluctuated with highs between 7 and 13 ppt, and lows between 0.5 and 2.5 ppt. LS 7 fluctuated with highs between 5 and 10 ppt, and lows between 0.5 and 2 ppt. LS 7 had two distinct spikes beyond 15 ppt on 13 October and 14 October 2022. LS 9 fluctuated with highs between 15 and 23 ppt, and lows between 2 and 10 ppt.

5.2.1.3 *Conclusions*

It was determined that salinity at LS 1, LS 2, LS 6, and LS 9 had higher salinity concentrations than other lift stations during Phase 1. Thus, three follow-up location at LS 1 and one follow-up location at LS 9 were recommended during Phase 2. LS 2 had very low flowrates, and thus further inspection was not prioritized. At LS 6, much of the high salinity concentration comes from PWCS 2, and so further inspection was not prioritized.

Of the lift stations monitoring during Phase 3, LS 1 and LS 7 had similar ranges of salinity concentrations. The high end of the salinity concentration fluctuations increased for LS 6 and LS 9 between Phase 1 and Phase 3.

5.2.2 Comparison of LS 5 to PWCS 4

5.2.2.1 *Purpose of Comparison*

The purpose of this comparison is to see how the PWCS 4 salinity concentration impacts the salinity concentration at LS 5 downstream based on the results of the first phase of monitoring.

5.2.2.2 *Methodology/Summary of Results*

The following data sources were used to calculate salinity loading values at LS 5 and PWCS 4.

1) LS 5 pump data provided by NBK-Bremerton
2) LS 5 wet well salinity data collected by WSP’s team
3) PWCS 4 pump data provided by NBK-Bremerton
4) PWCS 4 salinity data collected by WSP’s team

LS 5 wet well and PWCS 4 salinity data were collected by WSP's team during Phase 1 of monitoring. Salinity at LS 5 was generally below 1 ppt. Salinity spiked for 4 to 6 hours per day, usually reaching a maximum of 3.5 ppt.

Figure D2 in Appendix D compares the salinity concentration at LS 5 to PWCS 4. As can be seen, salinity concentration at PWCS 4 was generally below 1 ppt. Salinity reached to a maximum of 1.6 ppt on 7 April 2020. It was determined that salinity at LS 5 directly corelates to PWCS 4. Furthermore, it was concluded that LS 5 does not contribute greatly to salinity at NBK-Bremerton.

5.2.2.3 Conclusions

The spikes in salinity at LS 5 and PWCS 4 generally aligned, but there still appears to be other factors that impact salinity concentration at LS 5.

5.2.3 Comparison of LS 6 to PWCS 2

5.2.3.1 Purpose of Comparison

The purpose of this comparison is to see how the PWCS 2 salinity concentration impacts the salinity concentration at LS 6 downstream.

5.2.3.2 Methodology/Summary of Results

The following data sources were used to calculate salinity loading values at LS 6 and PWCS 2.

1) Pump data for LS 6 and PWCS 2 was provided by NBK-Bremerton
2) Salinity data at the LS 6 wet well and at PWCS 2 was collected by WSP's team

Salinity concentration data at the LS 6 wet well and at PWCS 2 were collected by WSP's team during Phase 1 and Phase 3 of monitoring. During Phase 1, salinity concentration at LS 6 fluctuated multiple times per day, with highs between 3 and 7.5 ppt and lows between 0.5 and 2 ppt. There were no distinguishable spikes in salinity concentration outside of the daily fluctuations. The monitoring device was placed into a manhole that PWCS 2 pumped to. This manhole may have received other flows recorded by the meter. NBK-Bremerton staff have indicated that flows from PWCS 2 should be relatively constant, as it mostly pumps out groundwater infiltration into DD 2.

During Phase 1, salinity at PWCS 2 fluctuated multiple times per day, with highs between 7 and 10.5 ppt and lows between 2 and 4 ppt. After 9 April 2020, it was noted that there are less salinity spikes per day at PWCS 2. However, salinity at LS 6 stayed the same.

During Phase 3, salinity concentration fluctuations at LS 6 were roughly the same as they were during Phase 1, but spiked to higher levels during Phase 3, sometimes reaching 13 ppt). PWCS 2 salinity fluctuated greatly with lows between 6 and 12 ppt, and highs of over 30 ppt during Phase 3.

Figure D3 compares salinity concentration at LS 6 to PWCS 2. It was determined that salinity at LS 6 correlated to PWCS 2 from 24 March to 9 April 2020. However, after 9 April 2020, spikes do not appear to PWCS 2 spikes or any other known factors, such as tides or time of day.

5.2.3.3 Conclusions

While PWCS 2 appears to impact the salinity concertation spikes at LS 6, there are likely other factors that also impact LS 6 salinity concertation. As LS 6 did not contribute to any spikes in salinity loading or salinity concentration discharged from NBK-Bremerton, no further investigation was prioritized.

5.2.4 Comparison of LS 7 to PWCS 1

5.2.4.1 Purpose of Comparison

The purpose of this comparison is to see how the PWCS 1 salinity concentration impacts the salinity concentration at LS 7 downstream based on the results of the first phase of monitoring.

5.2.4.2 Methodology/Summary of Results

The following data sources were used to calculate salinity loading values at LS 7 and PWCS 1.

1) LS 7 pump data provided by NBK-Bremerton
2) LS 7 wet well salinity data collected by WSP's team
3) PWCS 1 pump data provided by NBK-Bremerton
4) PWCS 1 salinity data collected by WSP's team

Salinity concentration data at the LS 7 wet well and at PWCS 1 were collected by WSP's team during Phase 1 of monitoring. Salinity concentrations at LS 7 fluctuate multiple times per day, with highs between 2 and 8 ppt, and lows between 0.5 and 3 ppt. There were no distinguishable spikes in salinity concentration outside of the daily fluctuations.

Salinity concentration at PWCS 1 fluctuated multiple times per day, with highs between 9 and 12 ppt, and lows between 3 and 6 ppt.

Figure D4 compares salinity concentration at LS 7 to PWCS 1. It was determined that LS 7 salinity concentration directly correlated to the PWCS 1 salinity.

5.2.4.3 Conclusions

PWCS 1 appears to significantly impact salinity concentration at LS 7.

5.2.5 Comparison of LS 8 to PWCS 3

5.2.5.1 *Purpose of Comparison*

The purpose of this comparison is to see how the PWCS 3 salinity concentration impacts the salinity concentration at LS 8 downstream based on the results of the first phase of monitoring.

5.2.5.2 *Methodology/Summary of Results*

Salinity concentration at the LS 8 wet well and at PWCS 3 were collected by WSP's team during Phase 1 of monitoring. Salinity concentration at LS 8 was not measured accurately (fluctuated between 0 to 2,500 ppt). Salinity at PWCS 3 was generally below 4 ppt. Salinity at PWCS 3 spiked from 2.2 to 15.91 ppt from 5 April through 13 April and went back to below 4 ppt after 14 April.

Figure D5 compares salinity concentration at LS 8 to PWCS 3.

5.2.5.3 *Conclusions*

As described in Section 5.1.6, it was determined that PWCS 3 and LS 8 do not contribute significant amounts of salinity to the sewer system.

5.2.6 Comparison of LS 1 to WB-3 and Pier D

5.2.6.1 *Purpose of Comparison*

The purpose of this comparison is to determine if the salinity concentration increases or decreases as the various lift stations and other flows enter the force main between LS 1 and WB-3 based on the results of the first phase of monitoring. Any differences in results between the LS 1 and WB-3 conductivity meters can be attributed to certain areas tributary to LS 10, LS 11, LS 12, and LS 13, which add to the site's shared force main downstream of LS 1 and upstream of WB-3. Comparing the salinity concentrations at LS 1 and Pier D can help determine the impact that Pier D flows had on LS 1.

5.2.6.2 *Methodology/Summary of Results*

The following data sources were used to compare salinity concentration values at WB-3 to LS 1.

1) Conductivity values at WB-3 (that represent the portion of flows at WB-3 that come from NBK-Bremerton) were obtained from the City
2) Temperature values at WB-3 were obtained from WSP's team
3) LS 1 conductivity data were provided by NBK-Bremerton
4) Pier D conductivity values were obtained from WSP's team
5) Pier D flowrate values were estimated in coordination with NBK-Bremerton

Figure D6 compares salinity concentration at LS 1 to WB-3. Salinity at LS 1 and WB-3 fluctuated multiple times per day. It was determined that salinity at LS 1 directly correlated with WB-3. It was noted that salinity low spikes at WB-3 started at 0.1 ppt but at LS 1 started at roughly 2.5 ppt. It means that downstream of LS 1 contribute low salinity concentrations to WB-3.

Figure D7 compares salinity at LS 1 to Pier D. It was determined that salinity at Pier D and LS 1 spiked with highs between 15 to 23 ppt and lows between 2.5 to 5 ppt. However, there was not any direct correlation between the salinity spikes at Pier D with LS 1.

5.2.6.3 *Conclusions*

As can be expected, the trends in salinity concentration at LS 1 and WB-3 match relatively closely, meaning that the various lift stations downstream of LS 1 have insignificant contributions to the salinity concentrations on the site.

As there were no correlation between salinity spikes at Pier D and LS 1, it can be assumed that the flows from Pier D are diluted significantly when they enter the shared force main before reaching LS 1. However, other observations provided by NBK-Bremerton staff indicate that carrier discharges in general significantly impact the average conductivity at LS 1. Refer to Section 5.5.1 for more information. The contribution of docked carriers is likely higher than what was captured during Phase 1 and Phase 3 of monitoring.

5.2.7 Comparison of WWTP vs CE-4, WWTP vs CE-1, and WWTP vs WB-3

5.2.7.1 *Purpose of Comparison*

The purpose of this comparison is to understand the impacts that salinity concentrations at CE-4, CE-1, and WB-3 have on the salinity concentration at the WWTP system headworks (influent). As discussed above, CE-1 and CE-4 represent sewer pump stations operated by the City.

5.2.7.2 *Methodology/Summary of Results*

The following data sources were used to compare salinity concentration values at WWTP, CE-4, CE-1, and WB-3.

1) Conductivity values at WB-3 (that represent the portion of flows at WB-3 that come from NBK-Bremerton) were obtained from the City for Phase 1 and Phase 3
2) Temperature values at WB-3 obtained from WSP’s team for Phase 1, and were assumed to be equal to LS 1 during Phase 3 as no temperature data was collected
3) CE-1, CE-4, and WWTP salinity data were provided by the WSP’s team during Phase 1. WWTP salinity data was also collected during Phase 3.

Figure D8 compares the salinity concentration at WWTP, CE-4, CE-1, and WB-3 during Phase 1. Salinity at all locations fluctuated multiple times per day. Salinity at WWTP spiked with highs between 5 to 7.5 ppt and lows between 0.5 to 3 ppt; at CE-4 with highs between 4 to 6 ppt and lows between 0.5 to 2 ppt; at CE-1 with highs between 6 to 9 ppt and lows between 0.5 to 3 ppt; and at WB-3 with highs between 10 to 25 ppt and lows between 0 to 5 ppt.

During Phase 3, the salinity concentration at the WWTP fluctuated with lows between 2 and 4 ppt, and highs between 6 and 8 ppt as shown on Figure B17.1. Figure B18.1 shows that the salinity fluctuated by about 2 ppt frequently, and the average salinity increased throughout the monitoring period. The salinity concentration never exceeded 6 ppt.

It was noted that salinity concentration at WB-3 is greatly higher than WWTP, CE-1, and CE-4 during Phase 1 and Phase 3.

5.2.7.3 Conclusions

The salinity concentration at the WWTP headworks was generally below 7.5 ppt, despite the higher concentrations observed at the WB-3 discharge from NBK-Bremerton. This is due to the dilution from the wastewaters from other lift stations in the City's system into the WWTP headworks.

5.2.8 Comparison of OWTS 1, 2, 4, and 6 Salinity Concentration

5.2.8.1 Purpose of Comparison

The purpose of this comparison is to evaluate the contribution that each OWTS has to the overall salinity concentration at NBK-Bremerton based on the results of the first and third phases of monitoring.

5.2.8.2 Methodology/Summary of Results

The following data sources were used to calculate salinity loading values at each OWTS.

1) OWTS discharge pump times, durations, and volumes provided by NBK-Bremerton
2) OWTS samples were provided by NBK-Bremerton, tested by WSP's field engineer to obtain salinity data for the first monitoring period, and tested by NBK-Bremerton staff for the third phase

OWTS samples were provided by NBK-Bremerton and tested by WSP's field engineer to obtain salinity data. Figure D9 compares OWTS salinity at OWTS 1, 2, 4, and 6. Salinity at OWTS 6 fluctuated between 5 to 6 ppt during the first phase of monitoring.

Salinity at OWTS 4 fluctuated between 1 to 4 ppt during the first phase of monitoring. Salinity at OWTS 1 was 4.2 ppt on 2 April and at OWTS 2 was 2.6 ppt on 15 April. It was determined that OWTS 6 had the highest salinity between all the OWTS, and that the OWTS did not contribute greatly to salinity at NBK-Bremerton during the first phase of monitoring.

During the third phase of monitoring, the salinity at OWTS 1 was consistently around 5 ppt. OWTS 2 had an average salinity of 14 ppt with a maximum of 23 ppt on

15 October 2021, and a minimum of 5 ppt on 25 October 2021. OWTS 3 had an average of 8 ppt, with values between 2 and 15 ppt.

During the third phase of monitoring, OWTS 4 had an average of 17 ppt, with higher values between 22 and 25 ppt occurring between 24 September and 6 October 2021. Per notes from NBK-Bremerton staff, salt water was used for dry dock cleaning at DD 2 due to shortage of backflow preventers related to having two carriers on base simultaneously. Normally, fresh water is used for this cleaning. This dry dock cleaning wastewater was collected by the OWTS plants.

OWTS 5 had no flows during the third monitoring period, and OWTS 6 had an average salinity of 14 ppt, with values consistently between 10 and 20 ppt.

As was discussed in 5.1.9 above, OWTS 1 to 5 all had minimal contribution to the overall salinity during the third phase of monitoring, while OWTS 6 had significant contributions, mainly resulting from the large volume of flow that OWTS 6 had during the third phase of monitoring.

5.2.8.3 *Conclusions*

It was determined that each OWTS has a low contribution to the overall salinity concentration discharged by NBK-Bremerton during the first phase of monitoring. During the third phase of monitoring, OWTS 6 had high flow volumes and moderately high salinity concentrations.

5.2.9 Comparison of MH 1-68, MH 1-25, and MH 1-3 to LS 1

5.2.9.1 *Purpose of Comparison*

As previously discussed, LS 1 has very high salinity loading, and Phase 1 results indicated that most of the salinity comes from the gravity system upstream and to the north of LS 1. MHs 1-68, 1-25, and 1-3 are all part of this upstream gravity system and were monitoring during Phase 2. By comparing the salinity concentration through each of these manholes and at LS 1, any source(s) of salinity in this upstream gravity system can be further pinpointed. Note that Phase 3 of monitoring included salinity loading calculations at additional manholes upstream of LS 1, and concluded that the gravity system upstream of LS 1 contributes less than 2 percent of the overall salinity loading at LS 1. Refer to Section 5.1.2 for more information.

5.2.9.2 *Methodology/Summary of Results*

The following data sources were used to calculate salinity concentration values at MH 1-68, 1-25, 1-3, and LS 1.

1) Conductivity and temperature values recorded by WSP's meters installed at MH 1-68, 1-25, and 1-3.
2) Conductivity values recorded by NBK-Bremerton's meter at LS 1.

MH 1-3 had salinity concentrations that were generally below 0.5 ppt, but spiked up to between 1 and 2.5 ppt every night at around midnight, consistently. MHs 1-25 and 1-68 had salinity concentrations that fluctuated on a daily basis, but stayed below 1 ppt.

5.2.9.3 Conclusions

All three follow-up locations had relatively low salinity concentrations that are much lower than at LS 1. Thus, it is expected that the salinity concentration into LS 1 increases somewhere upstream of LS 1 but downstream of MH 1-3, such as the area beneath Building 997 and the wet well structure of LS 1.

5.2.10 Comparison of LS 9 to MH 9-8, 9-1, and 9-5

5.2.10.1 Purpose of Comparison

As was summarized in Table 5 above, LS 9 had relatively high salinity concentration and loading values, so MH 9-8 was selected as a follow-up monitoring location to further pinpoint the sources of salinity into the gravity system upstream of LS 9. The purpose of this comparison is to see how salinity concentrations at MH 9-8 impact salinity concentrations at LS 9 downstream based on the results of the first phase of monitoring.

5.2.10.2 Methodology/Summary of Results

As discussed in Section 5.1.11 above, there conductivity/salinity data at MH 9-8 is inaccurate.

5.2.10.3 Conclusions

See Section 5.1.11 above for conclusions that can be made regarding LS 9 and MH 9-8.

5.3 Conductivity Observations [8]

Conductivity was measured in units of milli siemens per centimeter (mS/cm). Conductivity is a measurement of water's capability to pass electrical flow. This ability is related to the concentration of ions in water. Specific conductivity is a conductivity measurement made at 25 degrees Celsius.

Conductivity values were taken directly from the various meters installed at NBK-Bremerton. WSP obtained conductivity at each of the following locations: LS 1 to LS 9, PWCS 1 to 6, OWTS 1, 2, 4, and 6, Pier D, WWTP, CE-4, CE-1, WB-3, MH 1-68, MH 1-25, MH 1-3, and MH 9-8. Comparisons have been made where one location is downstream of another location or downstream of multiple locations. Conductivity comparison figures are provided in Appendix E.

[8] The following subsections have been revised heavily to include new monitoring and results: 5.3.1, 5.3.7, 5.3.8, 5.3.9, and 5.3.10. The remaining sections (5.3.2, 5.3.3, 5.3.4, 5.3.5, and 5.3.6) only received light revisions to specify monitoring phases.

The following comparisons have been made.

1) Comparison of LS 1 through 9
2) Comparison of LS 5 to PWCS 4
3) Comparison of LS 6 to PWCS 2
4) Comparison of LS 7 to PWCS 1
5) Comparison of LS 8 to PWCS 3
6) Comparison of LS 1 to WB-3 and Pier D
7) Comparison of WWTP to CE-4, WWTP to CE-1, WWTP to WB-3
8) Comparison of OWTS systems
9) Comparison of MH 1-68, MH 1-25, MH 1-3 to LS 1
10) Comparison of LS 9 to MH 9-8

5.3.1 Comparison of Lift Stations 1 through 9

5.3.1.1 Purpose of Comparison

This comparison was made so that the salinity loading attributed to each lift station can be compared against other lift stations during Phase 1 and Phase 3 of monitoring.

5.3.1.2 Methodology/Summary of Results

The following data sources were used to compare salinity concentration values at LS 1 to LS 9.

1) During Phase 1, LS 2 to LS 9 wet well conductivity data were collected by WSP's team
2) During Phase 1, LS 1 conductivity data were provided by NBK-Bremerton
3) LS 1 daily average conductivity data between February and September 2021, provided by NBK-Bremerton
4) During Phase 3, LS 1, 6, and 7 wet well conductivity data were collected by WSP's team, and LS 1 and 9 conductivity data was provided by NBK-Bremerton staff

Figure E1 compares conductivity at LS 1 to LS 9 during Phase 1. Figure E1 shows that conductivity at all lift stations fluctuated multiple times per day. Conductivity fluctuated at LS 1 with highs between 7 and 20 mS/cm, and lows between 2 and 5 mS/cm; at LS 2 between 2 and 20 mS/cm; at LS 3 between 1 and 7 mS/cm; at LS 4 between 0.2 and 1.5 mS/cm; at LS 5 between 0.5 and 5 mS/cm, at LS 6 with lows between 0.5 and 2 mS/cm and highs between 4 and 10 mS/cm; at LS 7 with lows between 1 and 4 mS/cm and highs between 4 at 10 mS/cm; and at LS 9 with lows between 3 and 7 mS/cm and highs between 10 and 15 mS/cm. Meter 7 at LS 8 did not measure accurate conductivity data.

Prior to Phase 3 of monitoring, NBK-Bremerton staff provided a summary of LS 1 daily average conductivity data for February 2021 through September 2021. During this time, two carriers arrived on site. Prior to the two carriers arriving, the average conductivity was 4.2 mS/cm. In early March 2021, CVN-68 arrived at Pier B and the average conductivity increased to 8.7 mS/cm. In late July 2021 CVN-71 arrived at Pier D and the conductivity increased further to 14.9 mS/cm.

Figure E1.1 compares conductivity at LS 1, 6, 7, and 9 during Phase 3. Similar to Phase 1, conductivity fluctuated multiple times per day. Conductivity ranges were generally the same as they were during Phase 1, but the high end of the conductivity fluctuations increased for LS 6 and 9 between Phase 1 and Phase 3.

5.3.1.3 Conclusions

It was determined that conductivity at LS 1, LS 2, LS 6, and LS 9 were higher than other lift stations. The gravity system upstream of LS 1 had an unexpectedly high salinity loading, and the previous 1998 study reported large amounts of infiltration into the sewer pipes upstream of LS 9. It was determined that LS 2 and LS 6 did not require follow-up locations, as LS 2 has such low flows that the overall salinity loading is negligible, and at LS 6 it was determined that a majority of the salinity loading comes from the upstream PWCS 2. Thus, three follow-up locations were recommended at LS 1 (MH 1-68, MH 1-25, and MH 1-3) and one follow-up location at LS 9 (MH 9-8).

The presence of CVN-68 and CVN-71 are correlated to significant increases in conductivity averages at LS 1.

For Phase 3, where conductivity was monitored at LS 1, 6, 7, and 9, the ranges were generally the same as they were during Phase 1, but the high end of the conductivity fluctuations increased for LS 6 and 9 between Phase 1 and Phase 3.

5.3.2 Comparison of LS 5 to PWCS 4

5.3.2.1 Purpose of Comparison

The purpose of this comparison is to see how PWCS 4 conductivity impacted the conductivity at LS 5 downstream during Phase 1.

5.3.2.2 Methodology/Summary of Results

LS 5 wet well and PWCS 4 conductivity data were collected by WSP's team. Conductivity at LS 5 fluctuated multiples times per day between 0.5 and 5 mS/cm. Conductivity spiked to approximately 9 mS/cm on 2 April at 21:10 for approximately 2 hours.

Conductivity at PWCS 4 fluctuated multiple times per day between 0.25 and 2.4 mS/cm. Conductivity spiked to 2.4 mS/cm on 8 April. Figure E2 compares conductivity at LS 5 to PWCS 4.

5.3.2.3 *Conclusions*

It was determined that LS 5 conductivity directly corelates to PWCS 4. Furthermore, it was concluded that LS 5 did not contribute greatly to salinity at NBK-Bremerton.

5.3.3 Comparison of LS 6 to PWCS 2

5.3.3.1 *Purpose of Comparison*

The purpose of this comparison was to see how PWCS 2 conductivity impacts the conductivity at LS 6 downstream.

5.3.3.2 *Methodology/Summary of Results*

LS 6 wet well and PWCS 2 conductivity data were collected by WSP's team during Phase 1 and Phase 3. During Phase 1, conductivity at LS 6 fluctuated multiple times per day with lows between 0.5 and 2 mS/cm and highs between 4 and 10 mS/cm. There were no distinguishable spikes in conductivity outside of the daily fluctuations.

During Phase 1, conductivity at PWCS 2 fluctuated multiple times per day with lows between 2 and 6 mS/cm and highs between 10 and 14.5 mS/cm. Figure E3 compares conductivity at LS 6 to PWCS 2. It was determined that conductivity at LS 6 correlated to PWCS 2 from 24 March to 9 April. However, after 9 April, conductivity do not appear to correlate to any external factors. It should be noted that other flows outside of PWCS 2 discharges may have impacted the PWCS 2 meter, as discussed further in Section 5.2.3.2 above.

During Phase 3, conductivity at LS 6 fluctuated with highs and lows similarly as Phase 1. PWCS 2 conductivity fluctuated with lows between 2.5 and 7 mS/cm and highs above 14,000 mS/cm.

5.3.3.3 *Conclusions*

During Phase 1, conductivity at LS 6 and PWCS 2 appears to be correlated prior to 9 April, but the correlation ends after 9 April. This indicates that there are other factors, within the gravity tributary system to LS 6, that impact conductivity.

5.3.4 Comparison of LS 7 to PWCS 1

5.3.4.1 *Purpose of Comparison*

The purpose of this comparison was to see how PWCS 1 conductivity impacts the conductivity at LS 7 downstream based on the results of the first phase of monitoring.

5.3.4.2 *Methodology/Summary of Results*

The following data sources were used to calculate salinity loading values at LS 7 and PWCS 1.

1) LS 7 pump data provided by NBK-Bremerton
2) LS 7 wet well salinity data collected by WSP's team

3) PWCS 1 pump data provided by NBK-Bremerton

4) PWCS 1 salinity data collected by WSP's team

LS 7 wet well and PWCS 1 conductivity data were collected by WSP's team. Conductivity at LS 7 fluctuated multiple times per day with lows between 0.5 and 2 mS/cm and highs between 4 and 10 mS/cm. There were no distinguishable spikes in conductivity outside of the daily fluctuations.

Conductivity at PWCS 1 fluctuated multiple times per day with lows between 2 and 6 mS/cm and highs between 10 and 14.5 mS/cm.

Figure E4 compares conductivity at LS 7 to PWCS 1. It was determined that conductivity at LS 7 directly correlated with PWCS 1. In addition, it was concluded that LS 7 does not impact greatly to salinity at NBK-Bremerton.

5.3.4.3 *Conclusions*

Conductivity at PWCS 1 appears to directly correlate to LS 7, indicating that there may not be a large contribution to conductivity from the gravity system upstream of LS 7.

5.3.5 Comparison of LS 8 to PWCS 3

5.3.5.1 *Purpose of Comparison*

The purpose of this comparison was to see how PWCS 3 conductivity impacts the conductivity at LS 8 downstream based on the results of the first phase of monitoring.

5.3.5.2 *Methodology/Summary of Results*

LS 8 wet well and PWCS 3 conductivity data were collected by WSP's team. Conductivity at LS 8 was not measured accurately (fluctuated multiple times per day from 2 to 13,617 mS/cm). Conductivity at PWCS 3 fluctuated multiple times per day with highs between 1.5 to 17 mS/cm and lows between 0.5 to 10 mS/cm.

Figure E5 compares conductivity at LS 8 to PWCS 3. PWCS 3 did not have high conductivity during the four-week period of sampling. Therefore, it was determined that LS 8 does not contribute greatly to the salinity at NBK-Bremerton.

5.3.5.3 *Conclusions*

As described in Section 5.1.6, it was determined that PWCS 3 and LS 8 do not contribute significant amounts of salinity to the sewer system.

5.3.6 Comparison of LS 1 to WB-3 and Pier D

5.3.6.1 *Purpose of Comparison*

The purpose of this comparison is to compare differences in results between the LS 1 and WB-3 conductivity meters during the first phase of monitoring, which can be attributed to certain areas tributary to LS 10, LS 11, LS 12, and LS 13. Comparing the conductivity at LS 1 and Pier D can help determine the impact that Pier D flows had on LS 1.

5.3.6.2 *Methodology/Summary of Results*

The following data sources were used to compare conductivity values at LS 1 to WB-3.

1) Conductivity values at WB-3 (that represent the portion of flows at WB-3 that come from NBK-Bremerton) were obtained from the City
2) Temperature values at WB-3 were obtained from WSP's team
3) LS 1 conductivity data were provided by NBK-Bremerton

Figure E6 compares conductivity at LS 1 to WB-3. Conductivity at LS 1 and WB-3 fluctuated multiple times per day. It was determined that conductivity at LS 1 directly correlated with WB-3. It was also noted that low conductivity values at WB-3 started at 0.1 mS/cm while at LS 1 started at 2.5 mS/cm. This is likely due to periods of no flow or low flow at WB-3 causing the conductivity meter to show extremely low conductivity due to the probe being exposed. During times when WB-3 was pumping, the conductivity closely matched the conductivity at LS 1. It is extremely unlikely that the WB-3 tributary areas downstream of LS 1 were able to significantly increase or decrease the conductivity at WB-3.

Figure E7 also compares conductivity at LS 1 to Pier D. It was determined that conductivity at both Pier D and LS 1 spiked with highs between 20 to 25 mS/cm and lows between 5 and 10 mS/cm. However, there was not any direct correlation between the conductivity spikes at Pier D with LS 1.

5.3.6.3 *Conclusions*

As can be expected, the trends in salinity concentration at LS 1 and WB-3 match relatively closely, meaning that the various lift stations downstream of LS 1 (LS 11, 12, and 13) have insignificant contributions to the salinity concentrations on the site.

As there were no correlation between salinity spikes at Pier D and LS 1, it can be assumed that the flows from Pier D are diluted significantly when they enter the shared force main before reaching LS 1. However, other observations provided by NBK-Bremerton staff indicate that carrier discharges in general significantly impact the average conductivity at LS 1. Refer to Section 5.5.1 for more information. The contribution of docked carriers is likely higher than what was captured during Phase 1 and Phase 3 of monitoring.

5.3.7 Comparison of WWTP vs CE-4, WWTP vs CE-1, and WWTP vs WB-3

5.3.7.1 *Purpose of Comparison*

The purpose of this comparison is to understand the impacts that conductivity at CE-4, CE-1, and WB-3 has on the conductivity at the WWTP system headworks (influent). As discussed above, CE-1 and CE-4 represent sewer pump stations operated by the City.

5.3.7.2 *Methodology/Summary of Results*

The following data sources were used to compare conductivity values at WWTP, CE-4, CE-1, and WB-3.

1) Conductivity values at WB-3 (that represent the portion of flows at WB-3 that come from NBK-Bremerton) were obtained from the City
2) Temperature values at WB-3 were obtained from WSP's team
3) CE-1, CE-4, and WWTP conductivity data were provided by the WSP's team

Figure E8 compares conductivity at WWTP, CE-4, CE-1, and WB-3. Conductivity fluctuated multiple times per day at all locations. Conductivity at WWTP fluctuated with highs between 8.5 to 12 mS/cm and lows between 1 to 4 mS/cm; at CE-4 with highs between 6 to 8 mS/cm and lows between 0.5 to 2 mS/cm; at CE-1 with highs between 6 to 8 mS/cm and lows between 1 to 3 mS/cm; and at WB-3 with highs between 20 to 25 mS/cm and lows between 0.2 to 5 mS/cm.

During Phase 3, the conductivity at the WWTP fluctuated with lows between 4 and mS/cm, and highs between 12 and 16 mS/cm as shown on Figure B17.1. Figure B18.1 shows that the conductivity fluctuated by about 4 mS/cm frequently, and the average conductivity increased throughout the monitoring period.

5.3.7.3 *Conclusions*

It was noted that conductivity at WB-3 is much greater than WWTP, CE-1, and CE-4. Thus, WB-3 contributes to salinity at WWTP more than CE-1 and CE-4 on a gallon by gallon basis. This also indicates that flows from WB-3 are diluted significantly before reaching the WWTP headworks. The daily flow volume from WB-3 is roughly 10 percent of what received by the WWTP.

5.3.8 Comparison of OWTS Plants

5.3.8.1 *Purpose of Comparison*

The purpose of this comparison is to evaluate the contribution that each OWTS has to the overall conductivity at NBK-Bremerton based on the results of the first and third phases of monitoring.

5.3.8.2 *Methodology/Summary of Results*

The following data sources were used to calculate salinity loading values at each OWTS.

1) OWTS discharge pump times, durations, and volumes provided by NBK-Bremerton
2) OWTS samples were provided by NBK-Bremerton, and tested by WSP's field engineer to obtain salinity data for the first monitoring period, and tested by NBK-Bremerton staff for the third phase

OWTS samples were provided by NBK-Bremerton and tested by WSP's field engineer to obtain conductivity data. Figure E9 compares OWTS conductivity at OWTS 1, 2, 4, and 6 during the first phase of monitoring.

During the first phase of monitoring, OWTS 6 conductivity fluctuated between 8 to 10 mS/cm. Conductivity at OWTS 4 fluctuated between 1.8 and 6.5 mS/cm. Conductivity at OWTS 1 was 6.92 mS/cm on 2 April and at OWTS 2 was 4.5 mS/cm on 15 April. It was determined that OWTS 6 has the highest conductivity between all other OWTS plants.

During the third phase of monitoring, the average conductivity was 8.8 mS/cm at OWTS 1, 25 mS/cm at OWTS 2, 13 mS/cm at OWTS 3, 27 mS/cm at OWTS 4, and 23 mS/cm at OWTS 6.

5.3.8.3 *Conclusions*

During the first phase of monitoring, each OWTS had a low contribution to the overall conductivity at NBK-Bremerton. During the third phase of monitoring, OWTS 6 had a larger contribution to the overall conductivity at NBK-Bremerton due to its large flow volumes and moderately high conductivity values.

5.3.9 Comparison of MH 1-68, MH 1-25, and MH 1-3 to LS 1

5.3.9.1 *Purpose of Comparison*

As previously discussed, LS 1 has very high salinity loading, and it is estimated that most of the salinity comes from the gravity system upstream and to the north of LS 1 based on indirect results of Phase 1 of monitoring. MHs 1-68, 1-25, and 1-3 are all part of this upstream gravity system and were selected for monitoring during Phase 2. By comparing the conductivity through each of these manholes and at LS 1, any source(s) of high conductivity in this upstream gravity system can be further pinpointed.

5.3.9.2 *Methodology/Summary of Results*

The following data sources were used to obtain conductivity values at MHs 1-68, 1-25, 1-3, and LS 1.

1) Conductivity values recorded by WSP's meters installed at MHs 1-68, 1-25, and 1-3.
2) Conductivity values recorded by NBK-Bremerton's meter at LS 1

MH 1-3 had salinity concentrations that were generally low, but spiked up every night at around midnight, consistently. Even during these spikes, conductivity was generally low. MHs 1-25 and 1-68 conductivity fluctuated on a daily basis, but stayed low.

5.3.9.3 *Conclusions*

All three follow-up locations had relatively low conductivity values, that are much lower than at LS 1. Thus, it is expected that the salinity concentration into LS 1 increases somewhere upstream of LS 1 but downstream of MH 1-3, such as the area beneath Building 997 and the wet well structure of LS 1.

5.3.10 Comparison of LS 9 to MH 9-8, 9-1, and 9-5

5.3.10.1 Purpose of Comparison

As was summarized in Table 5 above, LS 9 had relatively high salinity concentration and loading values, so MH 9-8 was selected as a follow-up monitoring location to further pinpoint the sources of salinity into the gravity system upstream of LS 9. The purpose of this comparison was to see how salinity concentrations at MH 9-8 impact salinity concentrations at LS 9 downstream based on the results of the first phase of monitoring.

5.3.10.2 Methodology/Summary of Results

As discussed in Section 5.1.11 above, the conductivity/salinity data at MH 9-8 is inaccurate.

5.3.10.3 Conclusions

See Section 5.1.11 above for conclusions that can be made regarding LS 9 and MH 9-8.

5.4 Other Observations[9]

5.4.1 Groundwater Salinity and Intrusion Observations

In order to establish an average salinity level of the groundwater at NBK-Bremerton, WSP's team performed instantaneous sampling at DD 4 and DD 6 throughout the first phase of monitoring. Additional samples were collected on 11 September 2020 at DDs 4 and 5. Samples were collected at the groundwater relief wells in the side tunnels of DDs 4, 5, and 6. Figure F1 in Appendix F shows the pH, conductivity, temperature, chlorides, and calculated salinity for each sample taken. The average salinity was 5.54 ppt (or approximately 9.6 mS/cm at 25 degrees Celsius) for DD 4 samples, 19.03 ppt (or approximately 30.0 mS/cm at 25 degrees Celsius) for DD 5, and 6.42 ppt (or approximately 11 mS/cm at 25 degrees Celsius) for DD 6 samples. The average across all DDs was 10.33 ppt (or approximately 16.9 mS/cm at 25 degrees Celsius).

NBK-Bremerton provided WSP with estimated values for daily groundwater intrusion into each DD during Phases 1 and 3 of monitoring. These values were estimated from PWCS daily flows on days with no rain. It should be noted that, even on days with no rain, there are still small miscellaneous flows to the DD floors from any vessels in a DD. In most DDs, there is a small amount leakage at the caisson seat seals in the first few days after a new seal. The caissons leak in all the drydocks, but DD 4 and DD 6 appear to drain the leakage to the side tunnels and back to the bay through the drainage pumps. Any caisson leakage and miscellaneous flows are insignificant in comparison to groundwater intrusion into the dry docks.

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[9] In Section 5.4, the only subsection that received revisions was Section 5.4.2. Other subsections only discuss items related to the results of the first two phases of monitoring.

Estimated salinity loading due to groundwater intrusion to each DD was calculated by combining average groundwater salinity and estimated groundwater intrusion values. For DDs 4, 5, and 6, the average salinity concentration at each DD was used, and for DDs 1, 2, and 3, the average salinity concentration was used. Table 8 below summarizes these calculations. For Phase 3, a conservative estimate, provided by NBK-Bremerton staff, was used to calculate salinity loading.

Table 8. Estimated Salinity Loading due to Groundwater Intrusion into Dry Docks

Dry Dock	Estimated Groundwater Intrusion (GPD)	Average Salinity (ppt, g/L)	Salinity Loading (kg/day)	% of Total WB-3 Salinity Loading (~17,979 kg/day for Phase 1, 19,910 kg/day for Phase 2)
Phase 1				
1	6,000	10.33	233	1.29%
2	24,000	10.33	934	5.19%
3	2,000	10.33	78	0.43%
4	2,000	5.54	42	0.23%
5	17,000	19.03	1,219	6.78%
6	90,000	6.42	2,183	12.14%
Phase 3 (with conservative salinity estimate)				
1	1,000	16	60	0.30%
2	11,000	16	664	3.33%
3	2,000	16	121	0.61%
4	2,000	16	121	0.61%
5	20,000	16	1208	6.16%
6	0	16	0	0.00%

As can be seen, DD 6 had the highest salinity loading during Phase 1 due to groundwater intrusion, with 2,183 kg/day or 12 percent of the total salinity loading from WB-3. Intrusion at DD 2 and DD 5 contribute roughly 4.3 percent and 4.4 percent, respectively, of the overall NBK-Bremerton salinity loading. Intrusion at DD 1, DD 3, and DD 4 all contribute less than 2 percent of the overall NBK-Bremerton salinity loading. It should be noted that DD 4 has recently (2015) had groundwater relief wells installed, which could help explain its low intrusion and salinity loading values. This recent project is described further in Section 7.3 below.

During Phase 3, DD 2 and DD 5 contributed roughly 3.3 and 6.1 percent, respectively, of the salinity loading at WB-3. Flows from the rest of the dry docks was negligible.

It should be noted that the calculated estimated groundwater intrusion in Table 8 above are generally higher than the recorded flowrate associated with each DD PWCS during the monitoring period.

5.4.2 Impacts of Rainfall on Sewer Flowrates and Salinity[10]

In order to estimate the impacts that rainfall has on NBK-Bremerton's sewer flowrates, and salinity loadings, WSP has compared the overall flowrate and salinity loading at LS 1 to the rainfall recorded during the monitoring periods.

According to data provided by NBK-Bremerton, from NOAA weather station F0240 in Bremerton, there was 0.77 inch of rainfall on 30 March 2020, 0.68 inch of rainfall on 22 April, and 0.43 inch of rainfall on 23 April during the first phase of monitoring. Additionally, WSP acquired rainfall data from the same weather station for the third phase of monitoring, which indicated 0.33 inch of rainfall on 28 September 2021, 0.41 inch of rainfall on 30 September and also on 1 October, 0.33 inch of rainfall on 11 October, 0.58 inch of rainfall on 22 October, 0.33 inch of rainfall on 24 October, and 0.36 inch of rainfall on 25 October. Table 9 below summarizes these rainfall days and compares the sewer volume pumped and salinity loading on these days to average values associated with that monitoring period.

Table 9. Impacts of Rainfall on Sewer Flowrates and Salinity

Date	Rainfall Depth	LS 1 Pumped Volume (gallons/day)	LS 1 Average Pumped Volume	LS 1 Salinity Loading (kg/day)	LS 1 Salinity Average Salinity Loading
Monitoring Phase 1 (March 26 – April 25 2020)					
March 30	0.77"	856,000	592,000	NA*	NA*
April 22	0.68"	1,025,000	592,000	26,703**	18,975**
April 23	0.43"	825,000	592,000	23,318**	18,975**
Monitoring Phase 3 (28 September – 25 October 2021)					
28 September	0.33"	728,371	631,028	27,420	17,047
30 September	0.41"	841,117	631,028	23,626	17,047
1 October	0.41"	635,580	631,028	20,425	17,047
11 October	0.33"	670,474	631,028	16,677	17,047
22 October	0.58"	841,536	631,028	7,839	17,047
24 October	0.33"	782,102	631,028	9,450	17,047
25 October	0.36"	867,760	631,028	9,772	17,047

*As the conductivity data at NBK-Bremerton's LS 1 meter was inaccurate on March 30, salinity loading could not be calculated.

** While the salinity loading at LS 1 on April 22 and 23 is higher than average, it should be noted that the salinity loading increased to the range of 25,000 kg/day on April 21, one day prior to the rainfall event. This indicates that rainfall was not the cause of the above average salinity loading on April 22 and 23.

5.4.2.1 Conclusions

During the rainy days that occurred within the monitoring periods, total flow volume discharged from NBK-Bremerton increased to anywhere between 223,000 and 443,000 gallons greater than the average of 592,000 gpd during Phase 1, and fluctuated from anywhere between 64,000 gallons less than and 167,000 gallons greater than the average of 699,854 gpd during Phase 3. However, rainfall did not have a significant

[10] This section was revised heavily to include additional analysis made during Phase 3 of monitoring.

impact on salinity loading, which would be expected as rainfall would dilute the sewage, reducing the salinity concentration.

5.4.3 Impacts of Tides on Sewer Flowrates and Salinity

As tidal activity can impact groundwater levels in areas near the shoreline, there is a potential for the tides to have an impact on sewer flowrates, sewer salinity concentrations, and salinity loadings. If the tides impact groundwater elevations and pressure throughout the site, then it would be expected that tides would also impact flowrates and salinity, as infiltration of groundwater into the NBK-Bremerton sewer collection system may be occurring in some places.

In order to evaluate the impact that tides have on salinity levels within the system, WSP compared tidal data from NOAA's Seattle tidal station to flowrate and salinity concentration data from various meters. While there were fluctuations in flowrate and salinity concentrations in all of the meter data, WSP never observed a clear correlation to the tidal fluctuations at NBK-Bremerton meter locations. This indicates that the tides do not have a significant impact on salinity within the sewer system.

5.4.3.1 Conclusions

As there was no clear correlation between the tide and salinity/flowrate values at the various meter locations within NBK-Bremerton, WSP concludes that the tides do not have a significant impact on salinity within the sewer system.

5.4.4 Historic Data Observations

Figure F2 in Appendix F presents historic flowrates at LS 1 through LS 9 from 2010 to 2019. As can be seen, the average flowrate from the highest to lowest are LS 1, LS 5, LS 6, LS 7, LS 8, LS 4, LS 9, LS 3, and LS 2. Flowrate at LS 1 declined after 2015. Flows at LS 1 declined from 275 million gallons per year (mgy) in 2014 to 200 mgy in 2016. LS 5 has the highest average daily flowrate during the last 10 years after LS 1. The average flowrate at LS 5 is around 35 mgy from 2010 to 2019. Flowrate at all other lift stations are below 35 mgy.

NBK-Bremerton has made water conservation efforts over the last 10 years. These efforts may have increased the salinity concentration in effluent, as reductions of potable water usage would increase the concentration of salinity in the sewage. For example, if a building is converted to low flow toilets, these toilets will introduce less fresh water to the sewer system without reducing salinity into the system, thus increasing the salinity concentrations. In order to best analyze this, LS 1 historic data has been used as an estimator for total sewer discharge from the site. Figure 10 shows the annual average flowrate of LS 1 between 2010 and 2019, in million gallons per year, as well as the sum of flowrates from LS 2 to LS 8. The average trend is a reduction of approximately 7.3 mgy at LS 1, or roughly 3 percent of the 2010 to 2019 average flowrate of 236 mgy. Without historic conductivity/salinity data at the WWTP headworks, no clear conclusions can be made regarding the impacts that recent water conservation efforts may have made on the salinity levels in the City's sewer system. NBK-Bremerton has indicated that the average annual conductivity at WB-3 has remained relatively constant over the years (the average conductivity at WB-3 was 8.6 mS/cm from August 1996 to March 1997, per Table 1-8 of the City of Bremerton Water Reuse Feasibility Study of September 1998, and was 8.9 mS/cm in November 2021). This indicates that water conservation efforts have not significantly impacted the salinity levels in NBK-Bremerton's sewer system.

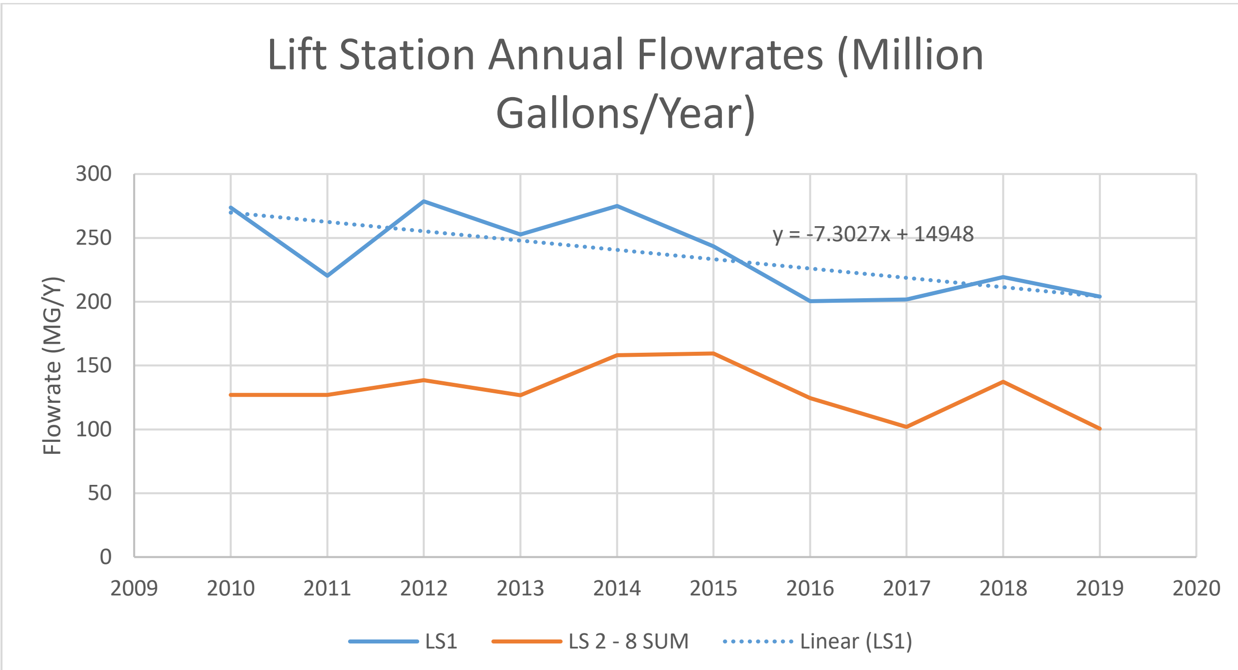


Figure 10. LS 1 Annual Average Flowrates between 2010 and 2019

5.4.5 City Sewer System Data Analysis

The average conductivity at each of the City locations during Phase 1 is as follows: 3.8 mS/cm at the WWTP headworks, 2.1 mS/cm at CE-4, 5.7 mS/cm at CE-1, and 7.4 mS/cm at WB-3. It should be noted that, while the average conductivity at WB-3 is only 7.4 mS/cm, the salinity loading is much higher due to periods of higher conductivity pairing with periods of higher flowrate. Compared to the City's ordinance limit of 6.0 mS/cm average for any 30-day period, WB-3 exceeds that limit, CE-1 (from East Bremerton) is close to that limit, and CE-4 and the WWTP headworks are well below the limit. It should be noted that, while the conductivity at WB-3 is higher than at CE-1, the salinity loading is roughly 20,000 kg/day for both locations, as discussed in Section 5.1.8.2.

5.5 Site Conditions that Impact Salinity Levels

It should be noted that most of the results in this report are taken from data obtained during the four-week monitoring periods in March and April 2020 and September and October 2021, and that the results may differ significantly outside of these monitoring periods depending on site conditions.

5.5.1 Presence of Docked Vessels

An aircraft carrier was docked at Pier D west during Phase 1, and at Pier B during Phase 3. Both had a significant impact on the flowrate and salinity of wastewater being discharged from NBK-Bremerton.

On 8 September 2020, NBK-Bremerton provided LS 1 data from 9 April to 17 May 2020 to better understand the impact that the docked aircraft carrier had on the discharge from the site. Between 9 April and 24 April, while the carrier was docked, the average conductivity was 10.7 mS/cm, and the average flowrate was 586,907 gpd. Between 28 April and 17 May, after the carrier had departed from Pier D, the average conductivity was 6.6 mS/cm, and the average flowrate was 394,675 gpd. Under the assumption that the aircraft carrier was the only change in site conditions, this indicates that the carrier contributed roughly 192,000 gpd and increased the conductivity by 62 percent at LS 1.

This generally matches additional data provided by NBK-Bremerton for the month of August 2020, which shows that the average conductivity at LS 1 dropped from 9.3 mS/cm (between 1 August and 21 August) to 7.1 mS/cm (between 24 August and 29 August), and the flowrate dropped from 394,606 to 282,017 gpd, once the carrier left.

Additional data from NBK-Bremerton staff indicates that conductivity levels at LS 1 roughly doubled in March 2021 when a carrier arrived, and increased by a similar amount again in July 2021 when another carrier arrived to NBK-Bremerton.

Docked vessels also increase the amount of high salinity water that is introduced to the sewer systems via the OWTS. While the OWTS had low salinity contributions during the Phase 1 and Phase 3, NBK-Bremerton staff have provided the following data related to OWTS.

1) During 2019, sampling done indicated that OWTS contribution to the overall salinity load ranged from 16 to 27 percent.
2) During 2019, sampling done indicated that OWTS 1 conductivity ranged from 6.9 to 27.2 mS/cm, OWTS 2 conductivity ranged from 15.4 to 30.8 mS/cm, OWTS 4 conductivity ranged from 8.5 to 18.9 mS/cm, and OWTS 6 conductivity ranged from 12 to 21.1 mS/cm. These values differ from what was recorded during both Phase 1 and Phase 3 of monitoring (refer to Section 5.3.8.2 for the OWTS conductivity during the two phases).

5.5.2 Variations in Groundwater Intrusion

Salinity contribution from DD groundwater intrusion into the PWCS may have been lower during the Phase 1 28-day monitoring period than it is on average. Data provided by NBK-Bremerton on 25 October 2020 indicates that:

1) DD 5 PWCS conductivity ranged from 21.6 to 36.7 mS/cm over 10 days in 2019,
2) DD 6 PWCS conductivity ranged from 22.3 to 27.5 mS/cm over 11 days in 2019,
3) DD 1 PWCS conductivity was 27 and 31 mS/cm over two days in 2019, and
4) DD 2 PWCS conductivity was 19 and 24 mS/cm over two days in 2019.

NBK-Bremerton used this data to estimate that the combined PWCS contribution to overall salinity loading was an average of 46 percent and maximum of 65 percent. These values are much higher than what was observed during Phase 1 (Section 5.4.1 estimates roughly 23 percent of salinity loading is due to groundwater intrusion to DD 1 through DD 6).

6.0 BOD EVALUATIONS AND SALINITY LOADINGS AT WWTP[11]

The City has reported two exceedances in 2015 above their BOD effluent limit at their WWTP. The City believes the high salinity in the influent is a potential cause for these BOD exceedances. Section 6.1 presents the history of BOD exceedances at the WWTP. Section 6.2 presents the efforts made by WSP to correlate BOD and CBOD levels at the WWTP to salinity levels from NBK-Bremerton. Section 6.3 presents efforts made by WSP to establish a maximum salinity level in the wastewater influent to allow the City to meet its previous BOD discharge limits.

6.1 History of BOD and CBOD Compliance at the City of Bremerton's WWTP

Per Table 10, three exceedances were recorded at the effluent in the past 10 years. There have been no reported exceedances since 1 April 2015, though it should be noted that the most recent permit (effective 1 December 2018) does not have a BOD effluent limit, so BOD effluent has not likely been recorded or reported. The City's current permit has had the BOD limit changed to an equivalent CBOD limit as allowed per regulations. It should be noted that Item No. 3 in Table 10 is a loading exceedance that was likely due to a rain event, and not a BOD concentration exceedance.

Table 10. Summary of BOD Violations*

No.	Violation	Violation Date	Parameter	Units	Monitoring Point Code	DMR Value	Limit Max
1	Numeric effluent exceedance	4/1/2015	BOD5	Mg/L	1	33	30
2	Numeric effluent exceedance	3/1/2015	BOD5	Mg/L	1	78	45
3	Numeric effluent exceedance	11/1/2011	BOD5	Lbs/Day	1	5,368	3,790

* The most recent permit (effective 1 December 2018) does not have a BOD effluent limit, so BOD effluent has not likely been recorded or reported

6.2 Correlation of NBK-Bremerton Salinity to WWTP BOD and CBOD[12]

To assess if there was any correlation between salinity levels and BOD_5 and $CBOD_5$ levels, WSP prepared an evaluation of the extent of any statistic correlation between the salinity in the wastewater being discharged from NBK-Bremerton at WB-3 and the WWTP influent and effluent wastewater concentrations of $CBOD_5$ during the first and third phases of monitoring. The City of Bremerton did not have adequate BOD measurements during the monitoring periods, so CBOD data was used. For the purposes of this report, CBOD levels can be assumed to be correlated to BOD levels, see Section 6.3.4 for more information. Specifically, WSP evaluated the correlation of the calculated average daily salinity at NBK-Bremerton versus the average WWTP influent and effluent $CBOD_5$. WSP additionally evaluated the maximum single salinity value found in any 4-hour period for each day in

[11] In Section 6.0, the only subsection that received updates was 6.2.

[12] This section received updates based on Phase 3 monitoring data at LS 1, the WWTP headworks, and BOD/CBOD data provided by the City. The conclusions drawn in Section 6.2.1 remain unchanged.

the data set in NBK-Bremerton effluent versus the average WWTP influent and effluent $CBOD_5$ as a sensitivity test to check for any correlation that could be associated with shorter-term salinity events at NBK-Bremerton.

The R-squared value or coefficient of determination is a statistical value that assesses how strong the relationship is between two variables. Researchers conducting trend analyses rely heavily on this coefficient to determine how one variable changes with respect to a second variable. R-squared values that are close to 1 indicate the trend line accurately fits the data (the trend line and data closely match). In the case where the statistic correlation plots of two variables with an R-squared value is close to 1, the variables are very highly correlated, and a change in one variable is reflected by a proportional change in the second variable. A data set with a statistic correlation of two variable plots with an R-squared value close to 0 indicates that trend line does not accurately fit the data (the trend line and data do not match).

Figure 11 presents the correlation plot for the salinity in the wastewater discharged by NBK-Bremerton at WB-3 versus the WWTP influent and effluent wastewater concentrations of $CBOD_5$ during Phase 1. The resultant R-squared values for NBK-Bremerton effluent salinity versus WWTP effluent of 0.0441 and NBK-Bremerton effluent salinity and the WWTP influent $CBOD_5$ of 0.0524 are both very low. These low R-squared values indicate that there are no clear correlations between either influent or effluent $CBOD_5$ values at the WWTP and the salinity of the wastewater discharged by NBK-Bremerton.

The R-squared values presented in Figure 12 of 0.009 and 0.0009 for trends based on the effluent daily 4-hour maximum salinity at NBK-Bremerton versus the WWTP influent and effluent wastewater concentrations of $CBOD_5$ are similar to those in Figure 11. They do not indicate any clear correlations between either of the influent or effluent $CBOD_5$ values at the WWTP and the salinity of the wastewater discharged by NBK-Bremerton The 4-hour daily maximums correlation evaluated the potential for any impact related to short-term salinity spikes events on the WWTP $CBOD_5$ levels as an added sensitivity to the daily average salinity impact evaluation.

The data set used to conduct the correlation assessments included WWTP influent and effluent $CBOD_5$ values and NBK-Bremerton effluent (WB-3) salinity for the period from 23 March 2020 to 27 April 2020.

Figure 13 and Figure 14 present the same calculations as Figure 11 and Figure 12 for Phase 3 of the monitoring, which occurred between 28 September 2021 and 25 October 2021. Similar to the results of Phase 1, low R-squared values on the Phase 3 data also indicate no correlations between influent or effluent $CBOD_5$ values at the WWTP and the salinity of the wastewater discharged by NBK-Bremerton.

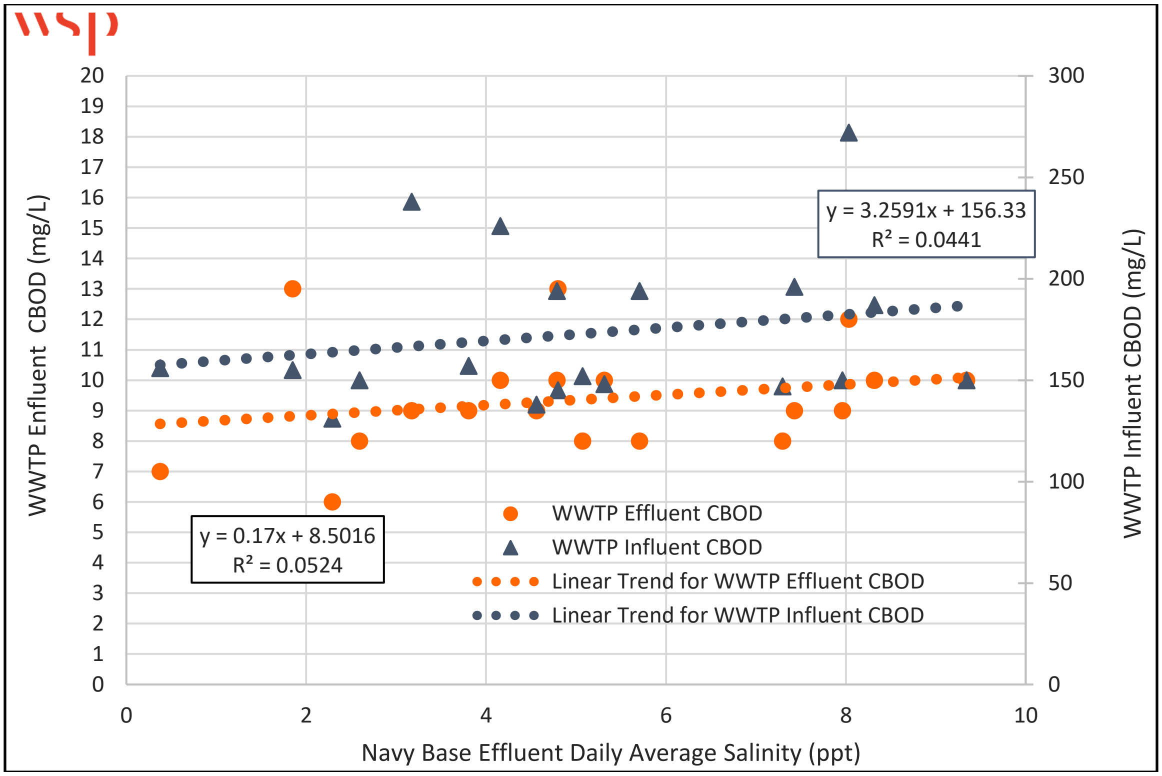


Figure 11. Phase 1 - Wastewater Treatment Plant Effluent and Influent CBOD5 versus NBK-Bremerton Daily Maximum Effluent Salinity

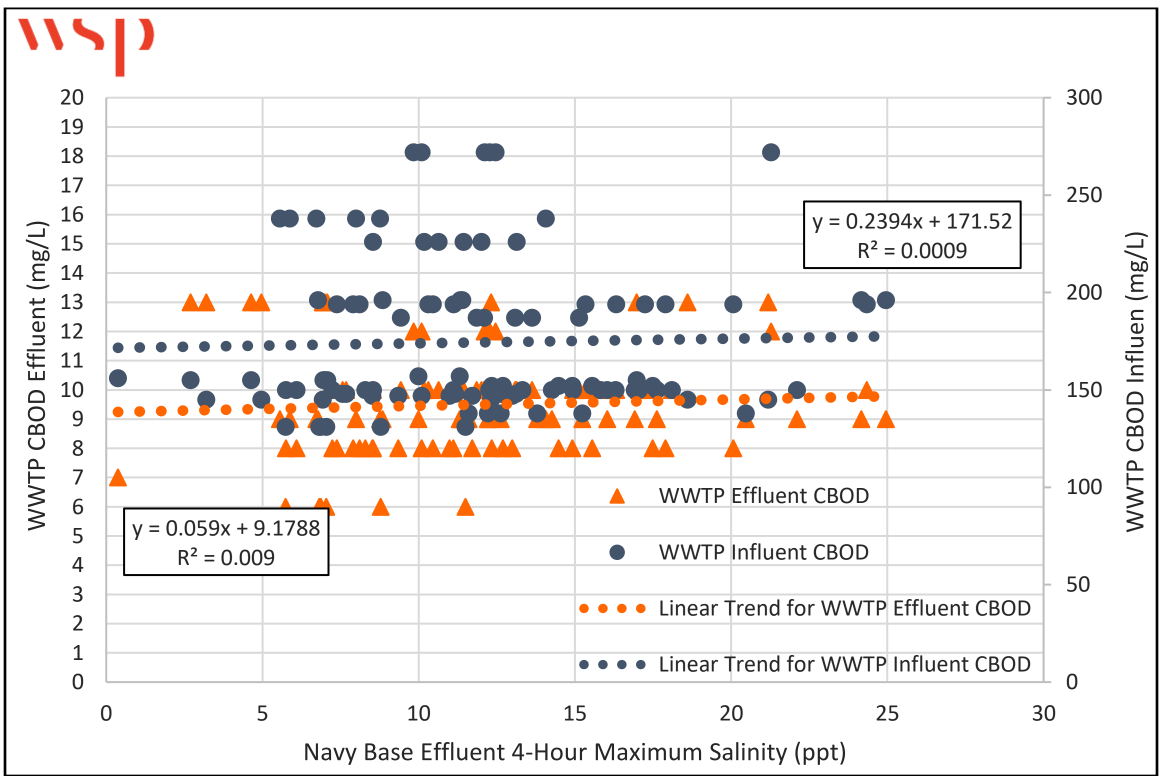


Figure 12. Phase 1 - Wastewater Treatment Plant Effluent and Influent CBOD5 versus NBK-Bremerton Daily 4-hour Maximum Effluent Salinity

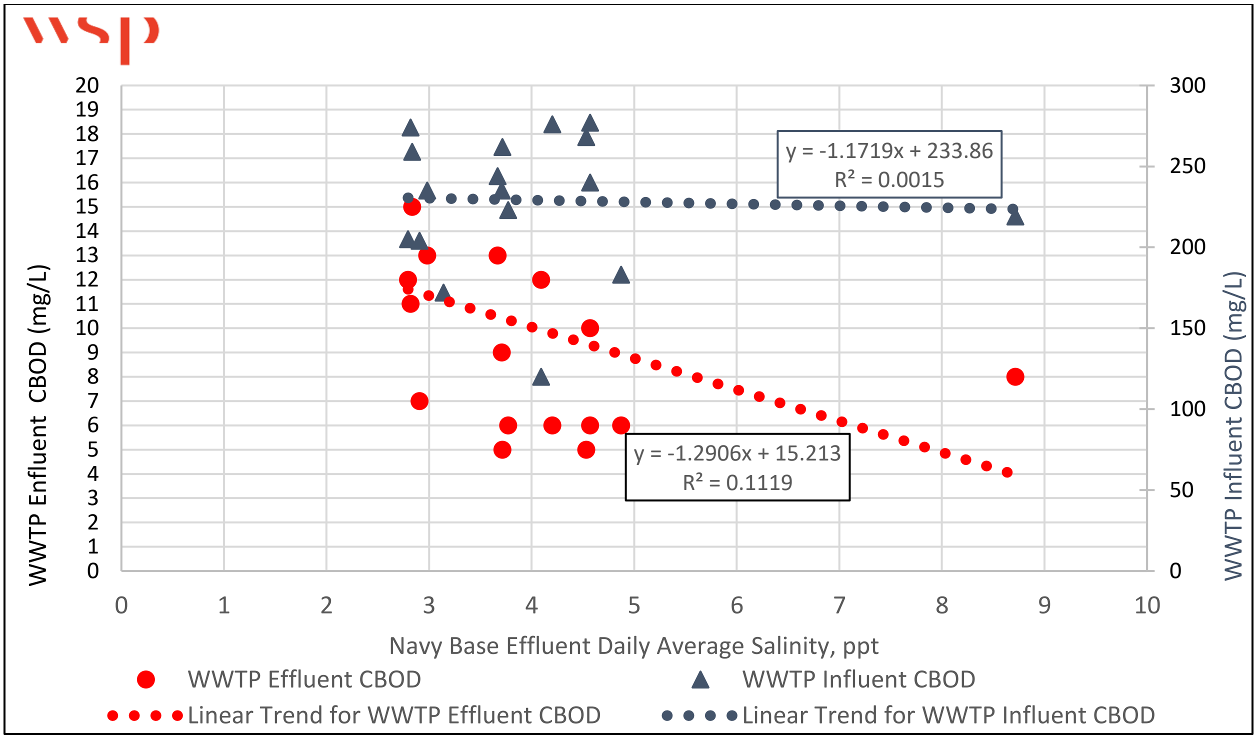


Figure 13: Phase 3 - Wastewater Treatment Plant Effluent and Influent CBOD5 versus NBK-Bremerton Daily Maximum Effluent Salinity

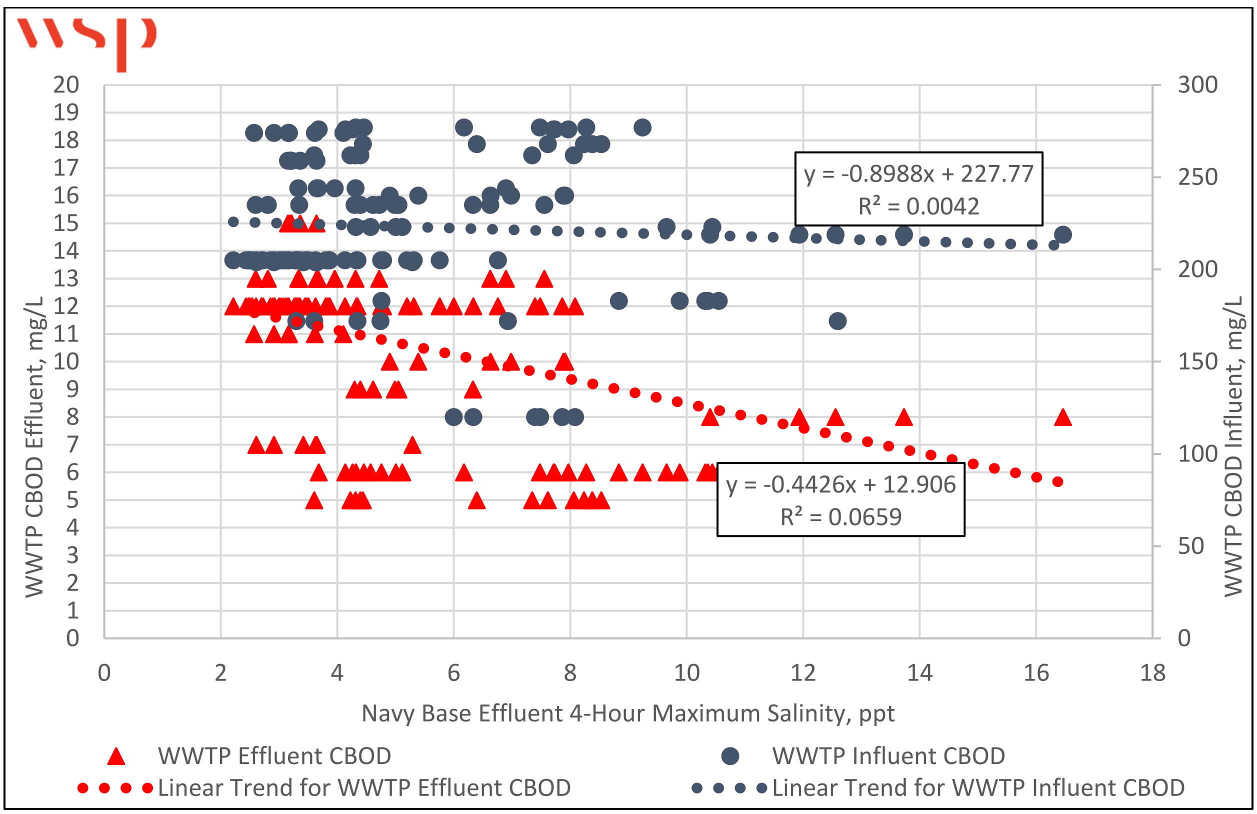


Figure 14: Phase 3 - Wastewater Treatment Plant Effluent and Influent CBOD5 versus NBK-Bremerton Daily 4-hour Maximum Effluent Salinity

6.2.1 Conclusions Drawn from Correlation of NBK-Bremerton Salinity to WWTP BOD and CBOD

Based upon the evaluation described above, WSP has concluded that there is no discernable correlation between NBK-Bremerton effluent salinity levels and either the influent or effluent BOD_5 or $CBOD_5$ levels at the WWTP during the periods of review.

6.3 Evaluation of the Maximum Salinity Level of NBK-Bremerton Wastewater

The purpose of this section is to present a summary of WSP's evaluation of the baseline or maximum salinity level of the incoming NBK-Bremerton wastewater relative to the effluent limits of the City's WWTP. Two separate revisions of the NPDES permit exist over the 2013 to 2020 period for the City's WWTP. Each permit has different discharge limits, monitoring requirements, and reporting and recording requirements. These differences are summarized below.

The most recent permit took effect on 1 December 2018 and expires on 30 November 2023. The monitoring requirements and effluent limits from this permit are shown in Table 11.

Table 11. BOD/CBOD Discharge Limits and Monitoring Requirements from Current Permit (1 December 2018 – 30 November 2023)

Parameter	Average Monthly Limit	Average Weekly Limit	Monitoring Requirements
$CBOD_5$ (May – September)	25 mg/L	40 mg/L	24-hour composite samples, 3 times per week at influent and effluent
	2,294 lbs/day	3,670 lbs/day	
	85% removal		
$CBOD_5$ (October – April)	25 mg/L	40 mg/L	24-hour composite samples, 3 times per week at influent and effluent
	3,232 lbs/day	5,171 lbs/day	
	65% removal		
BOD_5	None	None	24-hour composite samples, once per month, only at the influent

The previous permit was in effect from 2013 to 2018. The monitoring requirements and effluent limits from this permit are shown in Table 12 below.

Table 12. BOD/CBOD Discharge Limits and Monitoring Requirements from Previous Permit (1 August 2013 – 31 July 2018)

Parameter	Average Monthly Limit	Average Weekly Limit	Monitoring Requirements
BOD_5 (May – September)	30 mg/L	45 mg/L	24-hour composite samples, 3 times per week at influent and effluent
	2,752 lbs/day	4,128 lbs/day	
	85% removal		
BOD_5 (October – April)	30 mg/L	45 mg/L	24-hour composite samples, 3 times per week at influent and effluent
	3,878 lbs/day	5,817 lbs/day	
	65% removal		
$CBOD_5$	None	None	None

6.3.1 Salinity Levels Affecting Wastewater Treatment Efficacy and the Maximum Salinity Bremerton's WWTP Could Accept While Meeting Its Previous BOD_5 Limit

Based upon the numerical data available, there is no engineering means to establish a definitive baseline or maximum salinity that the Bremerton WWTP could accept and still meet its former BOD_5 permit limitations. The limited set of data from Phase 1 and Phase 3 of monitoring that contained NBK-Bremerton effluent (WB-3) salinity and the WWTP influent and effluent $CBOD_5$ indicated no appreciable correlation, and the effluent $CBOD_5$ levels were in compliance with the WWTP NPDES permit. The data set also did not include a number of process control variables and physical observations from the plant's operational data that would additionally be needed to establish a site-specific acceptable baseline or maximum salinity levels.

6.3.2 Summary of Research on Salinity Impacts on Activated Sludge Wastewater Treatment Process

Following is a brief summary of several research studies conducted to evaluate the impacts of salinity on the activated sludge process.

6.3.2.1 Salinity Impacts on Coastal Wastewater Treatment Facilities, published by Worcester Polytechnic Institute, by A. Krayer et al.

See Appendix H for the full Krayer report. In coastal locations, it is not unprecedented to find reported instances where infiltration and inflow (I/I) of seawater into the local wastewater collections systems has occurred. During these events, the salinity of the wastewater entering the wastewater treatment plants increases. For example, King County in Seattle, Washington, has also experienced similar I/I complications. In this paper the author noted that in King County the County's Wastewater Treatment Division had monitored locations in the combined sewer system and found that between 3 and 6 million gallons of saltwater enter the system each day.

The paper evaluated the specific effects of salinity on the sedimentation and aeration portions of the activated sludge processes to determine the effects of seawater on the process. The paper also indicated that a critical high end salinity threshold indicative of complete process failure was due to twofold findings; at salinity levels above 26.3 ppt (or approximately 41 mS/cm at 25 degrees Celsius), there is a significant decrease in turbidity removal in the effluent and at salinity levels above 30.0 ppt (or approximately 46.6 mS/cm at 25 degrees Celsius), flocs begin floating to the top of the water column (versus typically settling to the bottom). These observed conditions represent virtually complete failure of the treatment systems.

It is a fairly uniform finding of research that sustained material increases, or short duration spike levels of salinity in the wastewater, can inhibit the effectiveness of the activated sludge process. In particular, population size and diversity of the microbes vital to the treatment process are hindered. Three types of effects related to salinity discharges to activated sludge treatment systems have been identified.

- Inhibition of growth and respiration of the activated sludge biomass
- Salinity causing reduced oxygen's solubility in wastewater
- Very high salinity levels adversely impacting the liquid-solids separation process needed for effective treatment

The paper referenced (but did not provide the name of) a study conducted by the United Nations Educational, Scientific, and Cultural Organization-Institute for Water Education (UNESCO), which found that at salt contents of 1 percent (10 ppt), populations of key organisms responsible for the removal of nitrogen, phosphorus, and organic compounds in the activated sludge process are affected. The nitrification process, which is carried out by ammonium and nitrite oxidizing bacteria, was decreased by 20 to 30 percent. In addition, phosphate accumulating organism populations, responsible for the removal of phosphorus, were found to decrease 70 percent at salinity of 1 percent. In December 2021, Ecology issued the Puget Sound Nutrient General Permit, which requires the Bremerton WWTP to remove nitrogen from their wastewater, furthering the need for the City of Bremerton to aim for a maximum threshold salinity level of 10 ppt (or approximately 16.4 mS/cm at 25 degrees Celsius).

6.3.2.2 *Some Effects of High Salt Concentrations on Activated Sludge, Water Pollution Control Federation Journal*

The results from a study from 1966, published in the Water Pollution Control Federation Journal, which examined the effects of salinity on activated sludge, along with the findings of UNESCO, support the conclusion that microbe populations and diversity within activated sludge decrease as salinity increases. (A microbe population is needed to remove BOD.)

6.3.2.3 *Cultivation of Marine Activated Sludge to Treat Saline Wastewater, Harbin Institute of Technology*

In a study by The Harbin Institute of Technology, they tested the effects of varying levels of salinity on activated sludge. A type of sludge, domesticated activated sludge (DAS), was cultivated for 60 days using activated sludge from a treatment plant and continuously mixed with seawater. This sludge performed best in the range of 3 to 10 ppt (or approximately 16.4 mS/cm at 25 degrees Celsius) salinity. Although the DAS performed well in increased salinity, it could not withstand salinity over 10 ppt. The research also found that organisms could be cultured in solutions with elevated salt concentrations in an effort to adapt them to higher salinity. Other studies conducted by the Harbin Institute on cultivated marine sediment or using artificial saline water (vs seawater) showed lower tolerance levels to salinity but were less applicable to assessing seawater salinity impacts on an activated sludge treatment process.

These are important findings because they suggest that activated sludge exhibits ability to adapt to some measure of salinity and that the deleterious effect of the salinity is likely to occur based on a time/dose response. That is, it is probable to get the same adverse level of impact from a constant and tolerable threshold salinity level experienced over a long period or from a high salinity dose over a much shorter time period. Additionally, when the influent salinity levels are below a tolerable threshold salinity level, and when the salinity levels applied to the activated sludge process are relatively consistent, it is plausible that the activated sludge biomass can adapt and exhibit minimal adverse impact.

6.3.2.4 *High Salinity Wastewater Treatment, by M. Linaric*

The conclusion in this paper is summarized as follows: When salt concentrations were below 10 ppt microorganisms were able to acclimatize in several weeks and achieve the same initial activity as in raw sludge samples. When the salt concentration was above 30 ppt (or approximately 46 mS/cm at 25 degrees Celsius), the acclimatization process was very slow or impossible. (It should be noted again for reference that, as discussed in more detail in Section 5.2.7 above, the salinity levels at the WWTP headworks fluctuated with lows between 0.5 and 3 ppt, and highs between 5 and 7.5 ppt during Phase 1, and with lows between 2.5 and 4 ppt and highs between 7 and 10 ppt, with one spike to 13 ppt during Phase 3.)

In addition to the effect of salinity on the organisms within sludge, higher levels of salinity cause oxygen's solubility in wastewater to decrease. The Virginia Institute of Marine Science studied the effects of increased salinity on oxygen solubility, particularly in estuaries, and found that as salinity increases in a body of water, oxygen solubility decreases.

6.3.2.5 *Effects of Salinity on Wastewater Treatment Processes*

The activated sludge process is an aerobic process (i.e., needs dissolved oxygen in the process tank liquid) using a high concentration of microorganisms that are suspended in wastewater that break down the contaminants. These microorganisms require oxygen to grow new cell mass. The bacteria and protozoa in activated sludge are aerobic and require oxygen to grow and reproduce. Decreases in soluble oxygen available in the wastewater spurs greater competition amongst the organisms, hindering overall population size and growth rate. Fewer numbers and types of organisms decrease the effectiveness of the sludge to remove soluble organics from the wastewater process stream. Additionally, not only will the desired microorganisms die off, but filamentous microorganisms, those that adversely affect the settleability of sludge, will increase. Poorly settling sludge is a leading cause of significant activated sludge process failures.

Aeration is the primary means used to supply the activated sludge with oxygen. Diffusing oxygen into an activated sludge process is accomplished by compressing ambient air with mechanical blowers and using a diffusors system to distribute the air into the mixed liquor, which is energy intensive. The ideal range of dissolved oxygen (DO) content for microbial survival ranges between 2 to 5 mg/L. If DO levels drop below 2 mg/L, a significant increase in salinity of the wastewater with a corresponding decrease in oxygen solubility in the activated sludge basin may require the use of more energy to maintain the desired dissolved oxygen set point for process control.

The effects of salinity on oxygen solubility and diffusion are of importance to wastewater treatment because of the respective impact on the activated sludge process.

Elevated levels of salinity in the activated sludge treatment process present a number of challenges to the treatment plant's operational effectiveness. Sustained or short duration shock levels of salinity can negatively affect the organisms responsible for removing pollutants. Population size and diversity of these organisms decrease with increasing salinity. The amounts of dissolved oxygen, required by these organisms to grow, within the process stream also decreases as salinity levels within the system increases. This may leave the activated sludge less effective at removing pollutants from the wastewater. Aside from the impact of salinity on activated sludge, research clearly shows that significantly high salt contents in wastewater can also reduce the effectiveness of the sedimentation process, which can cause a treatment process failure. It should be noted that the salinity concentration at the WWTP headworks was generally below 7.5 ppt during Phase 1 and 8 ppt during Phase 3, as discussed in Section 5.2.7.3, which is roughly 3.5 times lower than the salinity level associated with complete treatment process failure (30 ppt, discussed in Section 6.3.2.1), and 1.3 times lower than the salinity level associated with impacts to populations of key organisms responsible for the removal of BOD in the activated sludge process (10 ppt, also discussed in Section 6.3.2.1).

6.3.3 Findings of Research

The collective findings of research on salinity impacts to activated sludge treatment all tend to consider a concentration of 10 ppt salinity as an upper limit below which the efficacy of activated sludge treatment and the BOD/CBOD levels and solubility are not negatively impacted.

Additionally, there was at least one instance where salinity shock doses of up to 5 ppt (or approximately 8.85 mS/cm at 25 degrees Celsius) did not demonstrate any perceptible impact on the activated sludge system at the City's WWTP. Several researchers demonstrated that activated sludge biomass can acclimate to some acceptable level of salinity. Lastly, the researchers tended to either look at impacts from shock doses of salinity or sustained constant levels of salinity activated sludge. Based on this summary of research, WSP is proposing a working premise for setting a baseline or maximum salinity [ppt] that the WWTP can accept while still meeting its old BOD_5 limit is as follows.

Based on findings during Phase 1 and Phase 3 that salinity concentration levels of approximately 5 ppt (or approximately 8.8 mS/cm at 25 degrees Celsius) did not have any notable impact of treatment efficacy, it can be said that a 5 ppt (or roughly 8.8 mS/cm at 25 degrees Celsius) average daily influent salinity concentration should ensure no impact. No data was available to determine if the spikes beyond 5 ppt (or approximately 8.8 mS/cm at 25 degrees Celsius) had any notable impact on treatment efficacy. However as most researchers saw limited or no impact to activated sludge systems providing secondary treatment like the Bremerton WWTP at up to 10 ppt (or approximately 16.4 mS/cm at 25 degrees Celsius) salinity, a 10 ppt daily maximum influent salinity concentration limit may be justifiable.

Salinity impact on activated sludge treatment systems is a complex and dynamic subject that involves a number of factors not typically measured in assessing WWTP compliance testing, such as BOD_5 and $CBOD_5$. Establishing a site-specific salinity limitation will likely require evaluation of activated sludge process metrics not generally measured. These metrics would need to be selected by completing a scoping study that evaluates the background of the WWTP's operational characteristics prior to, during, and after the violations. These metrics should be measured under a set of conditions created to isolate the impact of the salinity, and to exclude the impact of other potential variables to the extent possible.

The scope of this report did not include measuring all the parameters required under a set of specific conditions to focus on the impact of salinity only.

Even with consideration of these limitations, reductions of sources of salinity within NBK-Bremerton will result in reduced potential for impact to the City's WWTP. However, the majority of the salinity loading into the WWTP is coming from inside the City's own collection system, and therefore NBK-Bremerton's reduction effort alone may not be enough to cause any noticeable changes in salinity level at the WWTP. Additionally, NBK-Bremerton may have reasons to evaluate if flow equalization is a feasible control strategy to aid in limiting the variability due to shorter-term events with high salinity concentrations in the discharge.

In order to estimate a 30-day rolling average salinity level that NBK-Bremerton can meet to ensure that the WWTP influent does not exceed an average of 7.5 ppt, Phase 3 salinity and flowrate data for the WWTP and for NBK-Bremerton can be used. The 7.5 ppt as the average WWTP influent level was selected, as it is expected that an average of 7.5 ppt at the WWTP would not impact the removal of BOD. During Phase 3's 28-day monitoring period, the WWTP passed an average flow volume of 3,171,713 gallons and an average of 68,338 kg/day of salinity, giving a flow-weighted average salinity of approximately 5.67 ppt. Of these numbers, 631,027 gallons of flow and 21,583 kg/day of salinity came from NBK-Bremerton through WB-3 and LS 9 giving a flow-weighted average salinity of 9.03 ppt. Therefore, an average of 2,540,686 gallons of flow and 46,755 kg/day of salinity came from the City's system (by subtracting the NBK-Bremerton values from the WWTP values), giving a flow-weighted average salinity of approximately 4.86 ppt. Using these numbers, NBK-Bremerton could theoretically discharge its average of 631,027 gallons per day with an average of 43,291 kg/day of salinity, roughly 18 ppt, and the WWTP influent would still only see an average of 3,171,713 gallons per day and 90,046 kg/day of salinity, or roughly 7.5 ppt salinity.

This would only ensure that the average salinity level is below 7.5 ppt, and would not ensure that simultaneous spikes in NBK-Bremerton or the City of Bremerton's system do not bring the salinity level above 10 ppt at any given time. As described above, a more detailed statistical analysis of the various contributors to the City's system would be required to establish an absolute maximum salinity level that NBK-Bremerton could discharge in order to keep the City's WWTP below 10 ppt. Further, a more detailed analysis of the specific treatment processes at the City's WWTP is required to determine a salinity level at which the removal of BOD/CBOD is impacted.

6.3.4 Relationship of BOD_5 and $CBOD_5$

The task directive was to evaluate what salinity baseline or maximum salinity [ppt] the WWTP can accept while still meeting its old BOD_5 limit. As there was scant or no BOD_5 data available to conduct any direct comparisons, we pursued the development of calculated ratio between the WWTP influent BOD_5 and $CBOD_5$. Due to the inherent relationship between the two test methods, such a method can be used as a basis to extrapolate between $CBOD_5$ data, which is the test being performed currently at the Bremerton WWTP and the old BOD_5 limit.

The BOD_5 analytic test method is used to determine the pollutant strength of organic matter in a wastewater. In nature, the organic waste materials in wastewater serve as food for a biologic population under aerobic (oxygen containing) conditions. The BOD_5 test is essentially a bioassay procedure involving the measurement of oxygen consumed by living organisms, mostly bacteria, while they decompose the organic matter present in the waste, in a closed and controlled test system over five days. The BOD_5 test is quantitative because there is a quantitative or stoichiometric relationship between the amount of oxygen required to convert a definite amount of any given organic compound to carbon dioxide, water, and ammonia. The BOD_5 test is perhaps one of the most widely used tests in sanitary engineering. At wastewater treatment plants, the BOD_5 test is used to evaluate the efficiency of the biologic treatment processes.

The Environmental Protection Agency (EPA) has federal standards for allowable BOD_5 levels in wastewater discharges. Consequently, state regulators require it as a reportable measure in wastewater treatment plant discharge permits and required it to be periodically reported to determining compliance with those regulations. In recent times, regulators have begun considering or including other specific nitrogen compound based effluent limitations in wastewater treatment plant discharge permits. When doing so, there has been a tendency for regulators to avoid the potential double jeopardy associated with using a BOD permit limitation that includes measurement of nitrogen constituents and then a separate permit limitation for similar measurements of nitrogen constituents, such as TKN, ammonia, and nitrate. Consequently, there has been a shift to the use of $CBOD_5$ limitations being used in wastewater treatment plant discharge permits.

The CBOD test is a variant of the BOD test. Standard BOD results are based on oxygen depletion from both carbonaceous and nitrogenous substances in a wastewater sample. Nitrogenous materials in wastewater, such as urea, uric acids, ammonia, amino acids, nitrates, and other nitrogenous proteins, are also converted by living biologic organisms, which also consumes oxygen in wastewater systems and the BOD_5 test. CBOD measures DO depletion from only carbonaceous pollutant sources. The difference between the two tests is due to an inhibitor that is added to the CBOD test that prevents the bacteria from metabolizing the nitrogenous organic material and consequently eliminates the nitrogenous portion of the oxygen depletion from the $CBOD_5$ test. Ecology published the different laboratory methods for these two tests in the laboratories guidance document "Supplemental Guidance for the Determination of Biochemical Oxygen Demand (BOD_5) and Carbonaceous BOD ($CBOD_5$) in Water and Wastewater" in March 1998.

Wastewater's characteristic concentrations of nitrogenous substances can vary from location to location. However, there are typical proportions of both carbonaceous and nitrogenous substances in a given wastewater. So, for a given location, and provided that BOD_5 is a measure of both nitrogenous and carbonaceous oxygen demand and $CBOD_5$ is a measure of <u>only</u> the carbonaceous oxygen demand, one would expect a high degree of correlation between BOD and CBOD for that sample location. In fact, in the previously mentioned Ecology BOD/CBOD guidance document, they compared the BOD_5 and $CBOD_5$ of 18 different samples and they found; "there is a very consistent ratio of BOD_5 to $CBOD_5$ for a given sampling site." For those 18 different samples, the overall average ratio they found was 1.16 $BOD_5/CBOD_5$.

The EPA has also incorporated fixed ratios of BOD versus CBOD in its national wastewater treatment regulations. In 40 CFR § 133.102, they established minimum national secondary treatment standards for BOD_5 and $CBOD_5$ that have inherently included a ratio of 1.2 (i.e., "The 30-day average BOD_5 shall not exceed 30 mg/l"; and, "The 30-day average $CBOD_5$ shall not exceed 25 mg/l", hence 30 BOD_5/25 $CBOD_5$ = 1.2). As shown in Section 6.3 above, these treatment standards were the basis for both set of effluent limitations in the old and new Bremerton WWTP NPDES permits.

There were 166 WWTP influent BOD_5 samples that were paired on the same day with corresponding $CBOD_5$ tests in the data set provided. The sampling data spanned the period from October 2015 to December 2017 and consisted of approximately 9 samples arrayed over the course of each month for the first 16 months, then one paired sample each month for 7 months. WSP then tested each discrete data set (BOD_5:$CBOD_5$) for outlier sample values that exceeded statistical tests for acceptable variability. If any of the individual BOD_5 or $CBOD_5$ data points on a given day tested as an outlier, then the paired sample set for that day was then eliminated from the data set evaluated. Two paired BOD_5/$CBOD_5$ data sets were thrown out, as their technical validity was improbable and their inclusion may unnecessarily skew and bias the data. Having such a significant number of available paired influent BOD_5 and $CBOD_5$ samples ensures that the result will be highly representative ratio. Using the data made available, the resultant calculated ratio between the WWTP influent BOD_5 and $CBOD_5$ was 1.12.

In the data sets provided for Phase 1 and Phase 3, there was only one day with WWTP influent/effluent data for both BOD and CBOD. Consequently, an independent estimation of the BOD_5 to $CBOD_5$ ratio for the WWTP effluent could not be estimated from the available data. However, it is reasonable to assume that effluent BOD_5 to $CBOD_5$ ratio should be similar to the influent BOD_5 to $CBOD_5$ ratio estimated for the purpose of this task.

Consequently, it is possible to use a BOD_5 to $CBOD_5$ ratio of 1.12 as a prospective means to assess compliance with meeting the old BOD_5 limit rather than conducting both tests simultaneously, when predominantly only a significant number of $CBOD_5$ tests are being conducted at the Bremerton WWTP. The comparison of the old effluent BOD_5 NPDES permit limitations and the new effluent $CBOD_5$ permit limitations are discussed in Section 6.3 above. These effluent limitations in these permits are based upon the EPA's national secondary treatment standards for BOD_5 and $CBOD_5$.

7.0 AREAS IDENTIFIED AS HAVING HIGH SALINITY CONCENTRATIONS/LOADING[13]

Figure 15 presents the average salinity loading values recorded during first phase of monitoring, as percentages of the average salinity loading at LS 1. This information was used to determine which areas were significant contributors to salinity. As can be seen, LS 3, LS 6, LS 7, PWCS 1, PWCS 2, PWCS 5, PWCS 6, OWTS 6, and Pier D West all have relatively high salinity loading averages.

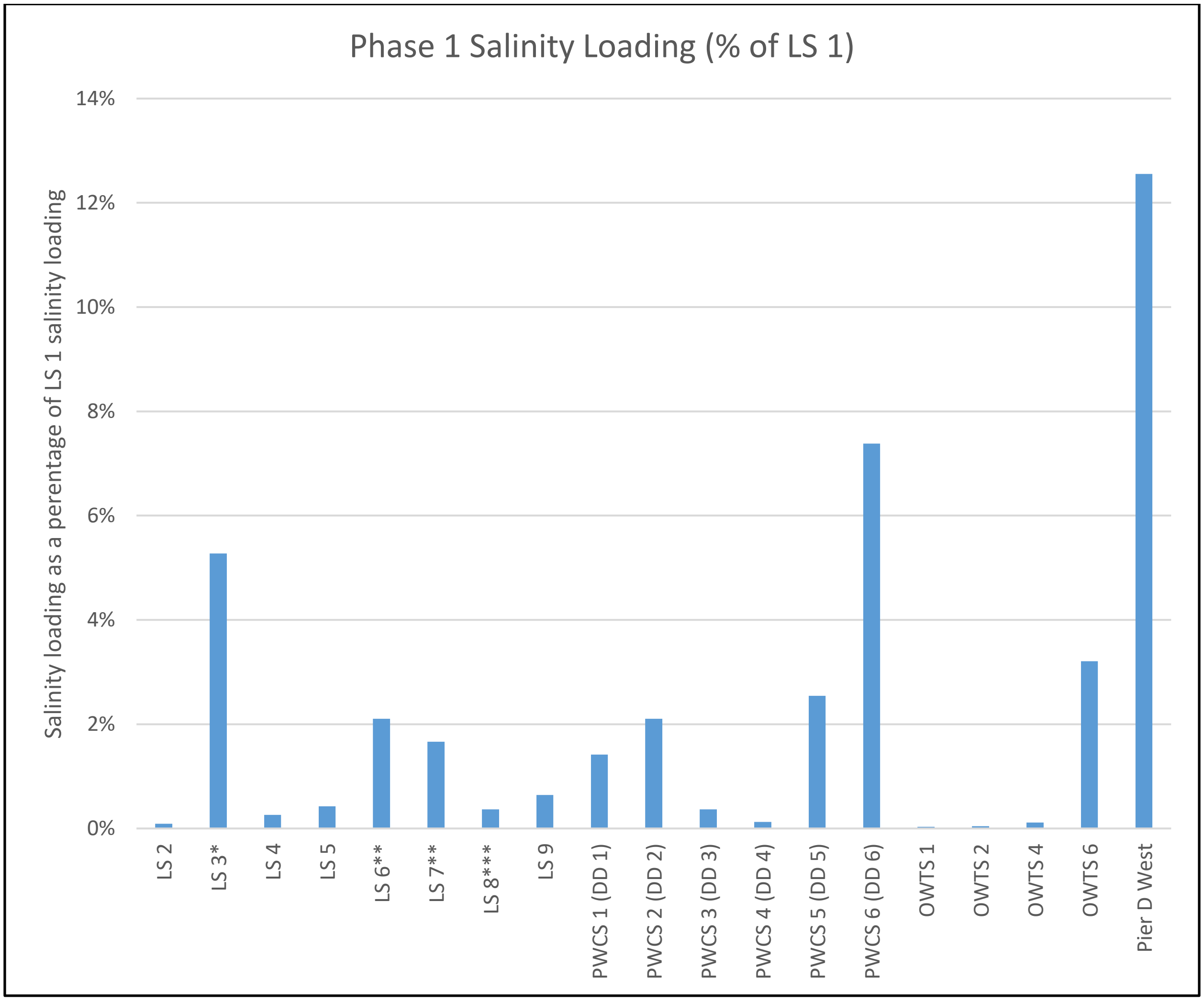


Figure 15. Phase 1 - Summary of Average Salinity Loading

* LS 3 salinity loading is high due to a spike in salinity concentration and flowrate that occurred between 3 April and 7 April 2020. For these five days, the average salinity loading was 5,400 kg/day, and the salinity spiked to above 20 ppt. Outside of these five days, the average salinity loading was 84 kg/day. NBK-Bremerton has stated that this period of time corresponds to when DD 6 was flooded, and suspects that during this time more water from the Sinclair Inlet leaked into the DD 6 pumpwell, which may have pumped it to LS 3.
** LS 6 and LS 7 show high salinity loading, but most of the salinity loading comes from PWCS 2 and PWCS 1, respectively.
*** As described in Section 5.1.6 above, the data at LS 8 is unreliable.

[13] Sections 7.0, 7.1, 7.2, 7.3, and 7.4 have been revised to include results of Phase 3 of monitoring. Section 7.5 has been added to the report.

Figure 16 presents the average salinity loading values recorded during the third phase of monitoring, as percentages of the average salinity loading at LS 1. As can be seen, LS 7, PWCS 5, OWTS 6, and MH 9-1 all have relatively high salinity loading averages.

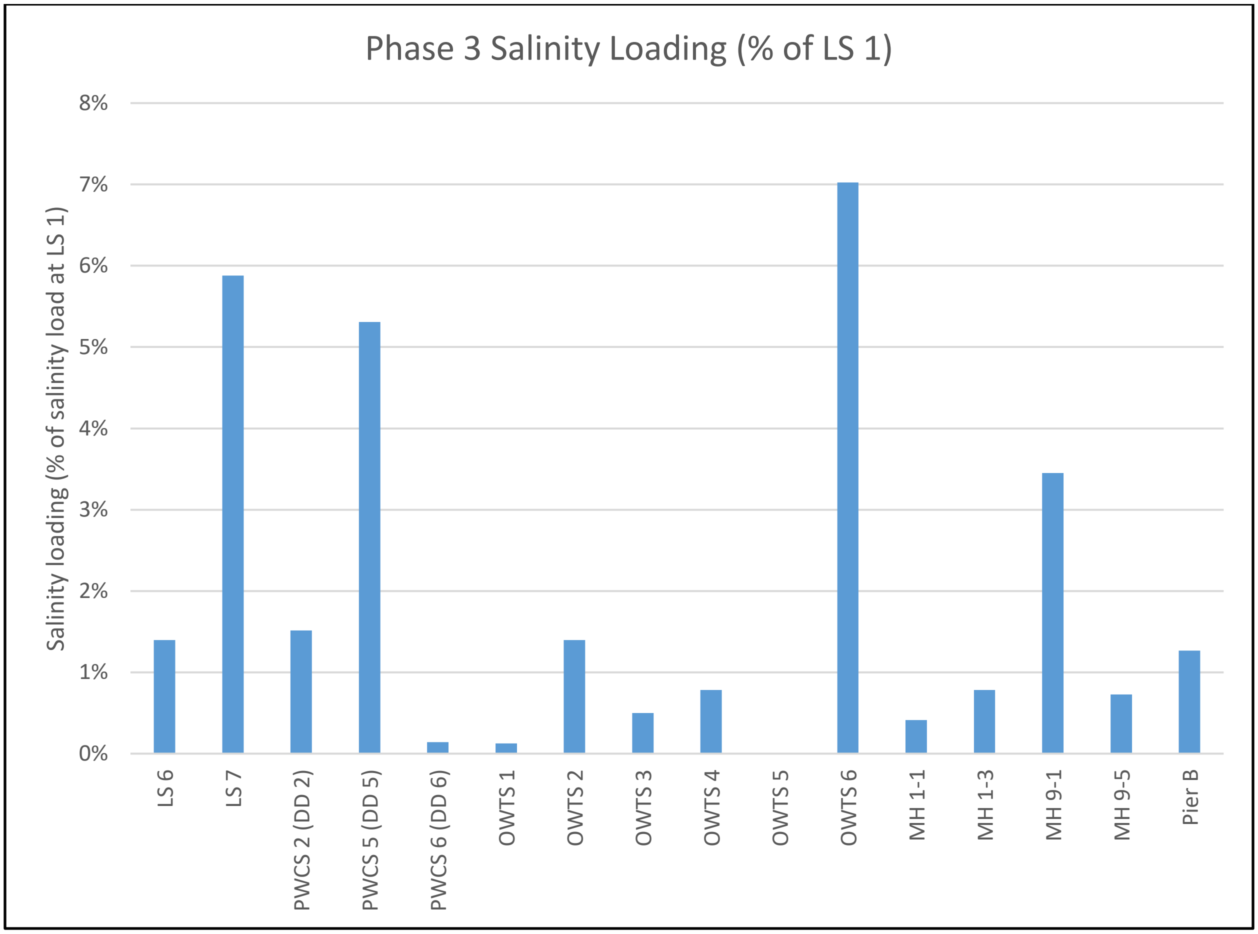


Figure 16: Phase 3 - Summary of Average Salinity Loading

Per NBK-Bremerton staff, the high average salinity loading at LS 7 during Phase 3 was likely due to abnormal discharges from PWCS 1 on 13 October and 14 October 2021, when an incorrect valve lineup caused bay water in DD 3 to cross over to DD 1 resulting in a discharge of bay water through PWCS 1 to LS 7. On these days, PWCS 1 discharge a total of 89,000 gallons, whereas on normal days PWCS 1 only discharged between 1,000 and 2,000 gallons per day.

Sections 7.1 to 7.4 present a summary of the locations that have high salinity concentrations or salinity loadings within NBK-Bremerton.

In general, high salinity at these various locations can be attributed to four significant sources: ship wastewater, groundwater intrusion leading to dry dock PWCS, OWTS treated water, and potential groundwater infiltration into the sanitary sewer.

7.1 Lift Station 1 Gravity Tributary Area

Through indirect monitoring, Phase 1 data shows that high salinity groundwater intrusion into the gravity sewer collection piping system has very significant impacts on the salinity load at LS 1 and that this area presents the highest potential to reduce the salinity load at LS 1.

A similar analysis of daily flow summaries for LS 1 to LS 8 for Phase 3, provided by NBK-Bremerton staff, indicated that 51 percent of the flow volume pumped out of LS 1 comes from sources outside of LS 2 to LS 8, such as various piers, OWTS, and PWCS. However, Phase 3 monitoring at MH 1-1 and 1-3, just upstream of LS 1, indicated that less than 2 percent of the salinity loading at LS 1 flowed through these manholes. Thus, it can be assumed that a significant amount of flow enters LS 1 through other connections to the site's shared force main, or in the wet well of LS 1, downstream of MH 1-1 and 1-3.

Recommendations to reduce the groundwater intrusion and thereby reduce the salinity loading on the sewer system are presented in Section 8.0.

7.2 Lift Station 9 Tributary Area

During the first phase of monitoring, LS 9 had salinity concentration fluctuations with highs between 6 and 12 ppt, and the salinity loading at LS 9 ranges between approximately 100 and 400 kg/day. During the third phase of monitoring, LS 9 salinity loading fluctuated between roughly 1,000 and 2,500 kg/day, and salinity loading at MH 9-1 fluctuated between roughly 50 and 1,500 kg/day. These values are relatively high considering that no PWCS pumps to LS 9.

The disproportionate volume of wastewater entering the LS 9 tributary area downstream of MH 9-8 (discussed in Section 5.1.11 above) during Phase 1, and the high salinity loading observed at MH 9-1 and LS 9 during Phase 3, indicates that there is likely groundwater intrusion into the sewer system that is upstream of LS 9 and downstream of MH 9-8. Monitoring at MH 9-5 during Phase 3 further pinpoints the sources of salinity to be between LS 9 and MH 9-5, and MH 9-5 had much lower salinity loading than MH 9-1, as shown in Figure C12 in Appendix C.

It should be noted that the WSP team observed large amounts of groundwater infiltration into the sewer pipes and structures during the conductivity and flowmeter installations at MH 9-1.

Recommendations to reduce the groundwater intrusion and thereby reduce the salinity loading on the sewer system are presented in Section 8.0.

7.3 Dry Dock Process Water Collection Systems (PWCS)

Each of the six DDs have groundwater intrusion/leakage through the floor that makes its way to the PWCS. Additionally, most DDs have a small amount of leakage at the caisson seat seals but most of this is discharged to the bay before entering the PWCS. The groundwater salinity levels are high. DD 2 discharges to LS 6, and caused LS 6 salinity loading values to be significant during Phase 1 of monitoring. The salinity levels were measured by WSP during Phase 1 and quantity of groundwater intrusion (leakage) data was provided by NBK-Bremerton for each DD. This data is summarized in Table 8 above.

DD 6, DD 2, and DD 5 had relatively high groundwater intrusion flow rates during Phase 1, and DD 5 had relatively high salinity loading during Phase 3, with the resultant high salinity loads added to the sewer system. DD 6 had no flows during Phase 3 due to a temporary fix that stopped groundwater flow. A permanent fix to the groundwater relief system for DD 6 is scheduled for 2023. Recommendations to reduce the groundwater intrusion and thereby reduce the salinity loading on the sewer system can be found in Section 8.0.

7.4 Other Potential Sources of High Salinity

7.4.1 DD 6 Abnormal Operations/Lift Station 3

LS 3 salinity concentrations were generally below 5 ppt, and salinity loading is generally below 100 kg/day. However, between 3 April and 7 April, the salinity concentration rose to values above 20 ppt and salinity loading rose to over 6,000 kg/day. Through correspondence with NBK-Bremerton staff, it was determined that these dates of high salinity concentration and salinity loading correspond to when NBK-Bremerton flooded the DD 6 to undock a vessel. It is likely that water from the Sinclair Inlet leaked into the DD 6 pumpwell and was pumped to LS 3. NBK-Bremerton has indicated that this event is an abnormality.

Refer to Figure B3 in Appendix B for a graph of the conductivity, salinity concentration, and temperature data recorded at LS 3.

7.4.2 PWCS 1 Abnormal Operations/Lift Station 7

Similar to LS 6, LS 7 had generally low salinity concentrations (fluctuations with highs between 2 and 8 ppt), the salinity loading fluctuated between 200 and 400 kg/day, which is significantly higher than most other lift stations. As discussed in Section 5.1.5, most of the salinity loading at LS 7 comes from PWCS 1. An abnormal event during at PWCS 1 during Phase 3, involving an incorrect valve lineup, caused saltwater to be discharged through LS 7. Recommendations to reduce the groundwater intrusion and thereby reduce the salinity loading on the sewer system are presented in Section 8.0.

Refer to Figure B7 in Appendix B for a graph of the conductivity, salinity concentration, and temperature data recorded at LS 7.

7.5 Dry Dock Oily Water Treatment Systems (OWTS)

Each DD has an OWTS plant that treats bilge water and ballast water discharged from vessels in that DD, and also treats some wastewater from the PWCS in certain rain events.

During Phase 1 of the study, the OWTS that had the highest salinity loading discharge was OWTS 6, with 573 kg/day of salinity, or roughly 3 percent of the salinity loading at LS 1 during Phase 1. However, during Phase 3 of monitoring, it was determined that OWTS 6 contributed 1,516 kg/day of salinity, or almost 9 percent of the salinity loading that passed through LS 1 during Phase 3. For three days during Phase 3, OWTS 6 had salinity loading values greater than 3,000 kg/day. On 16 October 2021, OWTS 6 had 4,740 kg of salinity loading (43 percent of the salinity loading at LS 1 on this day). A review of the OWTS discharge data provided by NBK-Bremerton staff indicates that all of the OWTS 6 discharge on this day occurred between 06:30 and 13:10. Recommendations to reduce the overall salinity loading of OWTS into the City's sewer system are presented in Section 8.0.

7.6 Ship Sewage Wastewater

The presence of docked vessels at NBK-Bremerton can greatly impact the total salinity loading and salinity concentration being discharged from the site. Section 5.5.1 discusses the large swings in average conductivity at LS 1 when ships arrived at NBK-Bremerton between Phase 1 and Phase 3 of monitoring. Figure 5 and Section 5.1 describes the salinity loading from docked carriers during Phase 1 and Phase 3 of monitoring.

8.0 POTENTIAL PROJECTS TO REDUCE OR ELIMINATE SOURCES OF HIGH SALINITY[14]

The following sections present potential CIPs and operational changes that can be implemented to reduce the salinity levels in NBK-Bremerton's sewer system. In general, the projects that will reduce the largest amount of salinity are ordered first.

1) Sections 8.1 to 8.11 present individual specific projects.

2) Section 8.12 presents a summary of the individual projects, including the potential impact that each project will have on the overall salinity load leaving NBK-Bremerton.

3) Section 8.13 presents a summary WSP's recommendations regarding each of these projects.

8.1 Potential Project 1: Sanitary Sewer Pipe Repair Project(s)

8.1.1 Sewer Inspection/Repair Project to Address LS 1

Phase 1 and Phase 3 of monitoring indicate widely varying levels of salinity entering the system near the gravity system upstream of LS 1. As is further discussed below, Phase 1 results indirectly estimated that high levels of salinity enter LS 1 through the gravity system upstream and to the north of LS 1. However, further monitoring in this gravity system during Phase 3 shows low salinity in this area

Based on Phase 1 of the project monitoring, data collection, and analysis, it was determined that approximately 65 percent of the salinity loading (about 12,454 out of 18,975 kg/day) leaving LS 1 was from the gravity flow system north of LS 1. This was the most significant source of salinity into the sewer system with the potential to be one of the easiest to correct. From Section 5.1.10 above, the source of the salinity load was highly likely to be groundwater intrusion into the sewer piping system in the area between LS 1 and MH 1-8, including laterals, of which about 92 percent (or 11,560 kg/day) is between LS 1 and MH 1-3. There was no other known potential source of salinity. Thus, of the 18,975 kg/day salinity loading at LS 1 during Phase 1, about 60 percent (or 11,560 out of 18,975 kg/day) was determined to have entered the sewer system between LS 1 and MH 1-3, which is a sewer piping segment that is about 225 feet long with some relatively short laterals. About 185 feet of this segment are under Building 997.

Based on Phase 3 of the project monitoring, data collection, and analysis, which included salinity and flow measurement at MH 1-1 and 1-3, just upstream of LS 1, only less than

[14] In general, the potential projects and design parameters discussed in Section 8 and its subsections remain unchanged. However, numerous minor edits have been made where the potential removal of salinity values are discussed to incorporate the additional Phase 3 data.

2 percent of the salinity flowing through LS 1 enters through the gravity system upstream, greatly reducing the justification of this potential project. However, as discussed in Section 5.1.1 above, a large amount of flow may be infiltrating into the wet well of LS 1, as 51 percent of the flow volume leaving LS 1 comes from sources other than LS 2 to LS 8.

It is recommended that the gravity sanitary sewer piping and manholes on the north leg of LS 1 that is within 510 feet of LS 1 (i.e., between LS 1 and MH 1-8, including laterals) be repaired by pipe and manhole replacement or by providing an internal cured-in-place pipe (CIPP) system to prevent high salinity groundwater intrusion. The extent of pipe repair or replacement in this recommendation must be confirmed by further study/investigation, including implementing closed circuit television (CCTV) video inspection of these sewer pipes. NBK-Bremerton initiated a CIPP repair project in 2018 but information regarding the extent of those repairs completed at the time of this study is unknown. Written video log summaries associated with the CCTV video performed as part of the repair project were reviewed, but thorough research, investigation, and assessment of the actual CCTV footage is not included in the scope of work of this study.

It should be noted there is already a history of groundwater intrusion into the sewer piping system at NBK-Bremerton, either through leaky joints, cracked/damaged piping, or both, particularly near LS 1. The groundwater table is typically high and seawater from the Sinclair Inlet floods back up into the adjacent storm sewer piping near Building 997. The shipyard initiated a CIPP repair project in 2018 entitled "Repair or Replace Degraded Sewer Infrastructure" with issue date of 24 January 2018 (Project No. 1626717), which is in progress. However, this project does not include repairs to the piping or manholes in the sewer system from MH 1-8 to LS 1, except the resealing of MH 1-3, MH 1-5, and MH 1-8. An existing 15-inch sanitary sewer main passes under Building 997 before it connects to LS 1 from the north. There is concern that the foundations for Building 997 may have settled over time with the potential for cracking this sewer main or causing separation of the piping at the joints in this area of high salinity loaded groundwater.

8.1.2 Sewer Inspection/Repair Project to Evaluate LS 9

In addition to the areas around LS 1 described above, there is suspected infiltration into sewer pipes upstream of LS 9 (see Section 5.1.11 above for further discussion). During Phase 1 of monitoring, LS 9 only contributed roughly 115 kg/day of salinity to the sewer system. However, during Phase 3 of monitoring, MH 9-1 (just upstream of LS 9) contributed 745 kg/day of salinity to the sewer system, or roughly 3 percent of the salinity loading at LS 1. CCTV inspection and repairs on any damaged pipe should be considered in the area upstream of LS 9 and downstream of MH 9-8.

8.1.3 Design Parameters

This recommendation should include a CCTV video inspection of the sewer pipes near LS 1 and LS 9. Because about 185 feet of the segment near LS 1 is under Building 997, piping replacement around Building 997 should be considered to avoid the potential for building foundations settlement on top of the piping. See drawings in Appendix G2 for the approximate area of this potential project.

8.2 Potential Project 2: DD 6 Mitigation of Groundwater Intrusion at Floor

During Phase 1 of monitoring, approximately 35 percent of the salinity load at LS 1 was from the east forced main (pumped sewer). When a CVN is in dock, the salinity loading approximately doubles from the CVN pumped sewage due to saltwater used for flushing plumbing fixtures. About 12.3 percent at LS 1 was from the DD 6 PWCS (as discussed above in Section 5.4.1). The PWCS discharges into the forced main system east of the LS 1 near the northwest corner of DD 6. However, during Phase 3 of monitoring, less than 1 percent of the salinity loading at LS 1 was from PWCS 6.

If salinity reduction is needed in addition to the recommendations included in Section 8.1 above and the current remediation project is not brought to completion (see 8.2.1.6), then it is recommended that the groundwater intrusion through the floor of DD 6 be further addressed. The existing groundwater relief (GWR) system for DD 6 has existing relief wells under the floor. However, a relatively small amount of intrusion can be attributed to corrosion of the lateral GWR piping system that gravity drains the groundwater from the wells to the DD side tunnels and discharges to the bay. This small amount of leakage at the laterals is about 62.5 gpm or 90,000 gpd out of the approximately 5 million gpd of relief groundwater (about 1.8 percent leakage). The intent is to stop all groundwater intrusion through the DD floor by repair/replacement of the corroded lateral GWR piping system and thereby reduce the flow into the PWCS. In addition to reducing the salinity introduced to the sanitary sewer system, keeping water off the DD floor increases DD safety. If it is determined that the repair of the corroded lateral GWR piping system is inadequate to stop the groundwater intrusion, it may be necessary to provide additional relief wells similar to DD 4.

At DD 4, before 2015, the original passive GWR system (circa 1942) relieved groundwater through dock floor penetrations and into surface channels along the dock floor. Sediment and debris build-up within the system and modifications to the DD floor restricted the groundwater flow, resulting in water migration through the dock floor. The resultant groundwater intrusion was repaired in 2015 by installing high-capacity relief wells placed along the west and east sides of the DD floor. A total of fourteen 53-foot-deep relief wells, including well pumps, were installed to relieve the underfloor groundwater to the side tunnels where the water is directed to the DD 4 drainage pumps that discharge to Sinclair Inlet through an existing permitted outfall. This solution avoids allowing high salinity groundwater onto the DD floor, into the PWCS, and into the sewer system.

It should be noted that once the new wells were installed, the use of the pumps has not always been necessary to achieve the desired pressure relief since there is gravity flow (pumps off) through the pump piping to the side tunnels. This repair project is an example of one way to further reduce the salinity loading from DD 6 and other DDs, thus reducing the salinity loading at LS 1. Note that groundwater intrusion and consequent salinity loading at LS 1 is now very low for DD 4 compared to DD 2, DD 5, and DD 6.

8.2.1 Design Parameters

The recommendation for additional relief wells at DD6 should include the following components and considerations after geotechnical confirmation of the DD 6 GWR flow rates and the number of wells needed. See drawings in Appendix G1 for a conceptual layout of DD 6 relief wells.

The shipyard shore operations personnel prefer passive wells systems. They are recommended instead of active (or pumped) wells for several reasons, including cost, well service life, and the ability to perform system maintenance during operational use of the DD. Note that available windows for relief well maintenance are limited and are subject to unpredictable docking schedules, making maintenance of pumps exceptionally difficult. An increased number of passive wells is preferred to meet flow requirements instead of high-capacity active wells.

8.2.1.1 Groundwater Relief Well Design

The design parameters for the GWR wells, including the number, size, and depths of wells, must be established based on the results of geotechnical field investigation and groundwater hydrogeological modeling during the design.

8.2.1.2 Groundwater Relief Pumps

Pumps are not desired, but if needed, based on the geotechnical reports and drydock construction limitations, the pump design must be based on sound engineering principles and practices. When pumps are required, each new GWR well must be provided with a well pump, including submersible motors, pumping capacity of up to 60 gpm (or more) at a maximum of 85 feet head. Also, approximately 180 linear feet of power cable attached to the pump motor with a waterproof seal rated for submergence under 100 feet of water is needed. Provide pumps with variable frequency drives (VFDs) controlled by a calibrated pressure transducer input in each well.

8.2.1.3 Pump Manufacturers

Three potential pump manufacturers are:

1) Grundfos
2) Flowserve (with Pleuger motor)
3) Goulds

8.2.1.4 Pump Controls

Provide the VFD with preprogrammed application macros to operate the pump without a separate programmable logic controller. Provide water level input to the VFD via a pressure transducer located in each GWR well. Each pump must have a dedicated VFD and independent control. All pumps can be running simultaneously. When the pump is commanded "on," the initial speed is ramped up quickly to provide the minimum flow to lubricate and cool the pump and motor. After this initial flow is established, the VFD must slowly ramp up or down to the design flow setting.

The control sequence through VFD macros is as follows.

- Pump "on" at water level Elevation 45.0 feet (adjustable).
- After initial start-up, the pump design flow of 60 gpm (adjustable) is maintained until the water reaches the "shutoff" level.
- Pump "shutoff" at water level Elevation 35.0 feet (adjustable).
- Provide a high water alarm when the water level is at Elevation 60.0 feet (adjustable).

8.2.1.5 Groundwater Relief System Components

Generally, GWR system components are as follows.

- Piping must transfer the groundwater from the wells to the DD drainage system, and it must support static and dynamic floor loading during the operational use of the DD.
- Pipe and fittings at pump discharge in GWR wells: 70/30 copper-nickel seamless tubing or titanium tubing.
- Pipe and fittings at pump discharge in a core drilled hole and side tunnel: High-density polyethylene (HDPE).
- Balancing Valves and Check Valves: Type 316 stainless steel, CPVC, or other non-metallic material, with flanged ends.
- Electrical: Provide surface-mounted power and control conduit and cables from the pump up to the nearest service gallery where the pump electrical disconnect will be located. Then use the existing duct banks and manhole system to route back to the electrical panel inside the electrical room in Pumpwell 6.
- Locate the VFDs in the pumpwell adjacent to the new panel and provide output filters to reduce voltage total harmonic distortion.
- All cables will be copper.
- Shielded VFD cables, rated for harsh operating environments (characterized by high voltage spikes, high noise levels, and adverse environmental conditions), must be provided for feeders between the VFD and the pump. The feeders keep the signal generated by the VFD cable from escaping and preventing noise generated outside the system from being picked up.
- Provide continuous feeder from the electrical disconnect at the service galleries to each GWR pump located in the relief wells (i.e., no splices are allowed).

- Provide rigid galvanized steel raceway in exposed locations subject to damage in the pumpwell. Provide extra heavy-duty fiberglass conduit and accessories in the DD and outdoor spaces.
- Low voltage conductors (including signal/control) must be Type THHN or XHHW-2 insulation rated for 600 volts. Conductors must be 12 AWG minimum. Low voltage conductors in the underground distribution system must be 12 AWG, Type XHHW-2 minimum for both power and control and signal wiring.

8.2.1.6 Current Groundwater Reduction Project at DD 6

It is reported that NBK-Bremerton has started working on a project to mitigate DD 6 groundwater intrusion problems. This potential project (different in design concept) is already under development by PSNS & IMF and NAVFAC NW. Preliminary engineering analysis and drafting of the project requirements and specifications are currently ongoing. If this reported project is completed, the above Potential Project No. 2 may be unnecessary.

8.3 Potential Project 3: DD 2 Mitigation of Groundwater Intrusion at Floor

About 2.0 percent of the salinity load at LS 1 is discharged from the DD 2 PWCS into the forced main system east of the LS 1.

If salinity reduction is needed in addition to the above recommendations, then it is recommended that the groundwater intrusion through the floor of DD 2 be mitigated with the installation of approximately 12 new gravity relief wells. These wells should be similar to the remediation work described for DD6 above. The intent is to stop all groundwater intrusion through the DD floor and thereby reduce the flow into the PWCS by an estimated average of 20,000 gpd (thus reducing the salinity loading by 459 kg/day, or 2.7 percent of the total NBK-Bremerton salinity loading). These calculations are discussed in Section 5.4.1 above. In addition to reducing the salinity introduced to the sanitary sewer system, keeping water off the DD floor increases DD safety.

8.3.1 Design Parameters

A study is recommended to confirm the DD hydrology and to confirm the number of relief wells needed to prevent water intrusion onto the DD 2 floor. DD 2 is the only PSNS DD designed as a full gravity graving dock, meaning it does not have an existing groundwater relief system. Full gravity graving dry docks have enough mass to resist external forces without pressure relief from a groundwater relief system. The floor is extra-thick due to the high mass design requirement, and record documents indicate that the floor is 18 feet 4 inches thick at the centerline, tapering to 11 feet thick at the perimeter walls. This proposed project requires additional study (compared with adding relief wells to the other dry docks at PSNS) because the other DDs are pressure relieved and already have groundwater relief systems. The recommended study should analyze whether drilling wells at DD 2 would negatively impact the structural system or the hydrostatic integrity of the dry dock. Relief well design parameters are similar to recommendations for DD 6 above. See drawings in Appendix G1 for a conceptual layout of DD 2 relief wells.

A floor crack allowing groundwater seepage is reported at the centerline near the north end. Since structural cracks like these are most difficult to fix, keeping the groundwater level below the floor is likely the best way to mitigate crack leakage.

8.4 Potential Project 4: DD 5 Mitigation of Groundwater Intrusion at Floor

About 1.5 percent of the salinity load at LS 1 is from the DD 5 PWCS discharged into the forced main system east of the LS 1.

If salinity reduction is needed in addition to the above recommendations, then it is recommended that the groundwater intrusion through the floor of DD 5 be mitigated with the installation of approximately 14 new relief wells. The intent is to stop all groundwater intrusion through the DD floor and thereby reduce the flow into the PWCS by an estimated average of 20,000 gpd (thus reducing the salinity loading by 1,200 kg/day, or 6 percent of the total NBK-Bremerton salinity loading during Phase 3). In addition to reducing the salinity introduced to the sanitary sewer system, keeping water off the DD floor increases DD safety.

8.4.1 Design Parameters

The design for DD 5 would be essentially the same as for DD 4 (except based on a passive relief well system) because DD 4 and DD 5 are nearly identical except for pumpwell locations. A study should be conducted to confirm the DD hydrology and the number of relief wells needed. Relief well design parameters are similar to recommendations for DD 6 above. See drawings in Appendix G1 for a conceptual layout of DD 5 relief wells.

8.5 Potential Project 5: Add PWCS Dilution Tanks to DD 6 PWCS Tank Farm

Potential Project 5 would allow NBK-Bremerton to store low-salinity rainwater on site. This rainwater could then be sent to the sewer when the conductivity at LS 1 is high, diluting the discharge from the shipyard. (Alternatively, high salinity sewage could be collected and stored on-site during times when the salinity concentration through LS 1 is at a peak and then slowly released at a later time when salinity through LS 1 is lesser.)

As currently designed, all process water sent to the existing tanks must be treated by the OWTS plants. To use the existing tanks for rainwater holding would require new bypass piping and controls.

This potential project involves providing new PWCS dilution tanks (holding tanks) to collect stormwater during rainfall events to dilute the sanitary sewer effluent. The existing PWCS holding tanks would not be used for the dilution project but would remain in service as currently used. During rainfall events, the salinity levels in the process water are lowered by the large volume of rain, but salinity still exists from groundwater intrusion through the DD floors. The intent is for the additional dilution tanks to provide relatively low salinity water that can then be discharged into the sewer on a delayed basis on non-rainy days. This mixing of detained diluted process water (with high rainwater content) with the more concentrated sewer effluent on non-rainy days would decrease the sewer salinity concentration, leaving LS 1.

This concept is technically feasible where heavy stormwater-laden process water can be collected and stored in dilution tanks until a non-rainy day. New pumps would discharge from new dilution tanks to the sewer based on LS 1 conductivity levels, as sensed by the existing LS 1 conductivity meter.

The effectiveness of this potential project is inhibited by the fact that this system is unreliable during the summer months. It is improbable that summer rains can maintain the stormwater volume needed to lower salinity to the desired concentrations. For example, if 150,000 gallons of PWCS dilution tank storage were provided, these 150,000 gallons would only reduce the salinity concentrations by approximately 25 percent for one day (assuming the total daily average flow rate is 600,000 gpd, and that the stored rainwater has zero salinity). Consequently, some other means of reducing the salinity during the summer months would have to be implemented.

WSP has evaluated the potential to use the existing PWCS tanks (instead of adding new tanks) to achieve the ability to store rainwater on site for discharge during periods of high salinity at LS 1. From an engineering standpoint, the current PWCS holding tanks could work, but this creates a system requiring significant attention from the operations staff. The operation would involve filling the PWCS tanks at the beginning of each rain event, then sending 950,000 gallons to the sewer (rather than the current operation where 950,000 gallons are sent to the sewer, then the water is diverted to the PWCS holding tanks). However, this operational change would also be inhibited by the following items.

1) The PWCS holding tanks would need to be emptied before each rainfall event because there would be no place for the high turbidity process water to go between rainstorms if the tanks were full. Also, PWCS operations staff cannot perfectly estimate when each rainfall event will occur. This operation would require that certain staff be partially dedicated to making decisions regarding when to empty/fill the existing tanks. This added work creates an excessive burden for the operations staff.

2) If the PWCS holding tanks are filled during each storm event, then the OWTS will be required to treat all of this water (rather than letting the rainfall from each storm event go directly to the City of Bremerton with NBK-Bremerton only treating the overflow). This additional treatment creates more maintenance and shortens the life of equipment in the OWTS plant.

3) The PWCS may already have fewer storage tanks than required for the design storm and operating conditions. The PWCS were evaluated for the two-year 24-hour storm event. The evaluation assumes additional loads to PWCS from groundwater intrusion or dry dock processes. At these design assumptions, a total of four more 40,000-gallon storage tanks would be required to capture the design storm and operating conditions. These tanks could be distributed across the shipyard, but should be located at dry docks with higher PWCS flows.

WSP has evaluated another potential change in operations suggested by NBK-Bremerton staff. Evaluate whether the process water destination can be changed to discharge directly to the Sinclair Inlet. The original sequence of operation from upgrade projects P-419, P-420, and P-422 discharged PWCS effluent to the Sinclair Inlet when the process water turbidity levels were below 4 Nephelometric Turbidity Units (NTU). It was postulated that the low NTU correlated with low copper levels in the effluent. WSP's team thinks this is a reasonable practice, as the system operators could do it at no capital cost, only a change in operations. However, the system operators ended this practice in recent years due to multiple copper exceedances in the wastewater discharged to the bay. System operators have suggested that the NTU sensors are old and the output signals appear to have become inaccurate. It may be that an upgrade to the NTU sensors is required to make this change possible.

8.6 Potential Project 6: Use Alternative Means for Freeze Protection of CHT Lines

As previously discussed, the CHT hoses are infrequently flushed with saltwater to prevent freezing. The potential to reduce salinity within the sewer system via operational changes related to CHT hose flushing was discussed throughout the various project meetings and correspondences. While the salinity in the flushing water is high, the low volume of flushed water and infrequency of flushing events inhibit the potential to reduce overall salinity from the base. It is estimated that less than a 0.3 percent reduction in salinity loading is possible.

8.6.1 Design Parameters

It is recommended to use an alternative means of freeze protection for CHT lines, such as heat tape or insulation. Per NBK-Bremerton staff, NBK-Bremerton has started using heat tape insulation on smaller CHT hoses where possible to reduce usage of saltwater for freeze protection.

8.7 Potential Project 7: Treatment of Discharge from Docked Vessels

As discussed in Section 5.1 and shown in Figure 5, the aircraft carrier docked at Pier D West contributed to roughly 12 percent of the total salinity loading recorded during Phase 1 of monitoring. Section 5.1 also discusses LS 1 daily average conductivity data between February 2021 and September 2021, which shows that the arrival of CVN-68 at Pier B in early March 2021 increased the average conductivity from 4.2 mS/cm to 8.7 mS/cm at LS 1. The arrival of CVN-71 at Pier D in late July 2021 further increased the average conductivity from 8.7 mS/cm to 14.9 mS/cm. Thus, the possibility of reducing salinity by treating ship discharge before entering NBK-Bremerton's sewer system was evaluated.

It was determined that there are numerous factors deleterious to the feasibility of treating ship sewage discharge (known as "Collection, Holding, and Transfer" or CHT), including:

1) Prior to any treatment that will reduce salinity of the ships CHT discharge, such as reverse osmosis, the discharge would first need to be treated biologically to the secondary level of treatment.

2) With flows higher than 100,000 gpd discharging from large, docked ships, the treatment facility would need to be larger than the area available near the piers on site.

3) Removing salinity from CHT effluent (largely saltwater) typically has very high energy demands, and operators will need to be employed and trained to operate and maintain the facility.

4) Any brine discharge would need to be discharged to an approved mixing zone offshore, as adding it back to the sewer system would counter the purpose of the treatment.

8.8 Potential Project 8: Conversion of the Carrier Restroom Facilities Sanitary Flush from Saltwater to Freshwater

As discussed in Section 5.1 and shown in Figure 5, the aircraft carrier docked at Pier D West contributed to roughly 12 percent of the total salinity loading recorded during Phase 1 of monitoring. Section 5.1 also discusses LS 1 daily average conductivity data between February 2021 and September 2021, which shows that the arrival of CVN-68 at Pier B in early March 2021 increased the average conductivity from 4.2 mS/cm to 8.7 mS/cm at LS 1. The arrival of CVN-71 at Pier D in late July 2021 further increased the average conductivity from 8.7 mS/cm to 14.9 mS/cm. Thus, the possibility of converting the CVN sanitary flush water from saltwater to freshwater was evaluated.

Piping systems onboard a CVN include firefighting, cooling, and sanitary facility flushing water, provided by a single non-potable water system. The non-potable system is supplied from the CVN saltwater fire main, typically drawing the saltwater from the bay or ocean. The CVN saltwater system connects to the ship-to-shore saltwater system in dry dock. Due to the configuration of the non-potable piping systems onboard a CVN, the conversion of the sanitary flush water from saltwater to freshwater would require either:

1) Outright replacement of all CVN saltwater flow requirements with freshwater, or

2) When in dry dock, routing temporary freshwater pipes/hoses to all 23 onboard flushing stations, effectively separating the sanitary flushing system from the saltwater system.

First, the outright replacement of CVN saltwater with freshwater is currently not possible. Per UFC 4-150-02, Table C-3, each CVN requires 10,000 gpm non-potable water to meet firefighting, cooling, and flushing flow requirements. Additionally, UFC 4-213-12, Table 24, which specifies utility requirements for DD 6, lists saltwater flow/pressure requirements of 12,000 gpm at 125 psi. This pressure is needed for firefighting. The existing freshwater system at NBK-Bremerton cannot provide the required flow and pressure and would require significant upgrades to the freshwater system. Upgrades would include replacing onboard plumbing fixture flush valves, thousands of feet of new shore distribution piping, and firefighting pumping stations, with substantial capital improvement costs. In addition, the City of Bremerton cannot currently provide this much freshwater.

Second, routing temporary freshwater pipes/hoses to the flushing stations is possible but impractical and ill-advised. There are 23 onboard flushing stations with near unsolvable logistical issues to make all the connections. It would also require many linear feet of temporary piping/hoses onboard the CVN and the coordination of outages to isolate the ship's fire main system to tie in the temporary freshwater systems while in dry dock. Additionally, there is sea growth, such as barnacles and mussels, inside the permanent saltwater piping systems onboard, which cannot live in freshwater. The dead sea growth would clog the onboard piping and flush valves, making them inoperable. These plumbing fixtures must continue to operate with saltwater while at sea. Considering that carriers frequently come and go at NBK-Bremerton, supplying temporary freshwater to the CVN is not feasible.

8.9 Potential Project 9: Treatment of OWTS Effluent for Discharge to the Sinclair Inlet

Although the OWTS contribution to overall salinity leaving NBK-Bremerton was roughly 3 percent during the monitoring period, other sampling done by NBK-Bremerton in 2019 showed that OWTS contribution ranged from 16 to 27 percent of the overall salinity loading. NBK-Bremerton has expressed interest in potentially treating the OWTS effluent to reduce the levels of copper and zinc so that it may be discharged to the Sinclair Inlet.

8.9.1 Design Parameters

Data from 2015 was used by NBK-Bremerton staff to estimate the copper and zinc levels in the OWTS discharge. In 2015, the average copper concentration was 26 parts per billion (ppb) and the maximum was 323 ppb, and the average zinc concentration was 59 ppb and the maximum was 395 ppb.

The current NPDES permit is dated 1994, and the EPA is currently drafting a new permit. NBK-Bremerton staff have indicated that they expect the new permit will contain a monthly average discharge limit of around 5 ppb for copper and a zinc monthly average limit of around 94 ppb, and that those are the only two metals of concern. NBK-Bremerton staff also indicated that they expect a 10 ppb copper discharge from the OWTS's treated effluent to be acceptable, as it is blended with groundwater prior to discharge.

If the OWTS effluent is to be treated directly and with no storage beforehand, the treatment systems should be capable of treating 200 gpm, as the OWTS effluent is pumped at 200 gpm. If the treatment system treats less than 200 gpm, an equalization tank should be provided to mitigate any difference between the OWTS discharge flowrate and the maximum flowrate of the treatment system.

In coordination with vendors, it was determined that the treatment processes to treat 100 gpm could be contained within two 40-foot standard shipping containers. In general, accumulated sludge could be stored and processed through a filter press prior to removal from site. This system would include an equalization tank to collect and store OWTS discharge prior to treatment, which allows the treatment process to use a flowrate of 100 gpm rather than 200 gpm. Additional polishers could be added to remove excess and meet the lower ppb requirements.

The treatment process currently uses a three-stage chemical reaction system with a clarifier and a filter press but is not able to meet the 10 ppb copper discharge level. From the equalization tank, the flow will be pumped to the chemical reaction system that processes pH adjustment, coagulation, and flash mix and slow mix flocculation. Each stage of the chemical reaction process will be individually sized to ensure adequate retention times and mixing speeds.

The chemically treated discharge will then gravity flow to an inclined plate clarifier that will perform mechanical separation of the suspended solids and water. Clarified water will overflow through a weir system to a final pH adjustment before discharge. From the bottom of the inclined plate clarifier, the accumulated sludge will be pumped to a sludge thickening and storage tank where the sludge will be proceeded through a filter press. Finally, the effluent of the filter press will return to the headworks for processing.

These additional treatment processes will reduce the copper and zinc levels after the oil is separated from the oily water.

Existing permitted outfalls should be used, meaning that OWTS discharge will need to be pumped and/or piped to the nearest approved outfall prior to being discharged to the Sinclair Inlet.

8.10 Potential Project 10: 150,000–gallon Sanitary Sewer Reserve Tank

Potential Project 10 evaluates a concept proposed by NBK-Bremerton staff at the kickoff meeting. The idea suggests using the existing 150,000-gallon reserve (surge) tank combined with LS 1 to normalize salinity levels through LS 1. The proposed normalization would be accomplished by controlled mixing of the stored (normal) wastewater with the periodic higher salinity wastewater (from CVN CHT discharge, for example) to equalize salinity levels at the LS 1 discharge.

The combined storage capacity of the LS 1 wet well and reserve tank is about 217,500 gallons before they overflow to Sinclair Inlet. However, to use the needed volume available in the reserve tank, the wastewater level in the LS 1 wet well will be so high that wastewater will back up in the gravity line, essentially making the reserve tank of little use for this purpose. Currently, the usable capacity of the reserve tank is only about 10,000 gallons due to the high elevation of the reserve tank. This proposed project would modify the interconnection between the reserve tank and LS 1 in order to take advantage of more of the volume of the reserve tank.

8.10.1 Evaluation and Design Parameters

Complex controls, piping changes, and transfer pumps are required for this project to be viable. This project would add increased operational complexity and required maintenance at LS 1 due to the complex controls and additional equipment. Design and installation include the following:

- Hydraulically separate the LS 1 wet well and the reserve tank by removing or closing the existing wastewater conduit common to both tanks.
- Provide new transfer pumps in the reserve tank to pump low salinity effluent to the LS 1 wet well for mixing and dilution during LS 1 high salinity influent periods.
- Provide new transfer pumps in the LS 1 wet well to pump low salinity effluent to the reserve tank for storage until needed.
- Provide control valves, conductivity meters, and electronic control strategies using the new transfer pumps to (1) divert low salinity influent to the reserve tank, (2) divert high salinity influent to the wet well, and (3) remix reserve tank effluent with wet well influent.

An option to design a new reserve tank with a much lower invert elevation and a new LS 1 sump, both designed to work in unison versus modifying the existing reserve tank, should be considered. As a minimum, this option should be studied further before embarking on Potential Project 10 as defined.

8.11 Potential Project 11: Change PWCS Discharge Destination to Sinclair Inlet

WSP has evaluated another potential change in operations suggested by NBK-Bremerton staff. Evaluate whether the process water destination can be changed to discharge directly to the Sinclair Inlet. The original sequence of operation from upgrade projects P-419, P-420, and P-422 discharged PWCS effluent to the Sinclair Inlet when the process water turbidity levels were below 4 NTUs. It was postulated that the low NTU correlated with low copper levels in the effluent. WSP's team believes this is a reasonable practice, as the system operators could do it at reasonable capital cost, with only a change in operations and an upgrade of all the NTU sensors. However, the system operators ended this practice in recent years due to multiple copper exceedances in the wastewater discharged to the bay. The existing NTU sensors are reaching the end of their useful life. It may be that an upgrade to the NTU sensors, including providing redundant sensors for improved reliability in each wet well, is required to make this change possible. The low turbidity dry dock groundwater intrusion should be able to be discharged to Sinclair Inlet using the turbidity sensor system once it can be verified that there is no copper in this low turbidity water.

8.12 Summary of Potential Projects Comparing Anticipated Salinity Reduction

Potential Project 1: Sanitary sewer pipe repair on the gravity sewer collection system upstream of LS 1, and the system between LS 9 and MH 9-8. Phase 1 results indicated that this potential project had the potential for 65 percent reduction in salinity load at LS 1. However, further monitoring done during Phase 3 indicate that the salinity loading from the sanitary sewer pipe upstream of LS 1 may be much less than what was estimated during Phase 1 (roughly 2 percent of the flows at LS 1).

Potential Project 2: Mitigation of groundwater intrusion at DD 6 has the potential for 12.3 percent reduction in salinity load at LS 1.

Potential Project 3: Mitigation of groundwater intrusion at DD 2 has the potential for 2.7 percent reduction in salinity load at LS 1.

Potential Project 4: Mitigation of groundwater intrusion at DD 5 has the potential for 1.5 percent reduction in salinity load at LS 1.

Potential Project 5: Adding Dilution Tanks to DD 6 PWCS tank farm (or at any other PWCS, OWTS, or other sewer discharge point) has the potential to prolong the release of saline water, reducing the salinity concentration in downstream sewer systems, but ultimately not impacting the salinity loading, making this project unneeded.

Potential Project 6: Using an alternative means for freeze protection of the CHT lines has the potential for roughly 0.3 percent reduction in salinity load at LS 1.

Potential Project 7: Treating discharge from ships to reduce the salinity entering NBK-Bremerton's sewer system has the potential to remove 12 percent or more of the total salinity load from NBK-Bremerton, while large ships are docked and discharging. However, it was determined that treatment is infeasible.

Potential Project 8: Conversion of the sanitary flush water from saltwater to freshwater has the potential to remove 12 percent or more of the total salinity load from NBK-Bremerton, while a CVN is in dry dock and discharging CHT. However, it was determined that conversion to freshwater is infeasible.

Potential Project 9: Treating OWTS effluent to discharge to the Sinclair Inlet has the potential to significantly reduce the amount of salinity (16 to 27 percent reduction) that NBK-Bremerton sends to the City's system during periods where the OWTS are under heavy use. The cost, quantity, and size footprint may be highly prohibitive for this potential project.

Potential Project 10: Using the existing 150,000-gallon sanitary sewer reserve tank to normalize salinity at LS 1 has the potential to prolong the release of saline water, reducing the salinity concentration in downstream sewer systems, but will ultimately not impacting the salinity loading. The project may allow more volume of the 150,000-gallon tank to be used.

Potential Project 11: Change PWCS discharge destination to Sinclair Inlet by reverting to the original control strategy and by upgrading the NTU sensors, including a redundant sensor for improved reliability. Change should result in significant reduction in process water discharge to LS 1.

8.13 Recommendations to Reduce or Eliminate Sources of High Salinity

Potential Projects 2 through 5 should be considered with the highest priority of the potential projects, they are the most feasible and have a high potential to reduce salinity discharge levels from NBK-Bremerton. Although the contributions from each PWCS varied between different phases of monitoring, the PWCSs in general were always large contributors to the overall salinity at NBK-Bremerton. Specifically, DD 6 and DD 5 should be given highest priority. Note that between Phase 1 and Phase 3 of monitoring, PSNS & IMF has planned a separate project to fix the groundwater intrusion at DD 5 PWCS.

Potential Project 6 has already been partially initiated by NBK-Bremerton staff, who have used heat tape on smaller CHT lines. This practice should be continued and expanded, as feasible, to reduce use of saltwater in NBK-Bremerton processes.

Potential Project 9 should be evaluated further to determine the feasibility. If feasible, it has significant potential to reduce overall salinity discharged from NBK-Bremerton.

Potential Project 11 should also be evaluated further to determine the feasibility of discharging PWCS flows to the Sinclair Inlet.

Potential Project 1 has a low potential to reduce the overall salinity discharged from NBK-Bremerton; however, the project would be relatively simple and can stop direct groundwater intrusion into the sewer system.

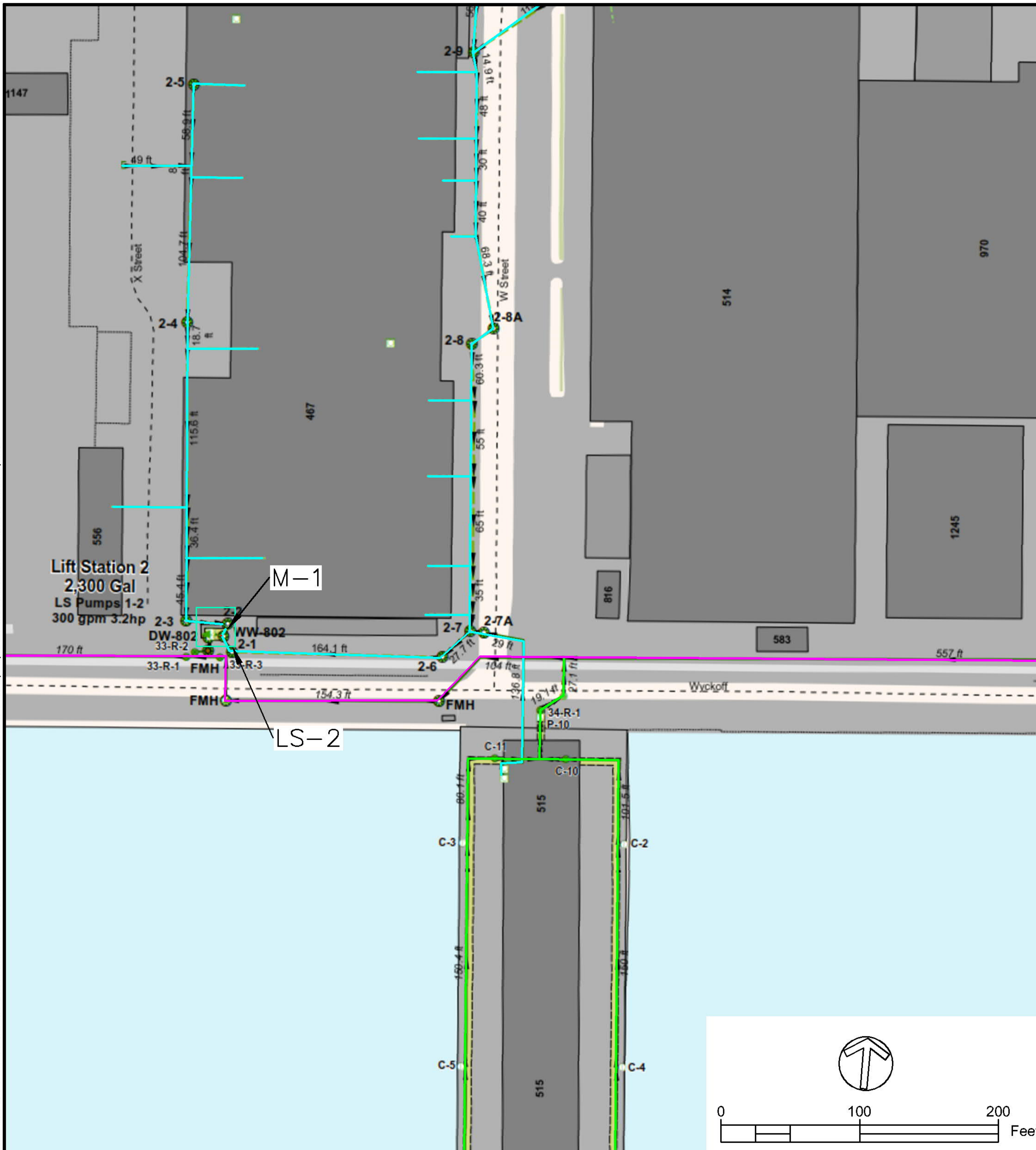
9.0 COST ANALYSIS

Cost estimate will be submitted under separate cover for the revised final report submittal in accordance with SAES Attachment (4), footnote 4.

10.0 ACRONYMS AND ABBREVIATIONS

BOD	biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
CCTV	closed circuit television
CHT	collection, holding, and transfer
CIP	capital improvement project
CIPP	cured-in-place pipe
City	City of Bremerton
DAS	domesticated activated sludge
DD	dry dock
DMR	discharge monitoring report
DO	dissolved oxygen
Ecology	Washington State Department of Ecology
EPA	Environmental Protection Agency
gpd	gallons per day
gpm	gallons per minute
GWR	groundwater relief
GWRP	groundwater relief pump
I/I	infiltration/inflow
LS	lift station
mgy	million gallons per year
MH	manhole
mS/cm	milli siemens per centimeter
NAVFAC	Naval Facilities Engineering Systems Command
NBK	Naval Base Kitsap
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OWTS	oily water treatment system
ppb	parts per billion
ppt	parts per thousand
psu	practical salinity unit
PSNS & IMF	Puget Sound Naval Shipyard and Intermediate Maintenance Facility
PWCS	process water collection system
SAP	Sampling and Analysis Plan
UNESCO	United Nations Educational, Scientific, and Cultural Organization-Institute for Water Education
VFD	variable frequency drive
WWTP	Wastewater Treatment Plant

Appendix A
Monitoring Station Location Exhibits



LEGEND

LIFT STATION

FORCE MAIN LINE

EXIST. GRAVITY LINE

EXIST. PRESSURE LINE

METER 1: LS2 WET WELL

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

WSP USA INC.
862 E. HOSPITALITY LANE
SUITE 350
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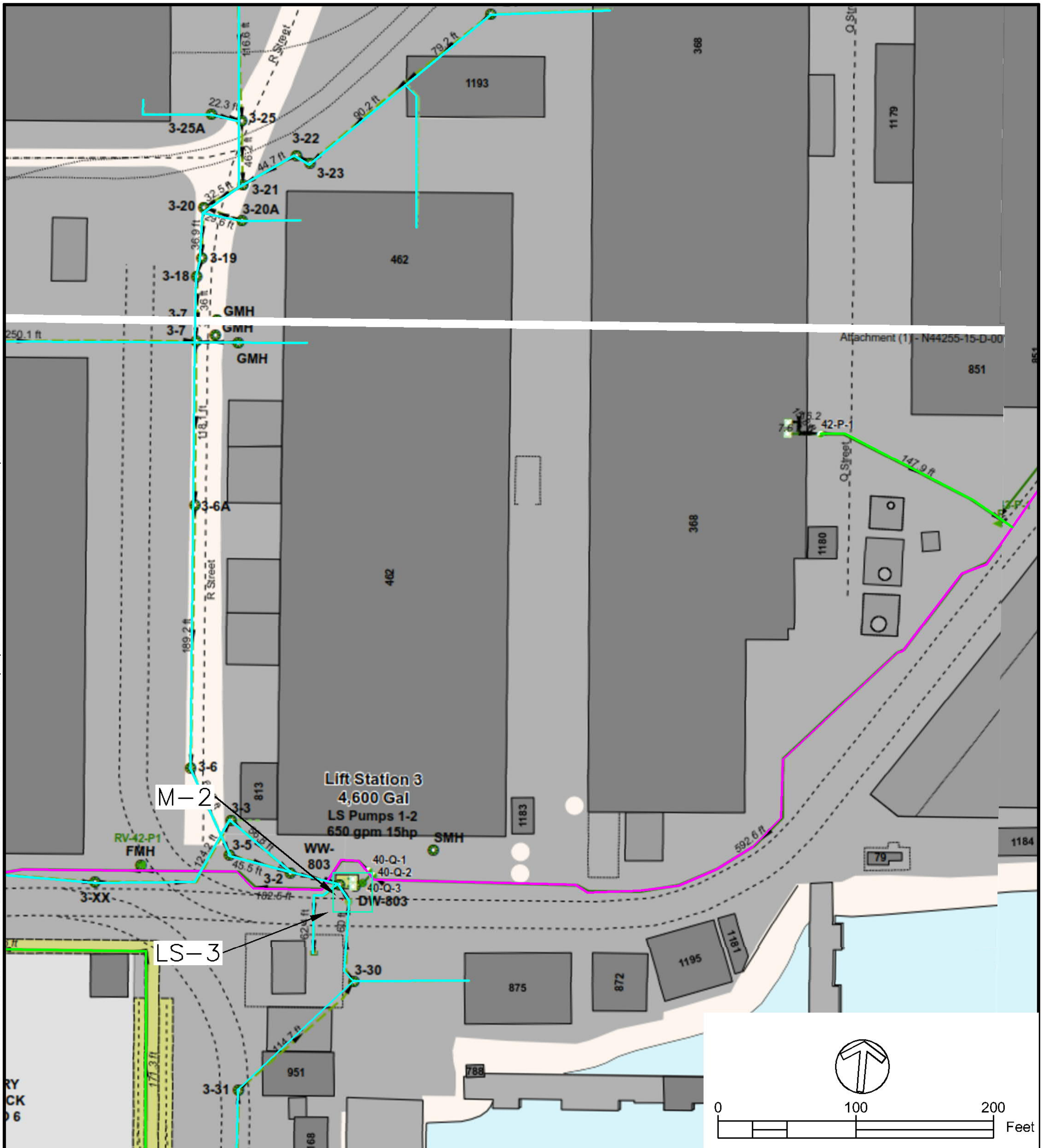

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LEGEND

LIFT STATION

FORCE MAIN LINE

EXIST. GRAVITY LINE

EXIST. PRESSURE LINE

METER 2: LS3 WET WELL

MONITORING STATIONS - SALINITY STUDY

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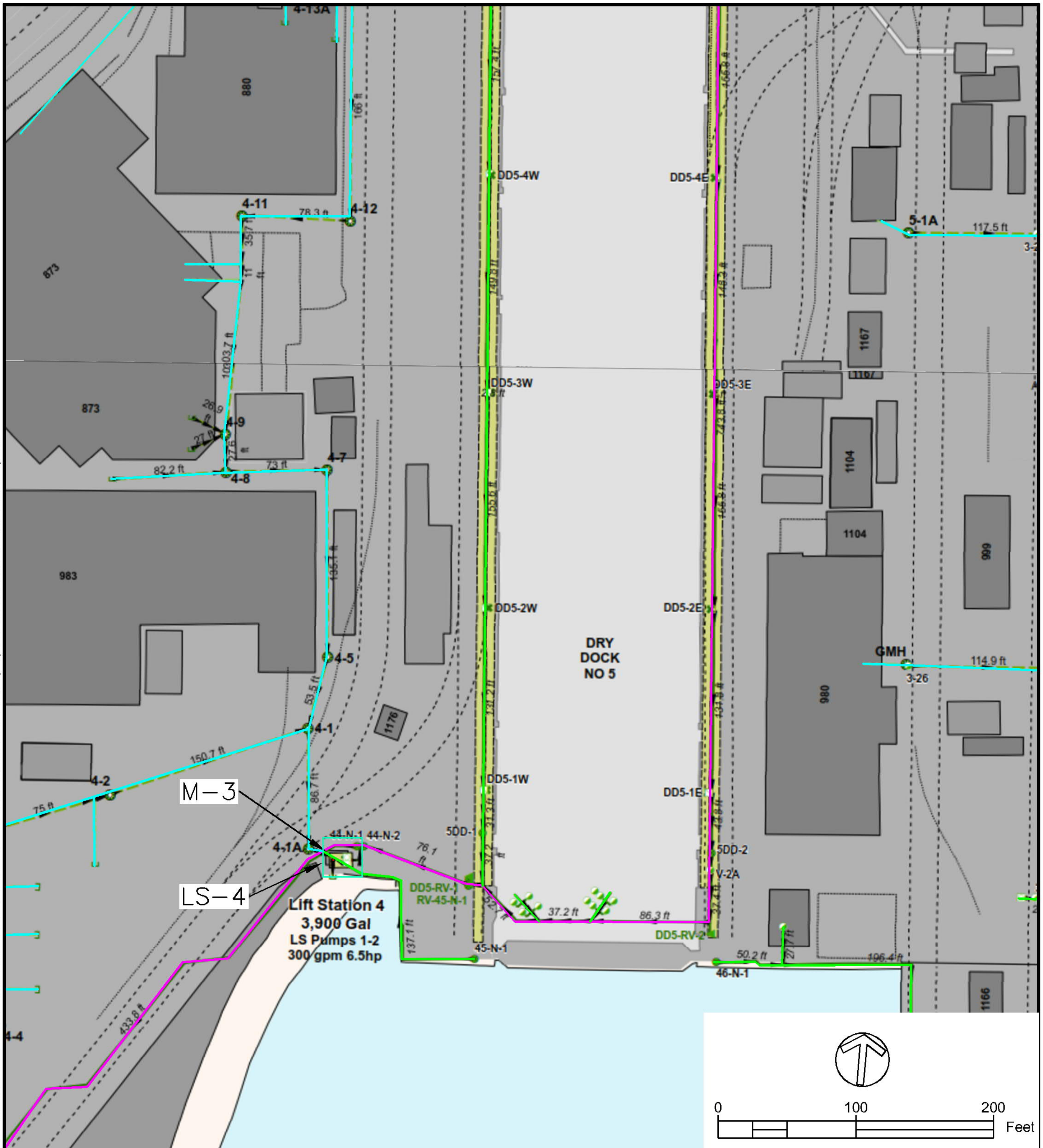

METER 3: LS 4 WET WELL

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

LEGEND

- LIFT STATION
- FORCE MAIN LINE
- EXIST. GRAVITY LINE
- EXIST. PRESSURE LINE

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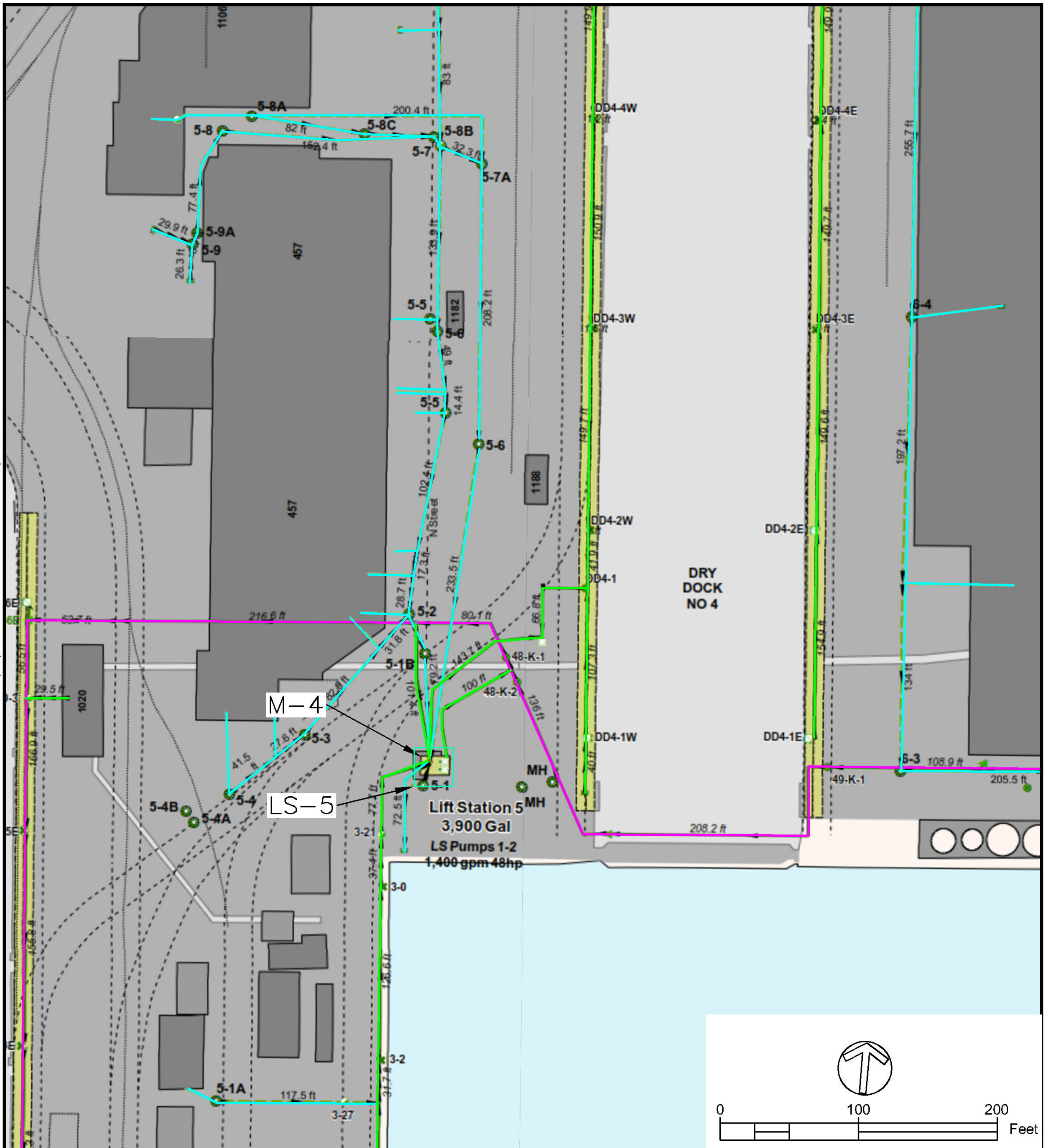

LEGEND

LIFT STATION

FORCE MAIN LINE

EXIST. GRAVITY LINE

EXIST. PRESSURE LINE

METER 4: LS 5 WET WELL

MONITORING STATIONS - SALINITY STUDY

CITY OF BREMERTON - NAVAL COMPLEX

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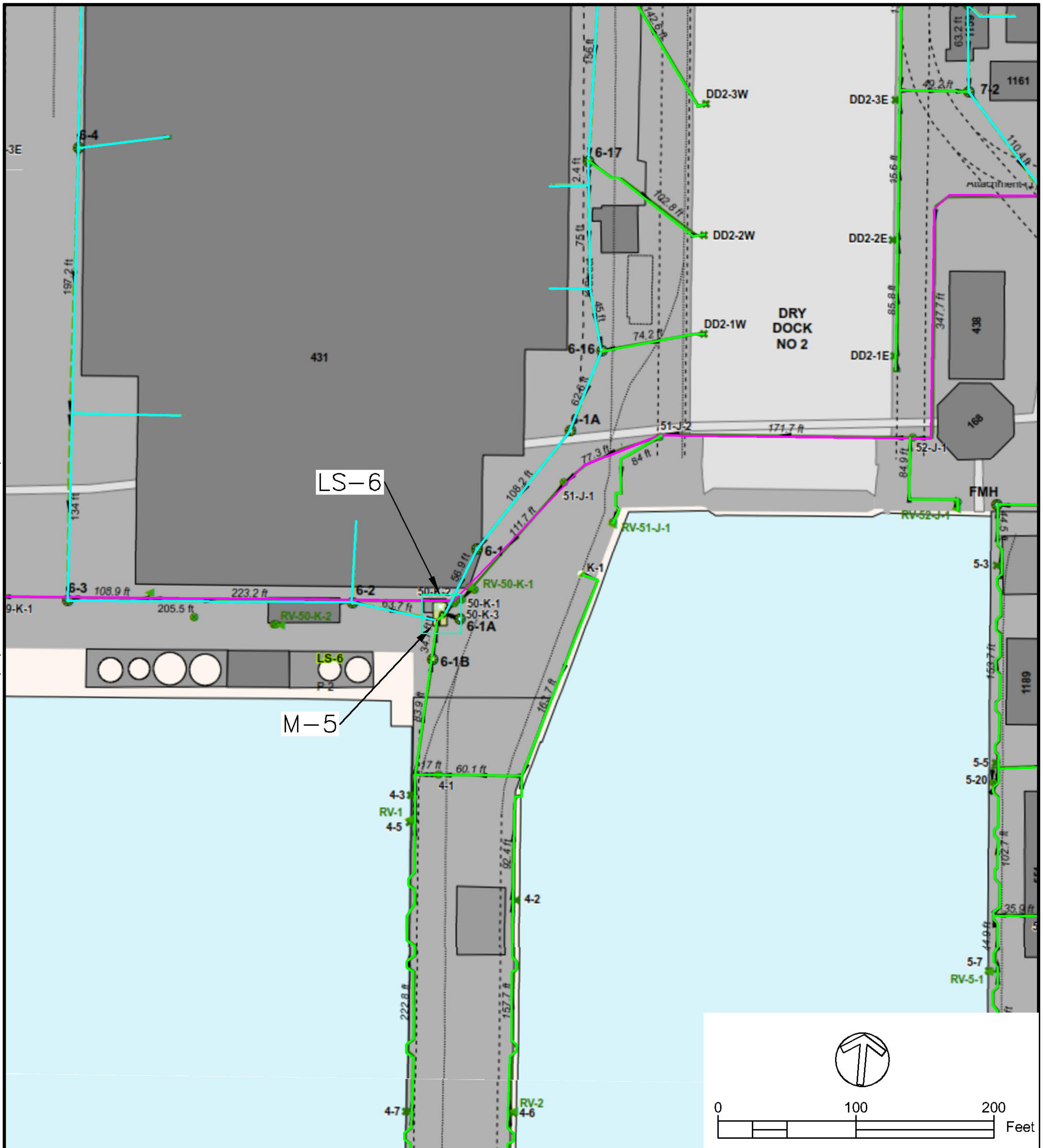

LEGEND

LIFT STATION

FORCE MAIN LINE

EXIST. GRAVITY LINE

EXIST. PRESSURE LINE

METER 5: LS 6 WET WELL

MONITORING STATIONS - SALINITY STUDY
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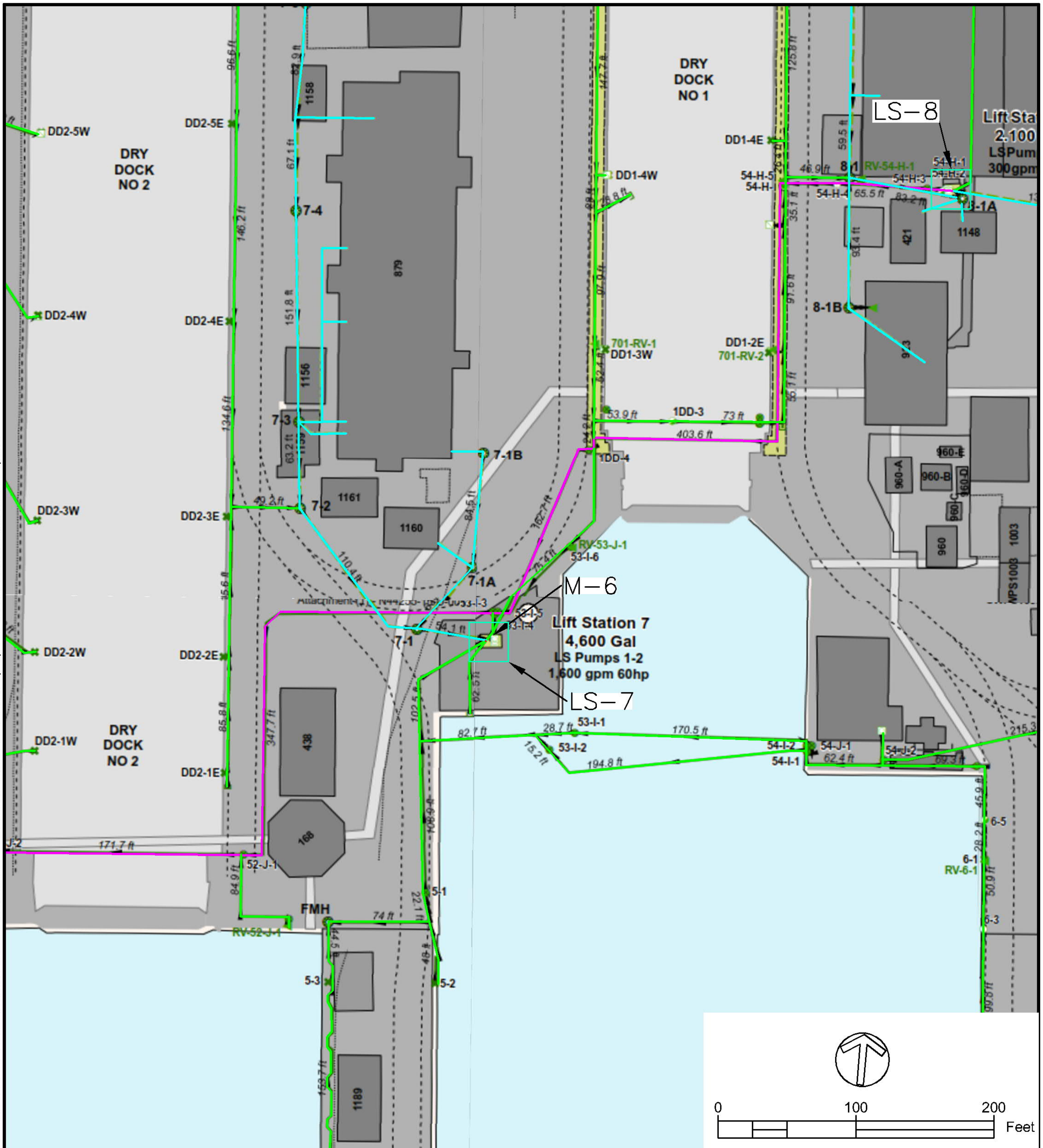

METER 6: LS 7 WET WELL

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

LEGEND

- LIFT STATION
- FORCE MAIN LINE
- EXIST. GRAVITY LINE
- EXIST. PRESSURE LINE

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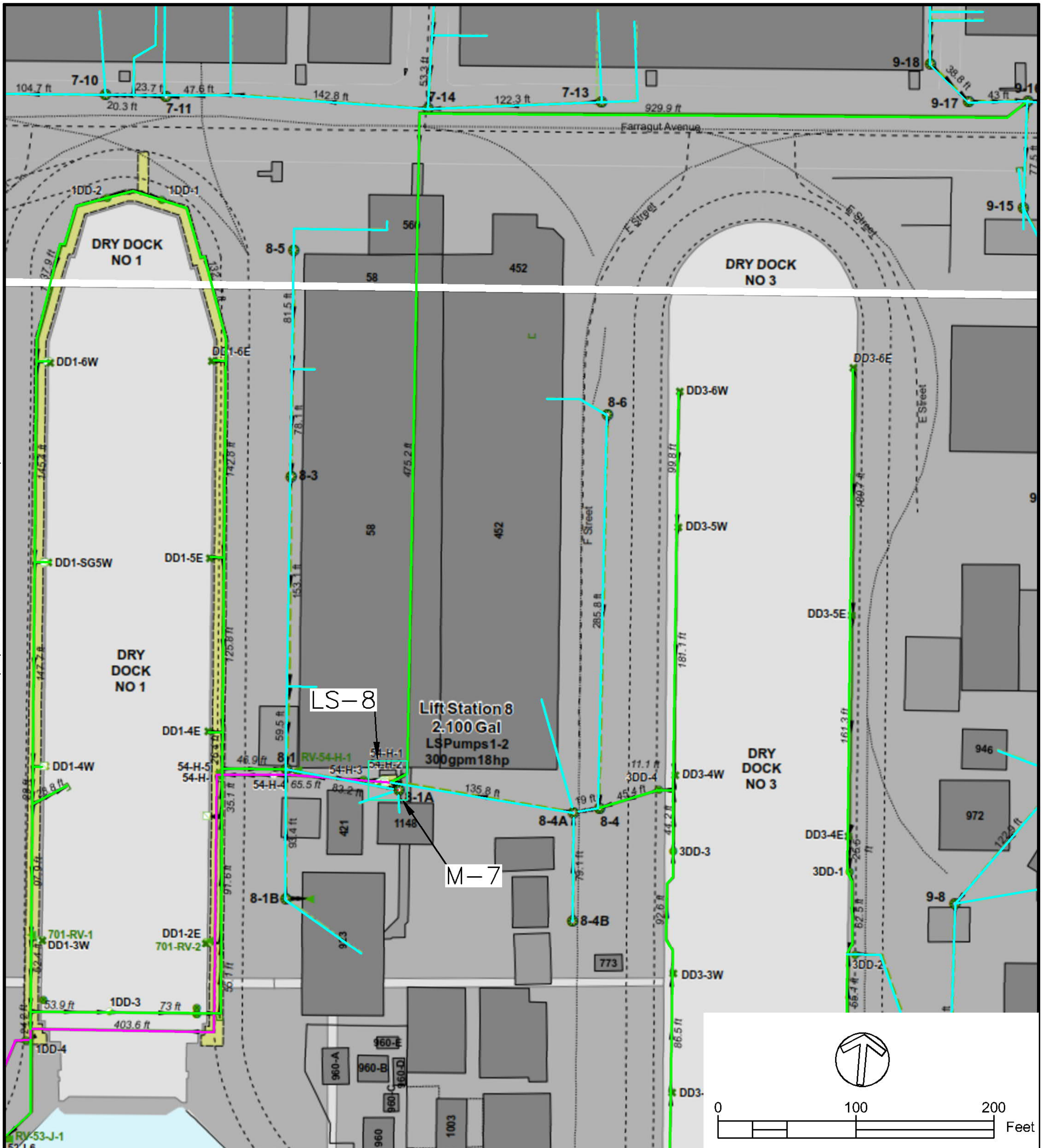

METER 7: LS 8 WET WELL

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

LEGEND

- LIFT STATION
- FORCE MAIN LINE
- EXIST. GRAVITY LINE
- EXIST. PRESSURE LINE

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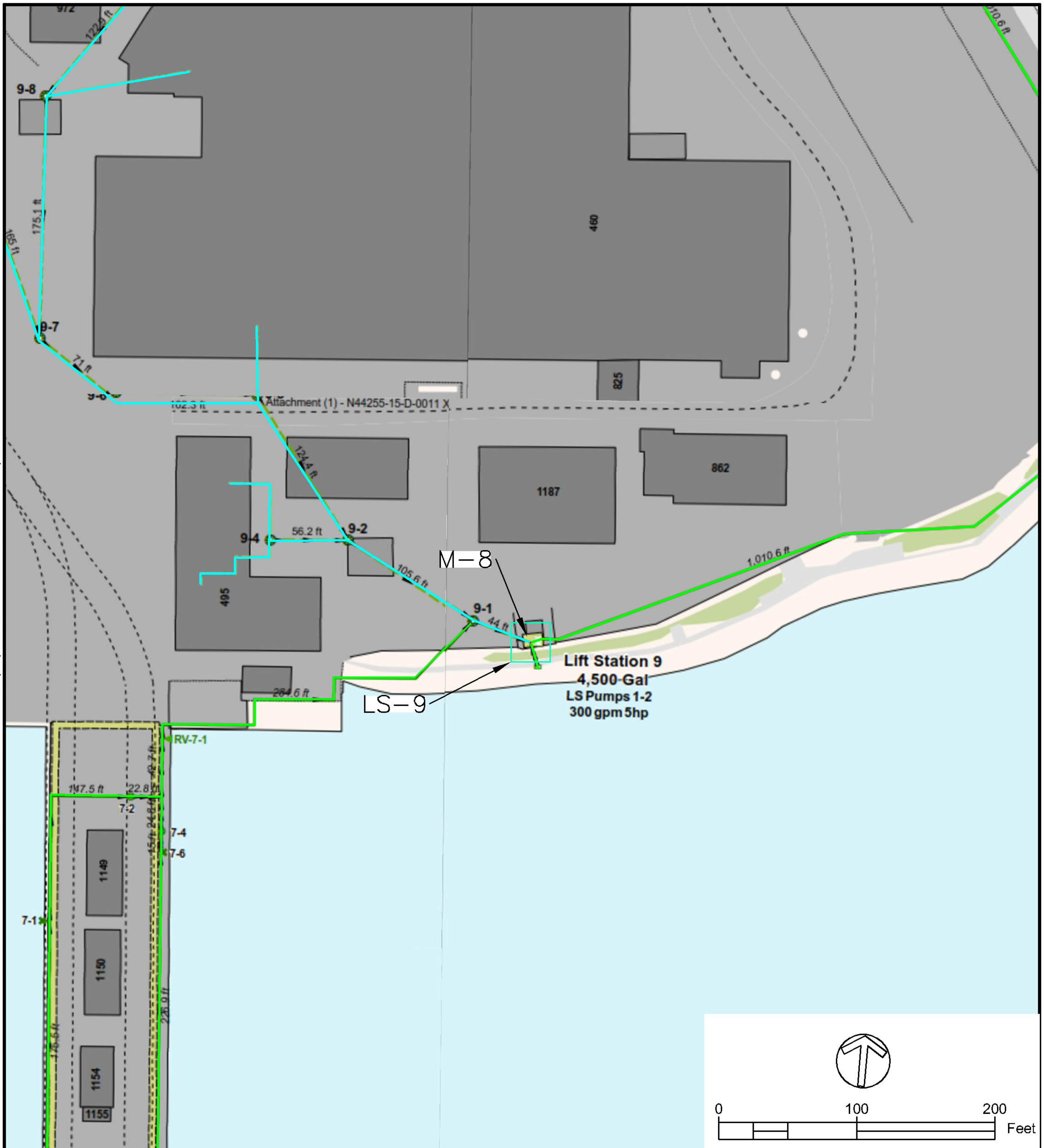

LEGEND

LIFT STATION

FORCE MAIN LINE

EXIST. GRAVITY LINE

EXIST. PRESSURE LINE

METER 8: LS 9 WET WELL

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

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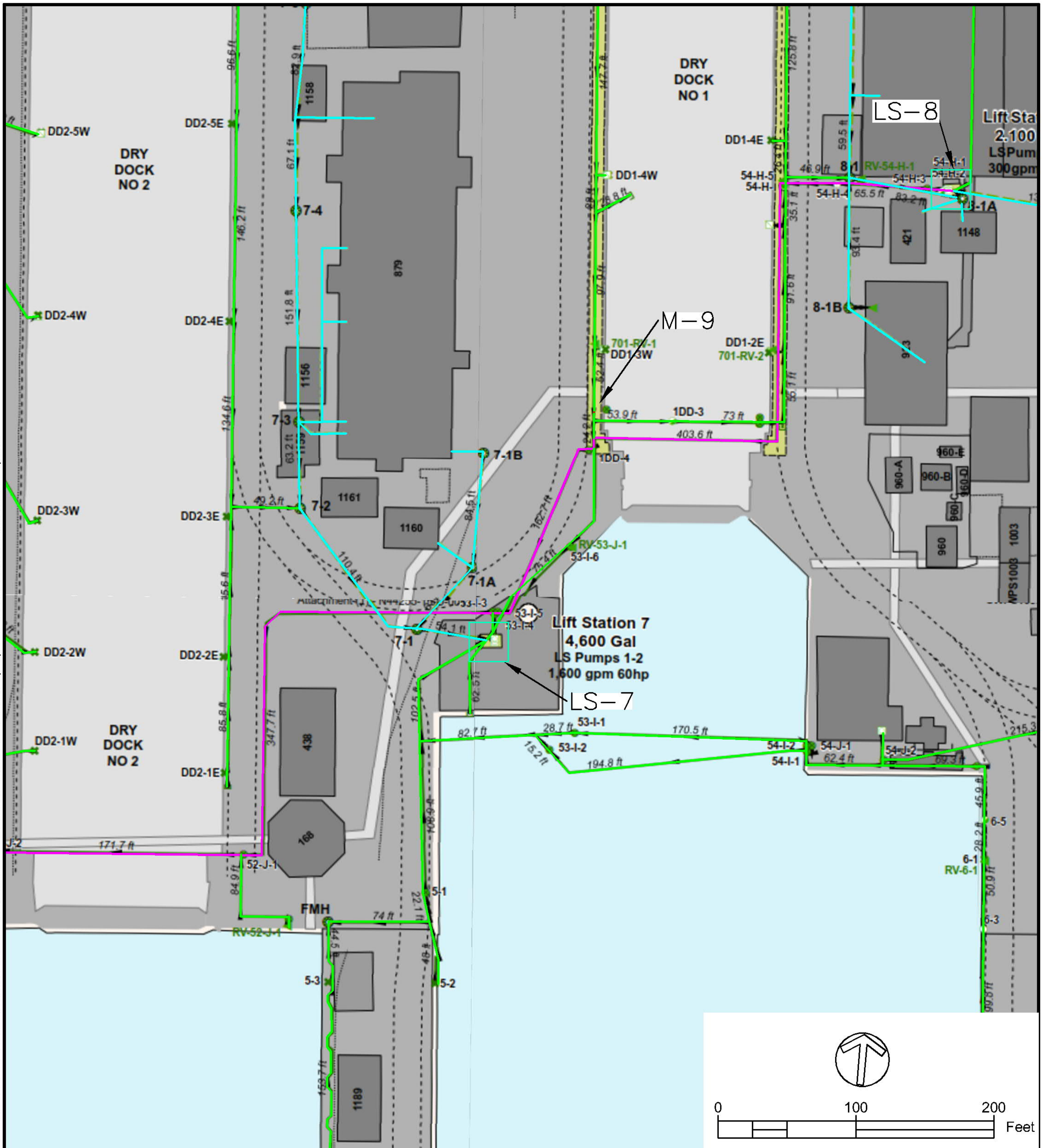

LEGEND

LIFT STATION
FORCE MAIN LINE
EXIST. GRAVITY LINE
EXIST. PRESSURE LINE

METER 9: DD1 PWCS

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

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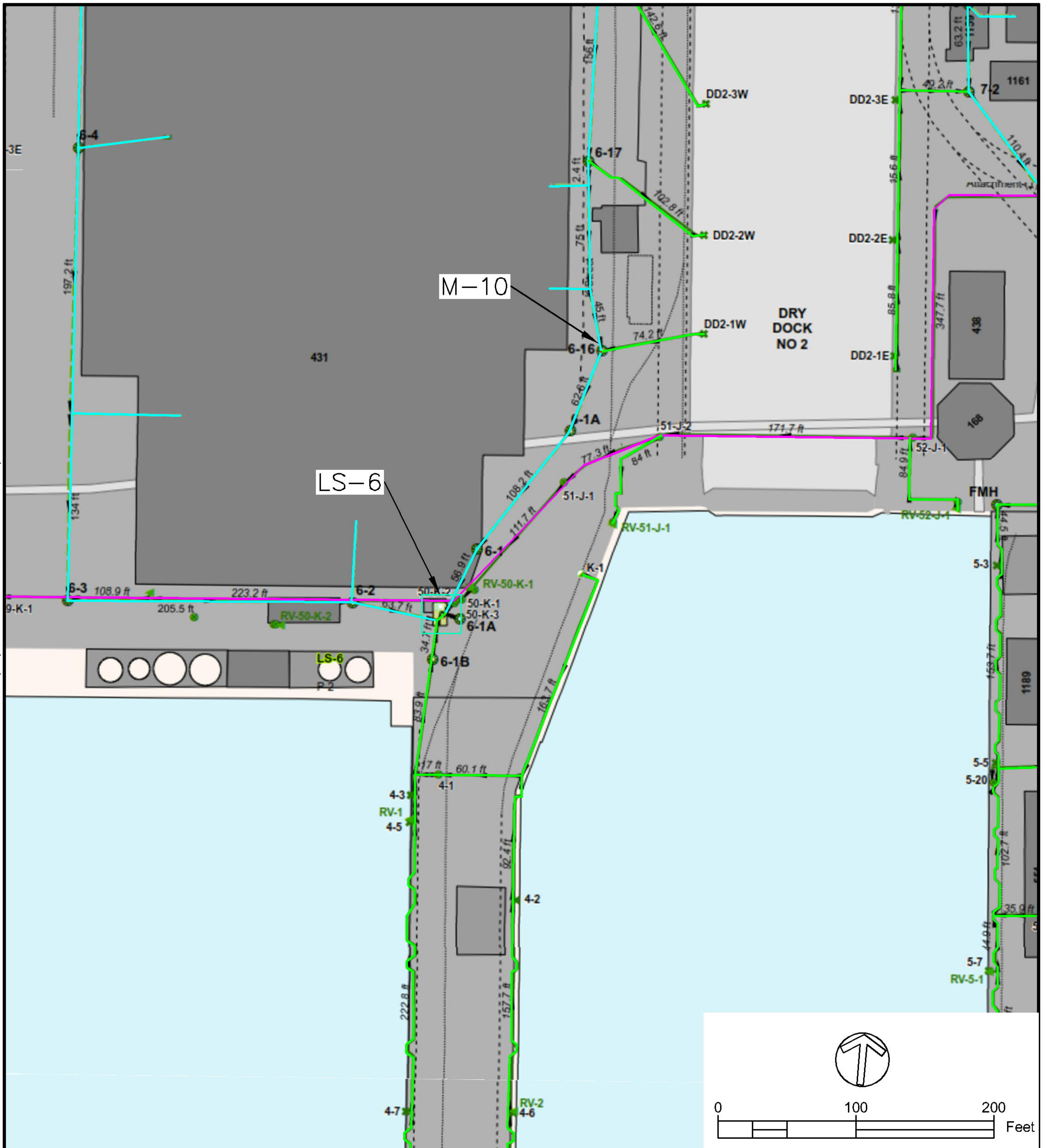

METER 10: DD2 PWCS (MH 6-16)

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

LEGEND

- LIFT STATION
- FORCE MAIN LINE
- EXIST. GRAVITY LINE
- EXIST. PRESSURE LINE

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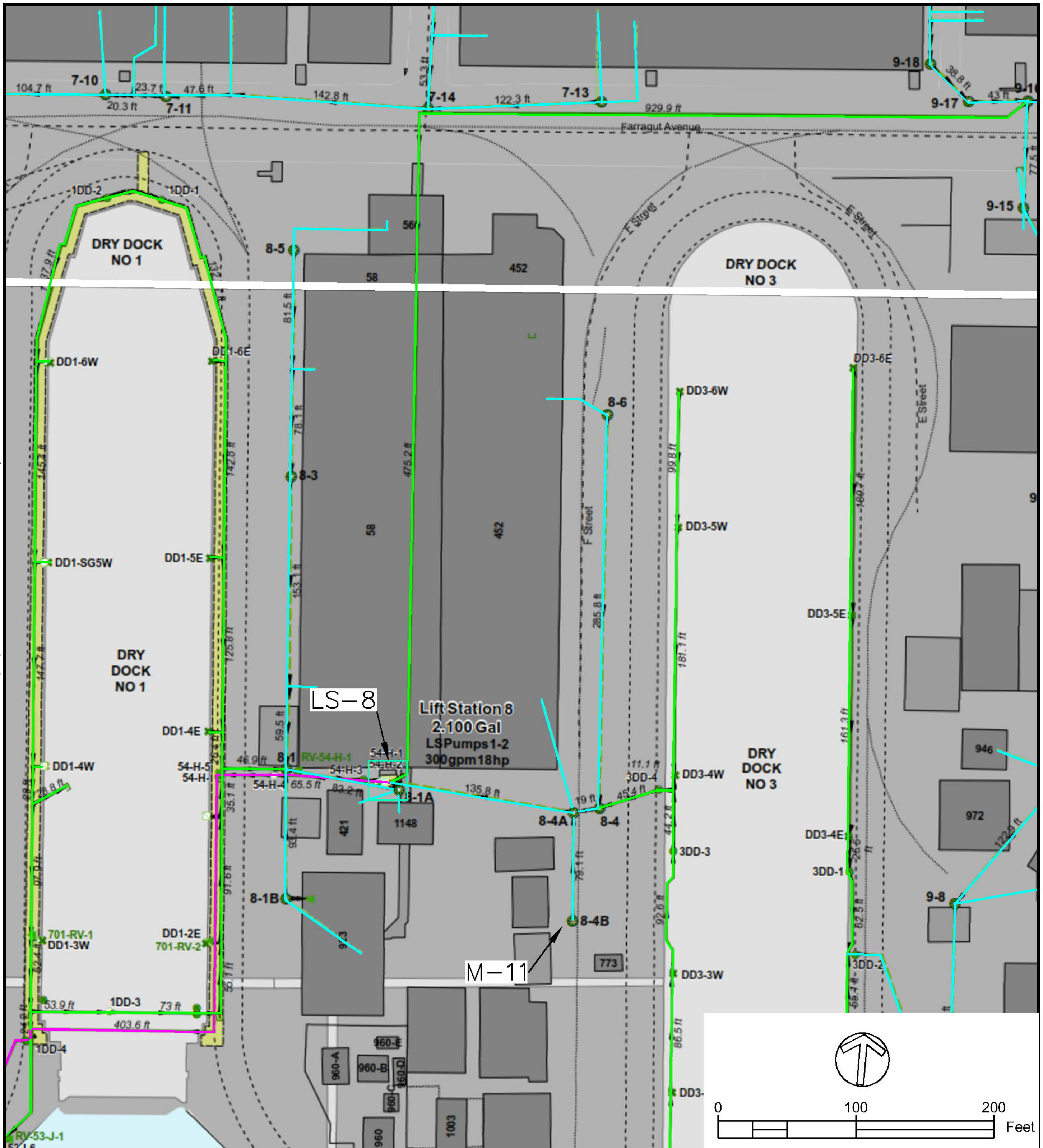

METER 11: DD3 PWCS (MH 8-4B)

LEGEND

- LIFT STATION
- FORCE MAIN LINE
- EXIST. GRAVITY LINE
- EXIST. PRESSURE LINE

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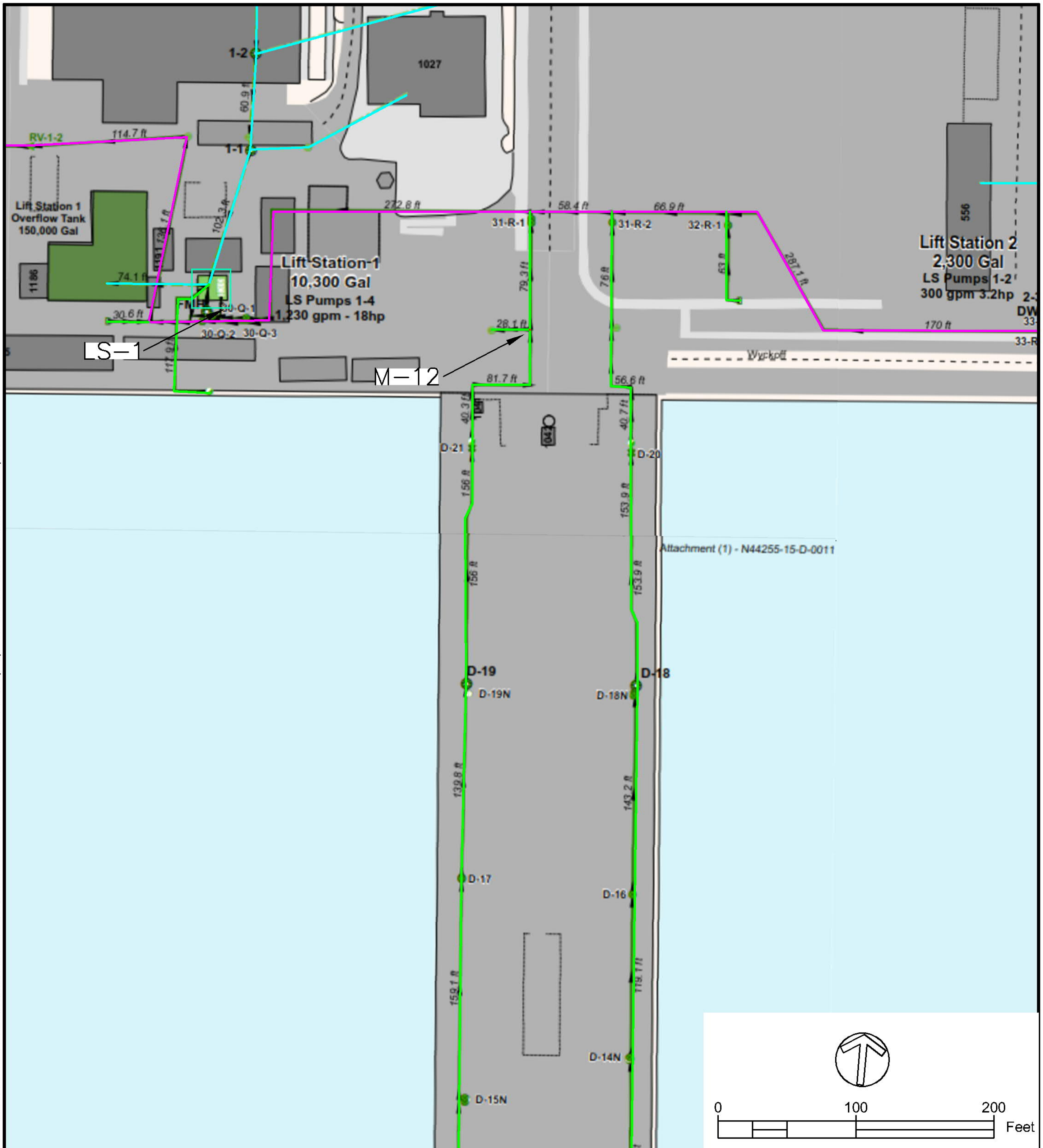

LEGEND

LIFT STATION

FORCE MAIN LINE

EXIST. GRAVITY LINE

EXIST. PRESSURE LINE

METER 12: PIER D WEST

MONITORING STATIONS - SALINITY STUDY
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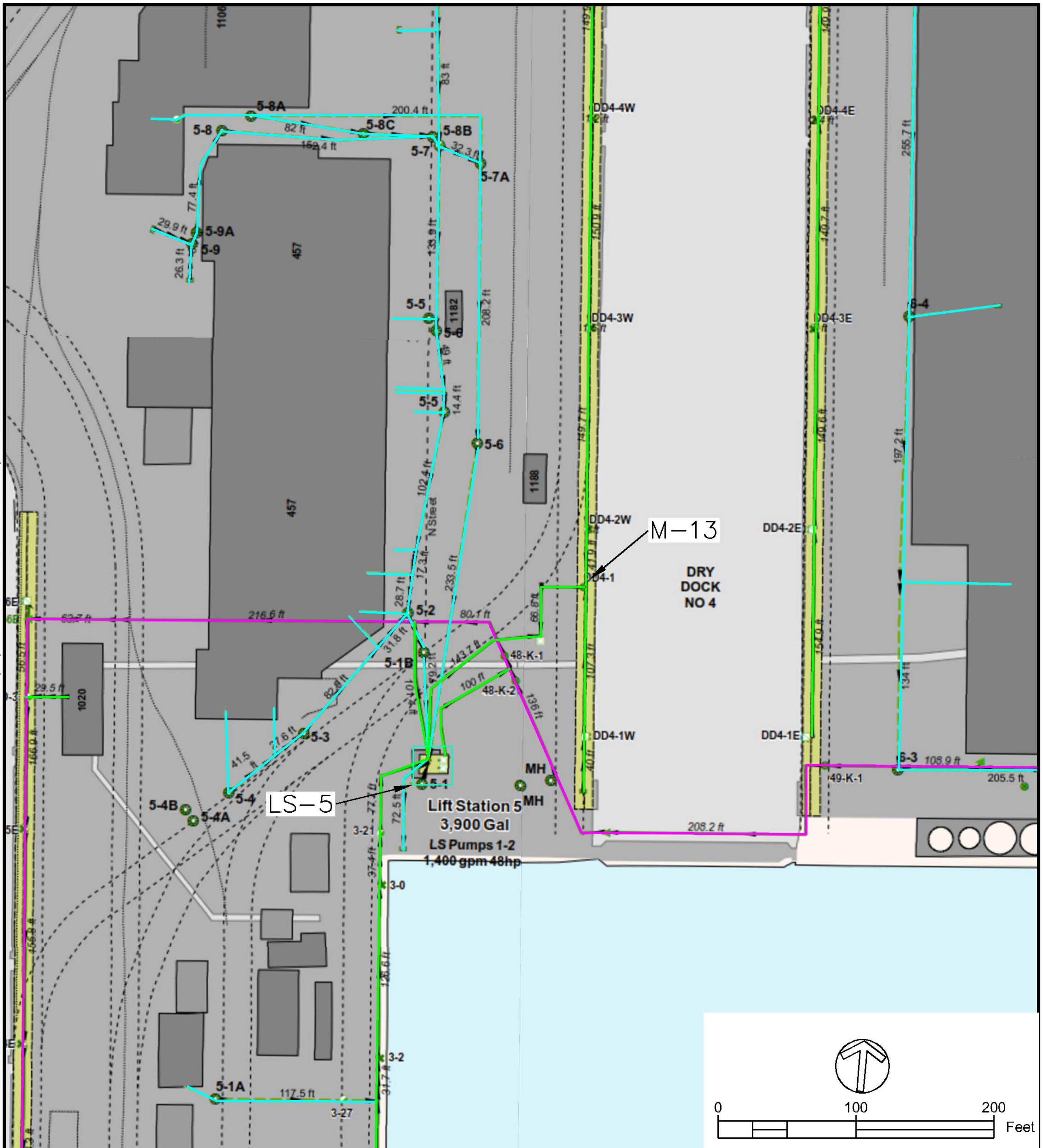

METER 13: DD4 PWCS

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

LEGEND

- LIFT STATION
- FORCE MAIN LINE
- EXIST. GRAVITY LINE
- EXIST. PRESSURE LINE

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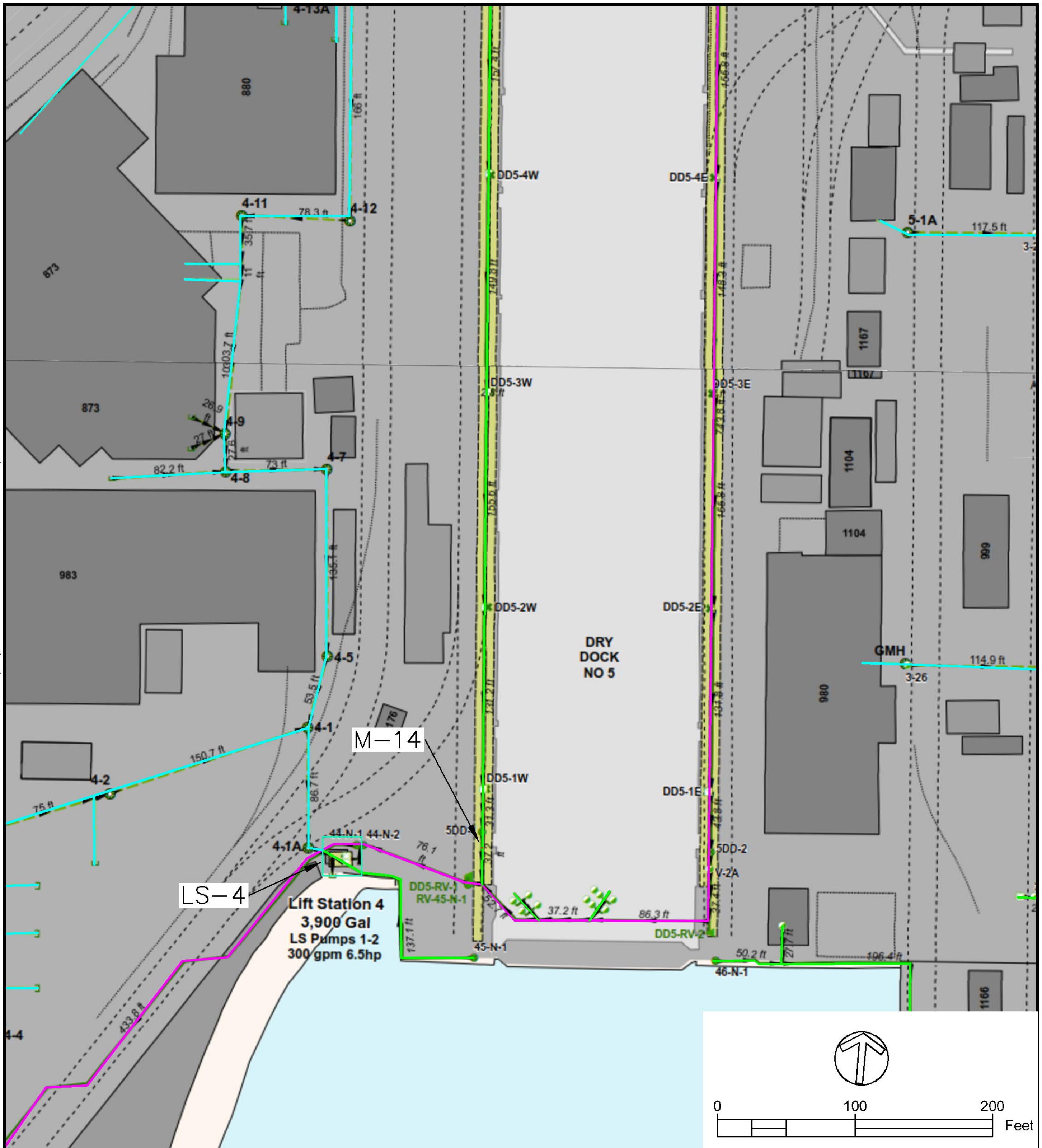

LEGEND

LIFT STATION

FORCE MAIN LINE

EXIST. GRAVITY LINE

EXIST. PRESSURE LINE

METER 14: DD5 PWCS

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

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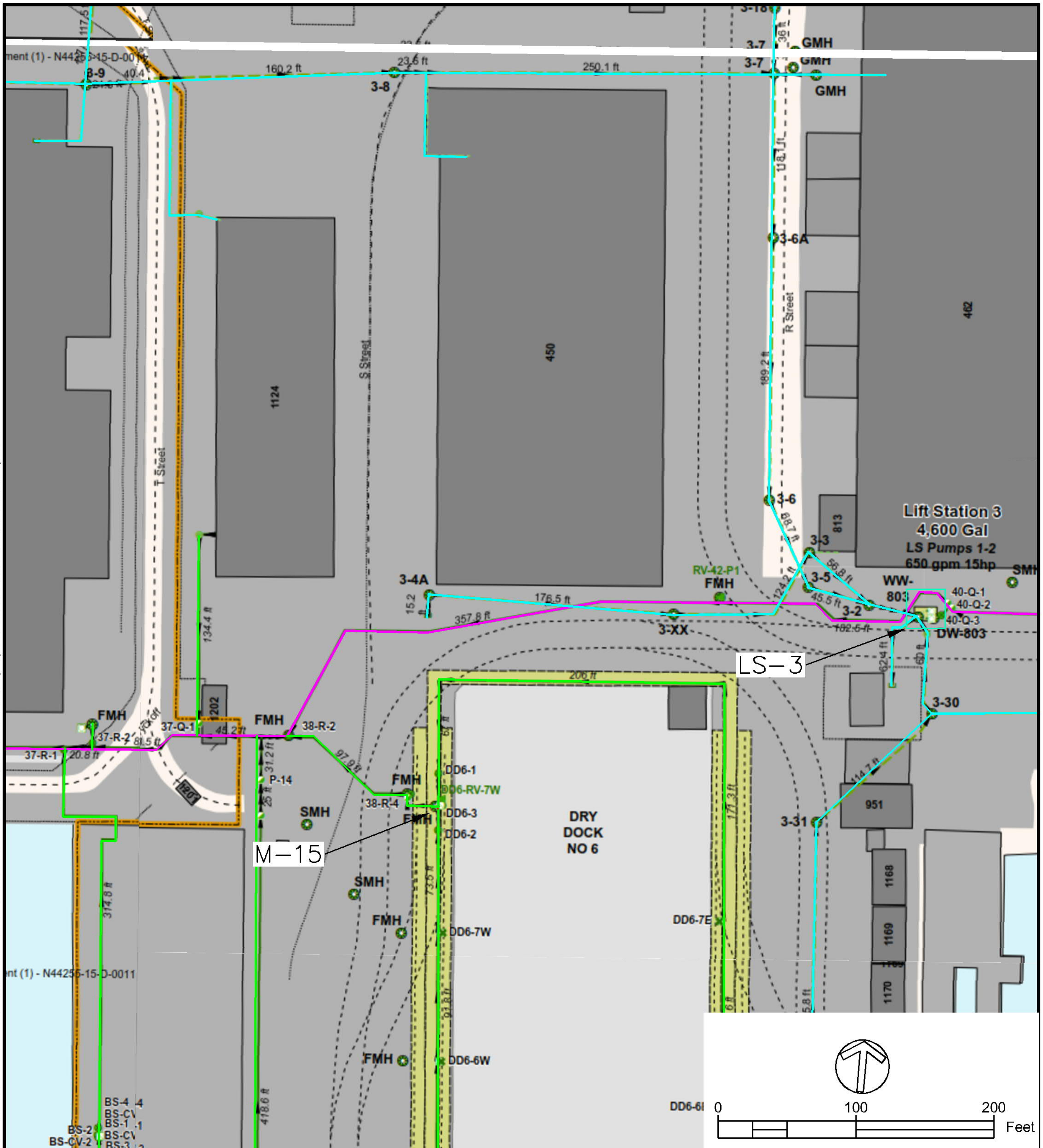

LEGEND

- LIFT STATION
- FORCE MAIN LINE
- EXIST. GRAVITY LINE
- EXIST. PRESSURE LINE

METER 15: DD6 PWCS

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

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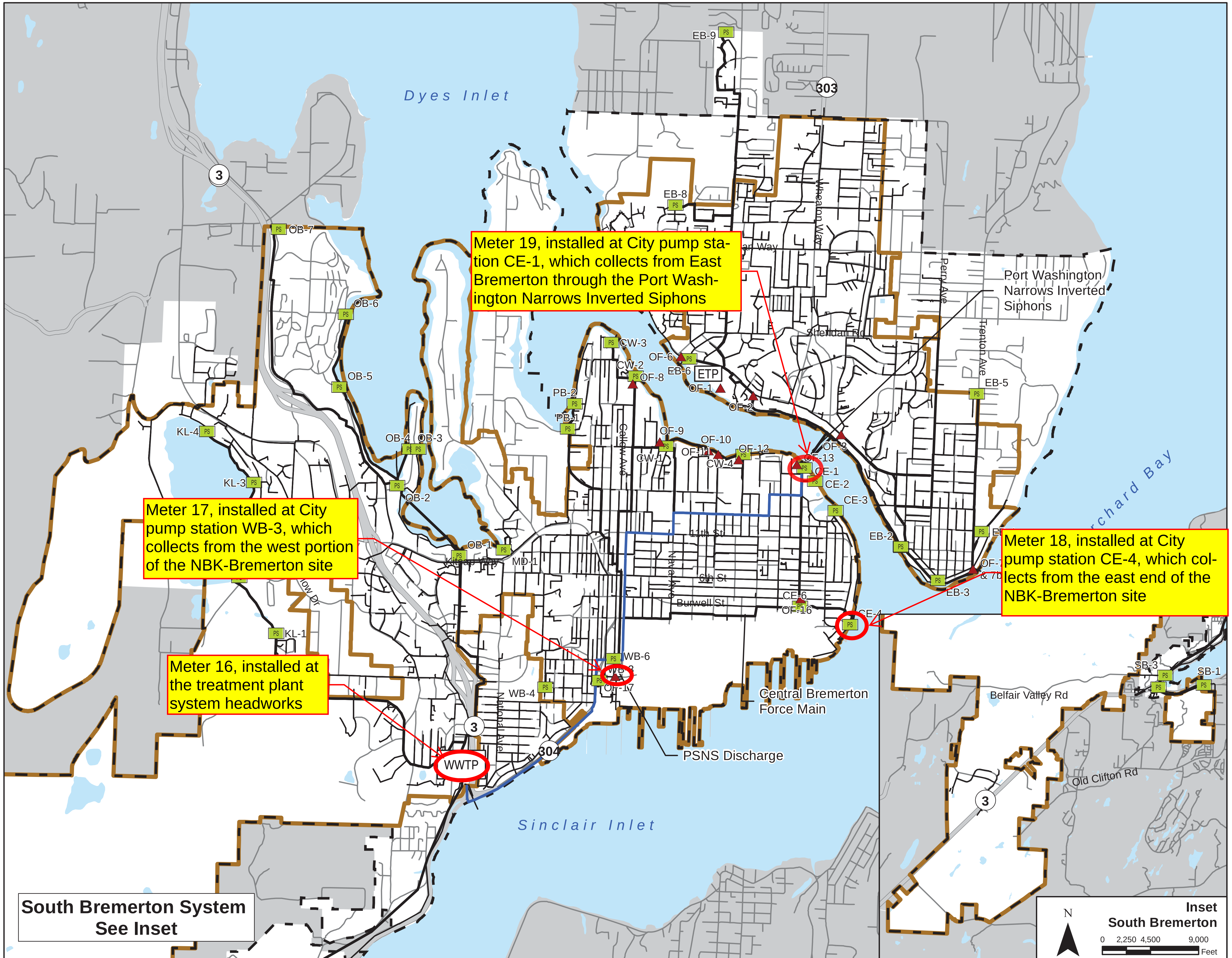


Legend

- Outfall
- SewerPumpStations
- Major Pipeline
- Crosstown Pipeline
- Sewer Main
- City of Bremerton
- Bremerton UGA
- Water Body
- Highway
- Streets
- WWTP — Westside Wastewater Treatment Plant
- ETP — Eastside Treatment Plant

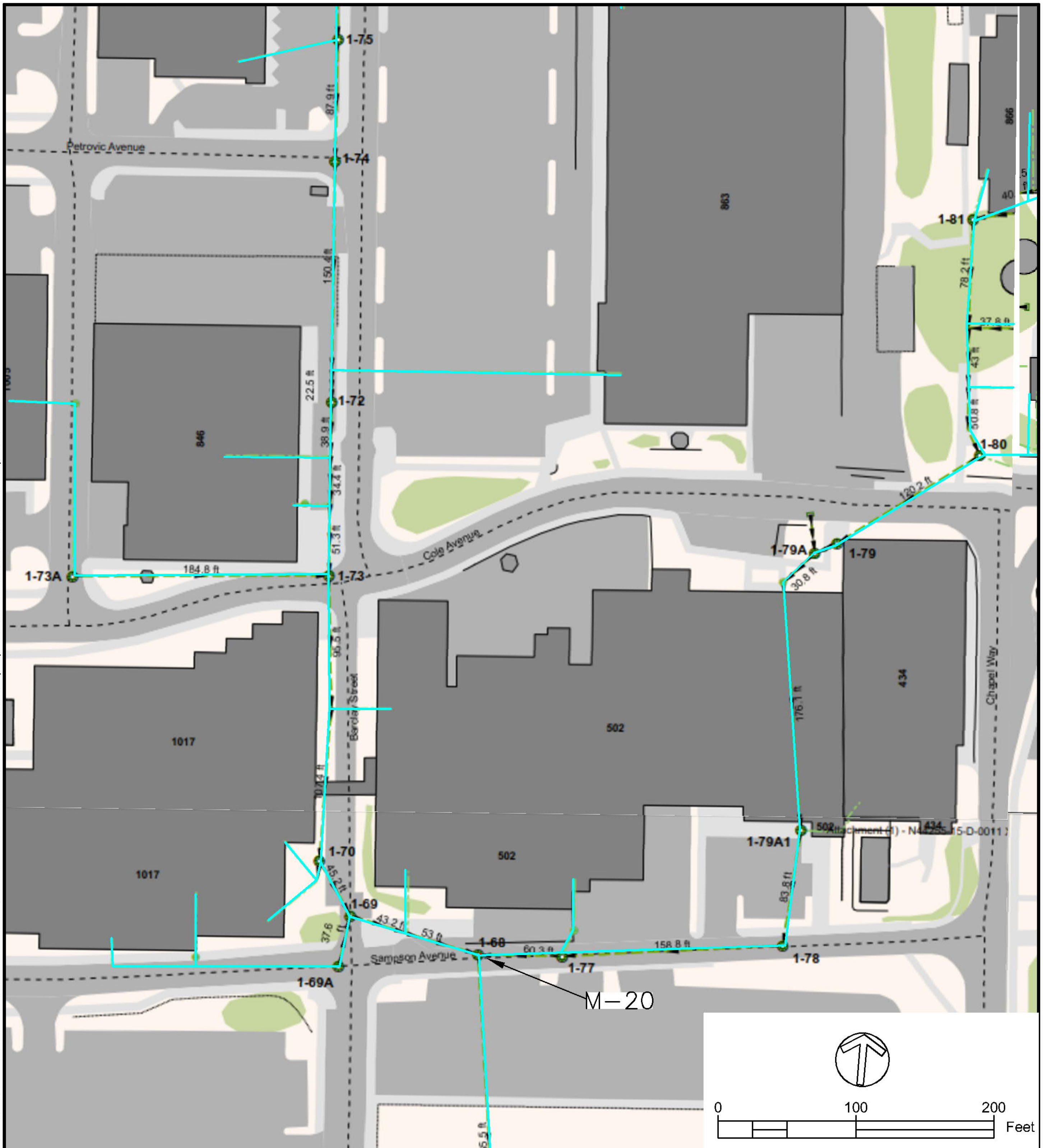
Source of Data:
1) Kitsap County GIS
2) City of Bremerton GIS

HDR
CITY OF BREMERTON

Figure 3-3
Existing Sewer System
Basin Map
CITY OF BREMERTON
WWCP UPDATE

N
0 750 1,500 3,000 Feet

Document Path: D:\GISDATA\Projects\wash\Bremerton\Map_Docs\Comprehensive Sewer Plan\Plan Figures\Figure 3-3 - Major Facilities UPDATED.mxd Print Date: 9/11/2014



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LEGEND

- LIFT STATION
- FORCE MAIN LINE
- EXIST. GRAVITY LINE
- EXIST. PRESSURE LINE

METER 20: MH 1-68

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

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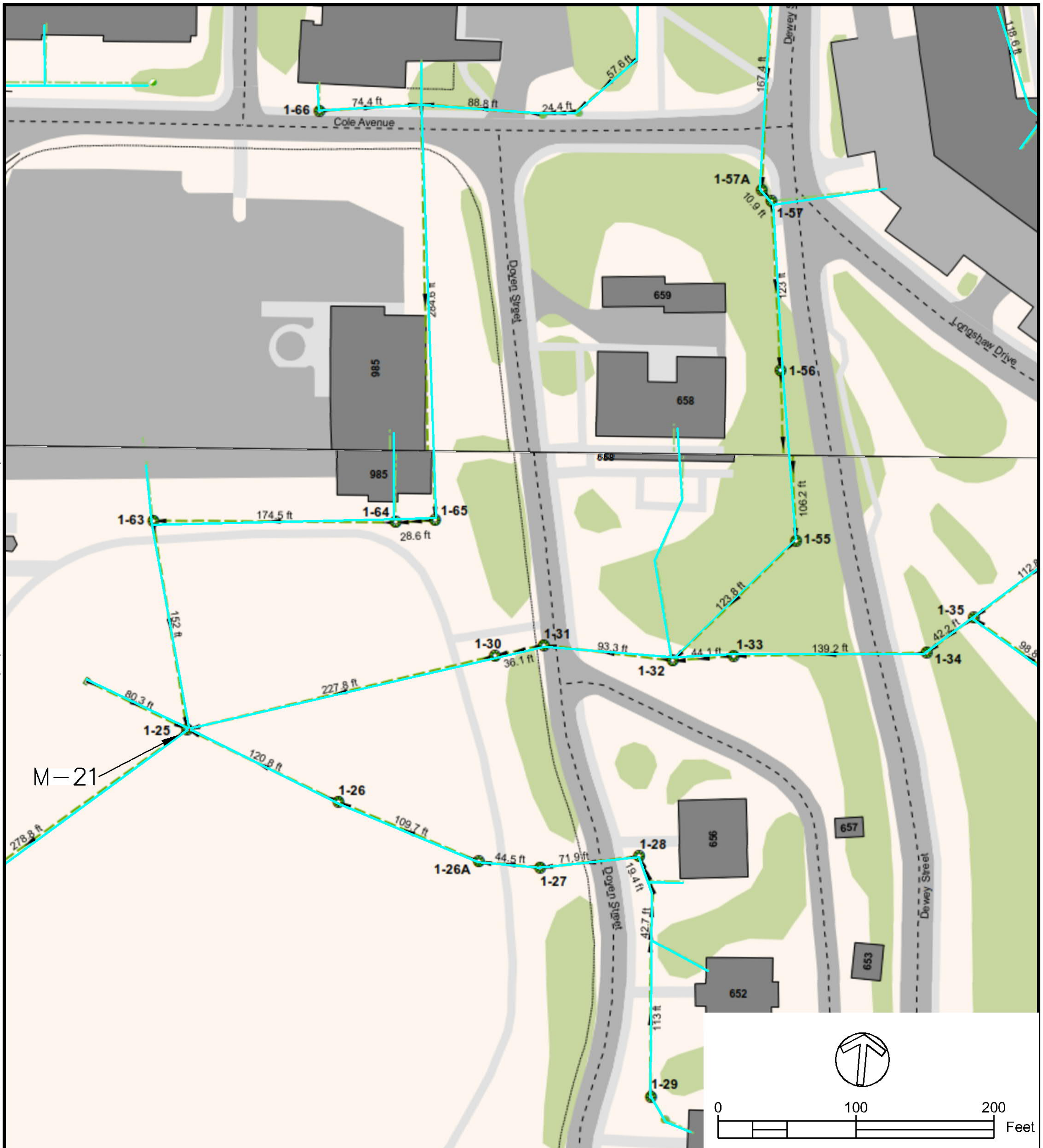

LEGEND

LIFT STATION

FORCE MAIN LINE

EXIST. GRAVITY LINE

EXIST. PRESSURE LINE

METER 21: MH 1-25

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

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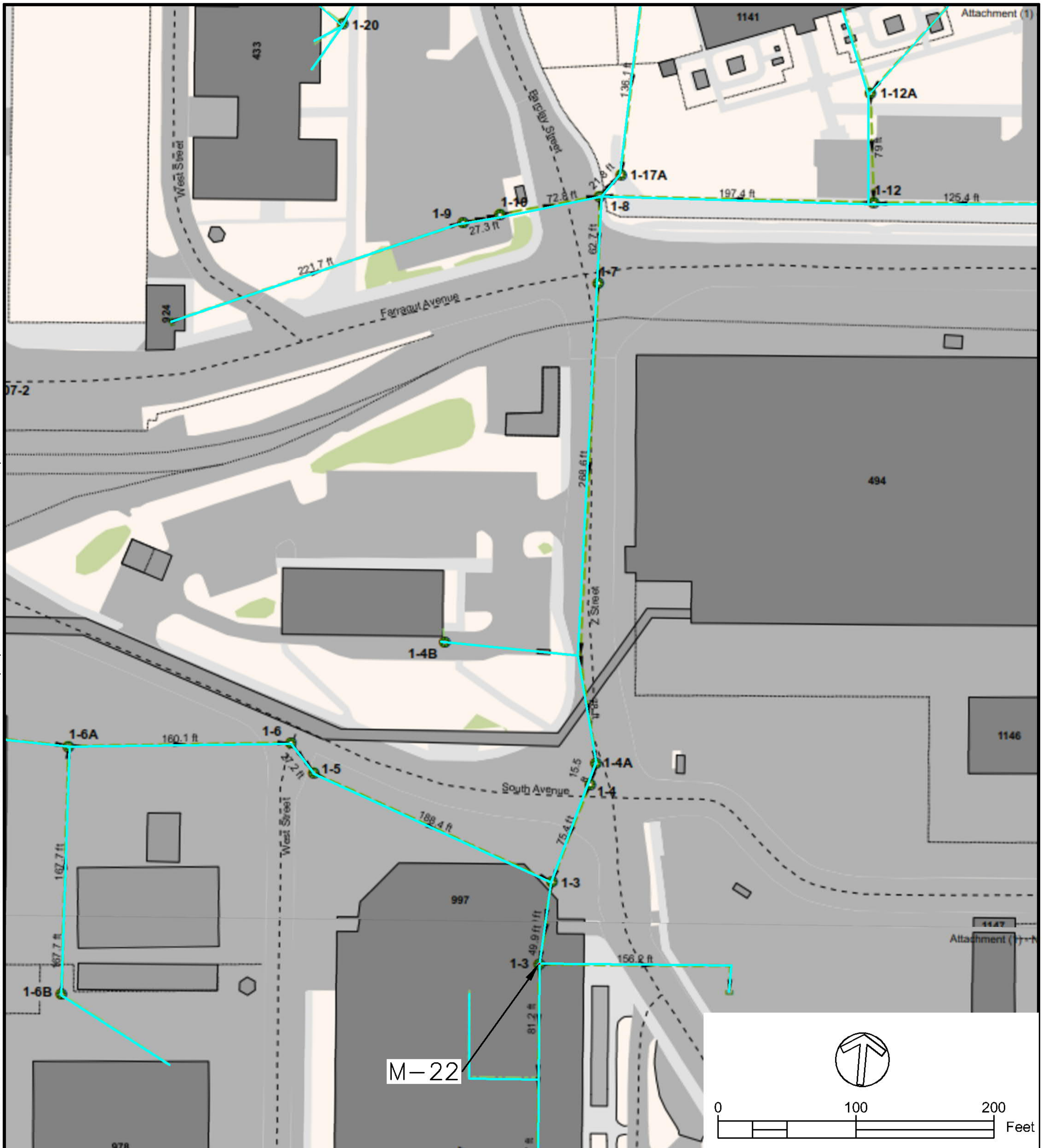

METER 22: MH 1-3

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

LEGEND

- LIFT STATION
- FORCE MAIN LINE
- EXIST. GRAVITY LINE
- EXIST. PRESSURE LINE

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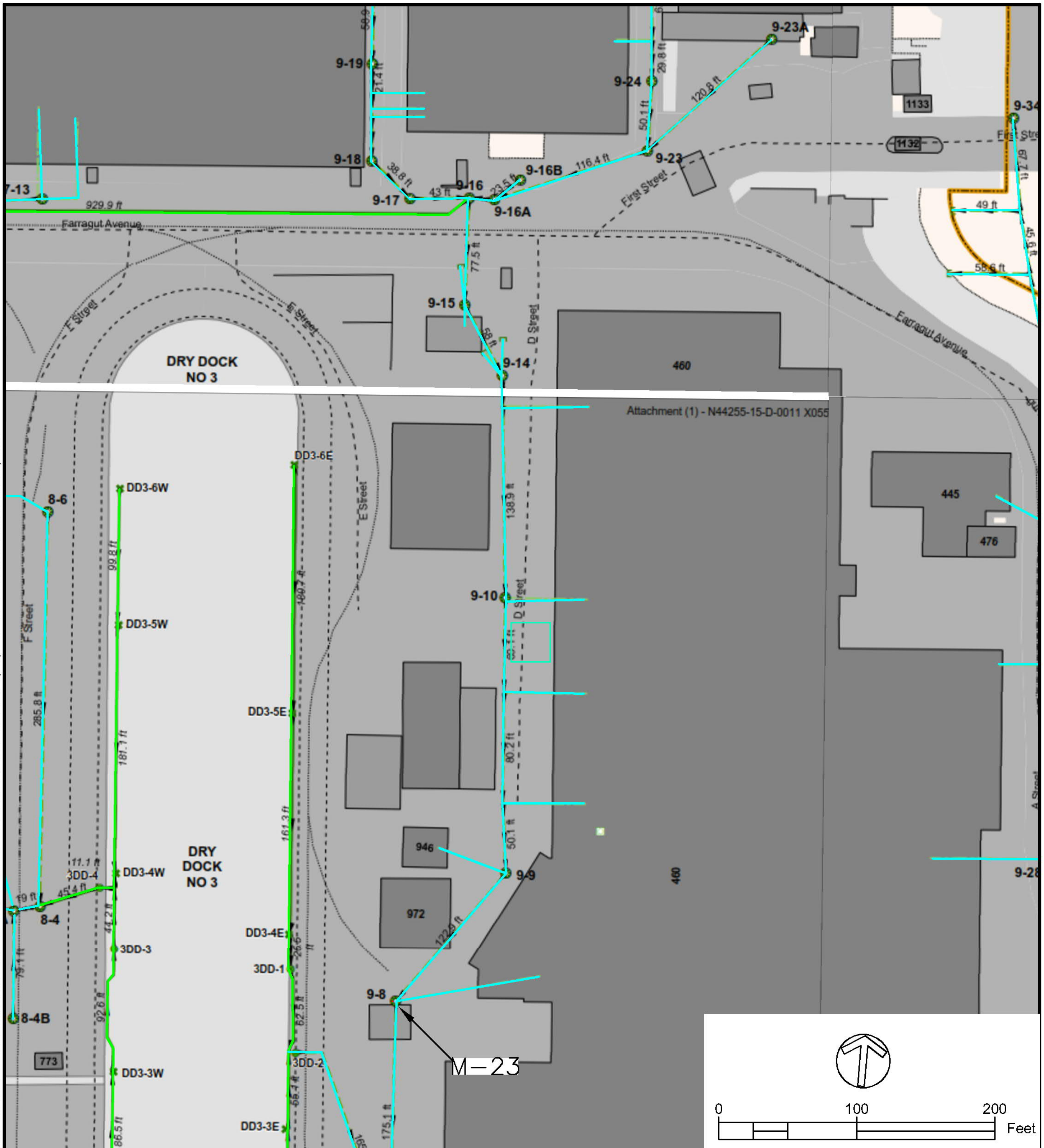

METER 23: MH 9-8

LEGEND

- LIFT STATION
- FORCE MAIN LINE
- EXIST. GRAVITY LINE
- EXIST. PRESSURE LINE

MONITORING STATIONS - SALINITY STUDY
CITY OF BREMERTON - NAVAL COMPLEX

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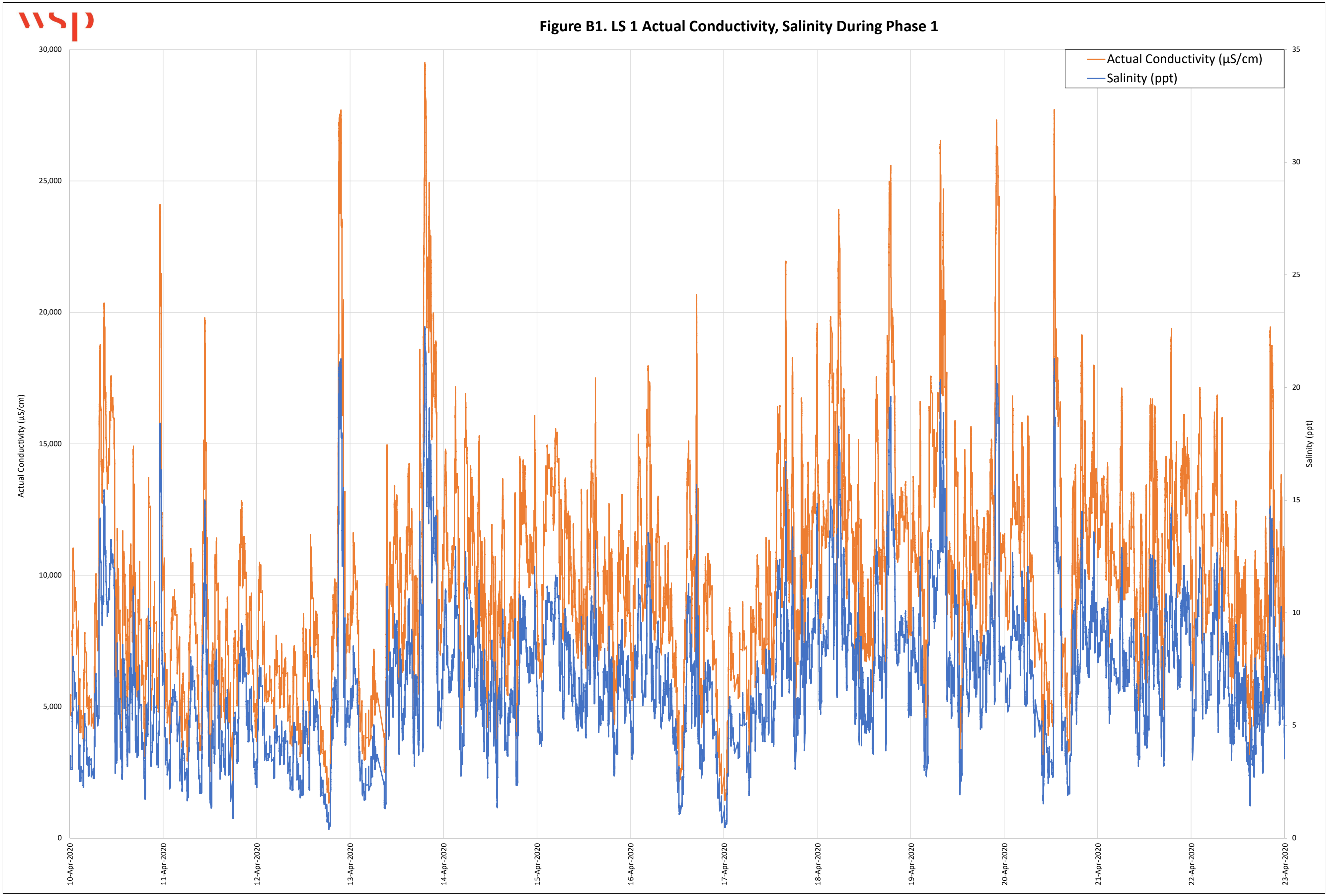
Appendix B
Meters 1 to 23 and Existing LS 1 Meter Data



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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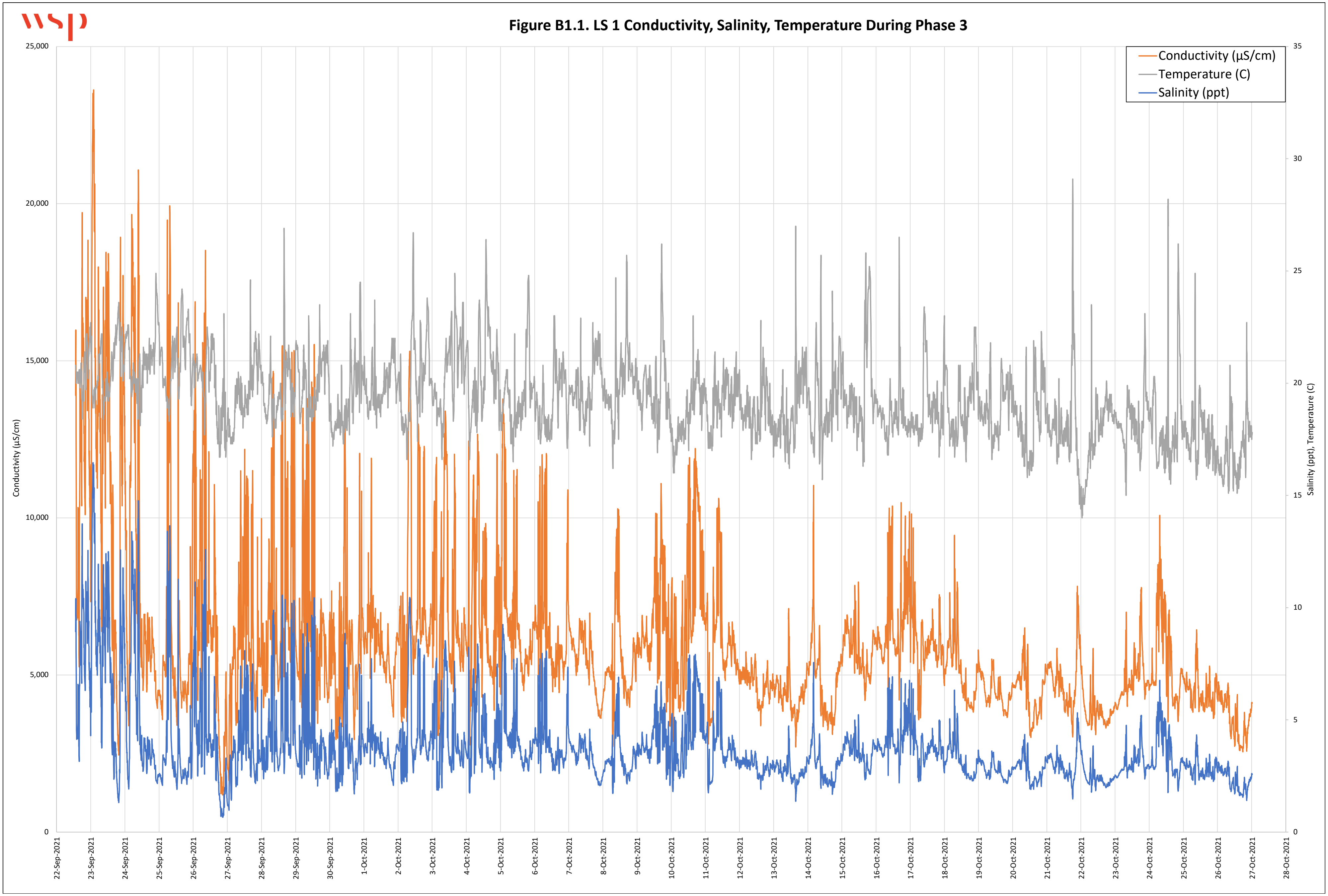

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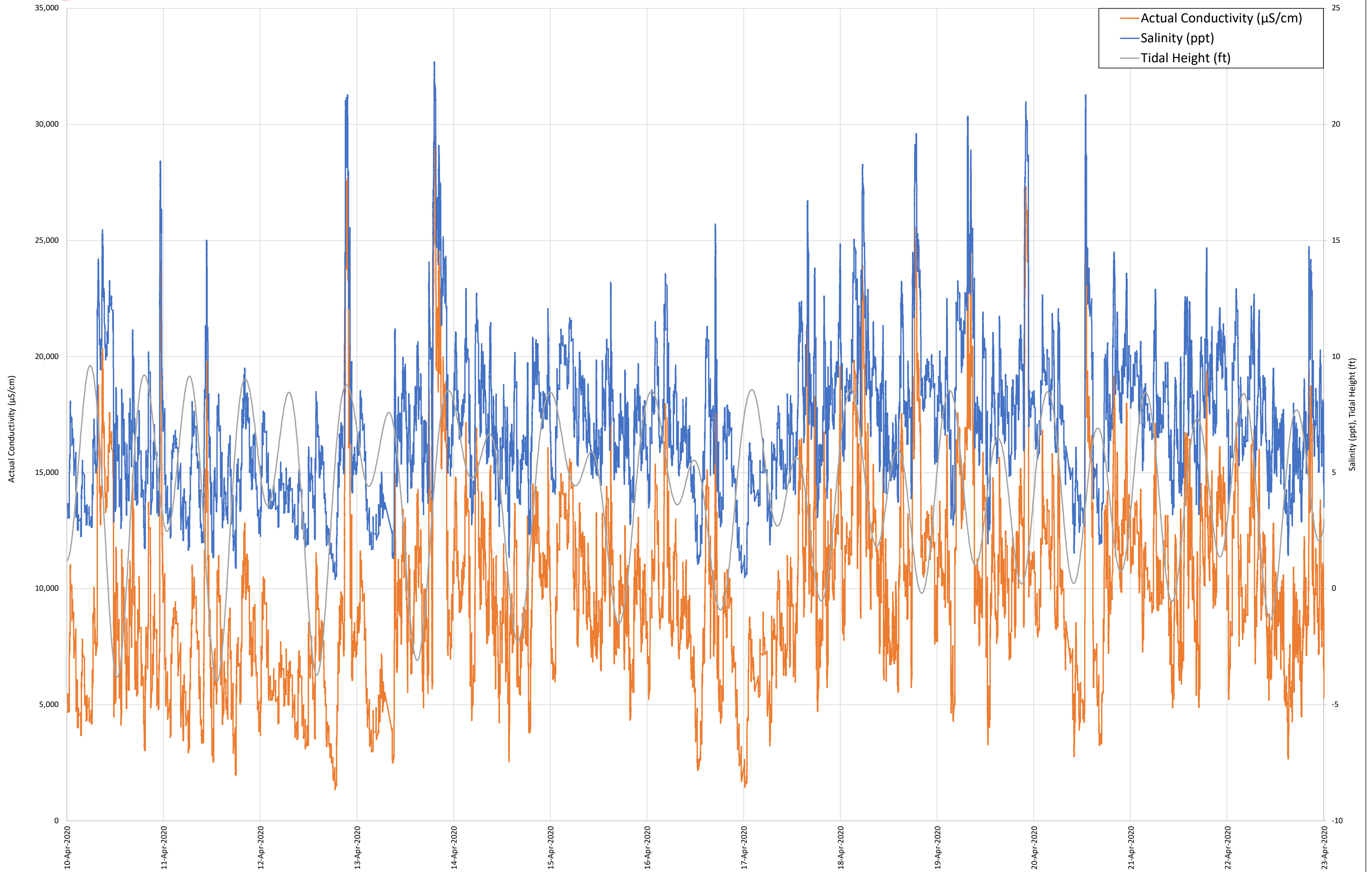
Figure B1.2 LS 1 Actual Conductivity, Salinity, Tidal Height During Phase 1



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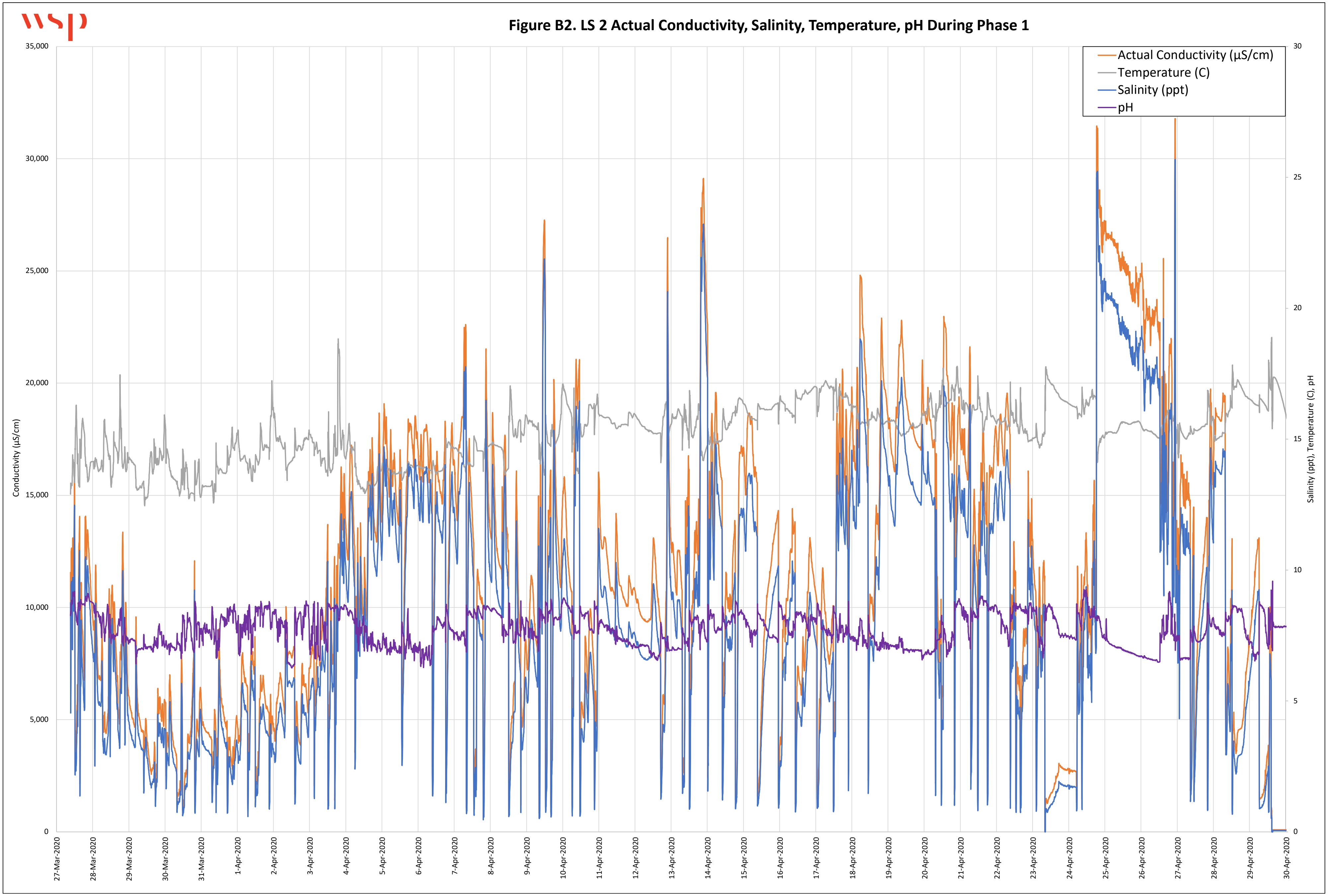

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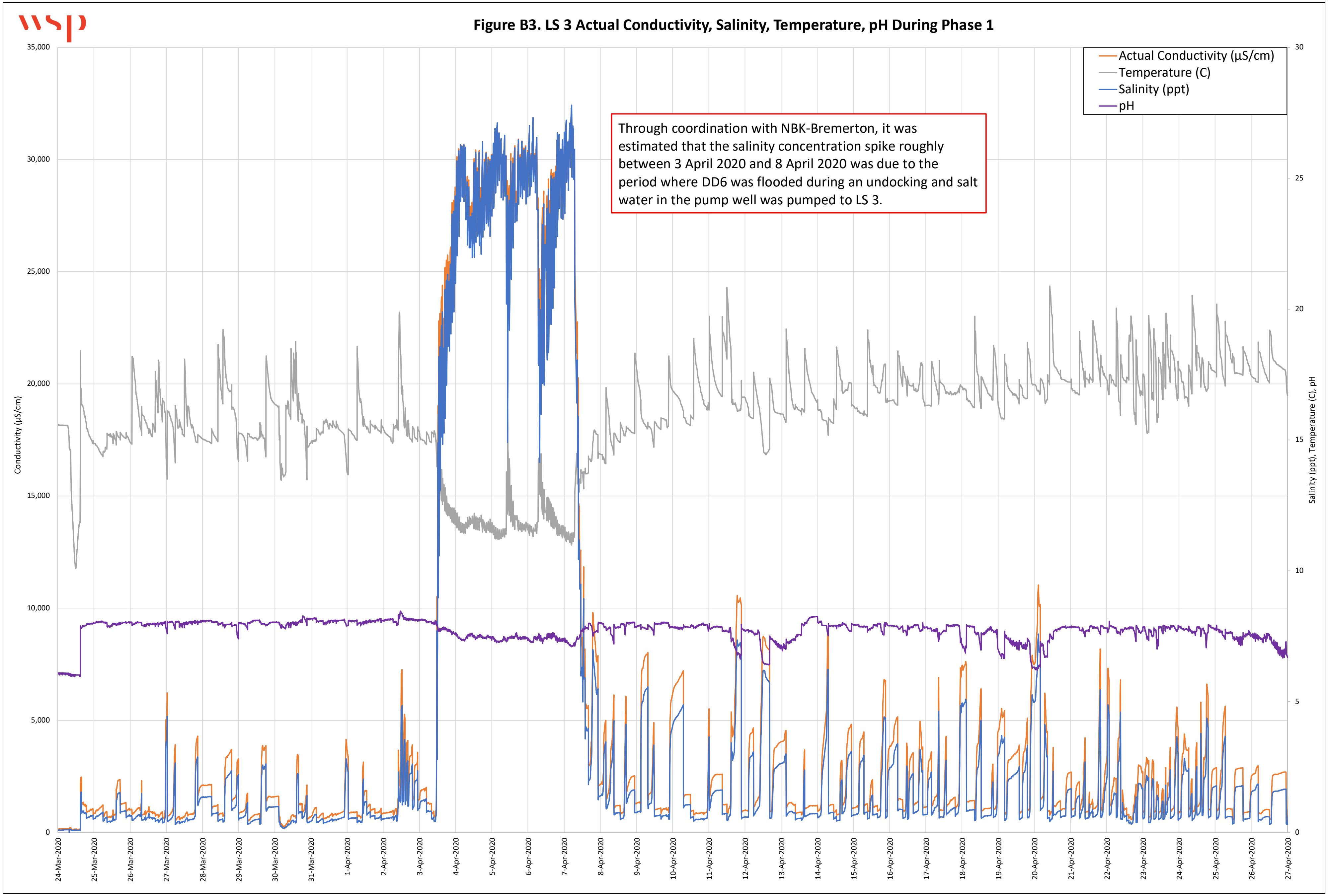

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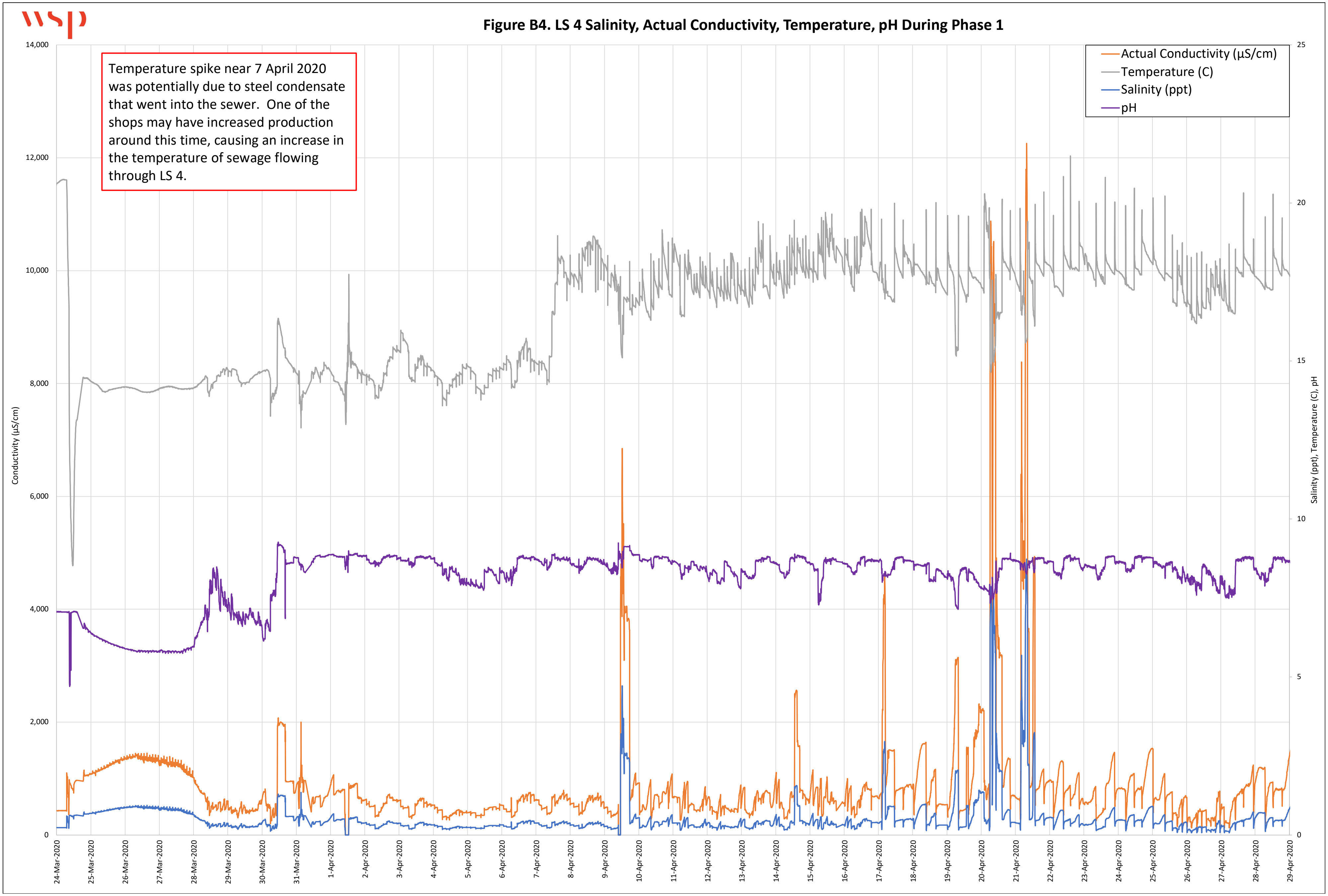

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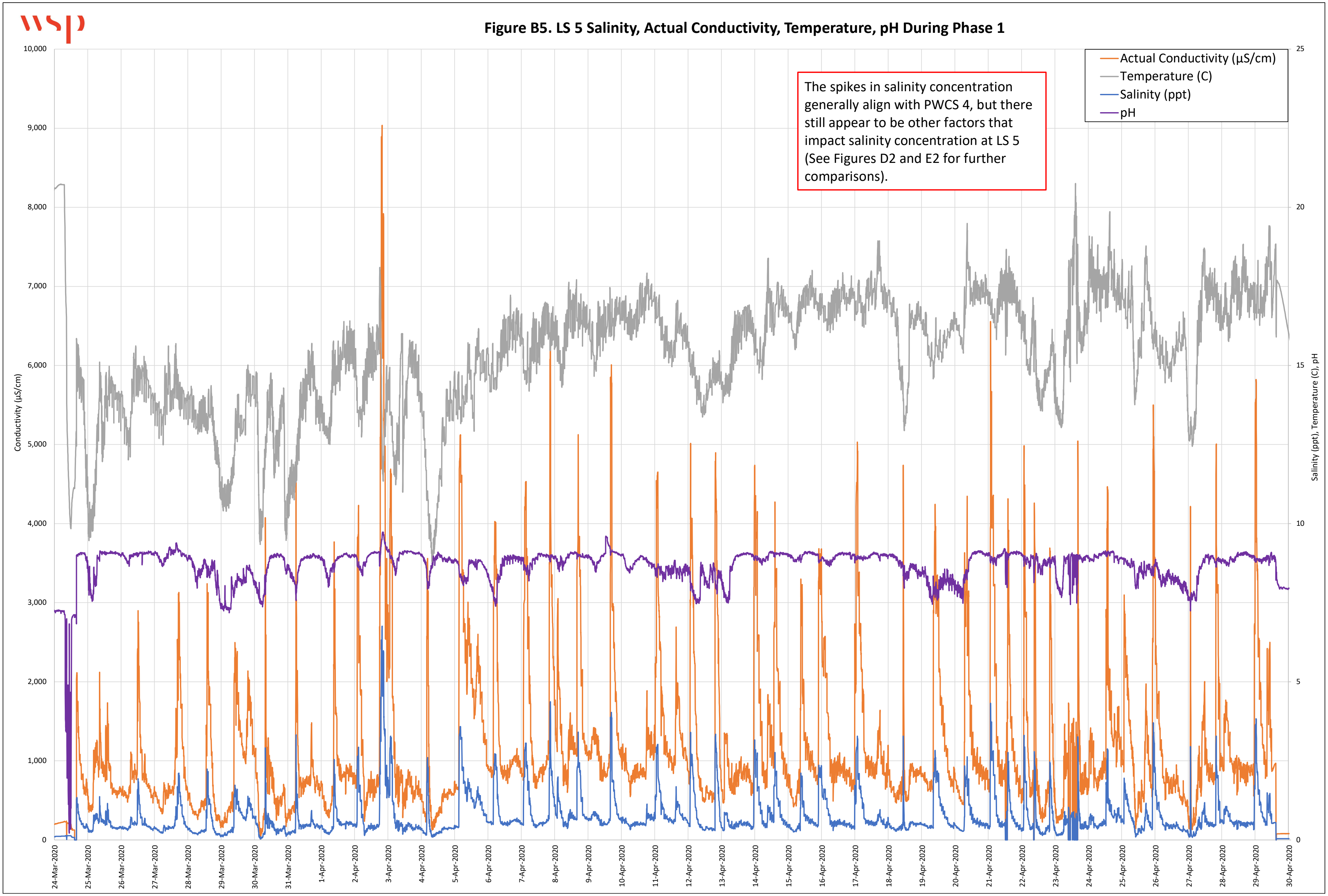

Figure B5. LS 5 Salinity, Actual Conductivity, Temperature, pH During Phase 1

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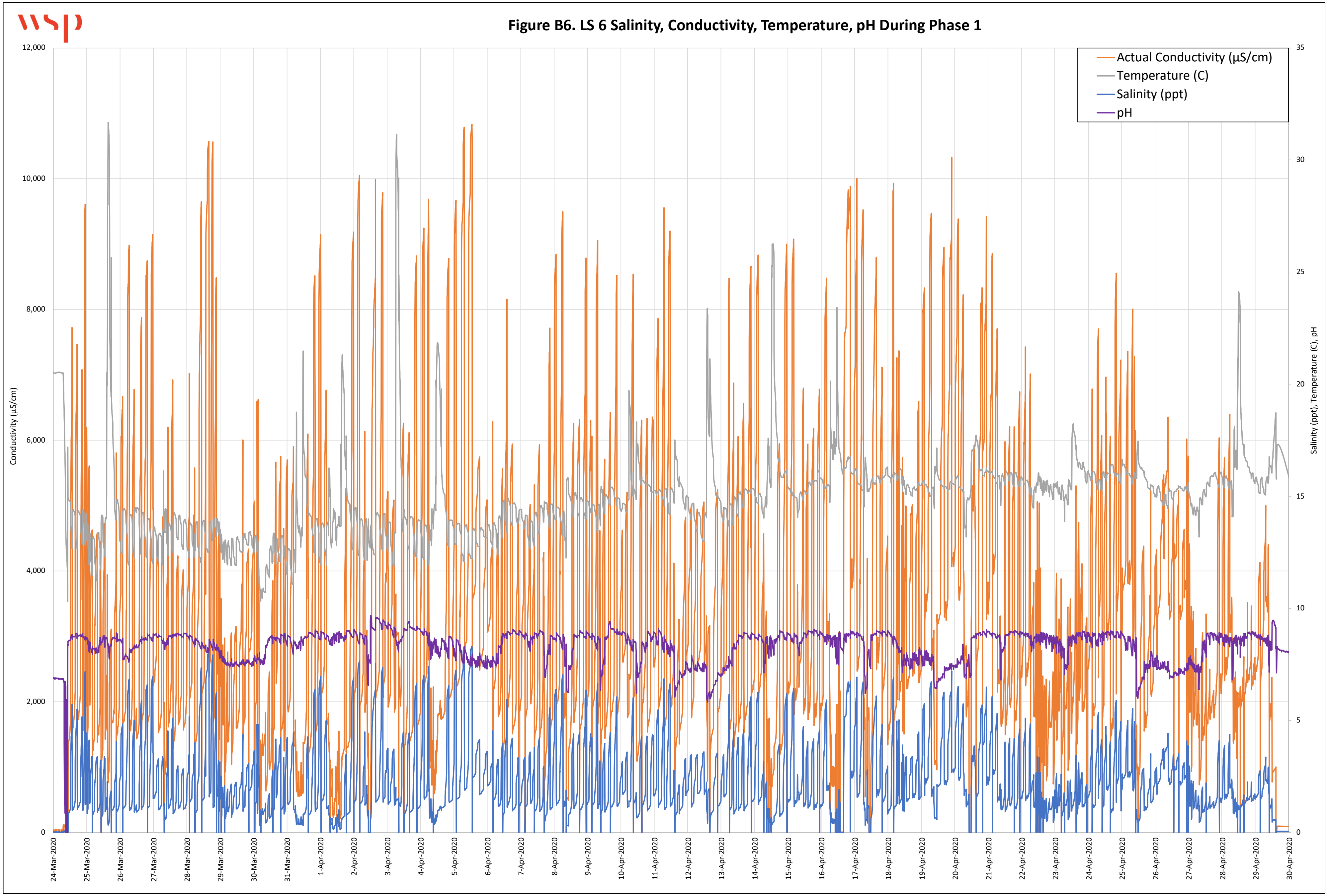
Project Number: WA16.0094.38



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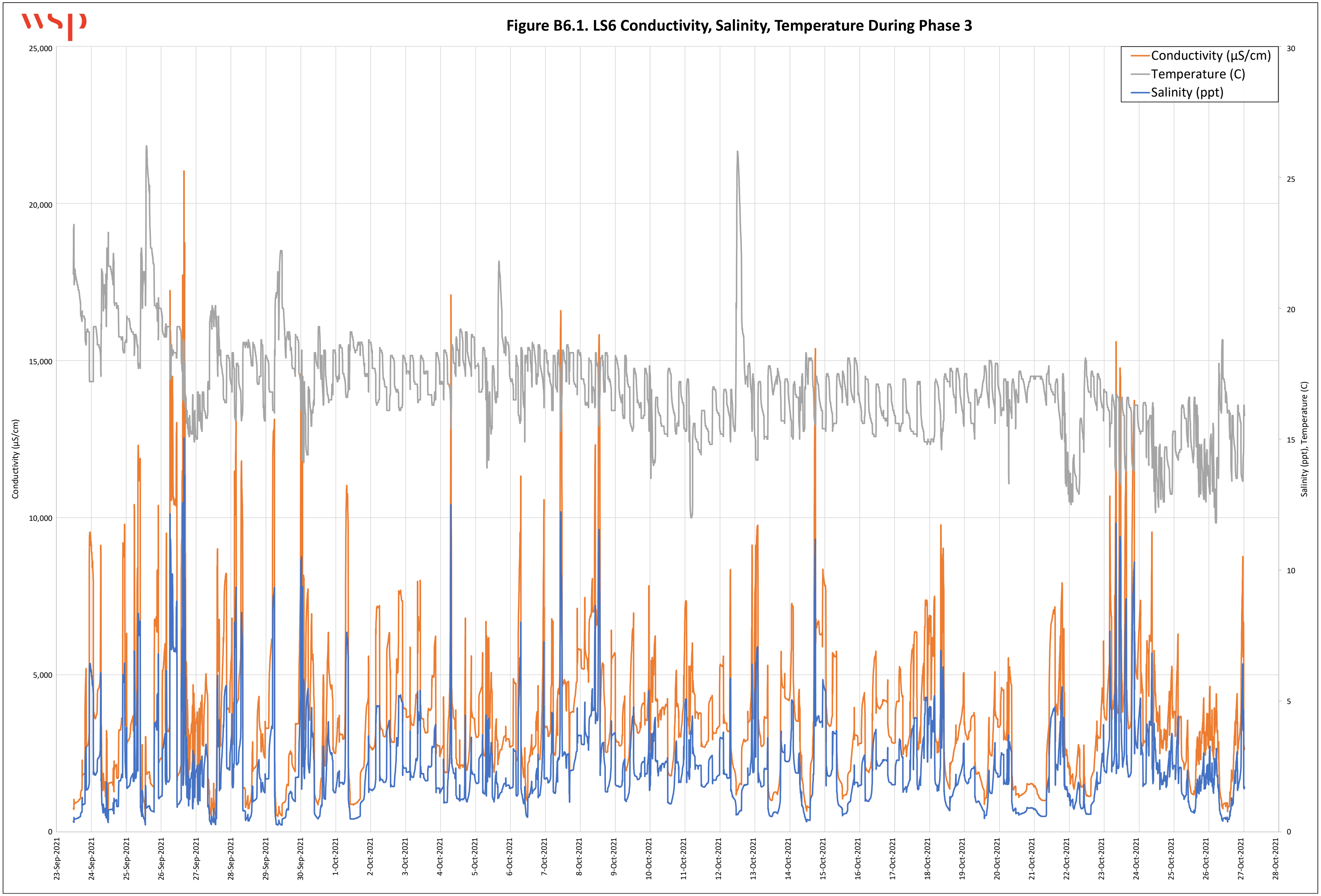

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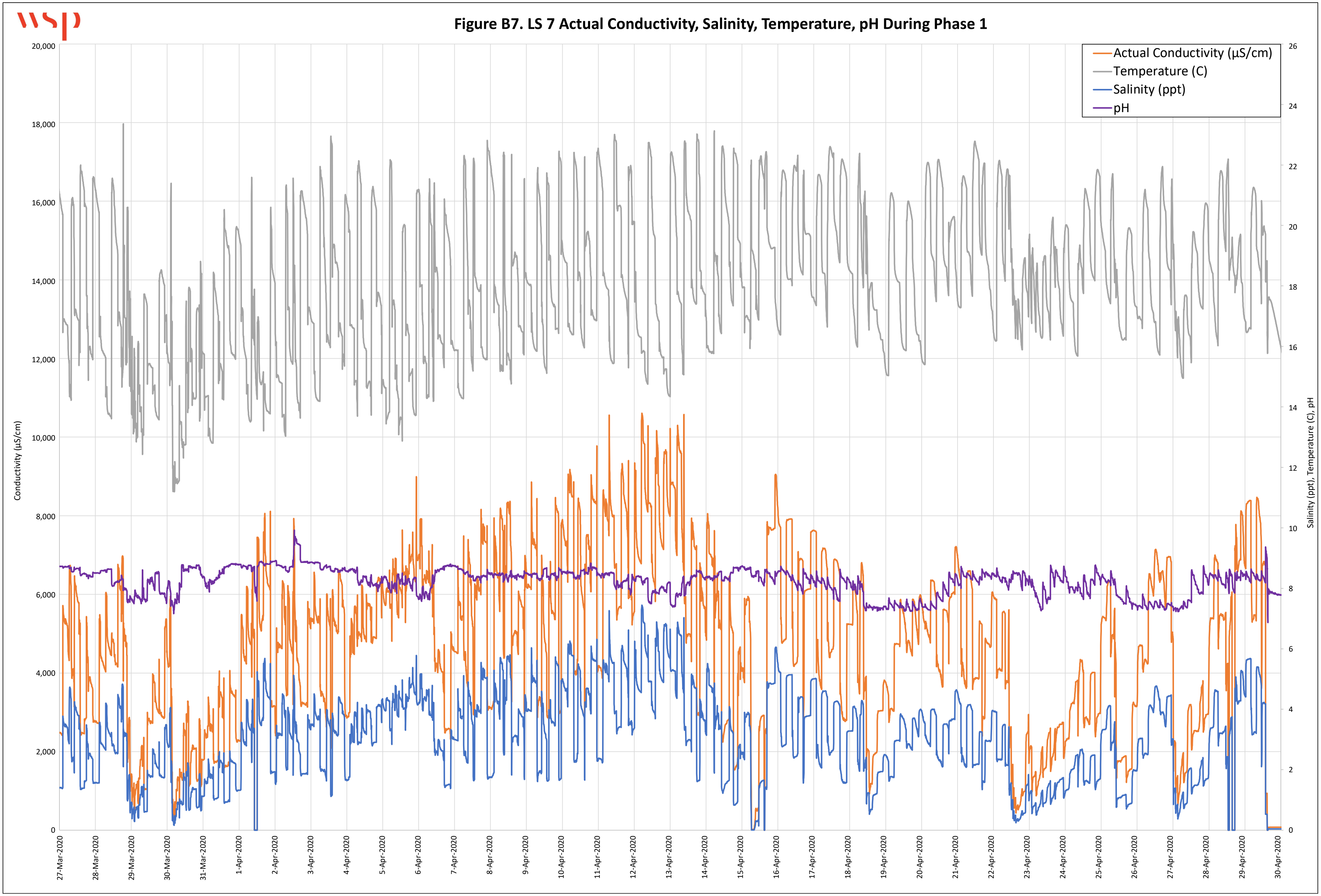
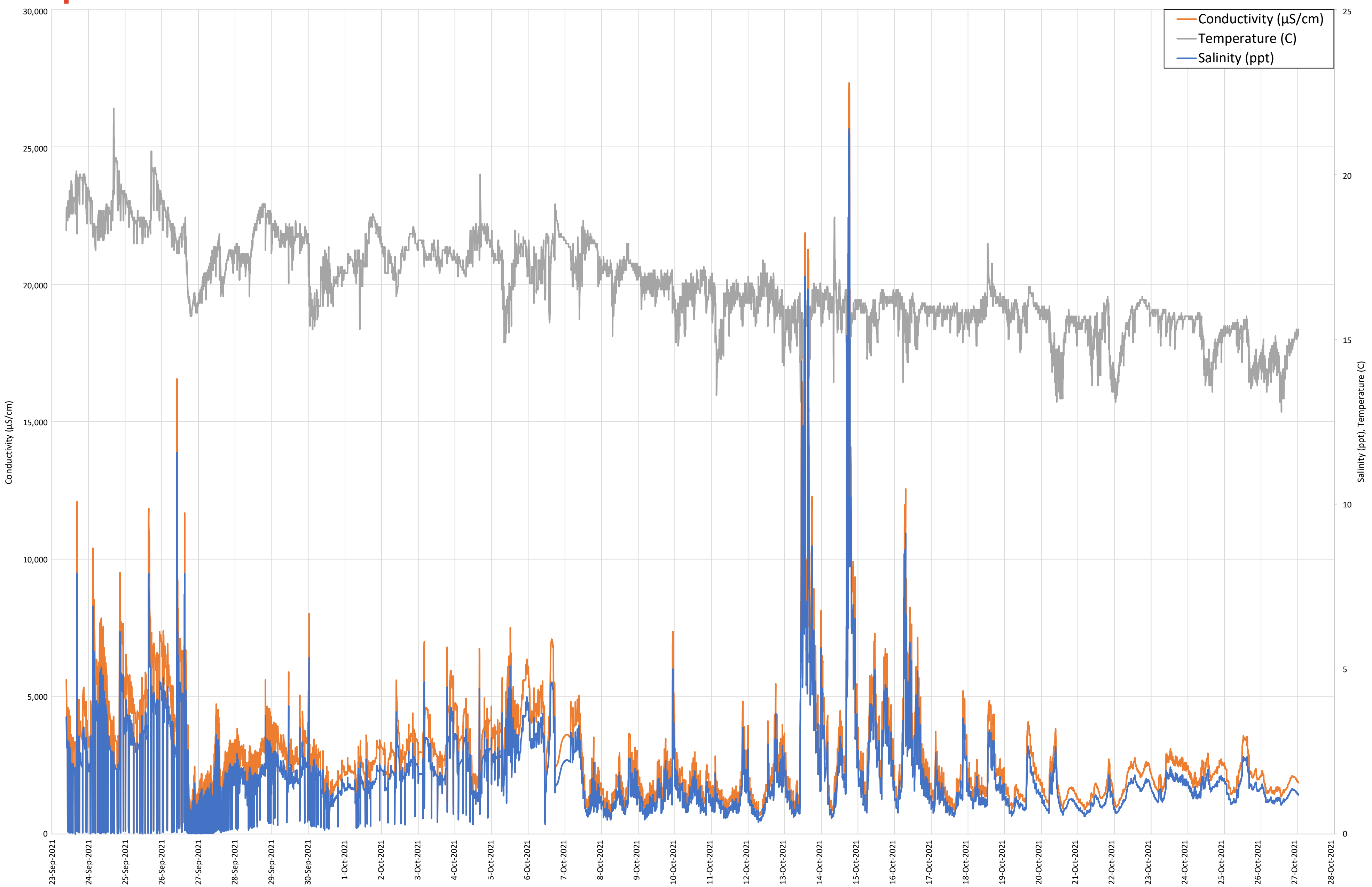


Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Figure B7.1. LS7 Conductivity, Salinity, Temperature During Phase 3



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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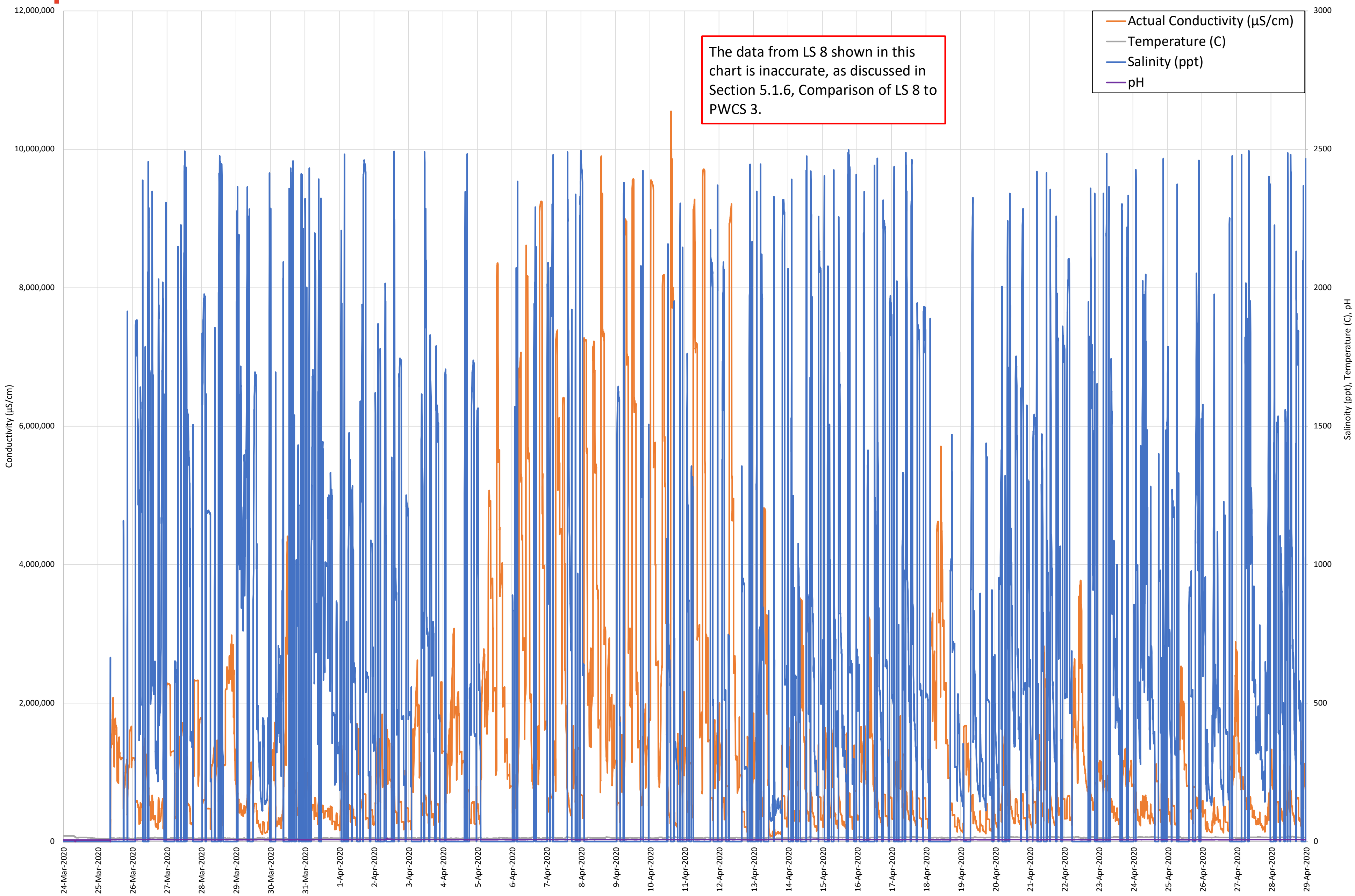
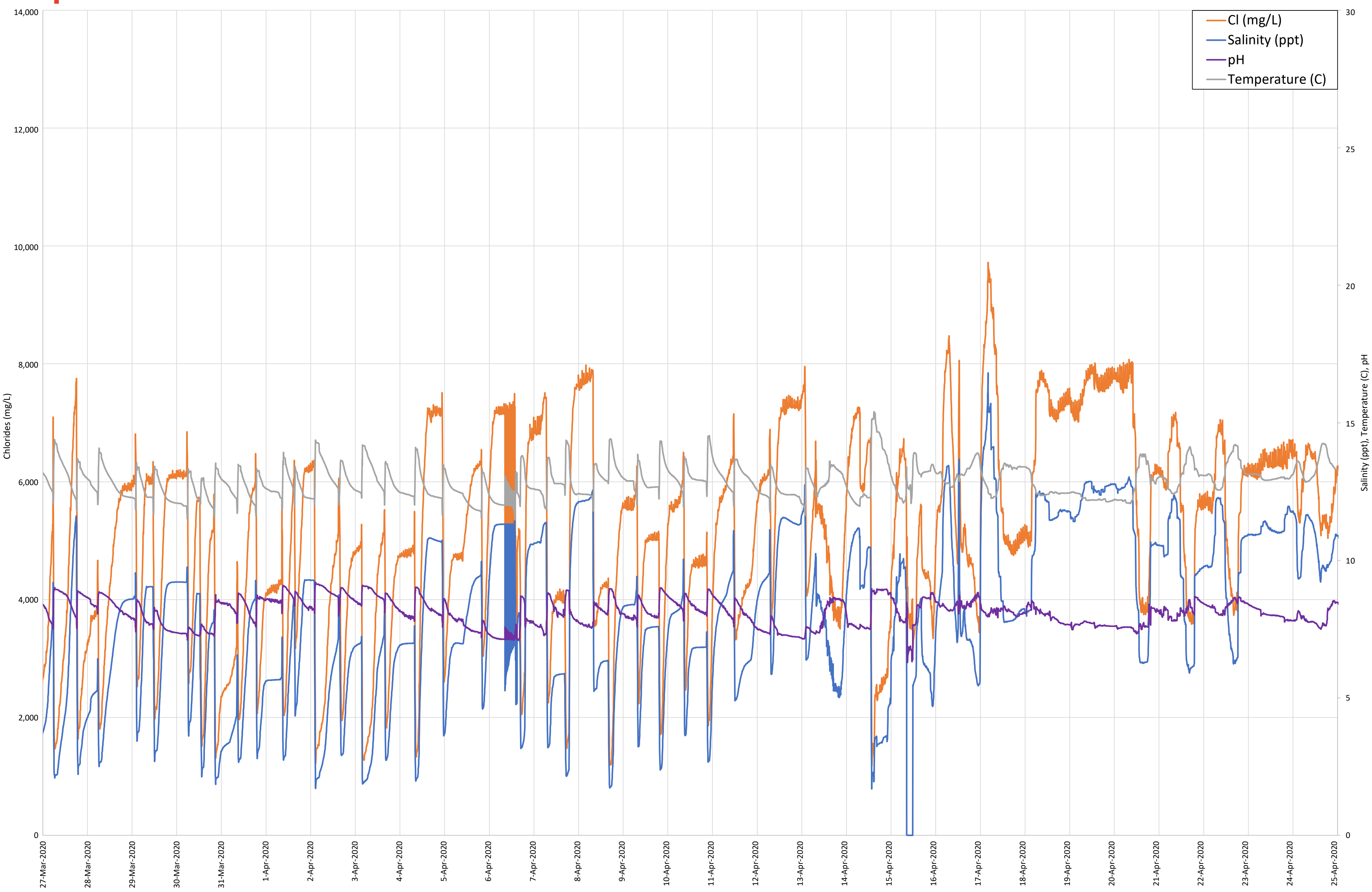
Figure B8. LS 8 Salinity, Actual Conductivity, Temperature, pH During Phase 1



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Figure B9. LS 9 Salinity, Temperature, pH, Chlorides During Phase 1



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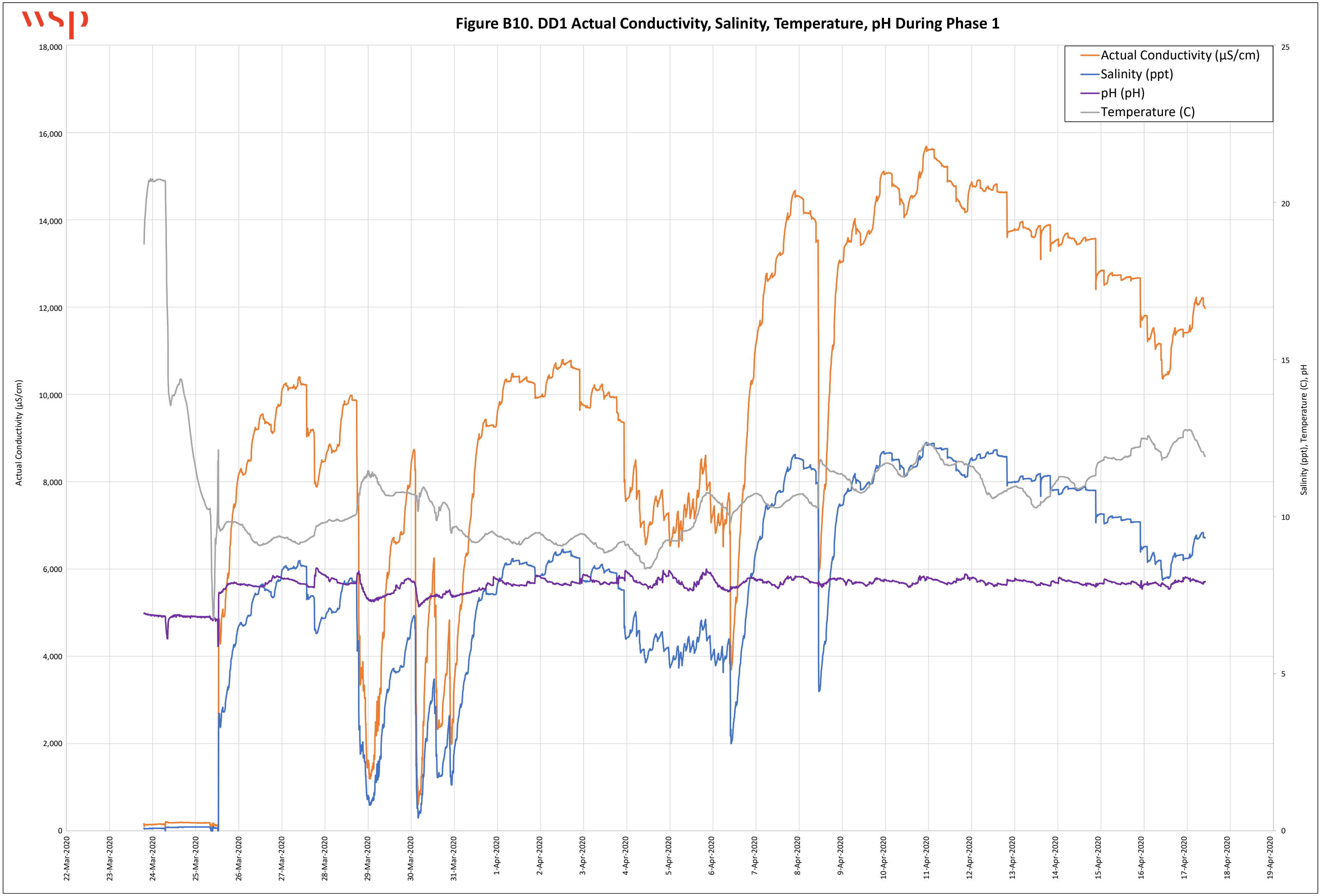

Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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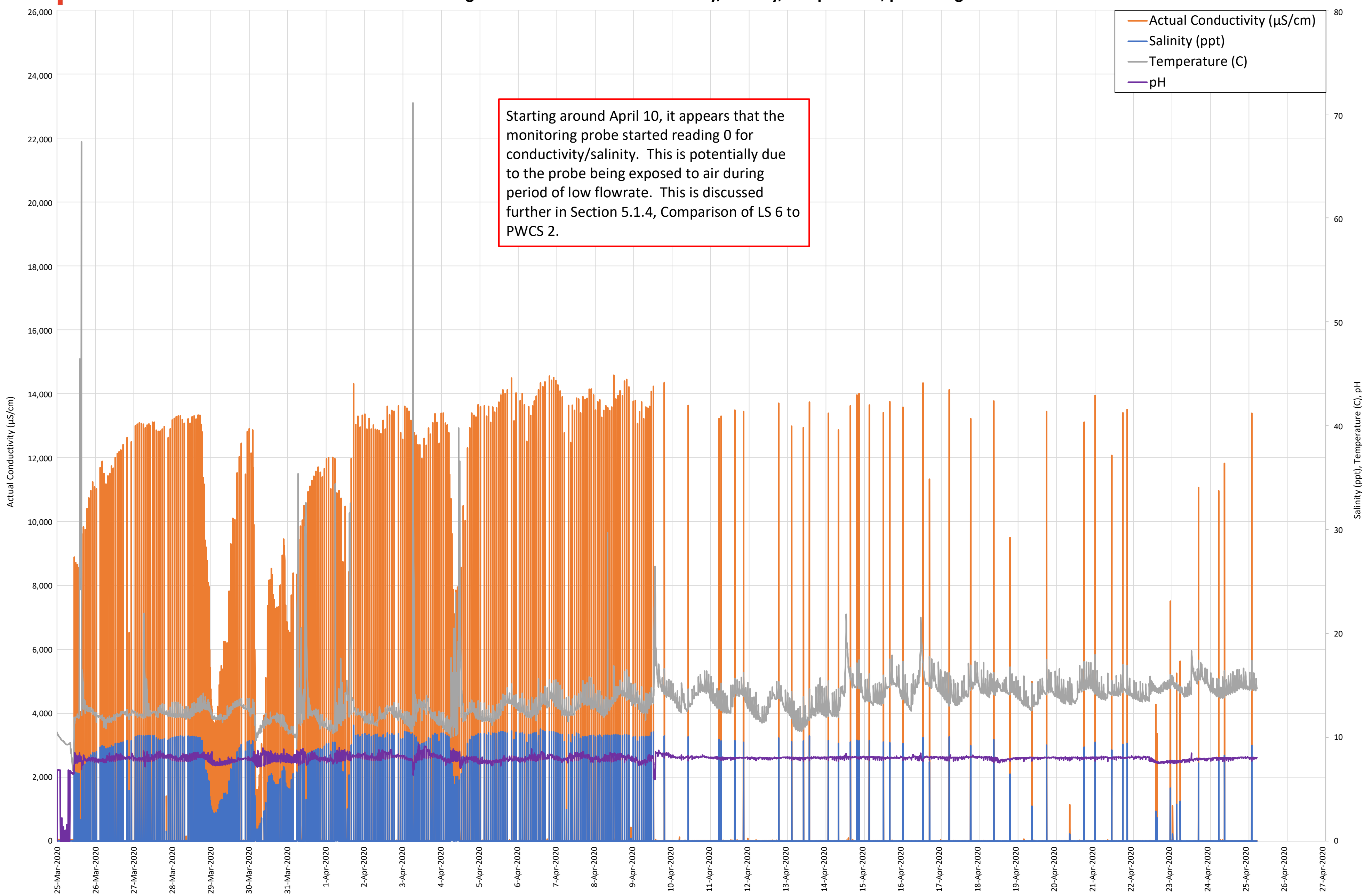
Figure B11. DD2 Actual Conductivity, Salinity, Temperature, pH During Phase 1



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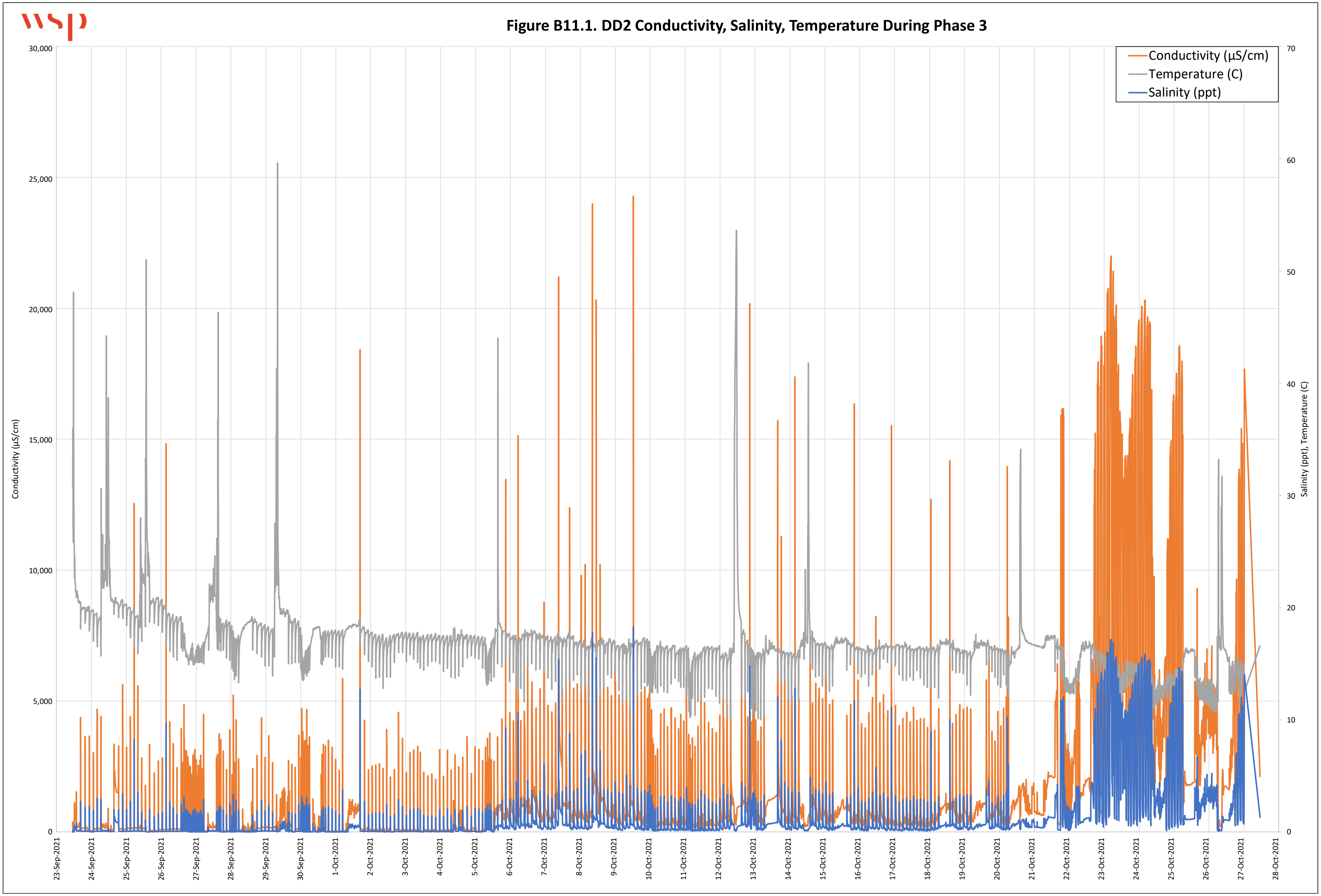

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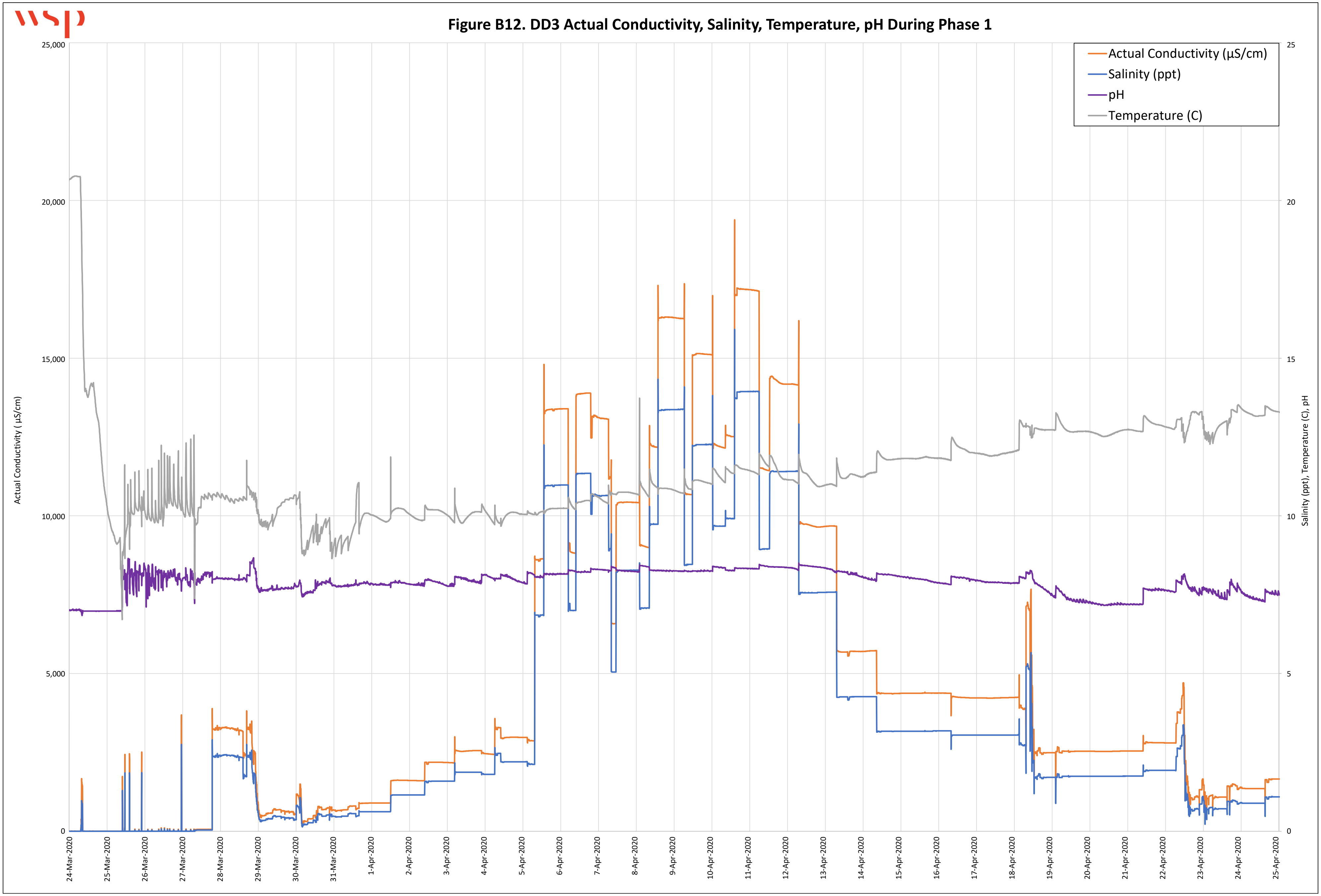

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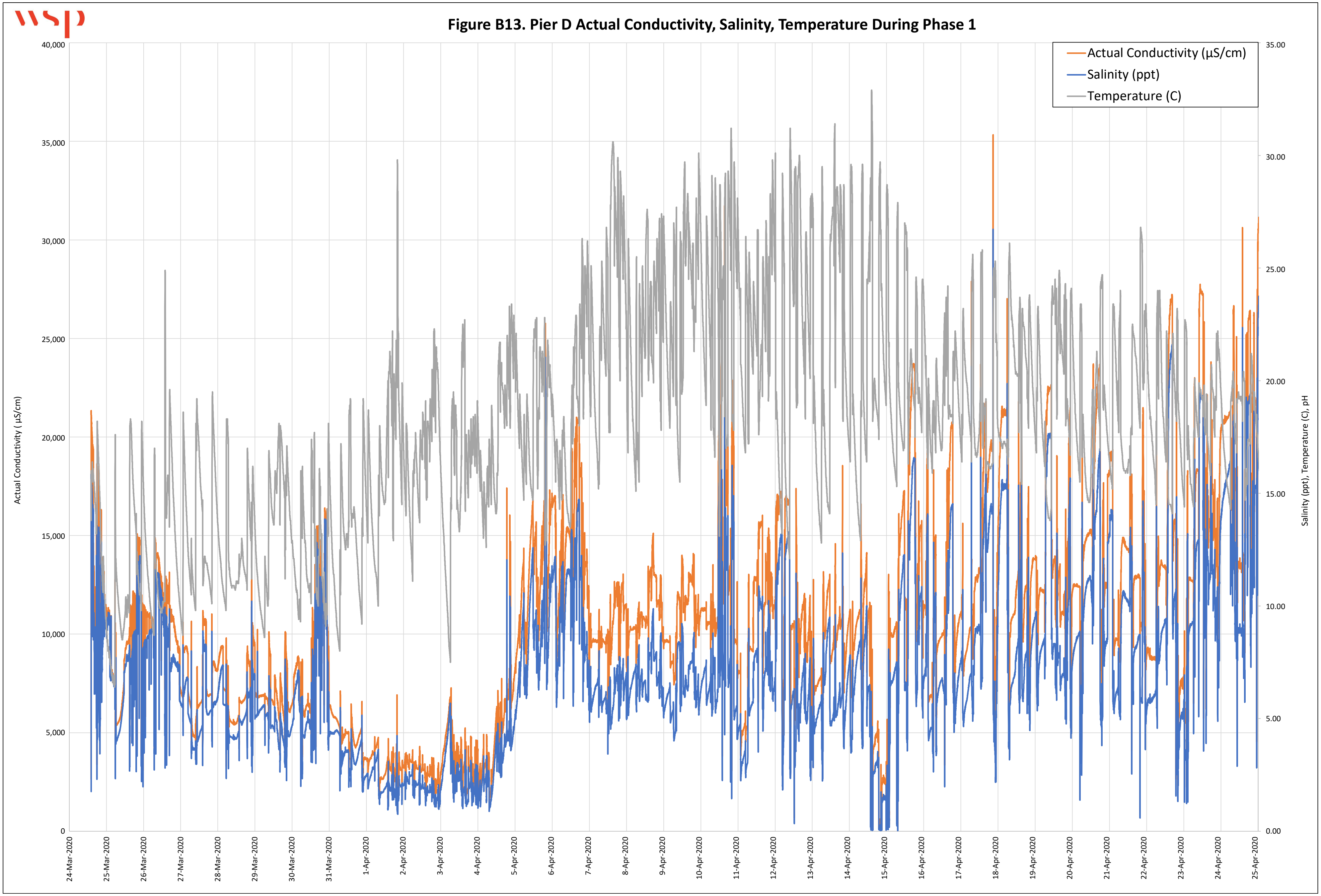

Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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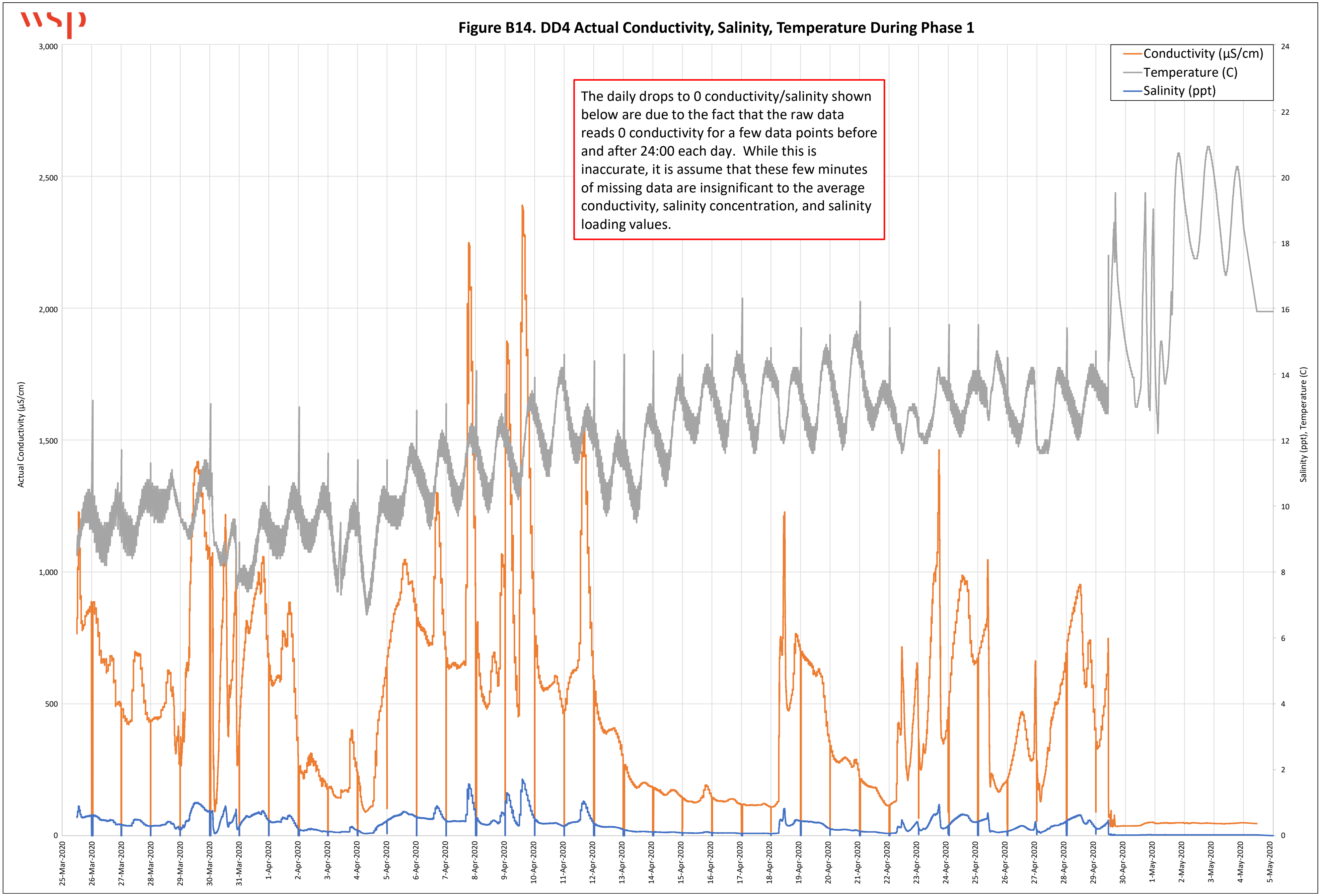
Figure B14. DD4 Actual Conductivity, Salinity, Temperature During Phase 1



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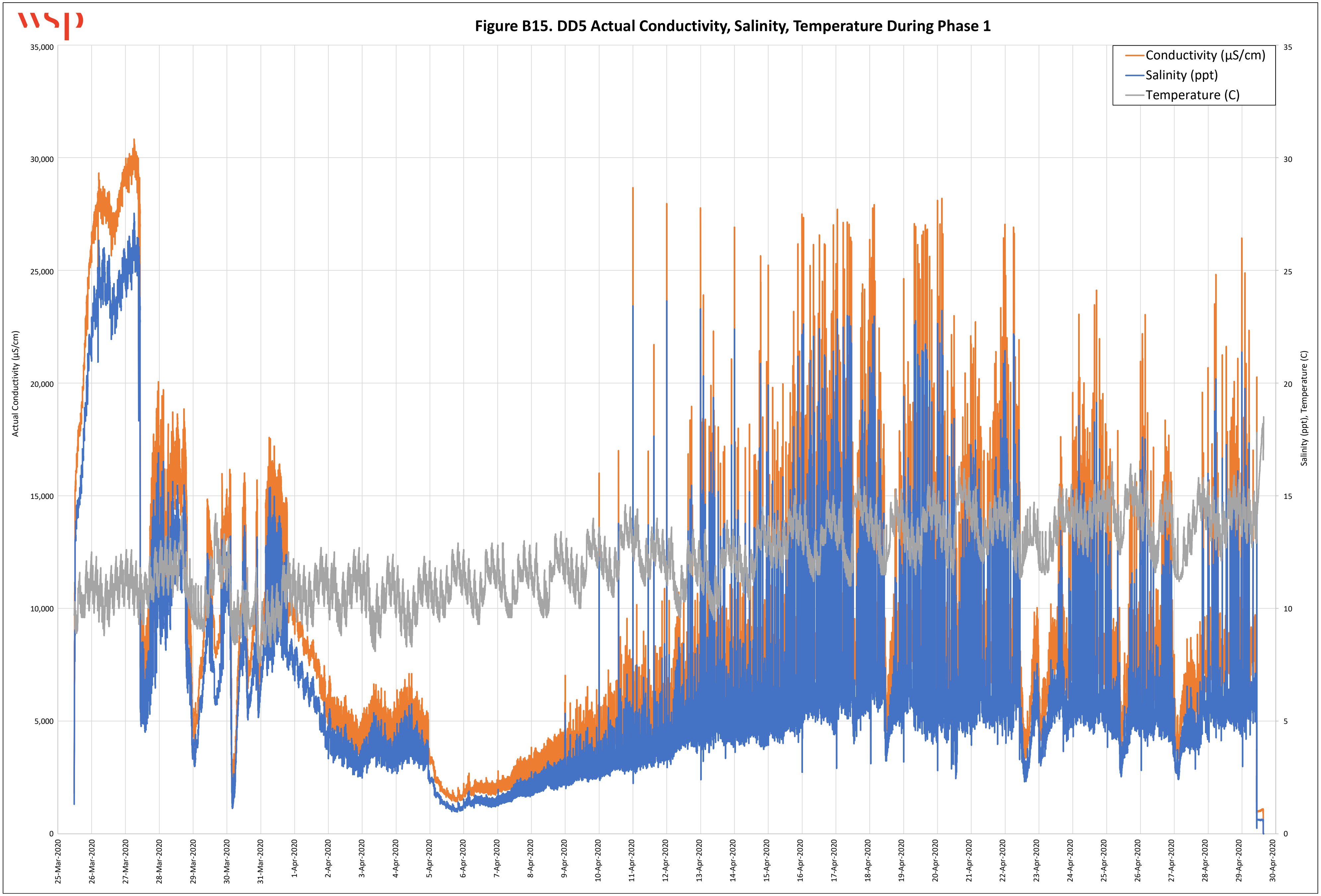

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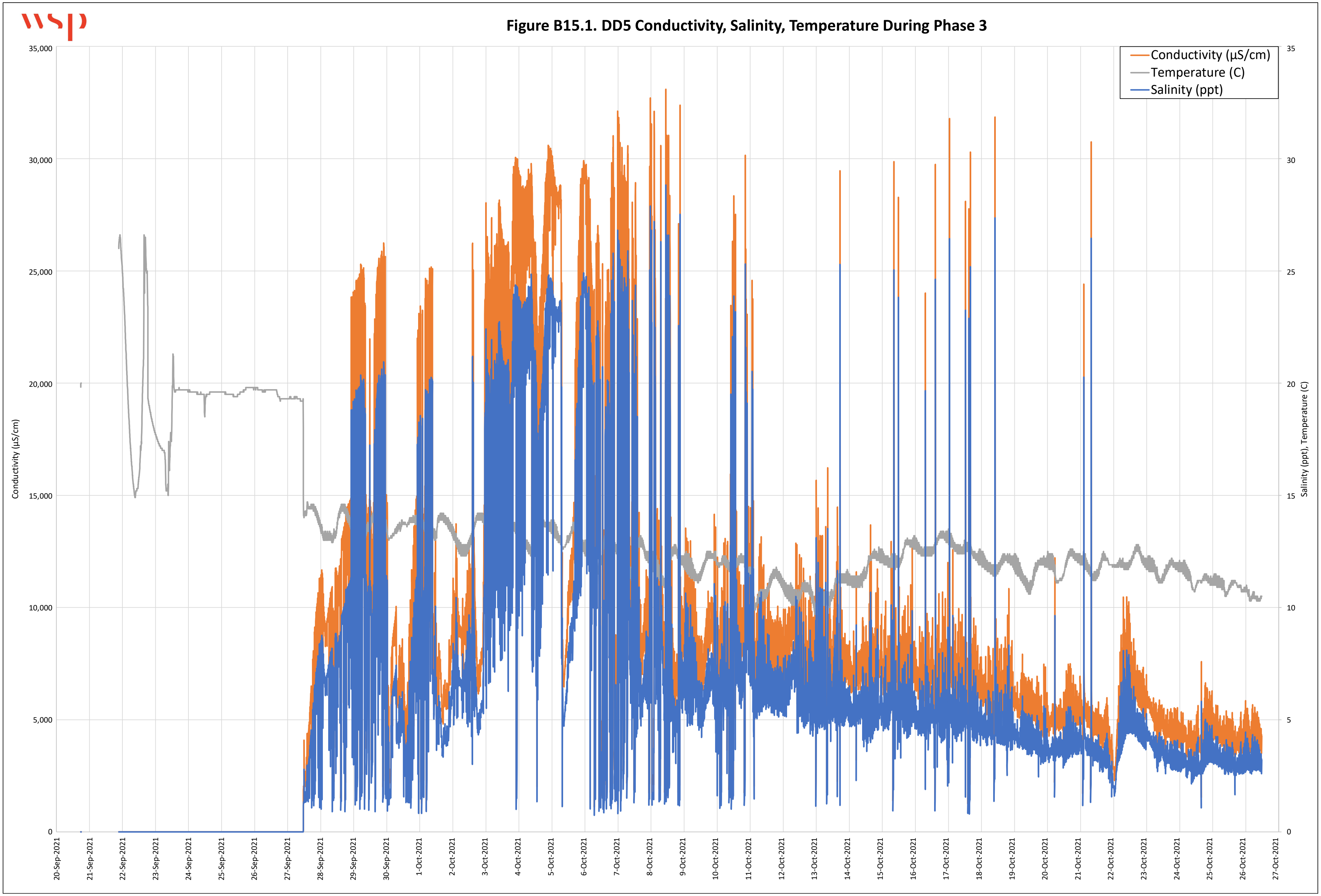

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Project Number: WA16.0094.38

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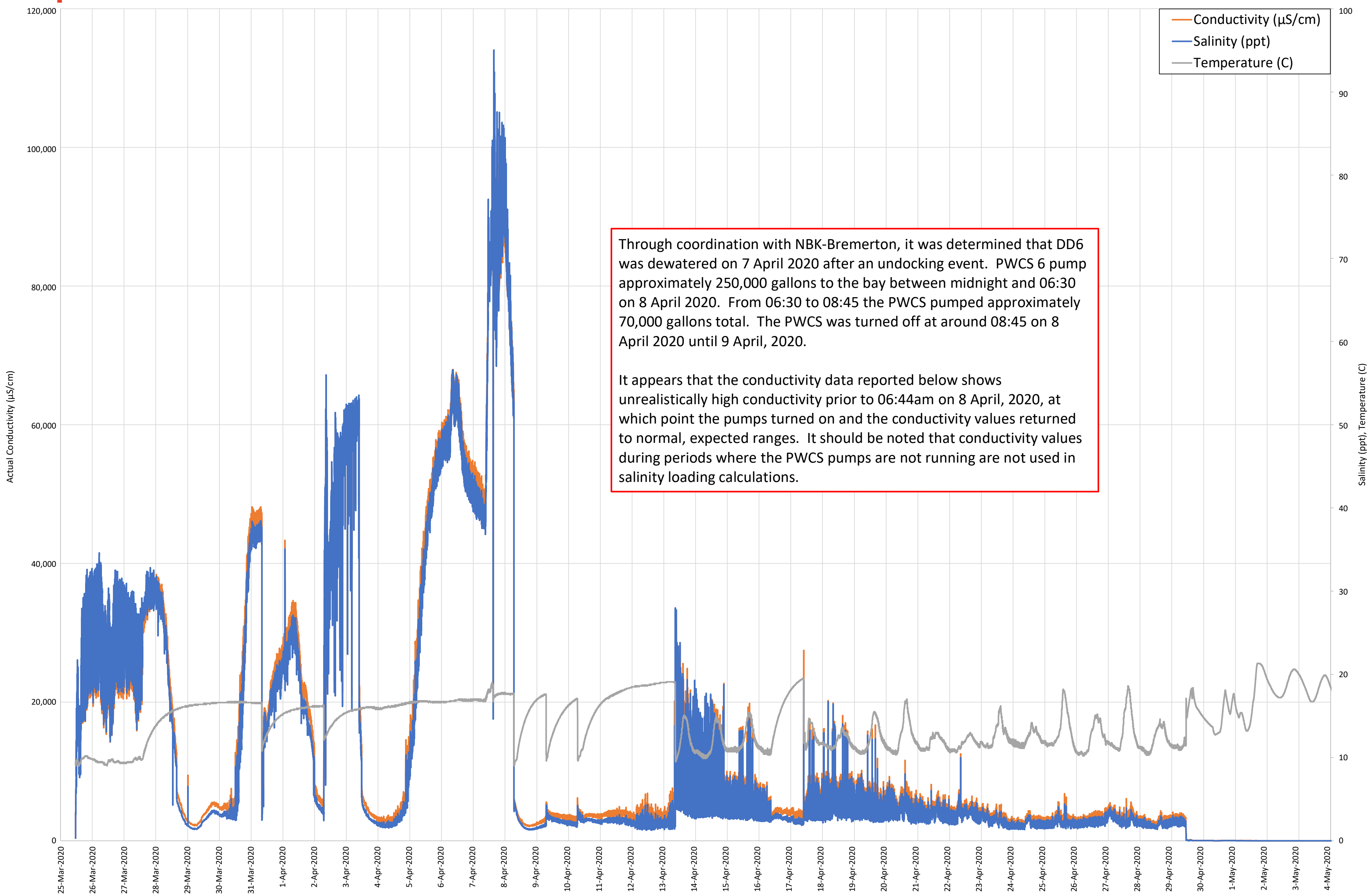
Figure B16. DD6 Actual Conductivity, Salinity, Temperature During Phase 1



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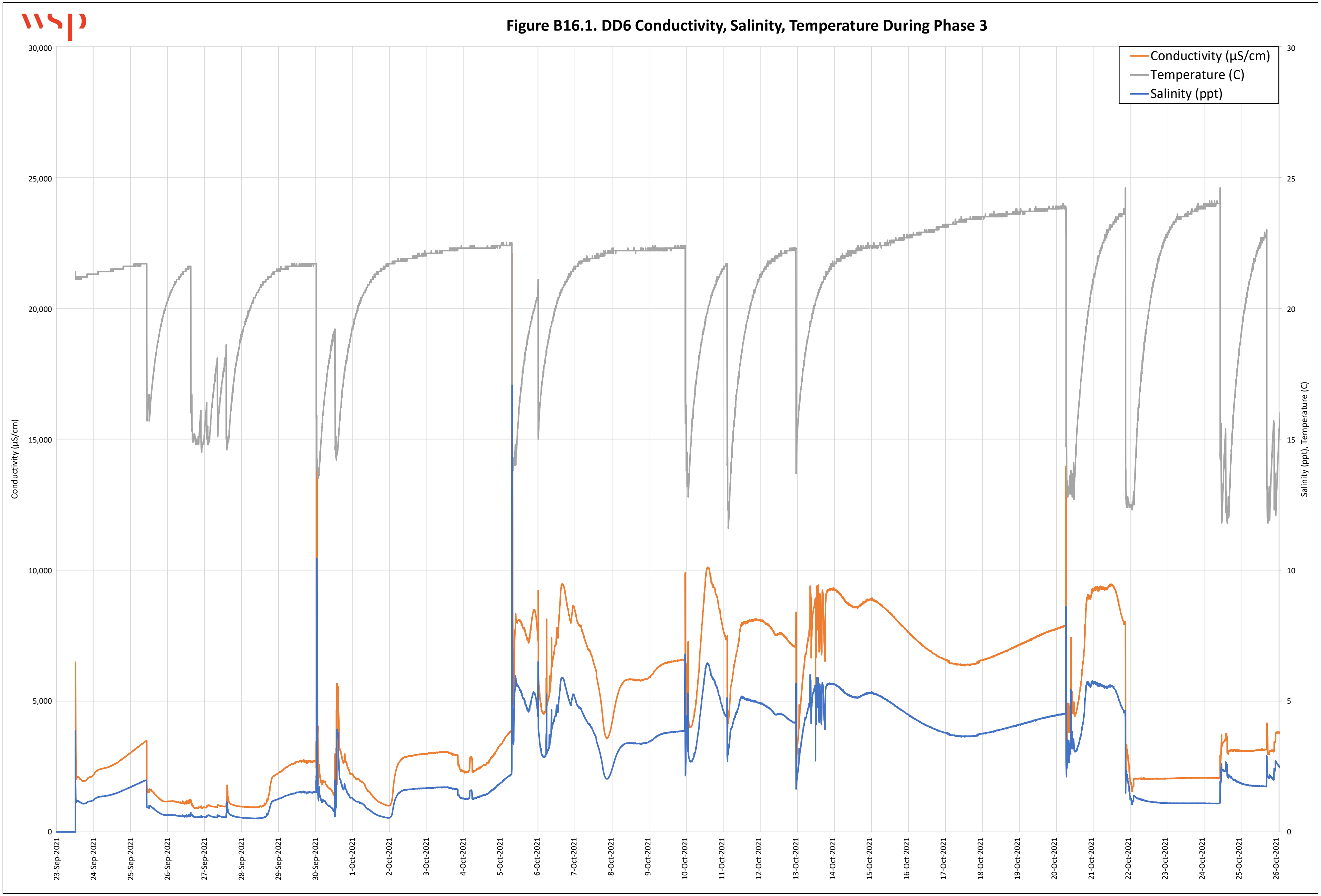

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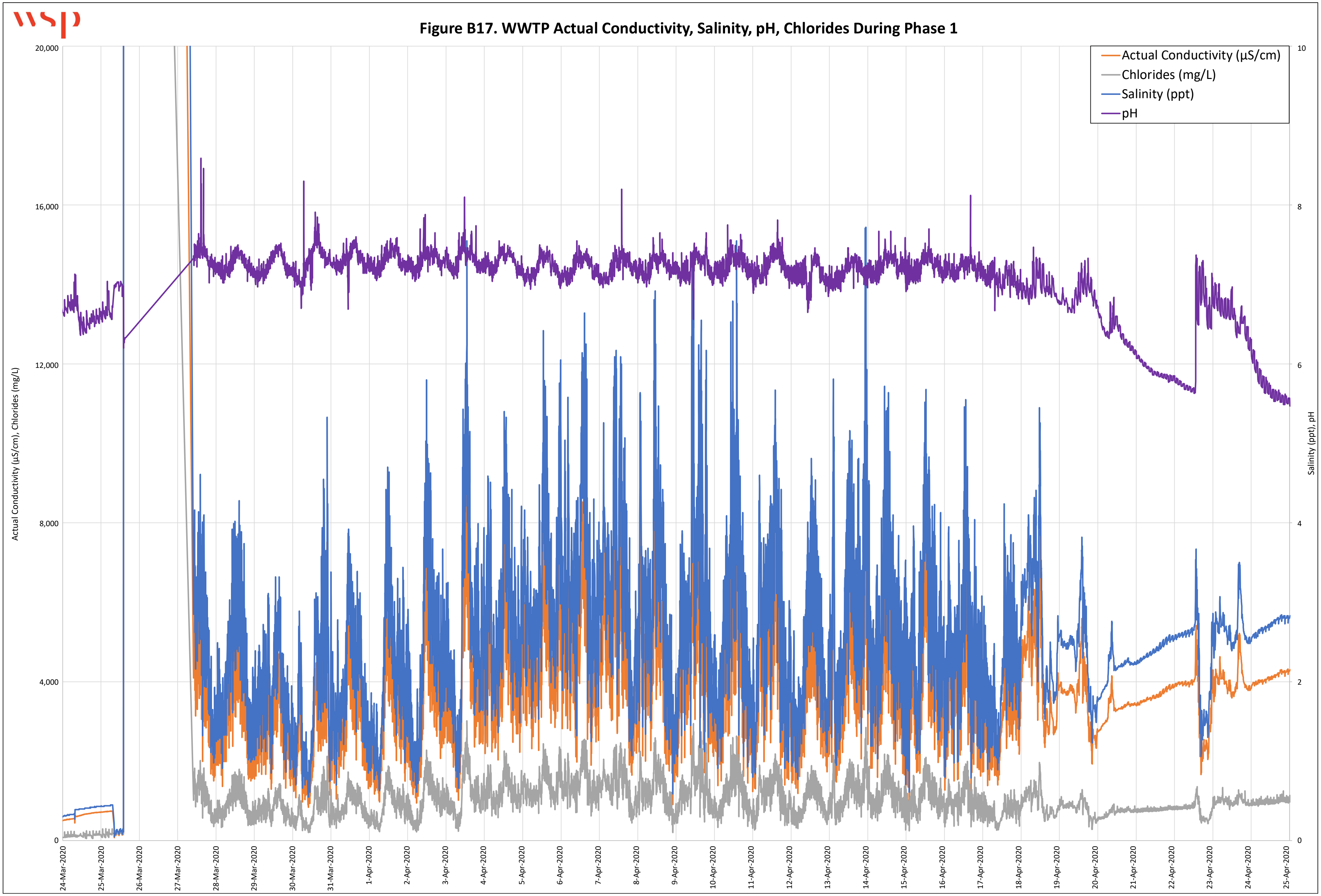

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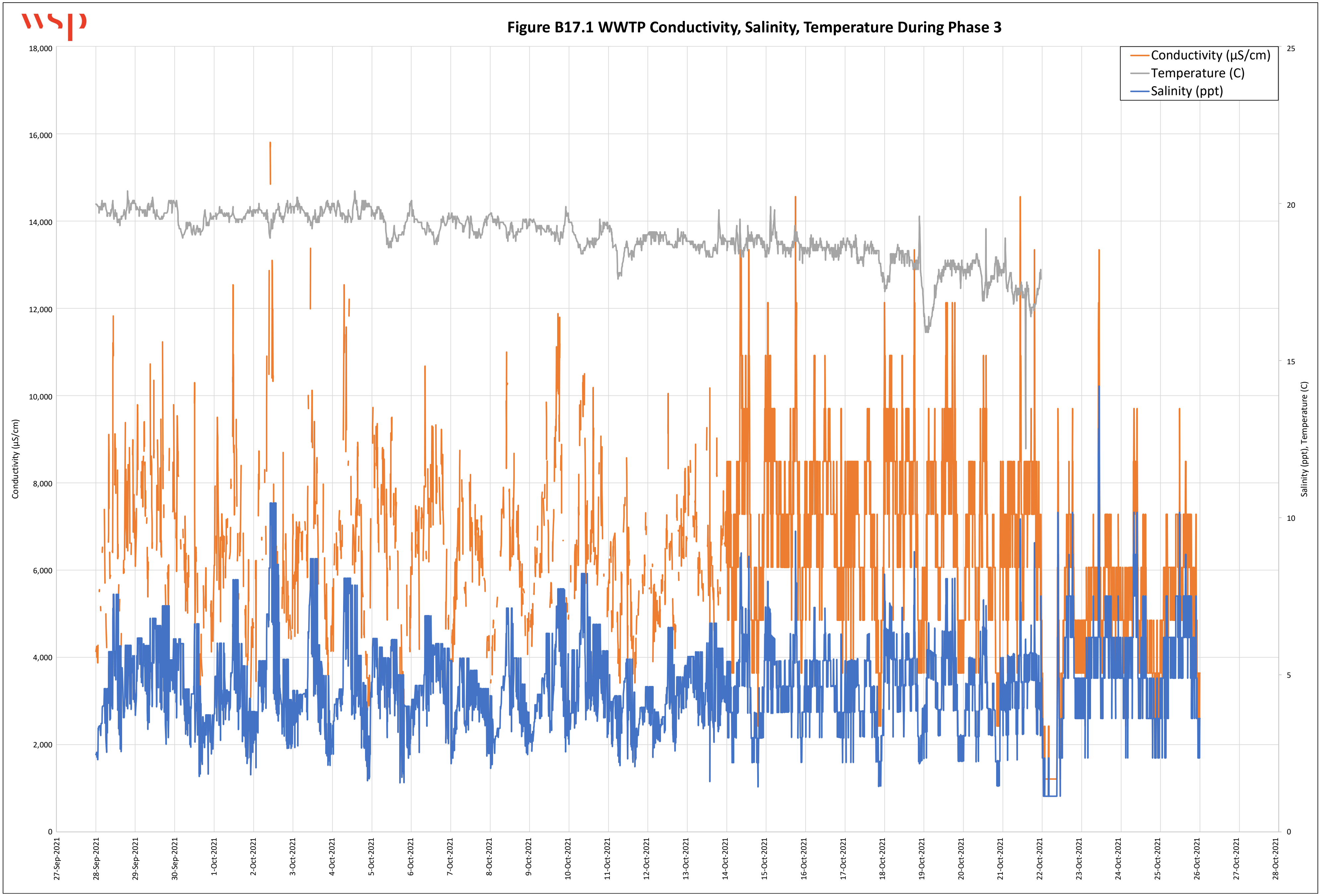

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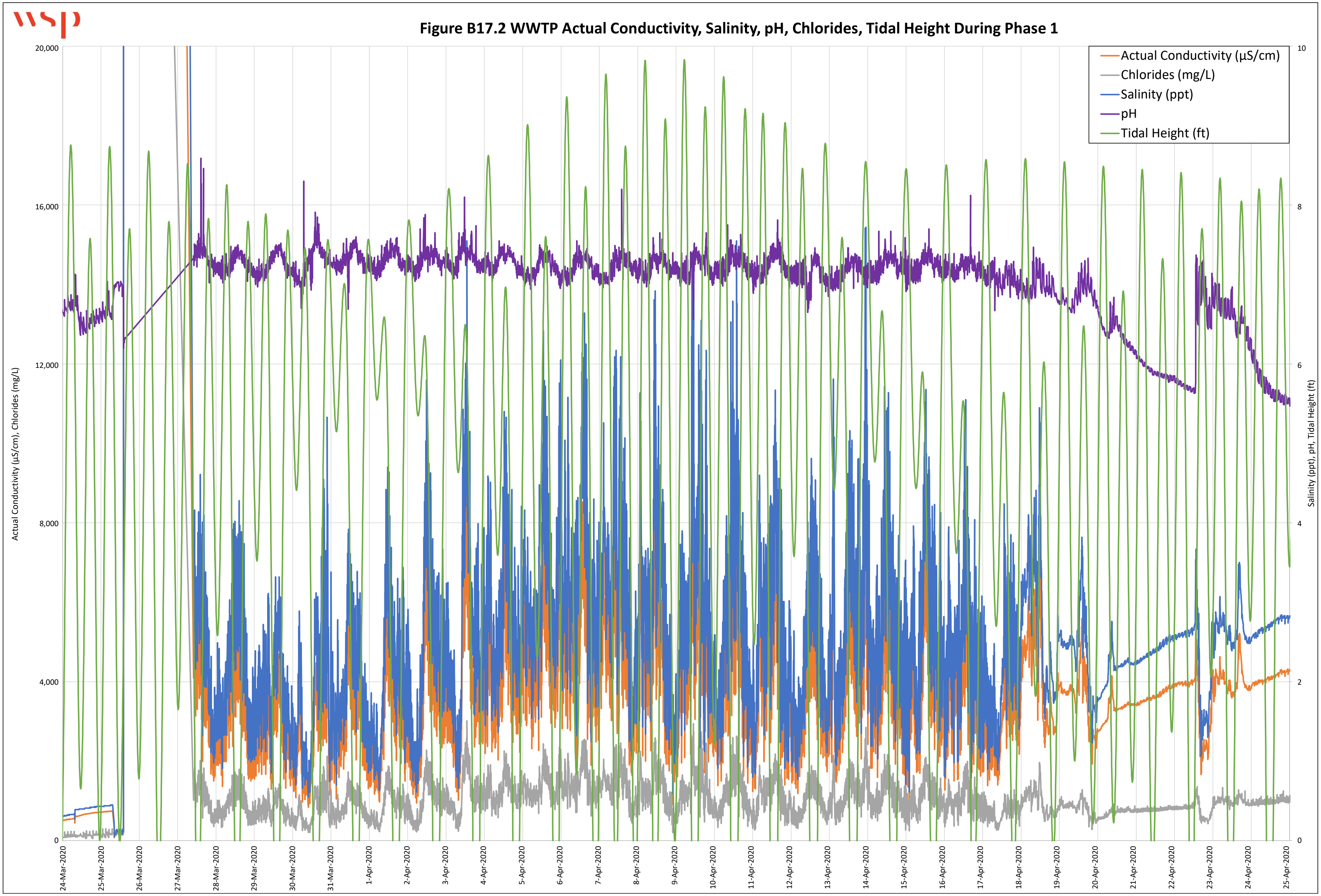

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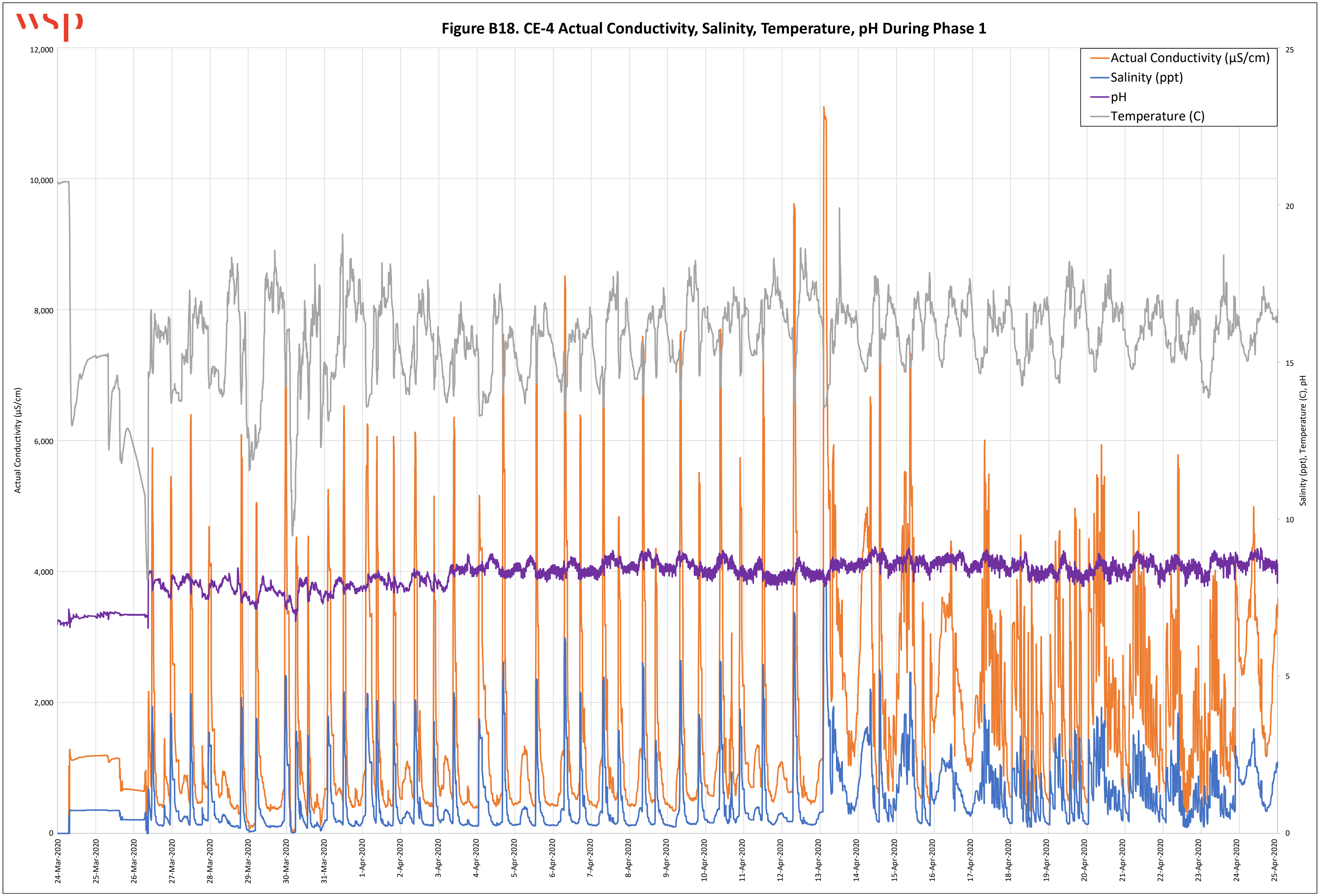

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Project Number: WA16.0094.38

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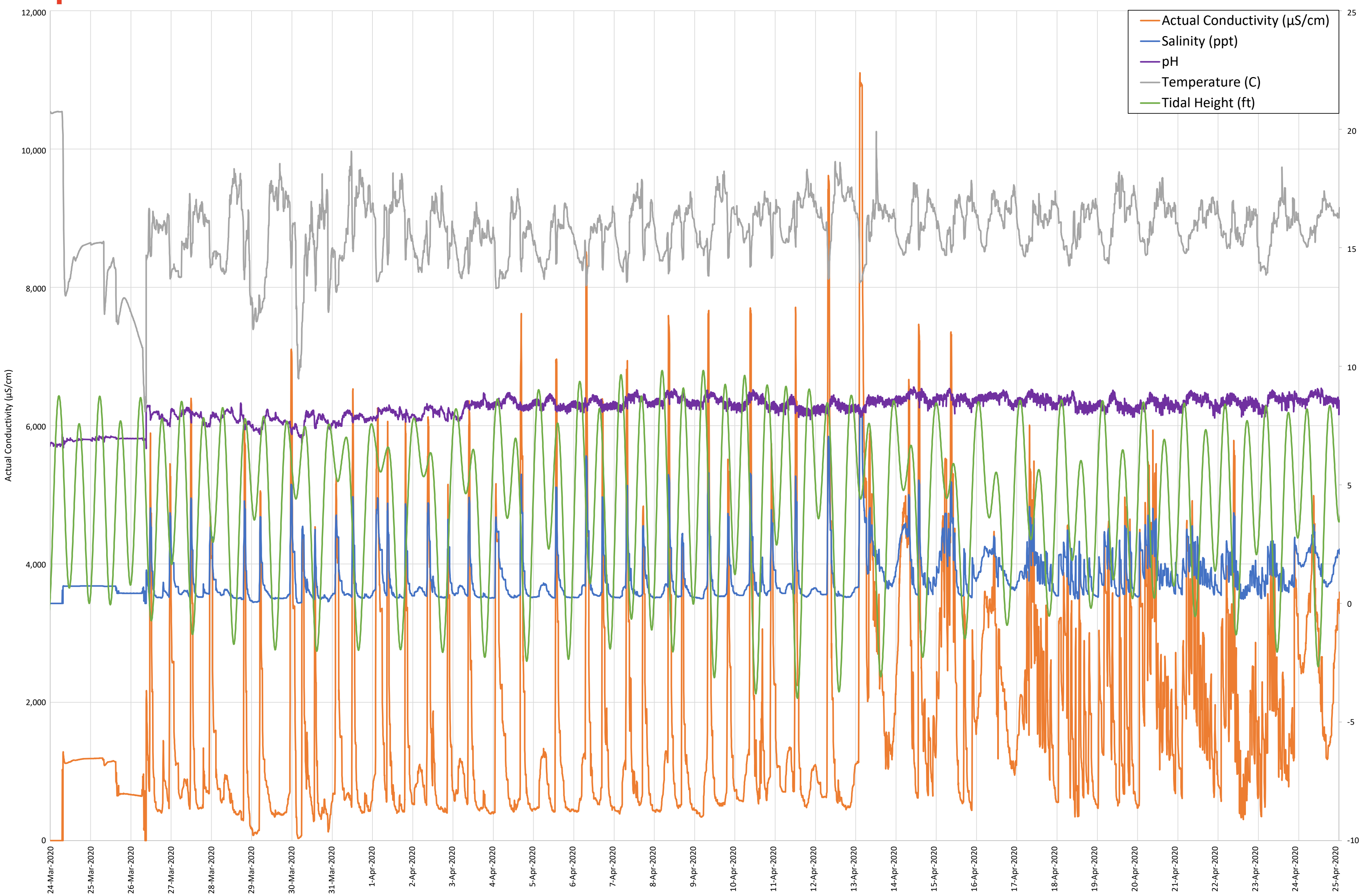
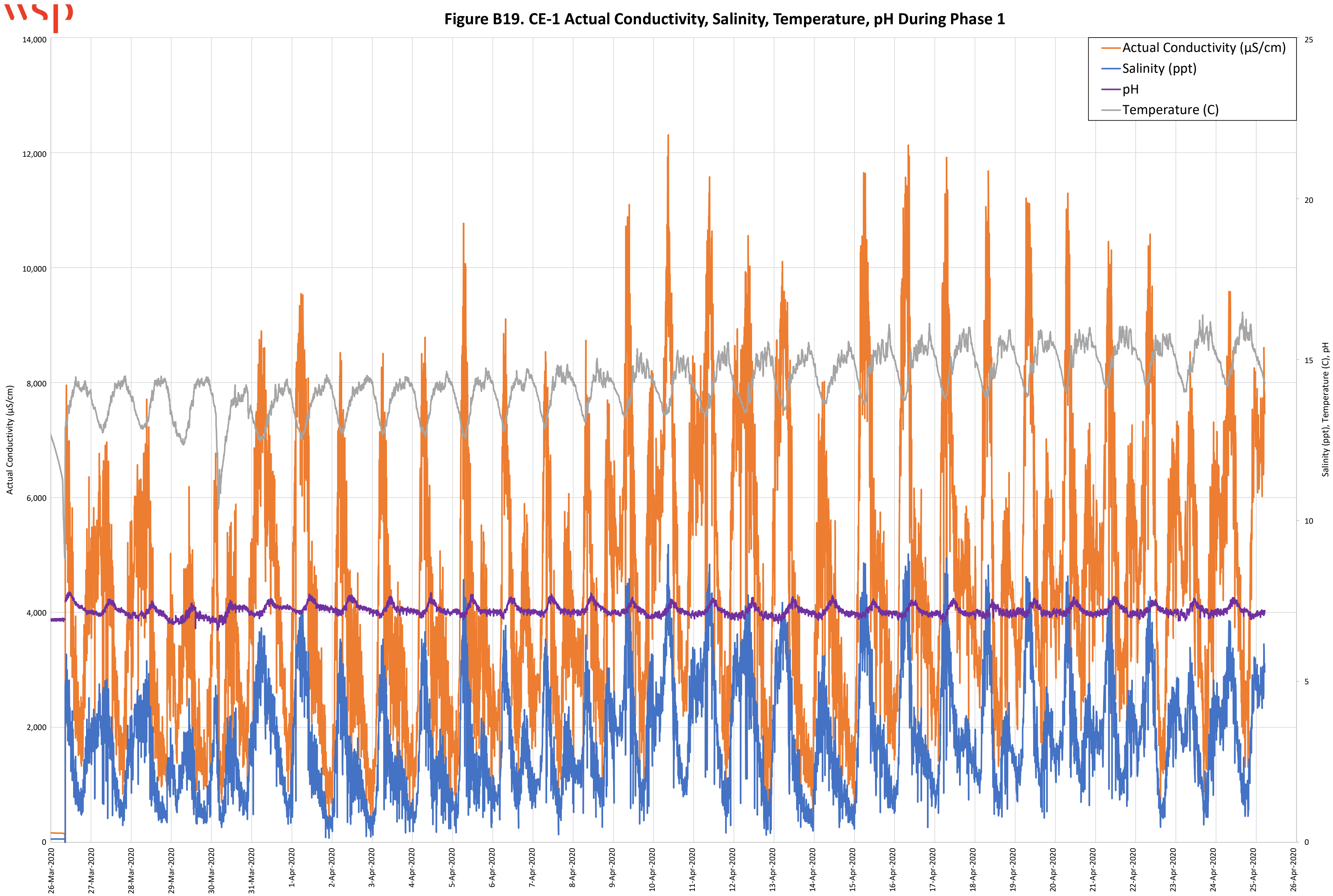
Figure B18.1 CE-4 Actual Conductivity, Salinity, Temperature, pH, Tidal Height During Phase 1



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Figure B19. CE-1 Actual Conductivity, Salinity, Temperature, pH During Phase 1



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Project Number: WA16.0094.38

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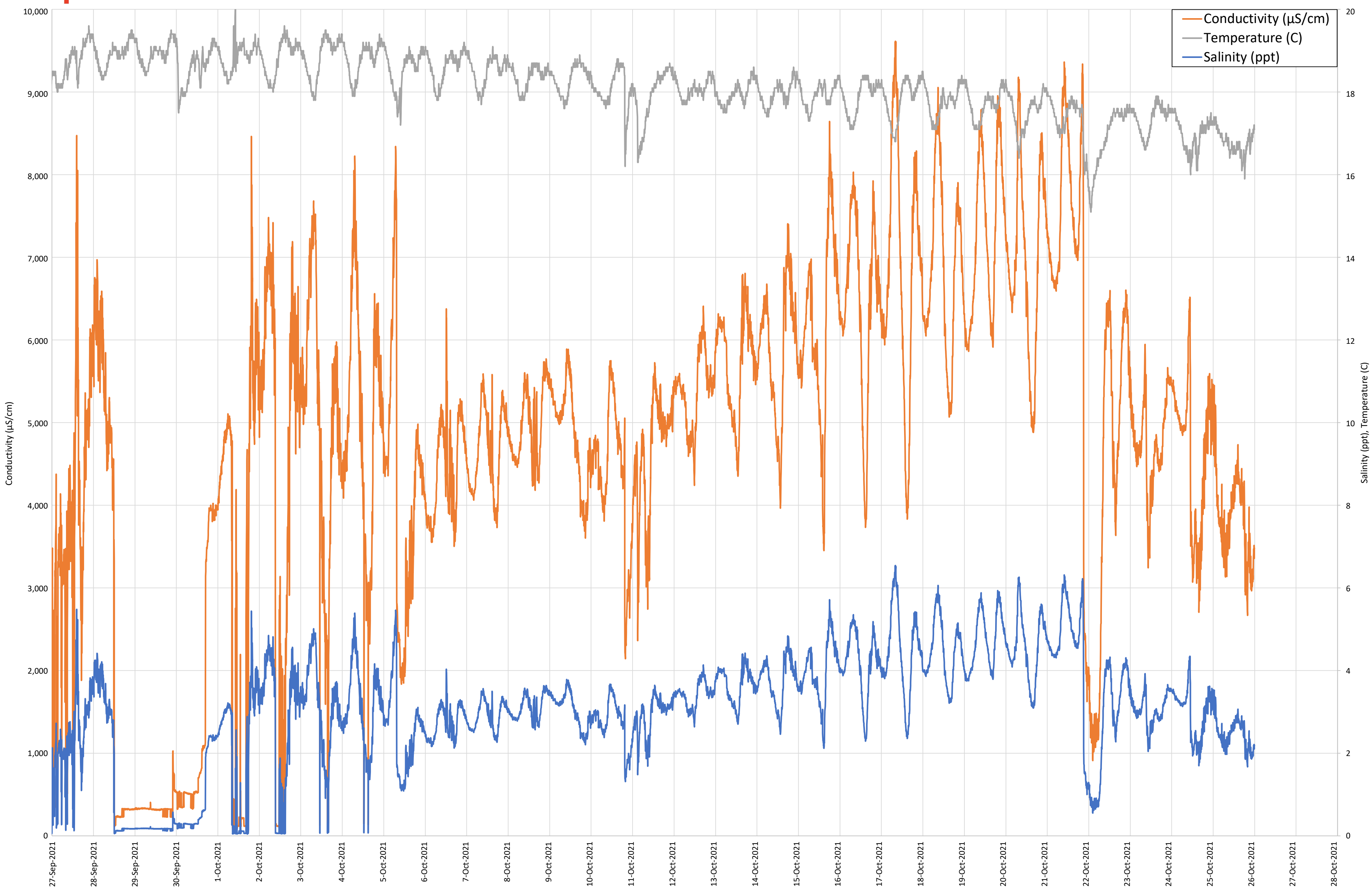
Figure B19.1. CE-1 Conductivity, Salinity, Temperature During Phase 3



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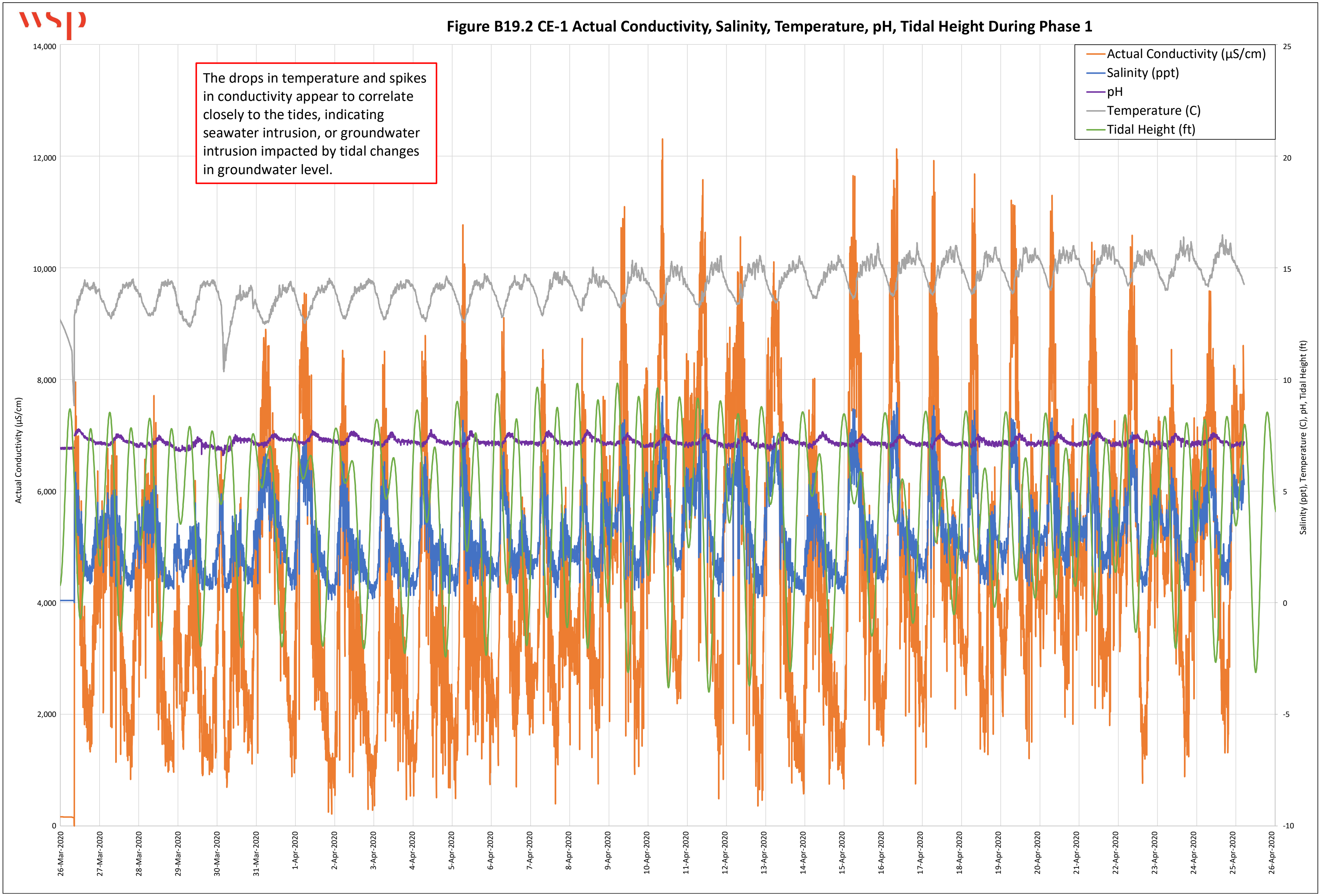

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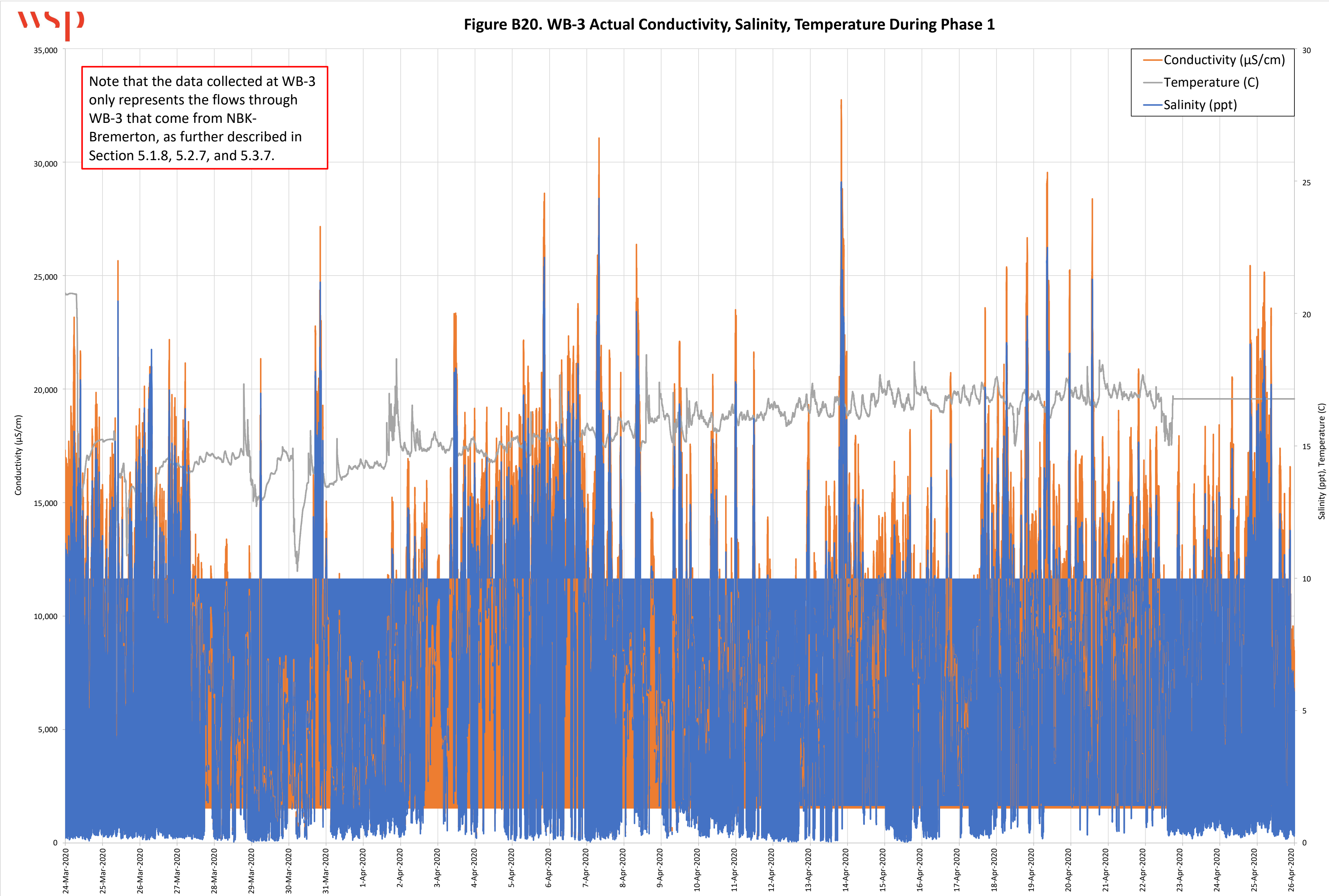

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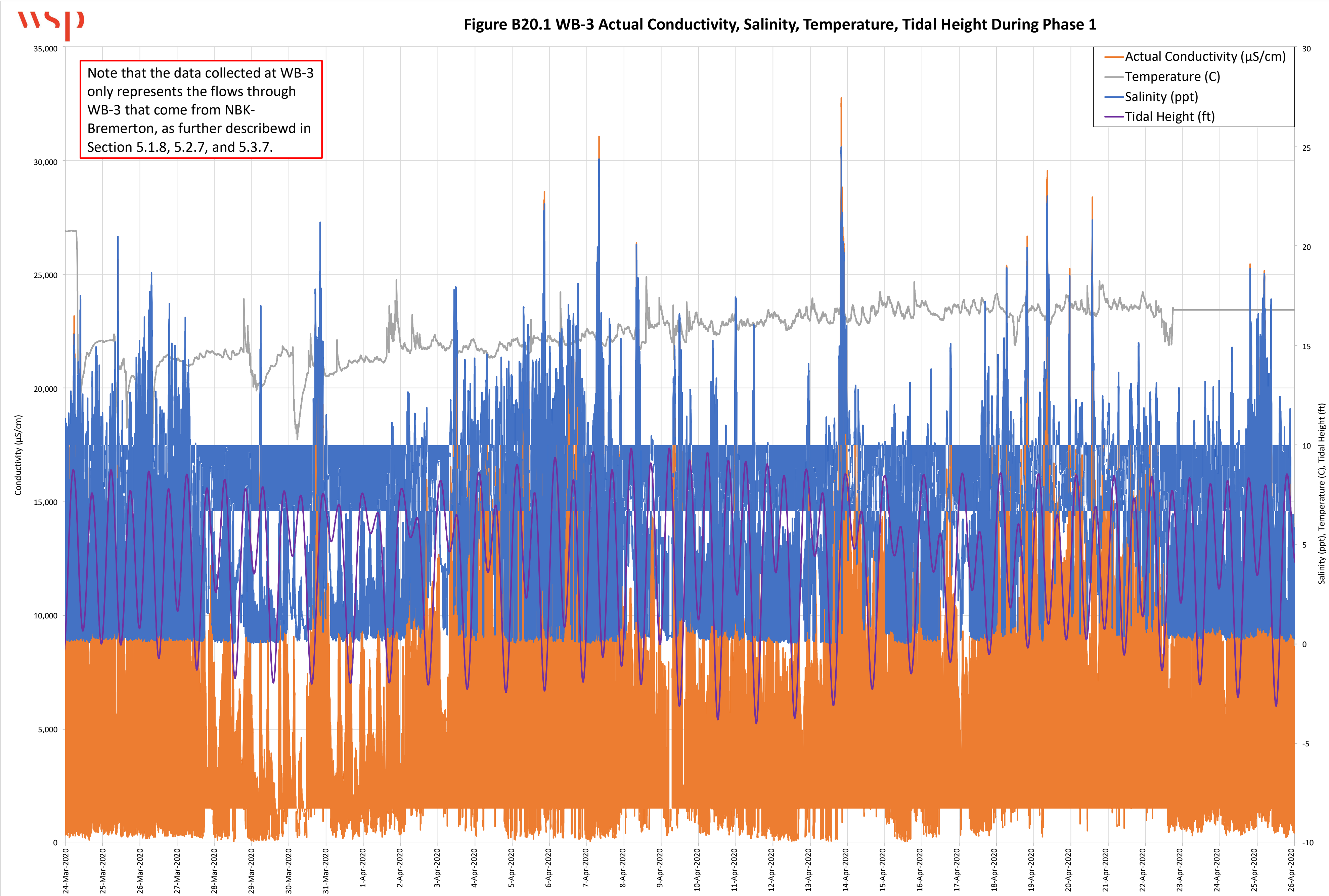

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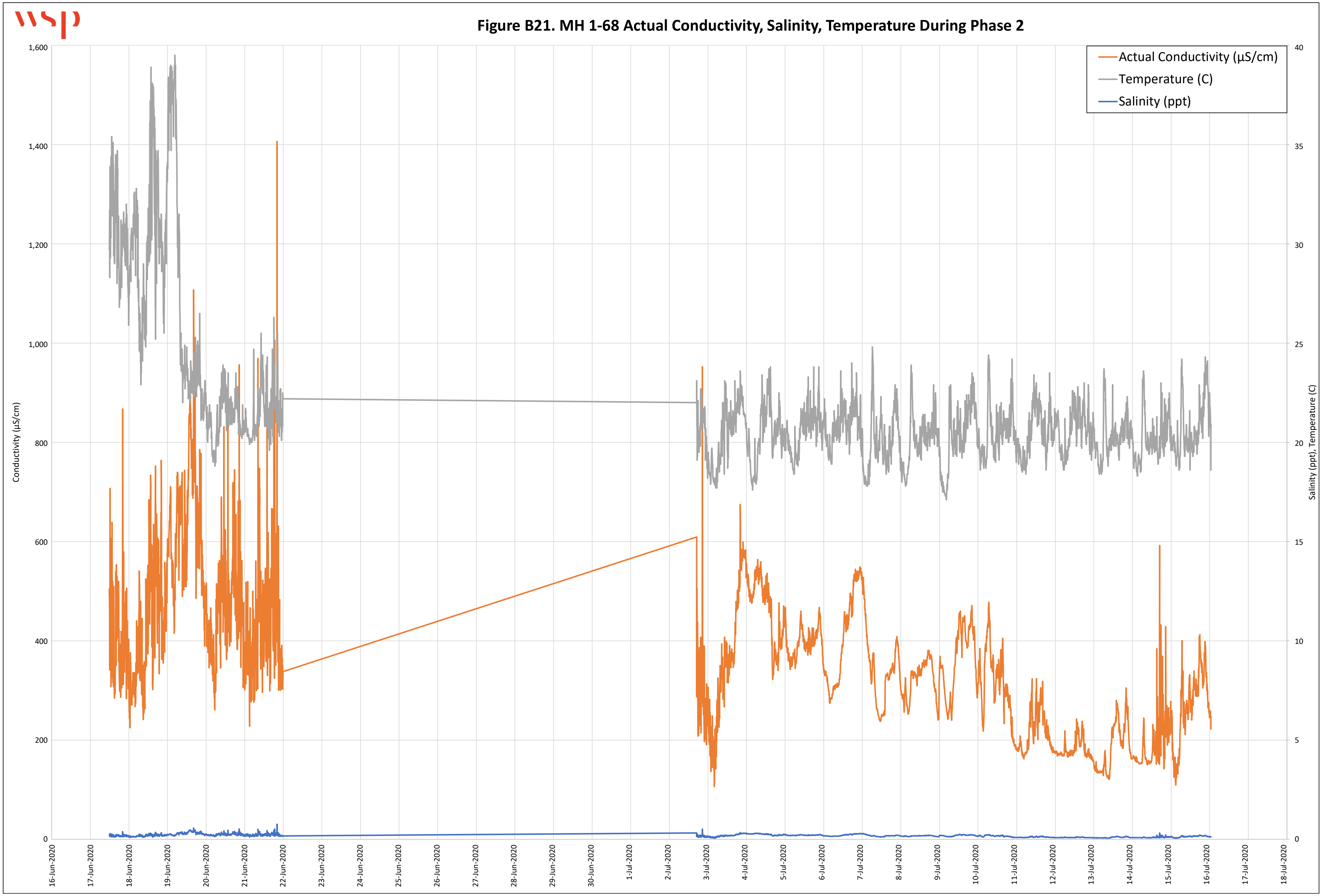

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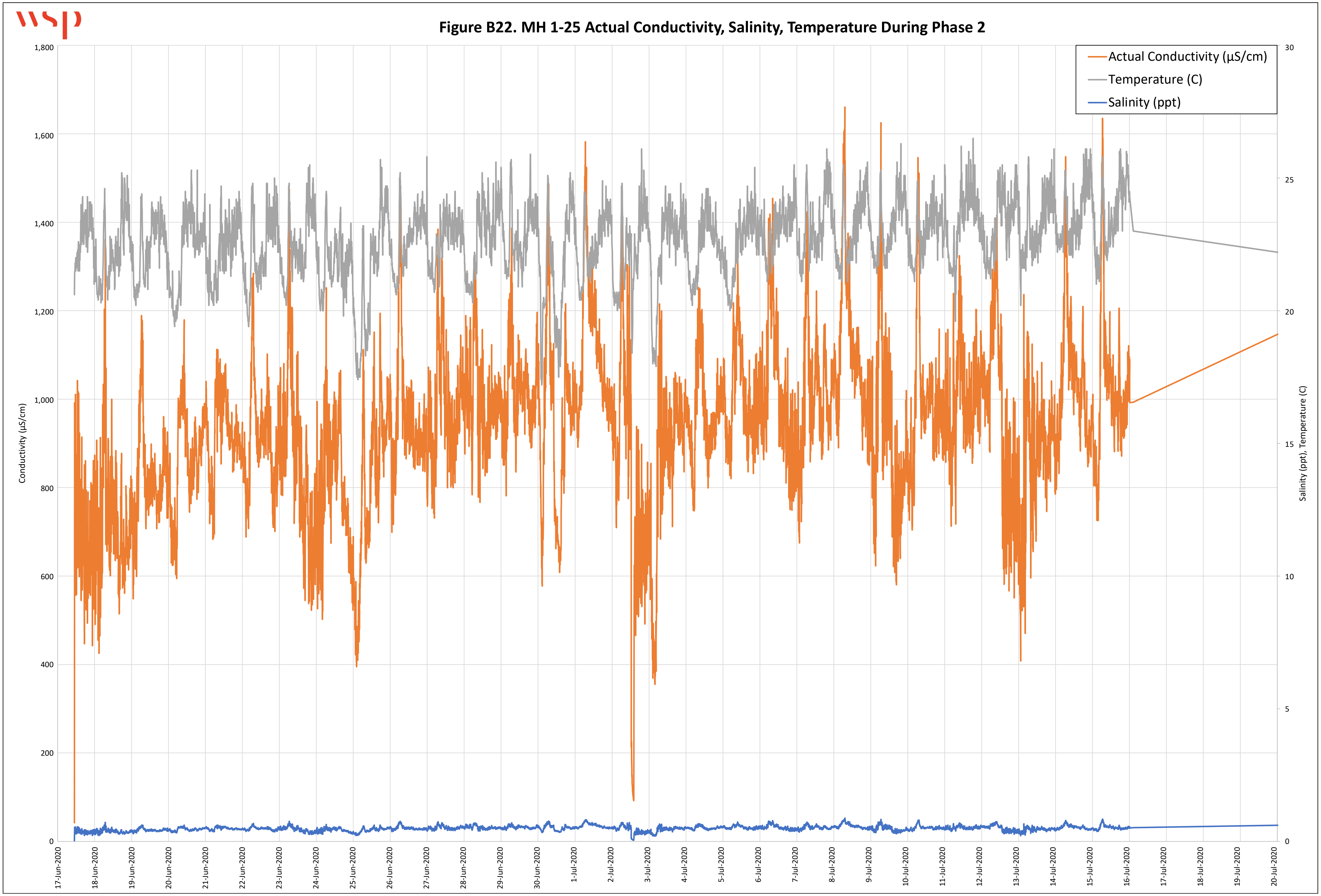

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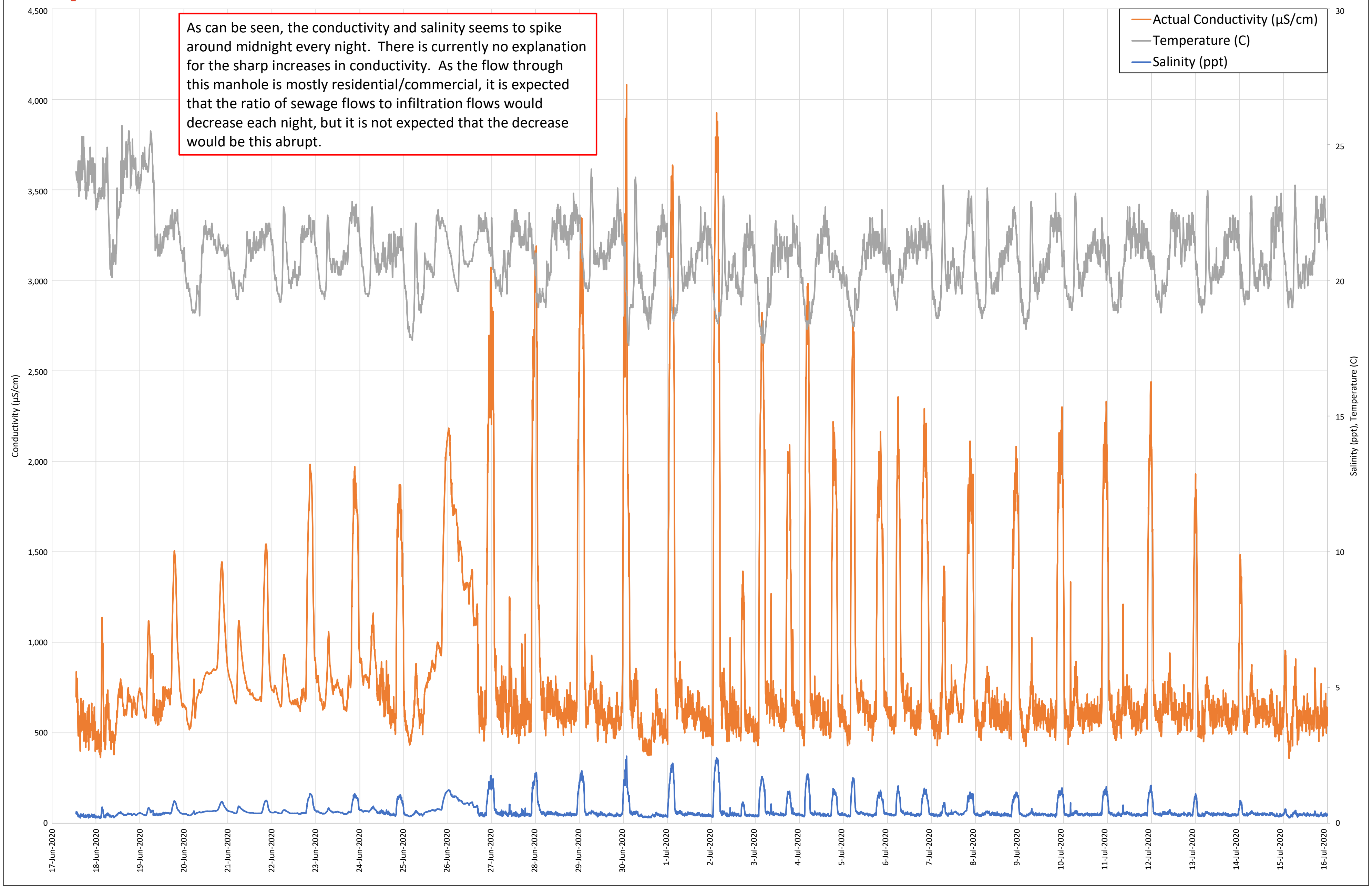
Figure B23. MH 1-3 Actual Conductivity, Salinity, Temperature During Phase 2



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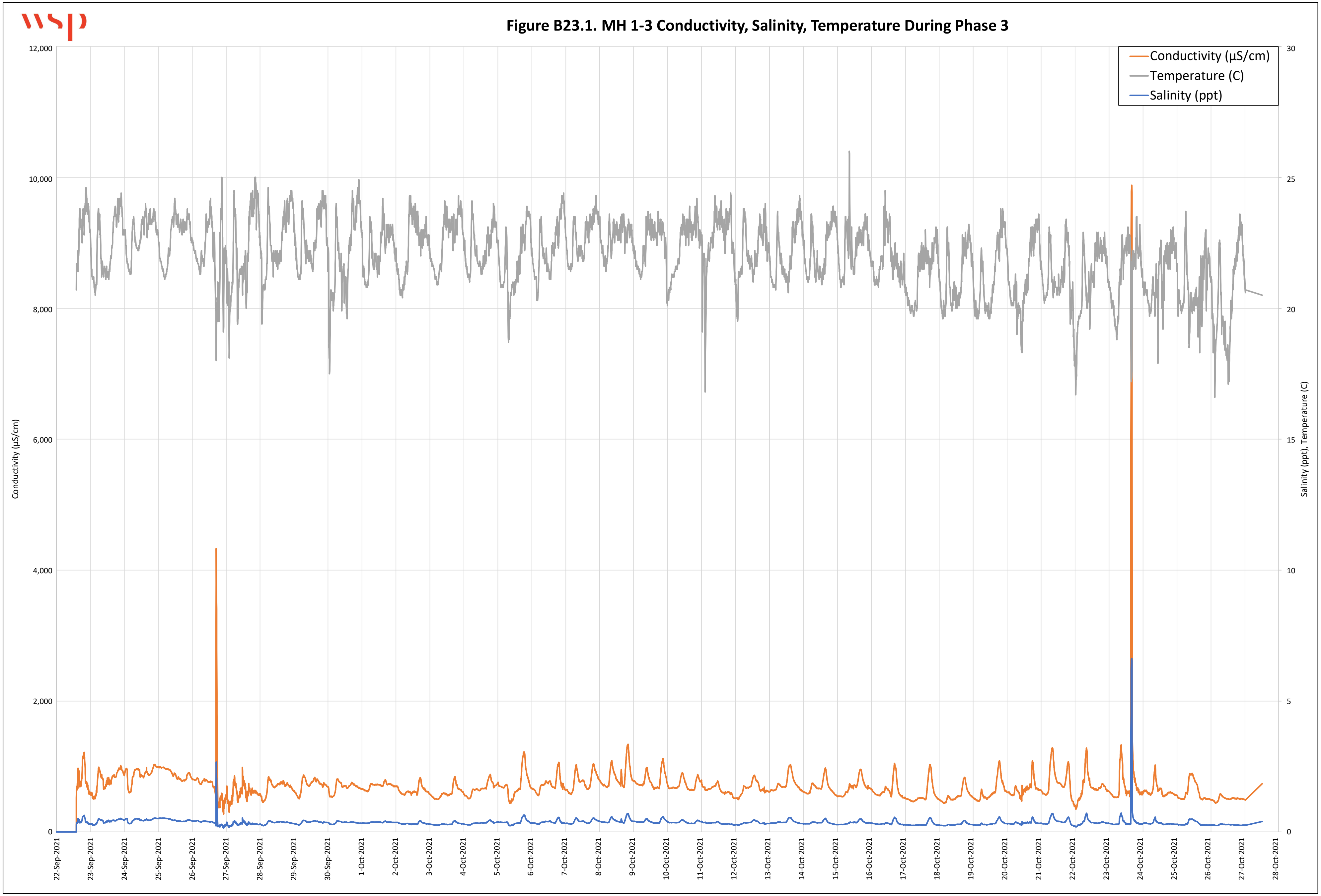

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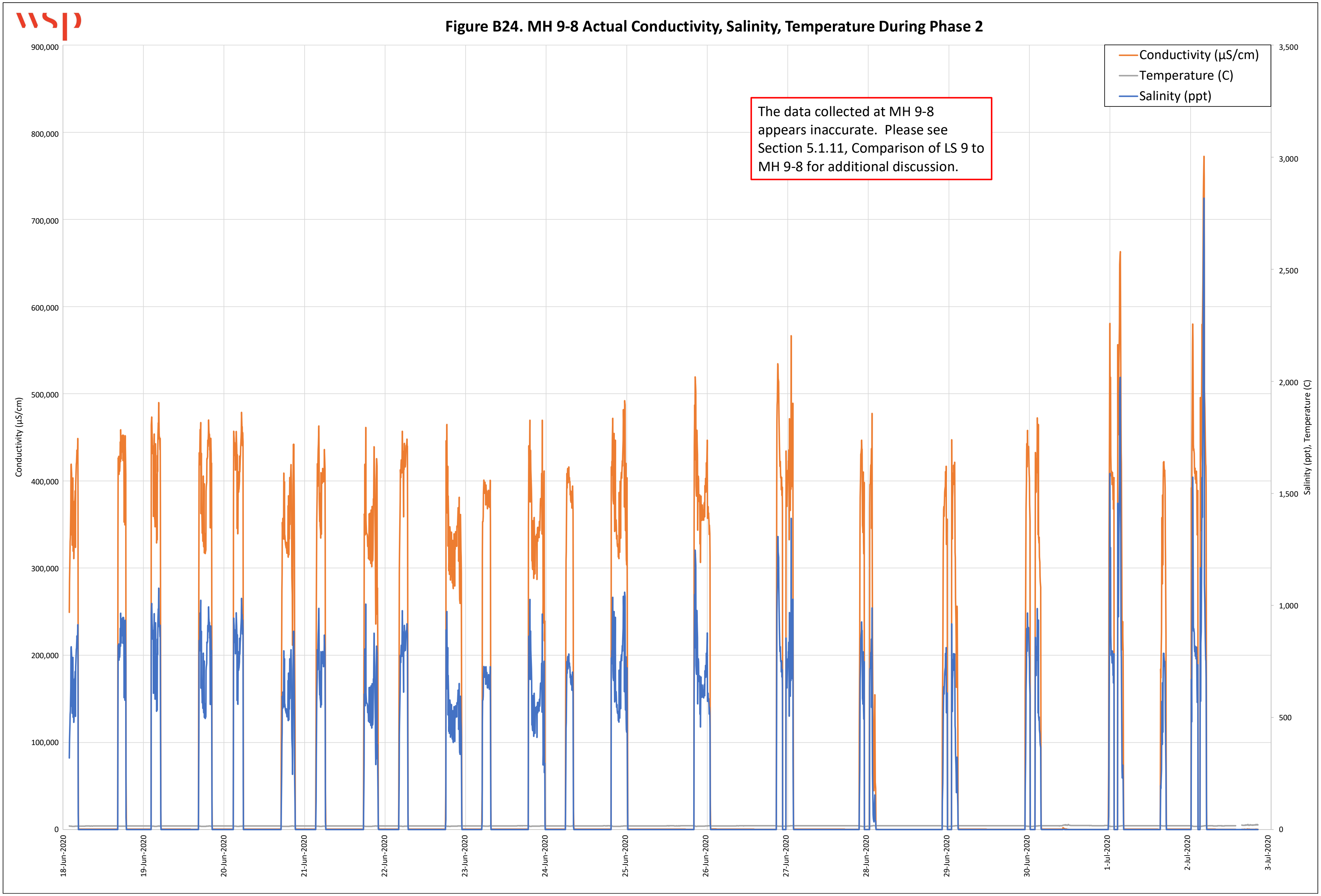

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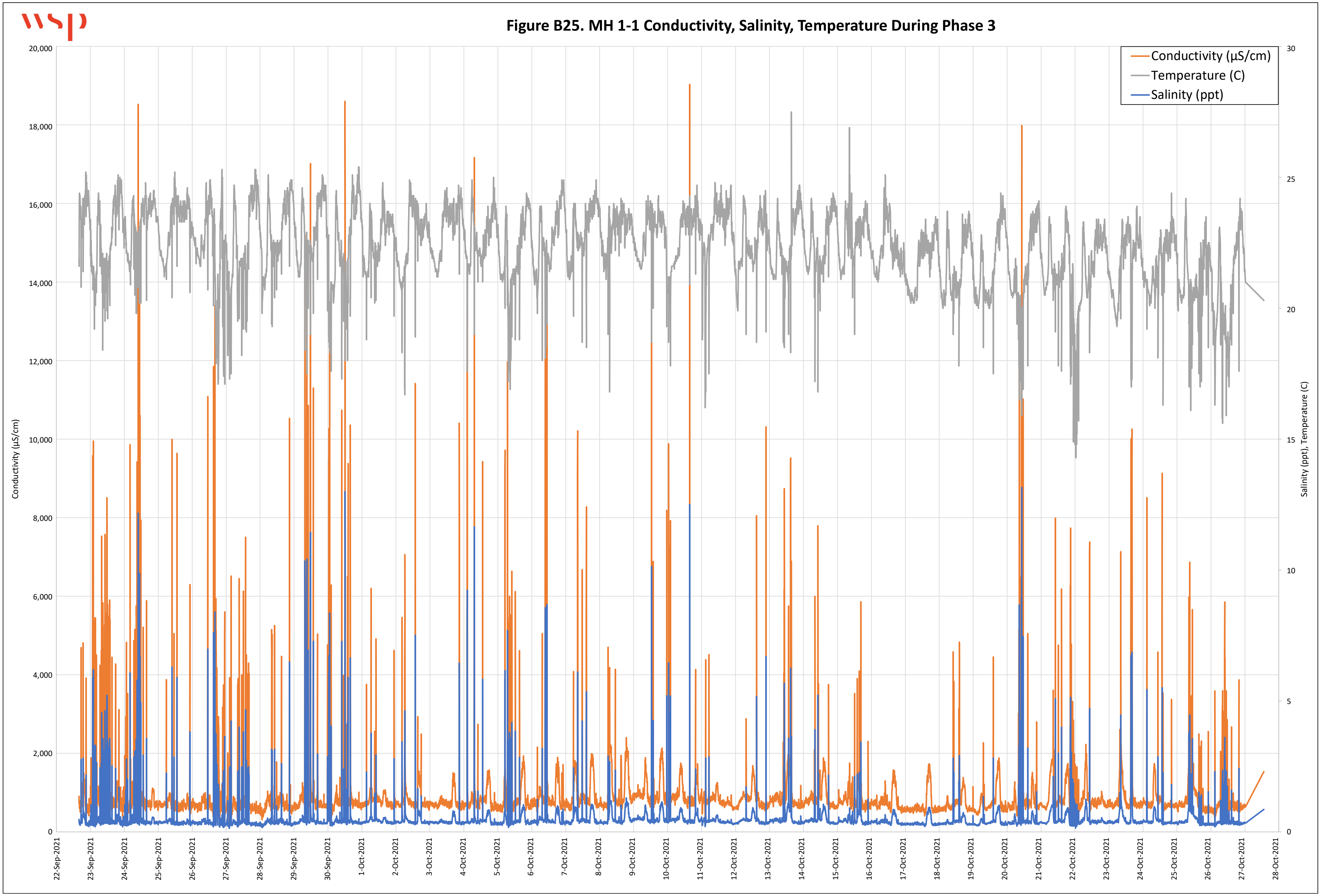

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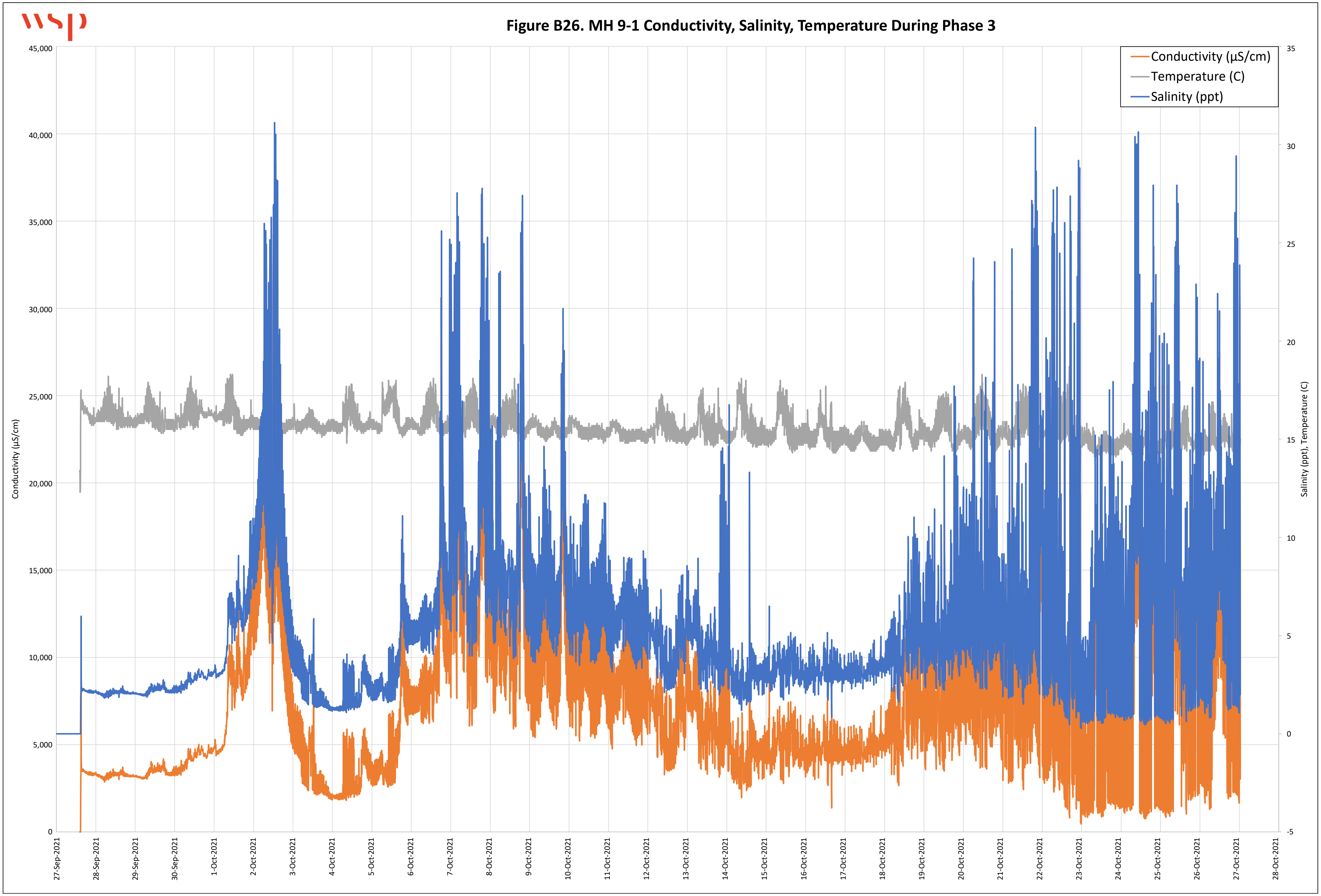

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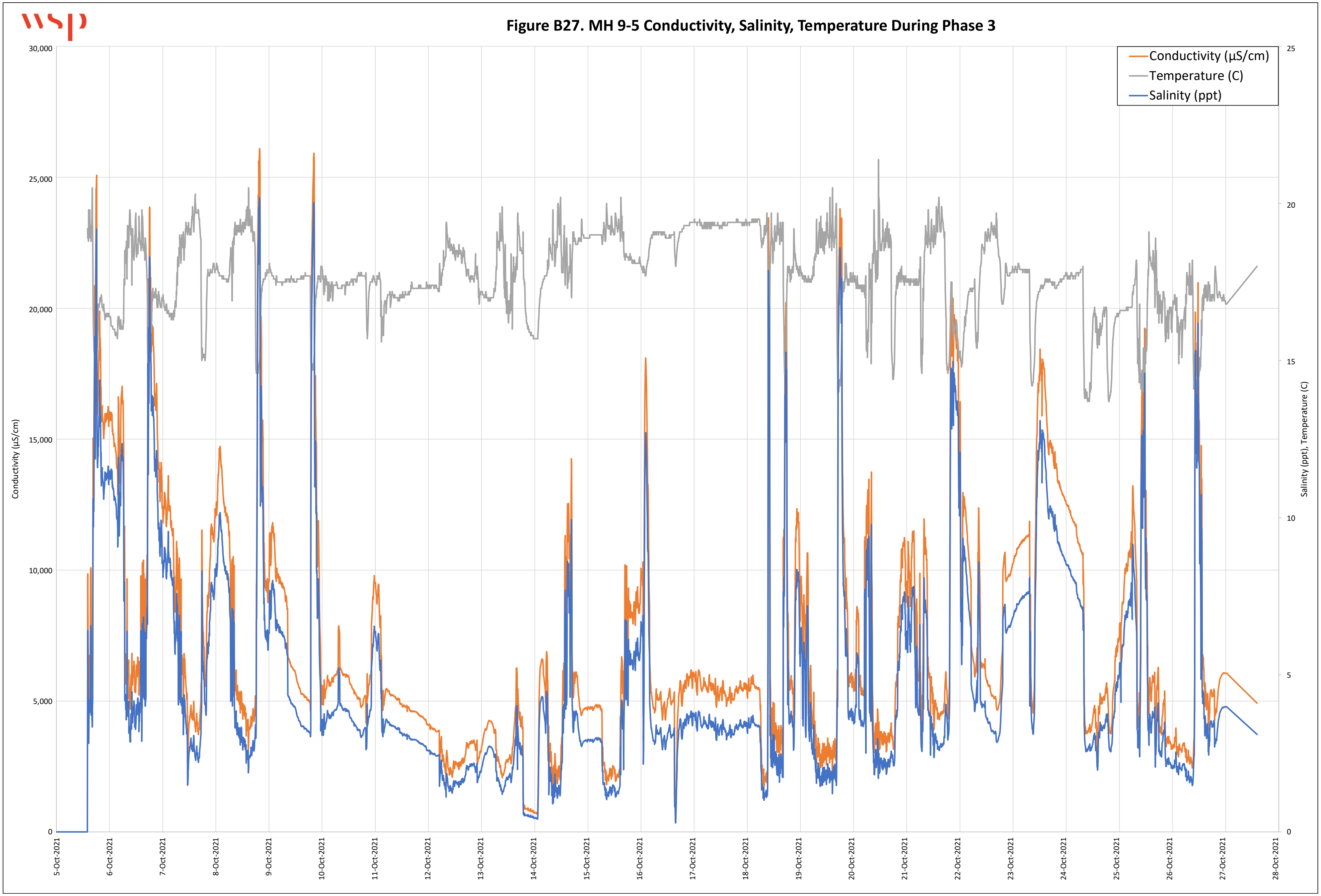

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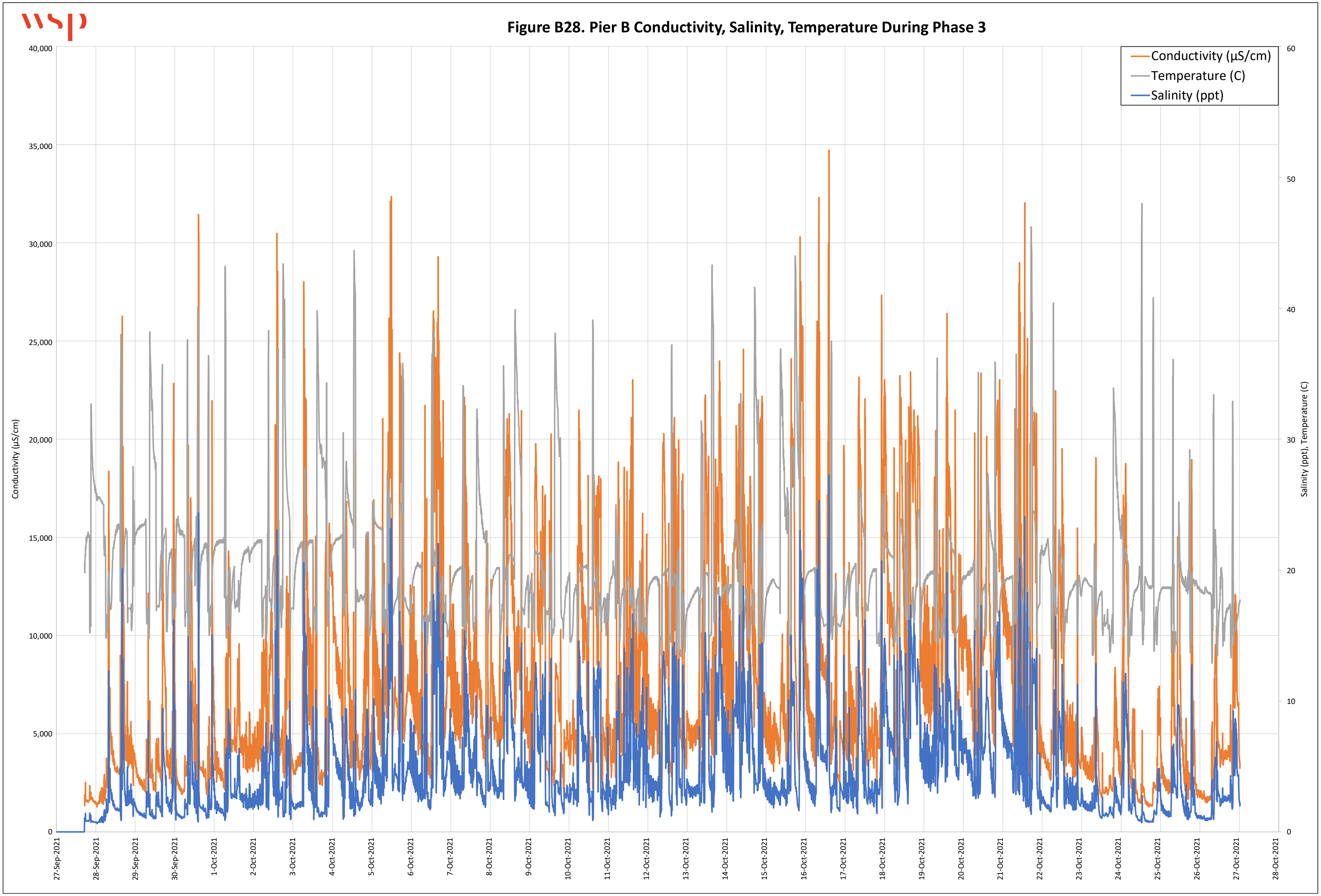

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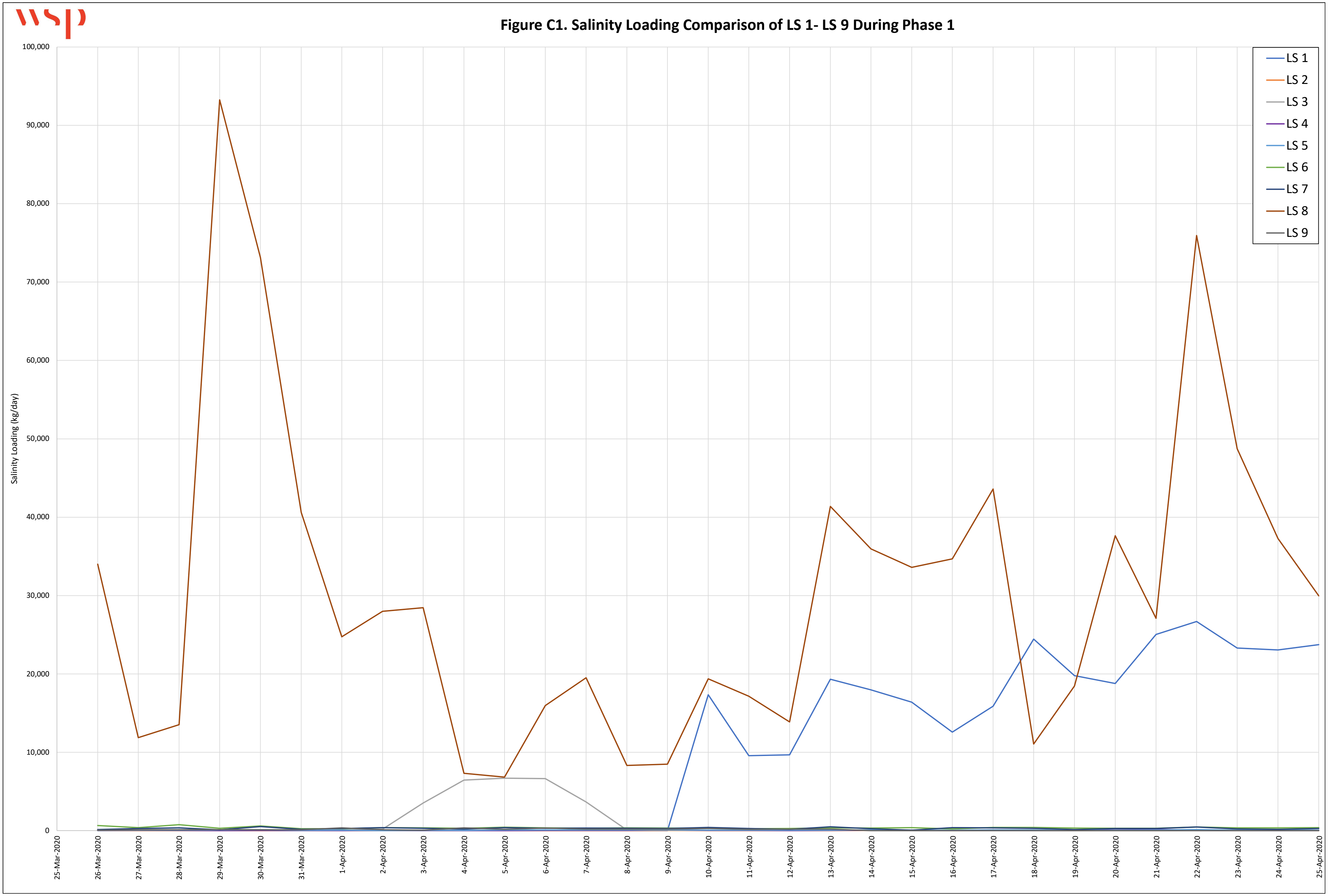
Appendix C
Salinity Loading Comparison Data



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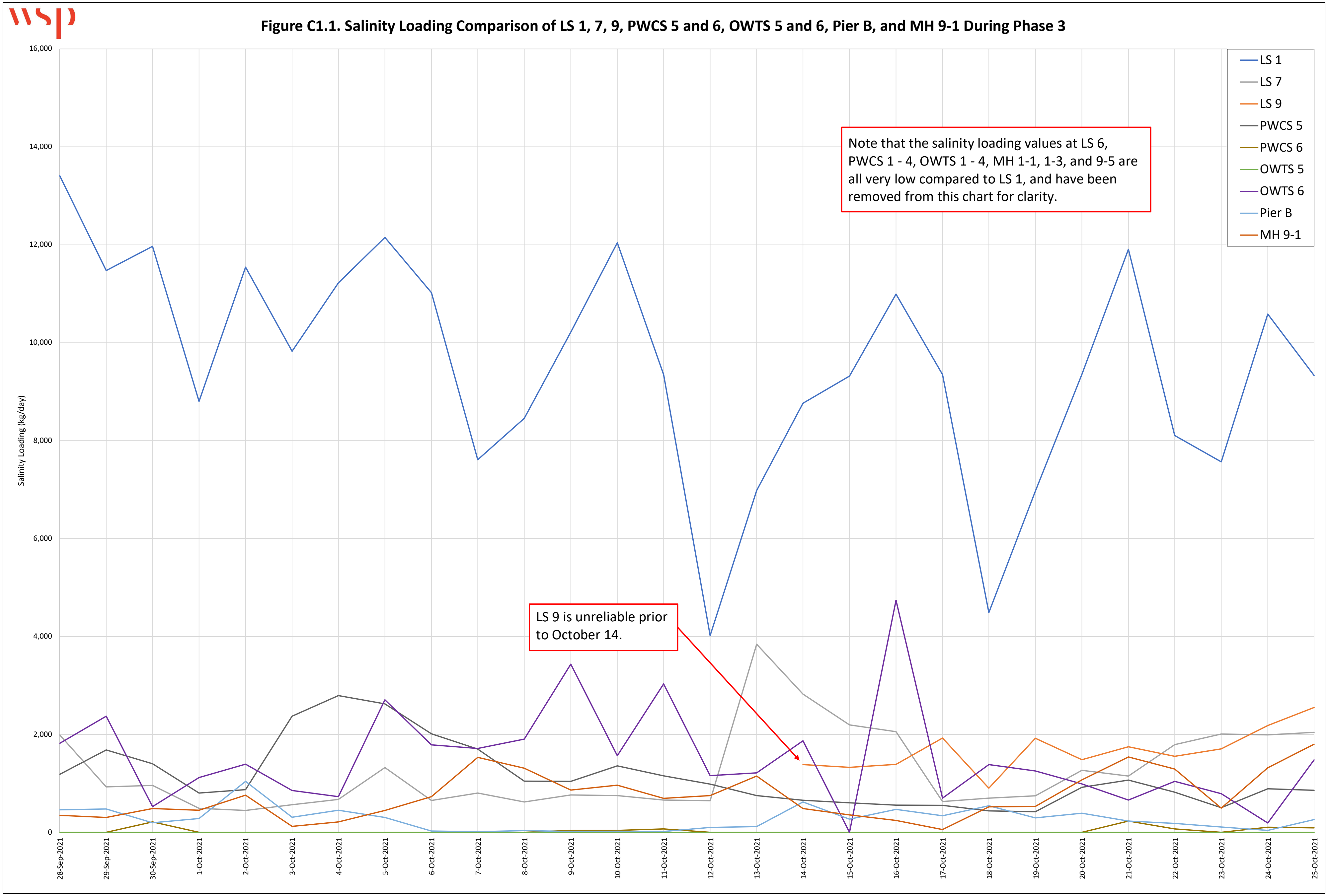

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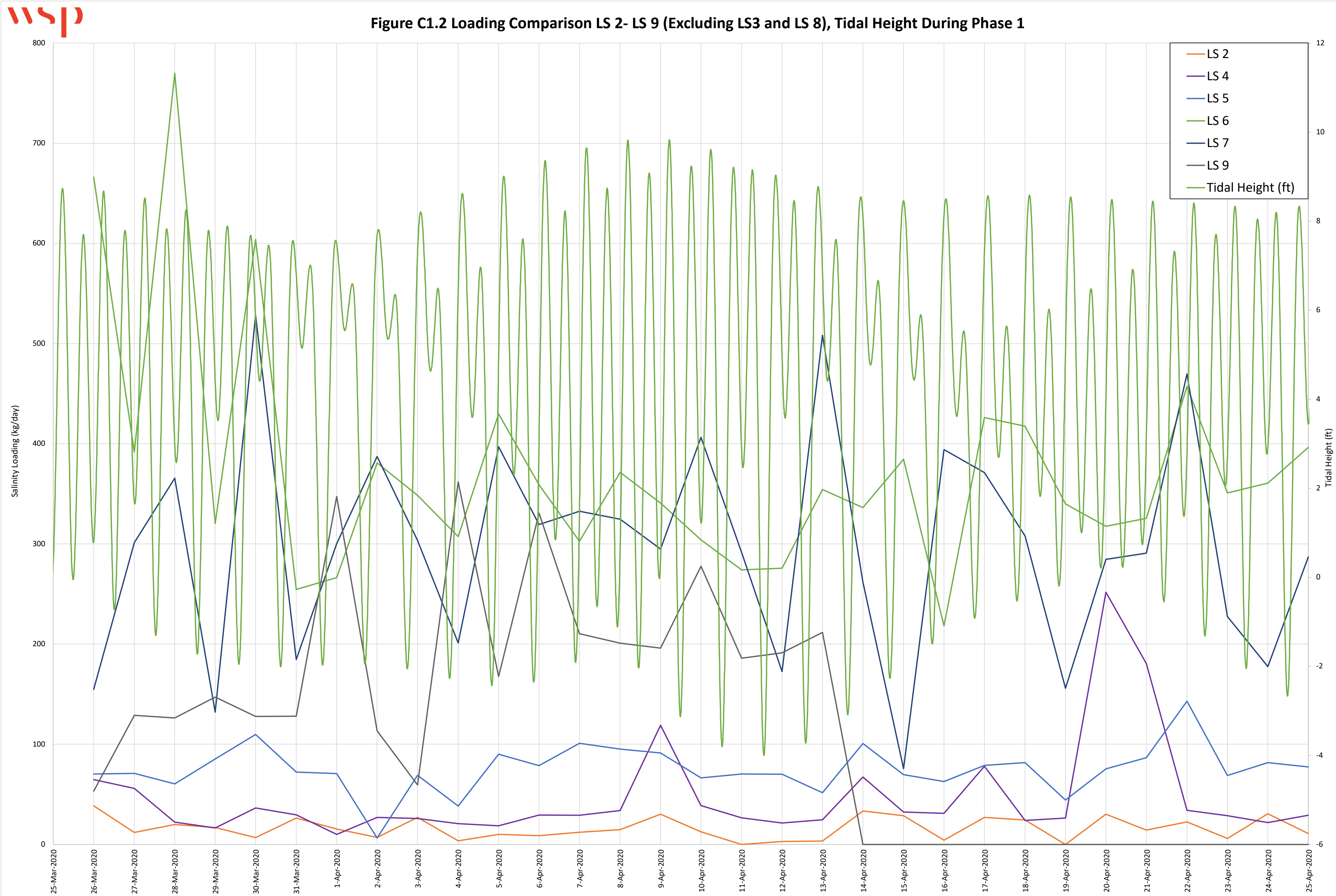

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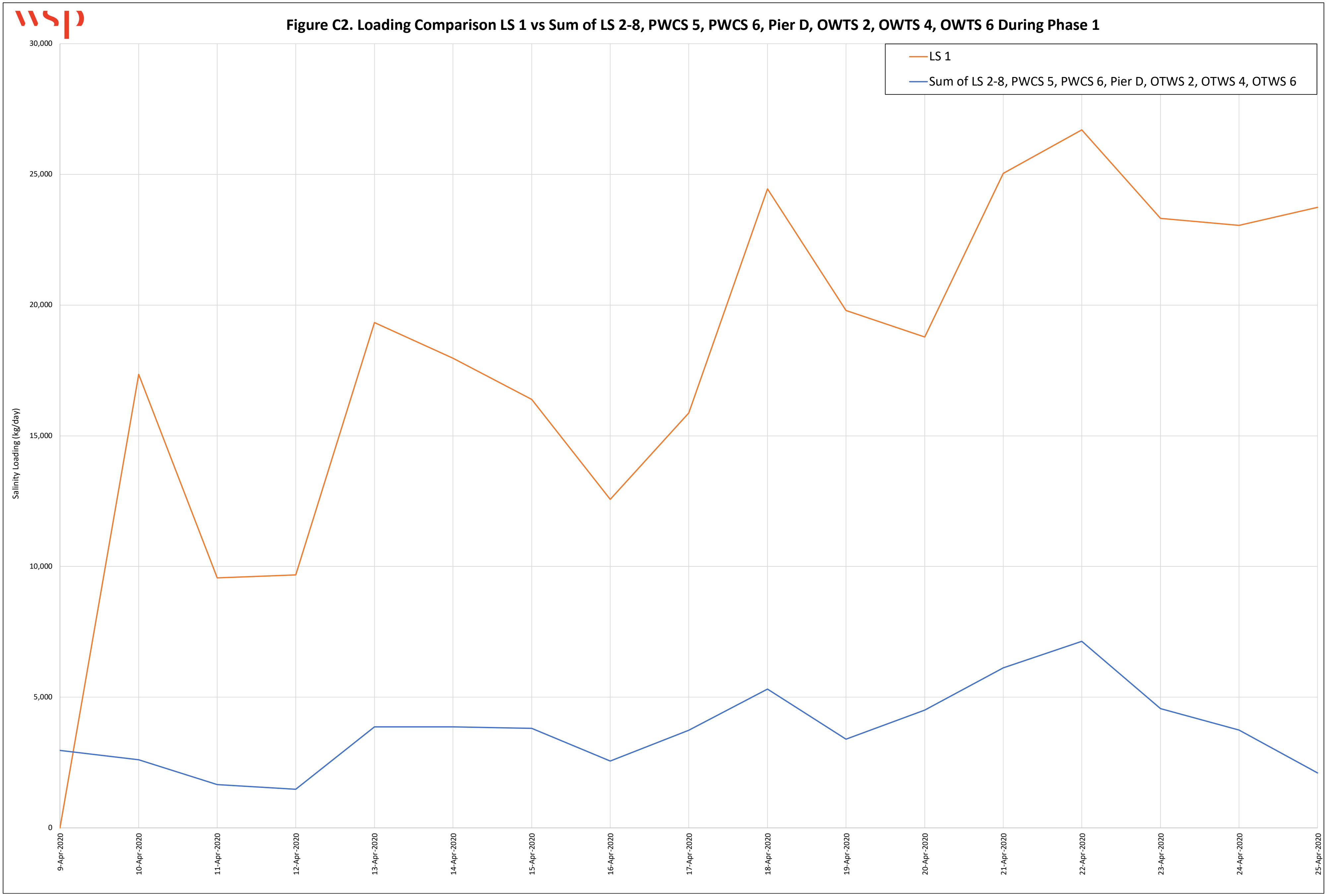

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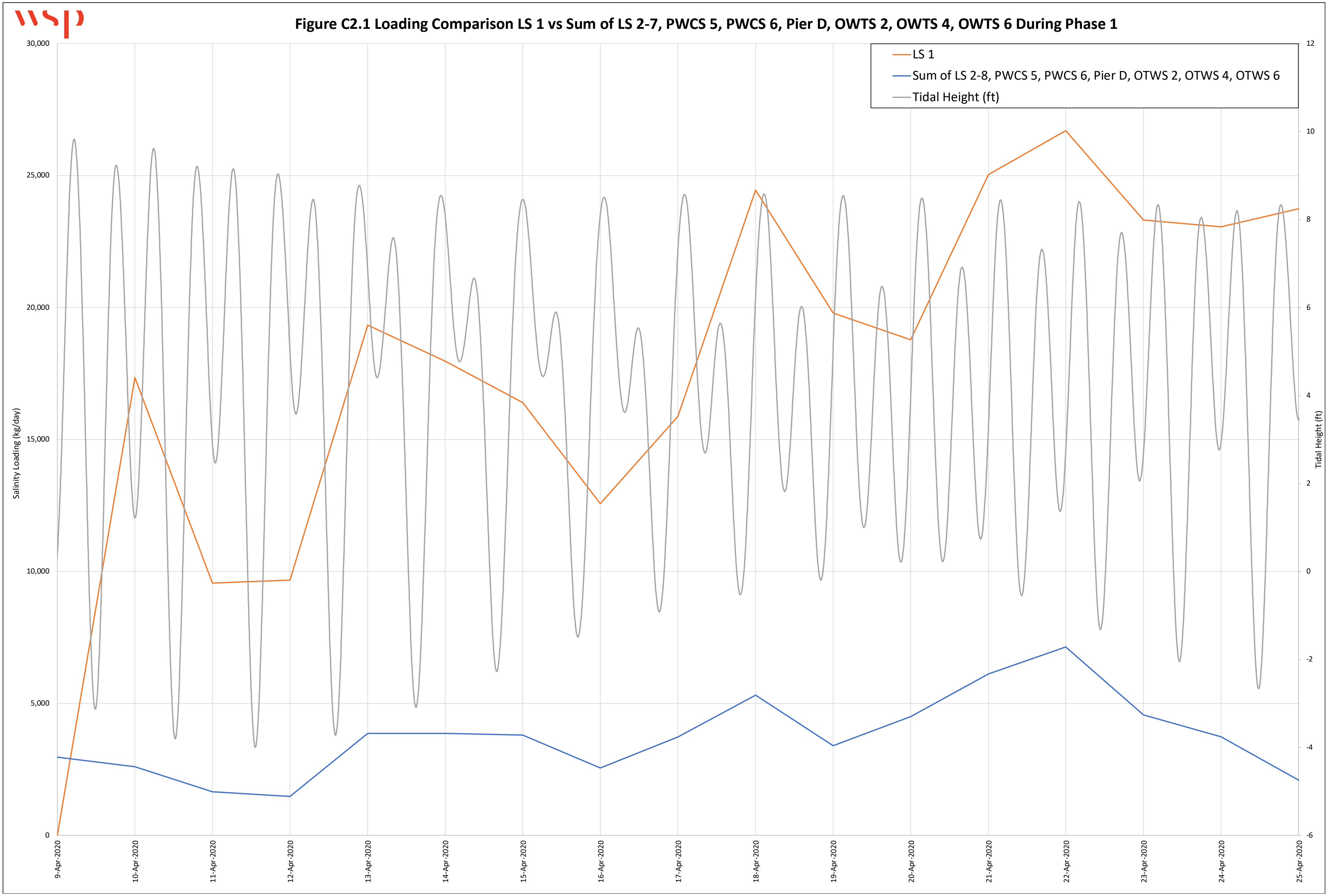

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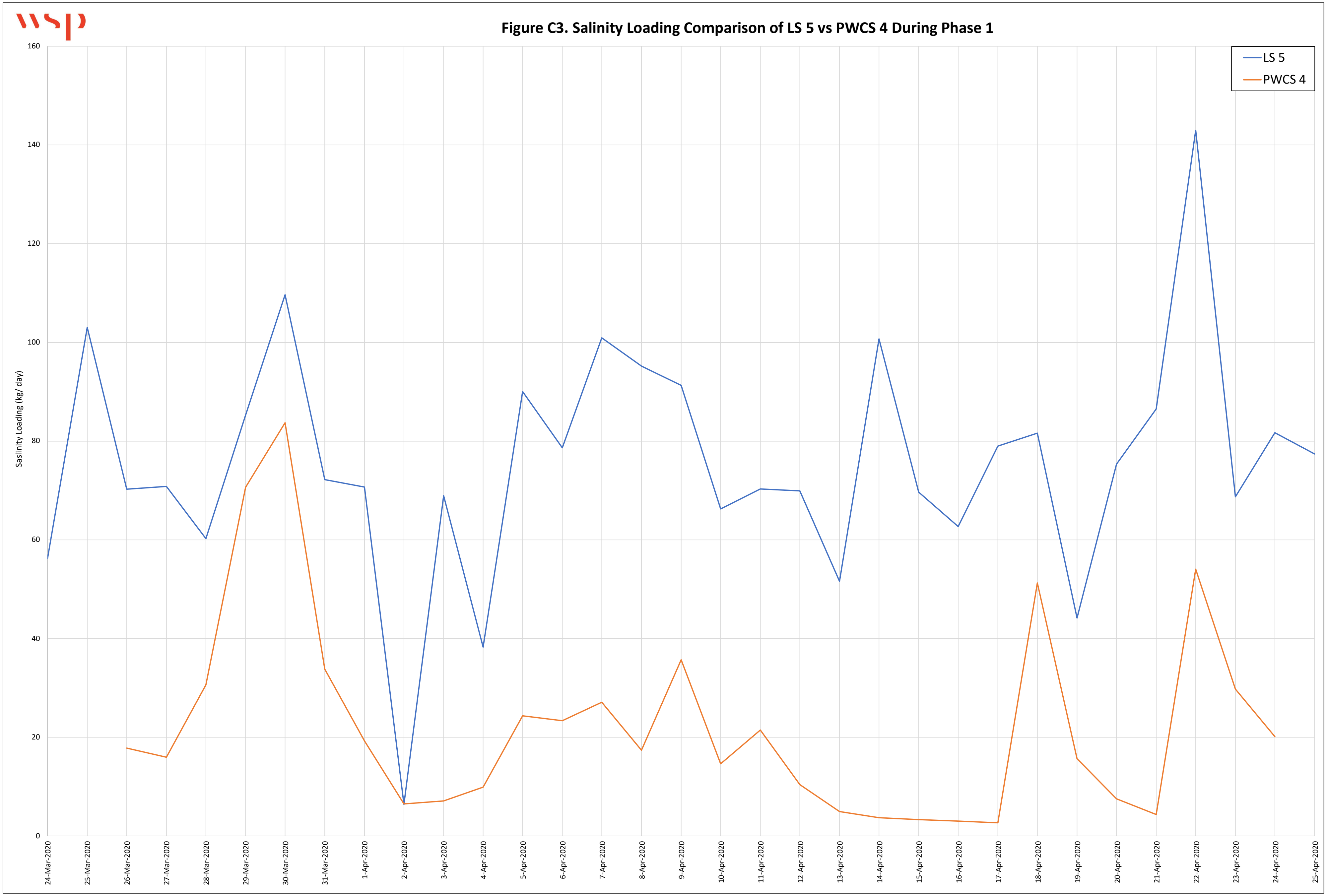

Project Name: Bremerton Salinity Study
Project Number: WA19.0094.38

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Figure C4. Salinity Loading Comparison of LS 6 vs PWCS 2 During Phase 1

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Project Number: WA16.0094.38

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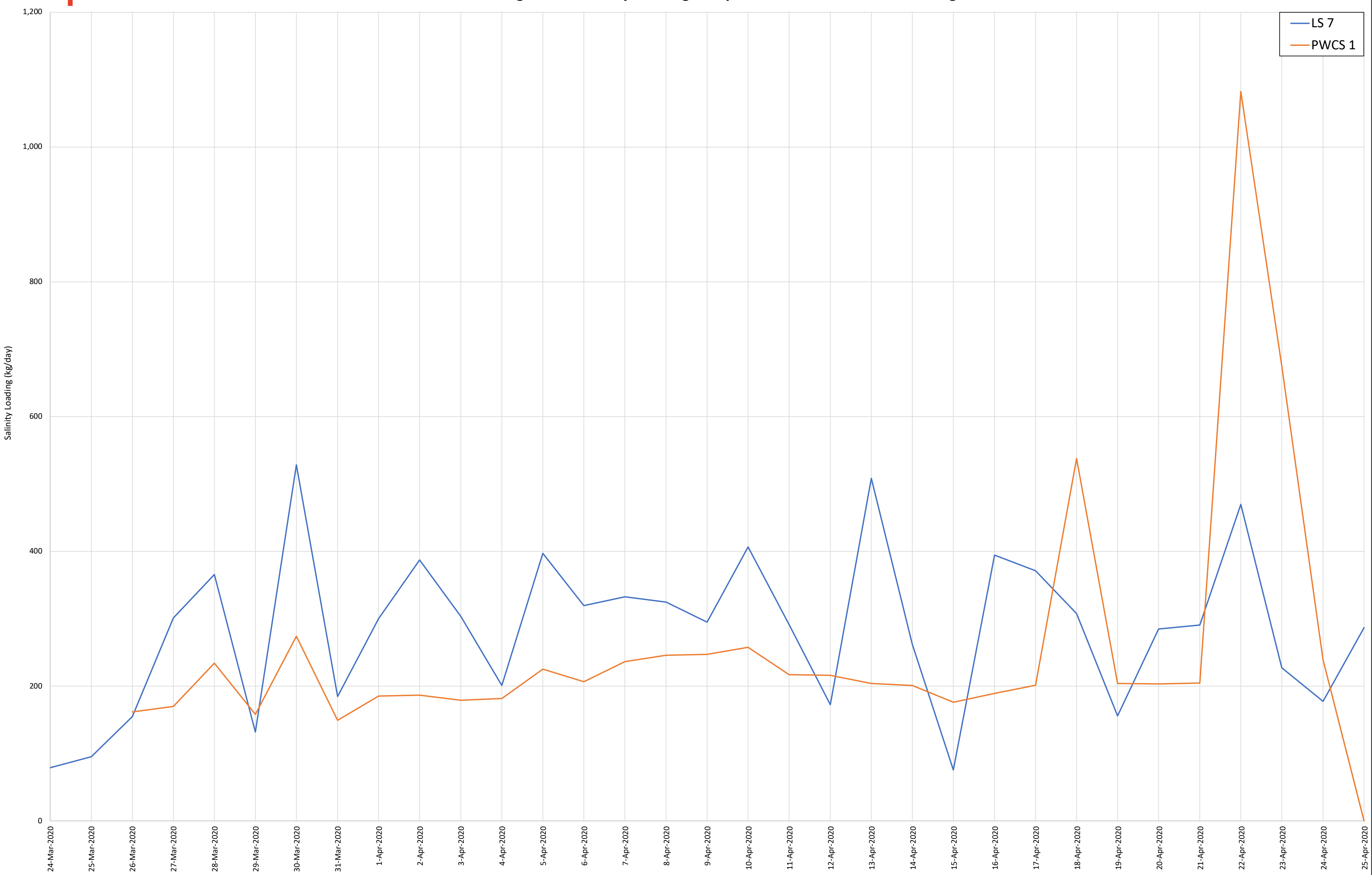
Figure C5. Salinity Loading Comparison of LS 7 vs PWCS 1 During Phase 1



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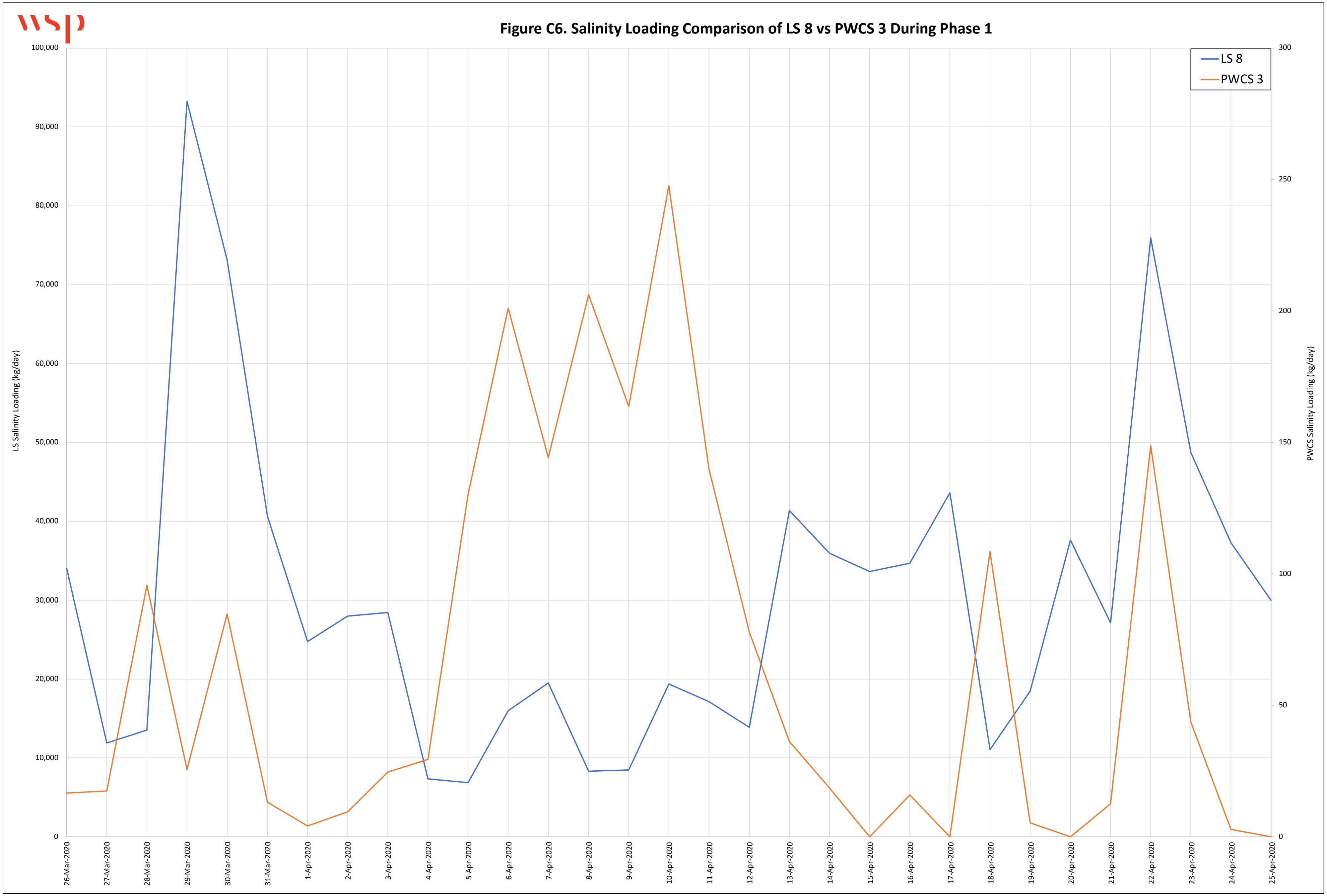

Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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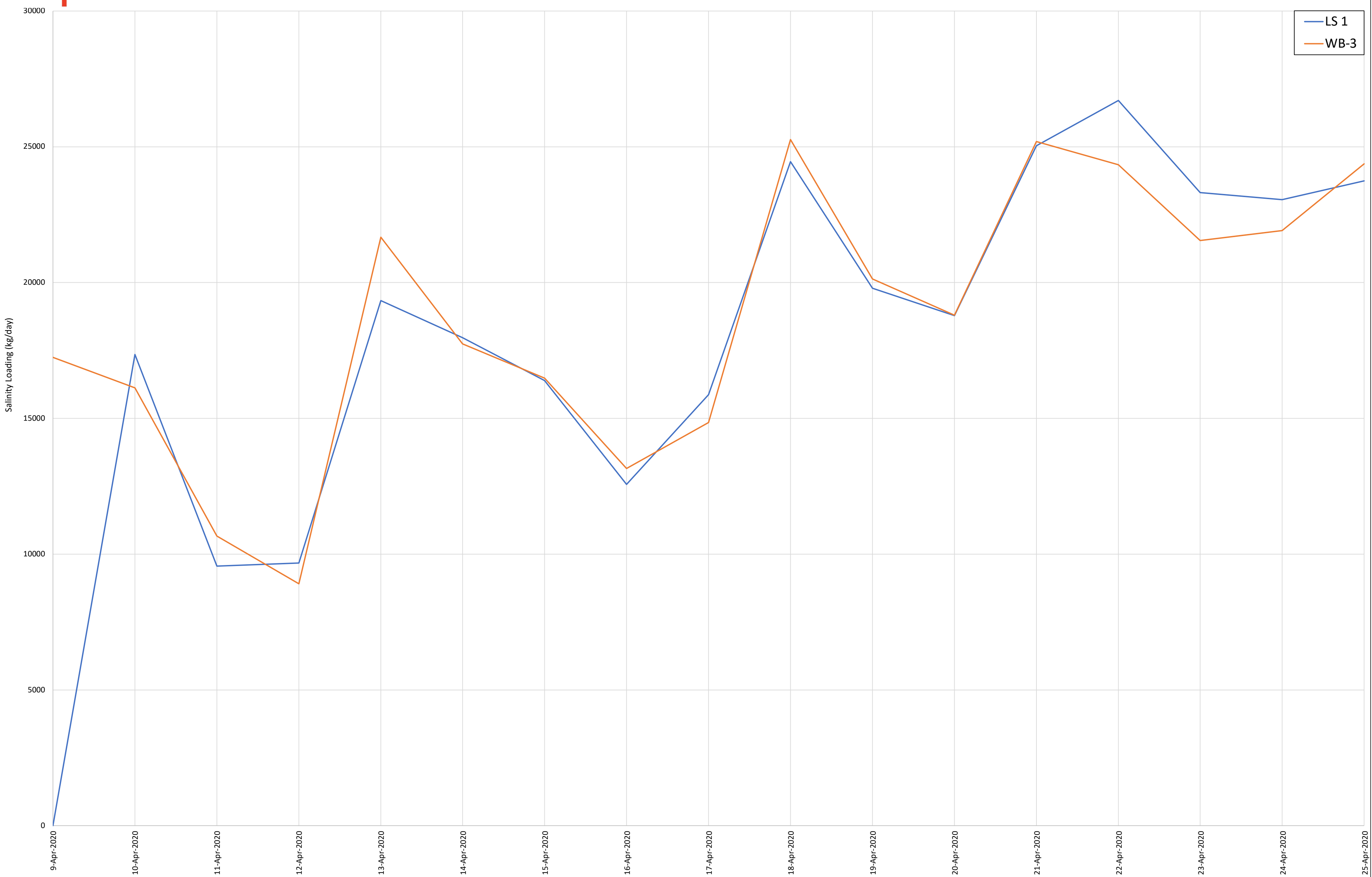
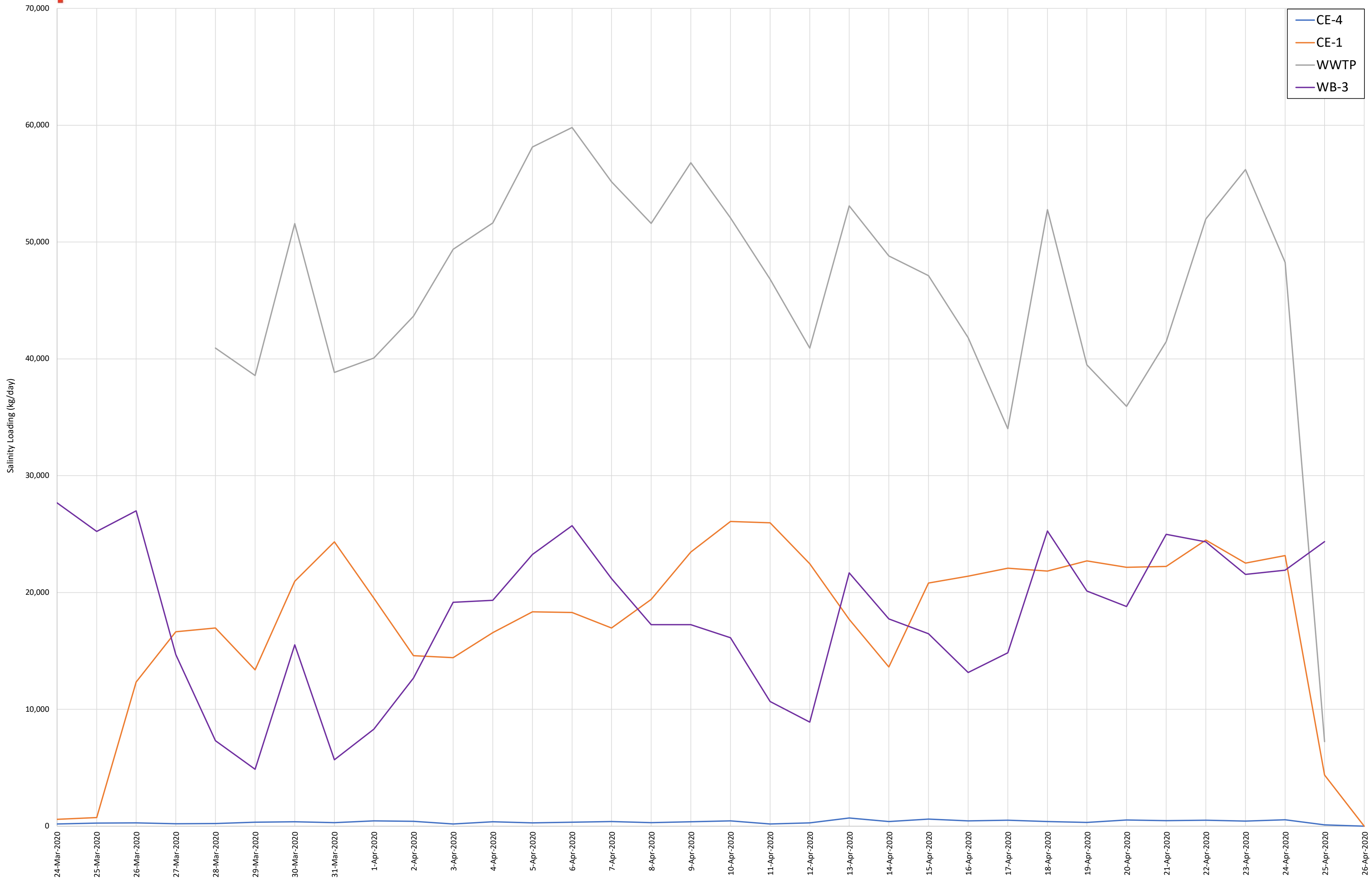
Figure C7. Salinity Loading Comparison of LS 1 vs WB-3 During Phase 1



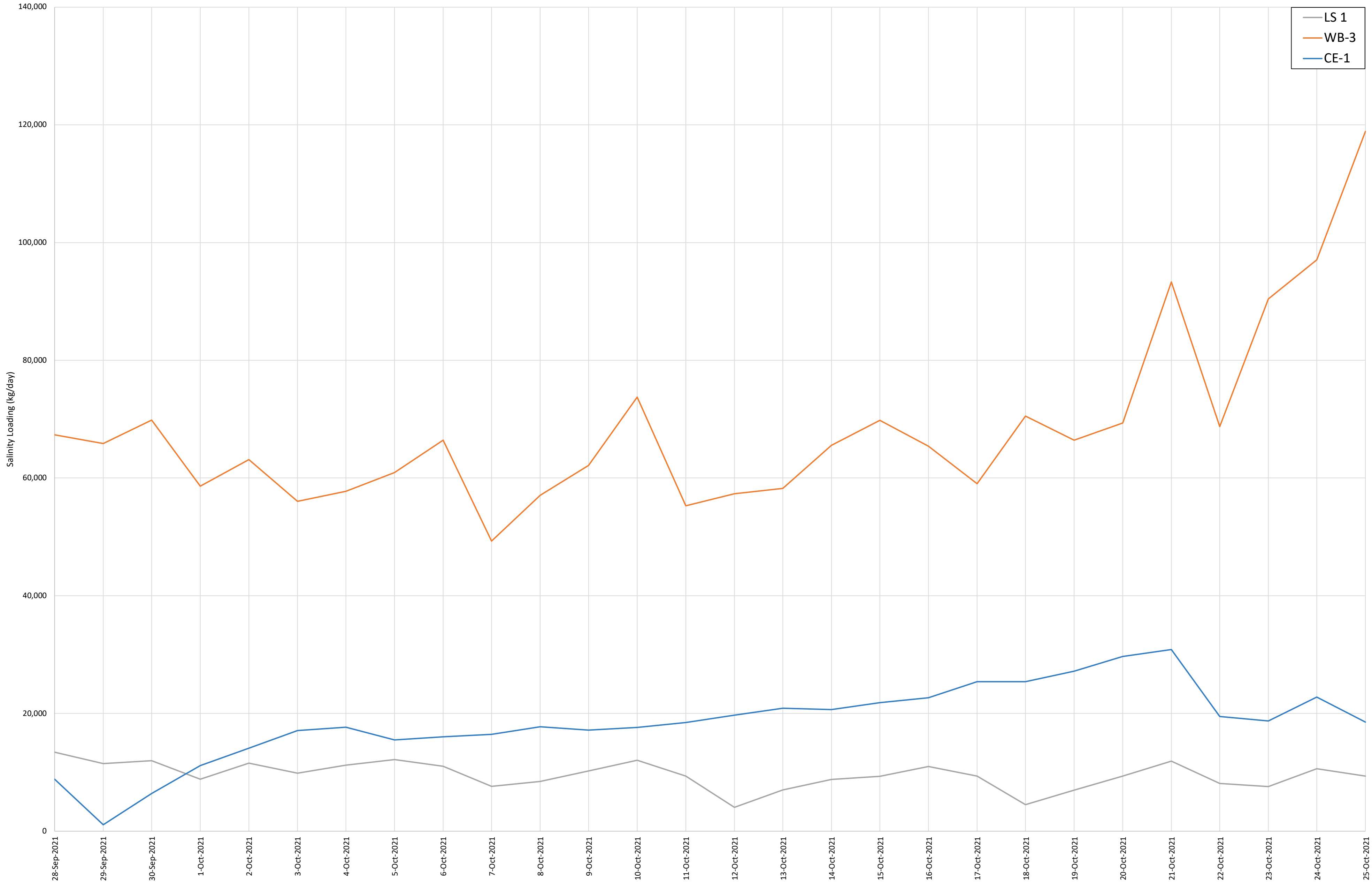
Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Figure C8. Salinity Loading at CE-4, CE-1, WWTP and WB-3 During Phase 1



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Figure C8.1. Salinity Loading Comparison WWTP, CE-1, and LS 1 During Phase 3



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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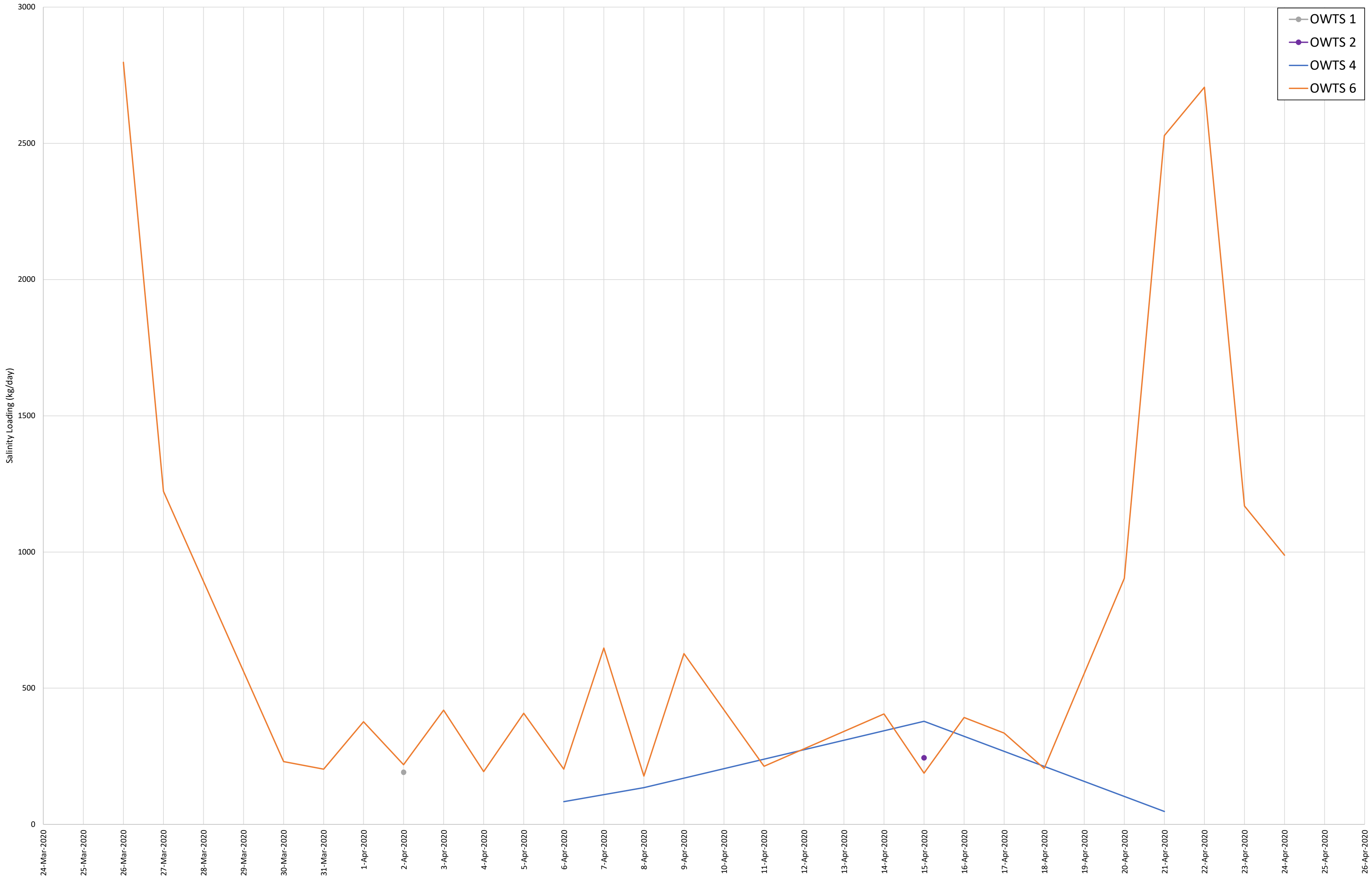
Figure C9. Salinity Loading Comparison of OWTS Systems During Phase 1



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Project Number: WA16.0094.38

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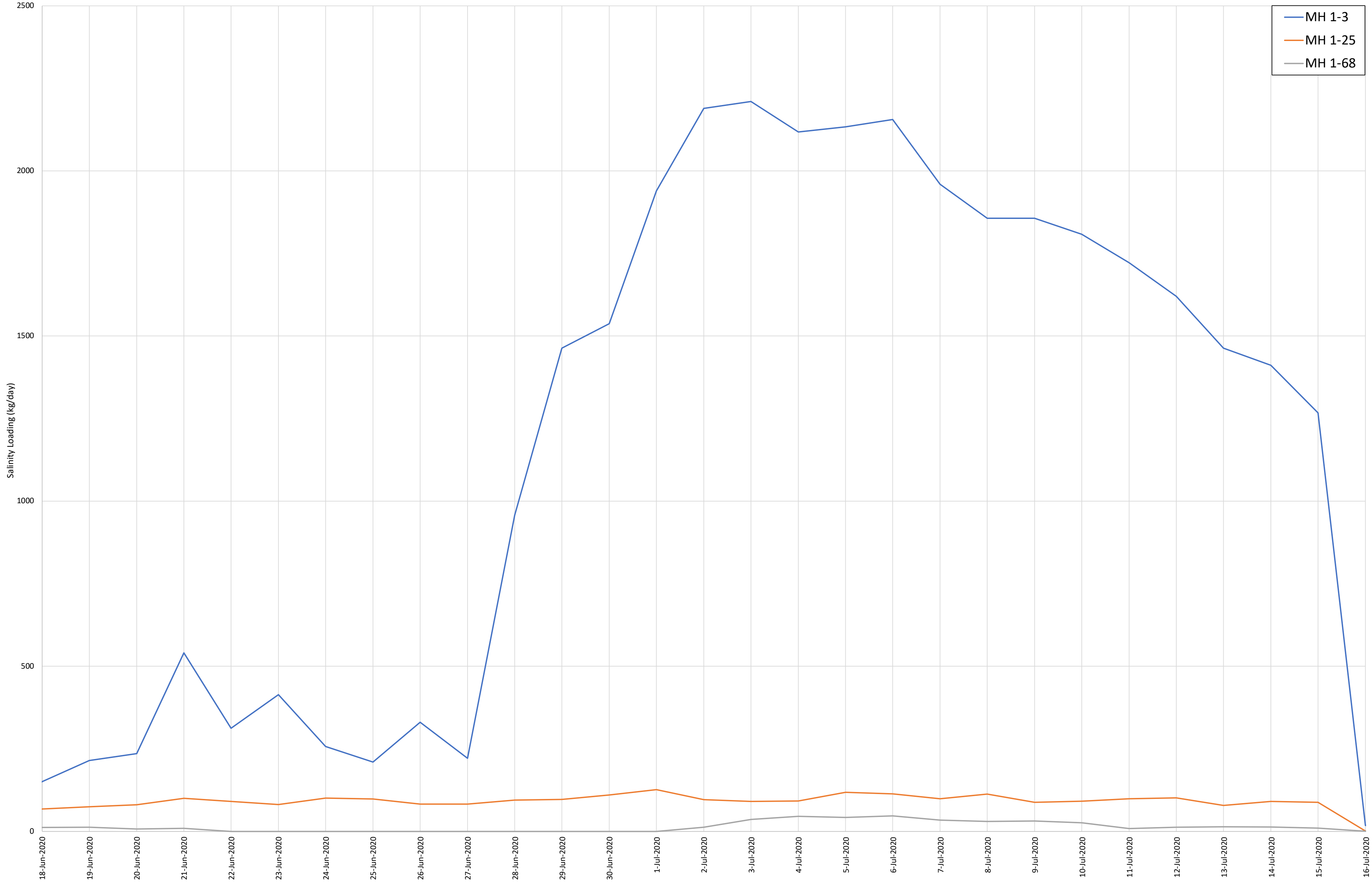
Figure C10. Salinity Loading Comparison of MH 1-3, MH 1-25, MH 1-68 During Phase 2



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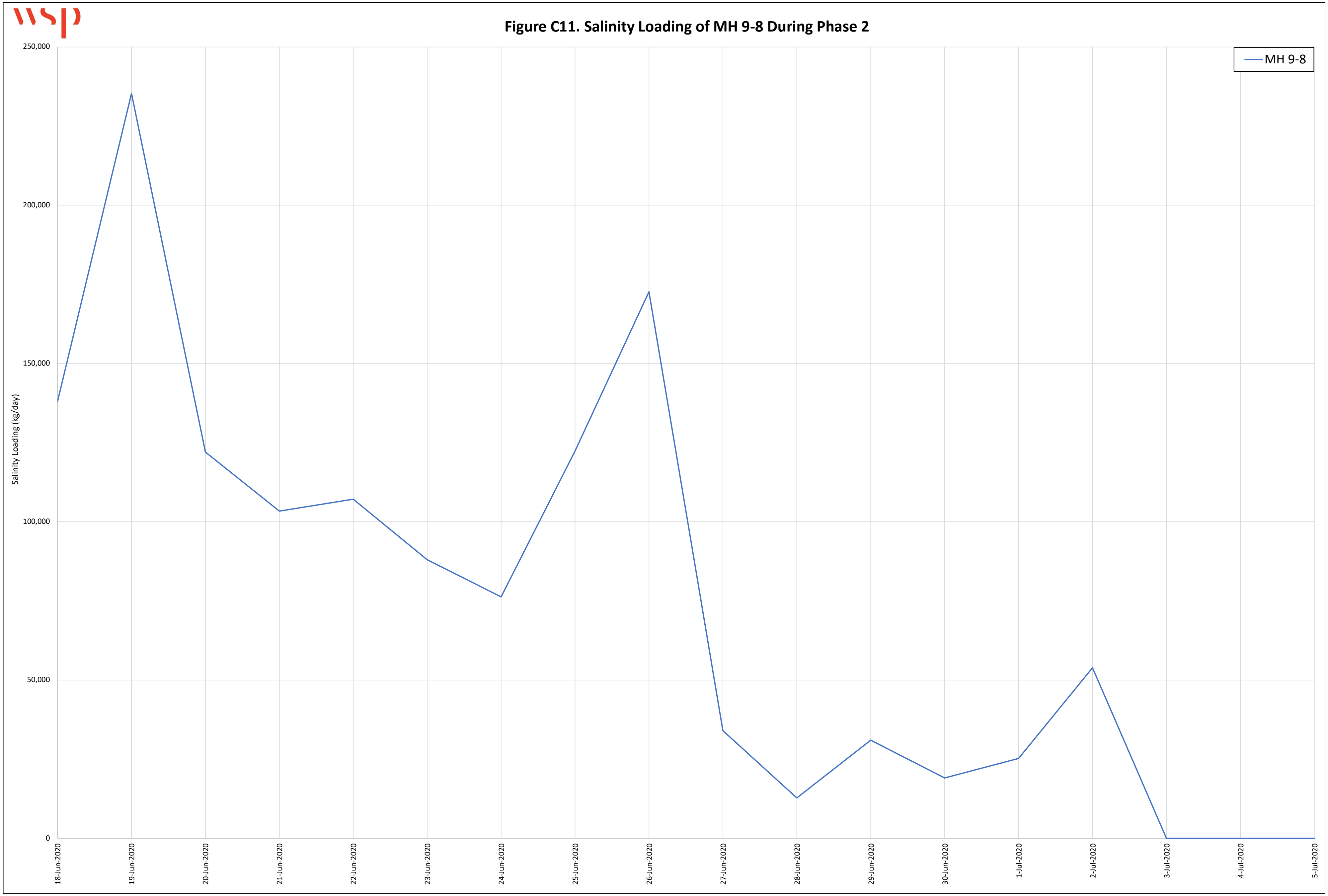
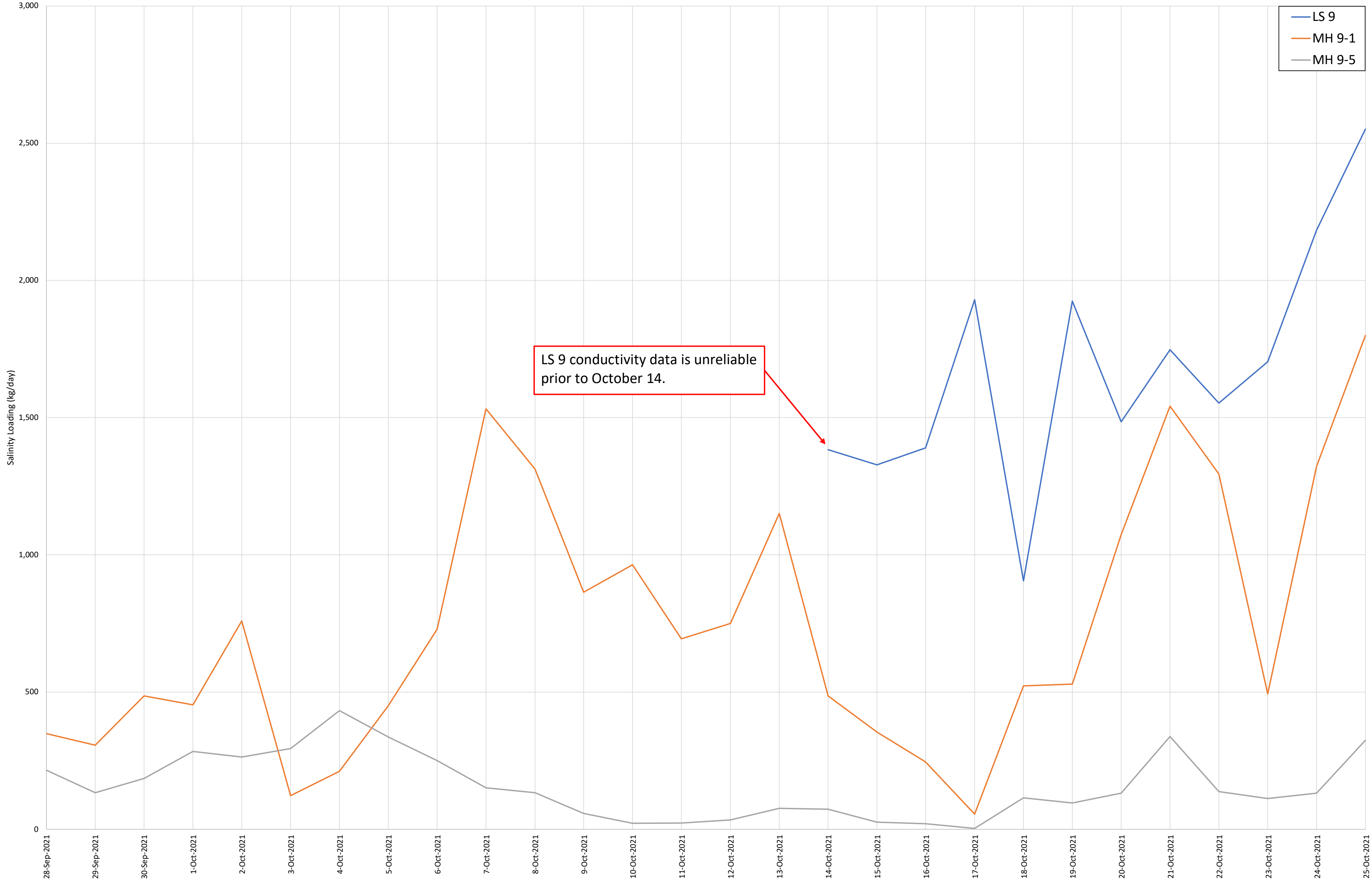


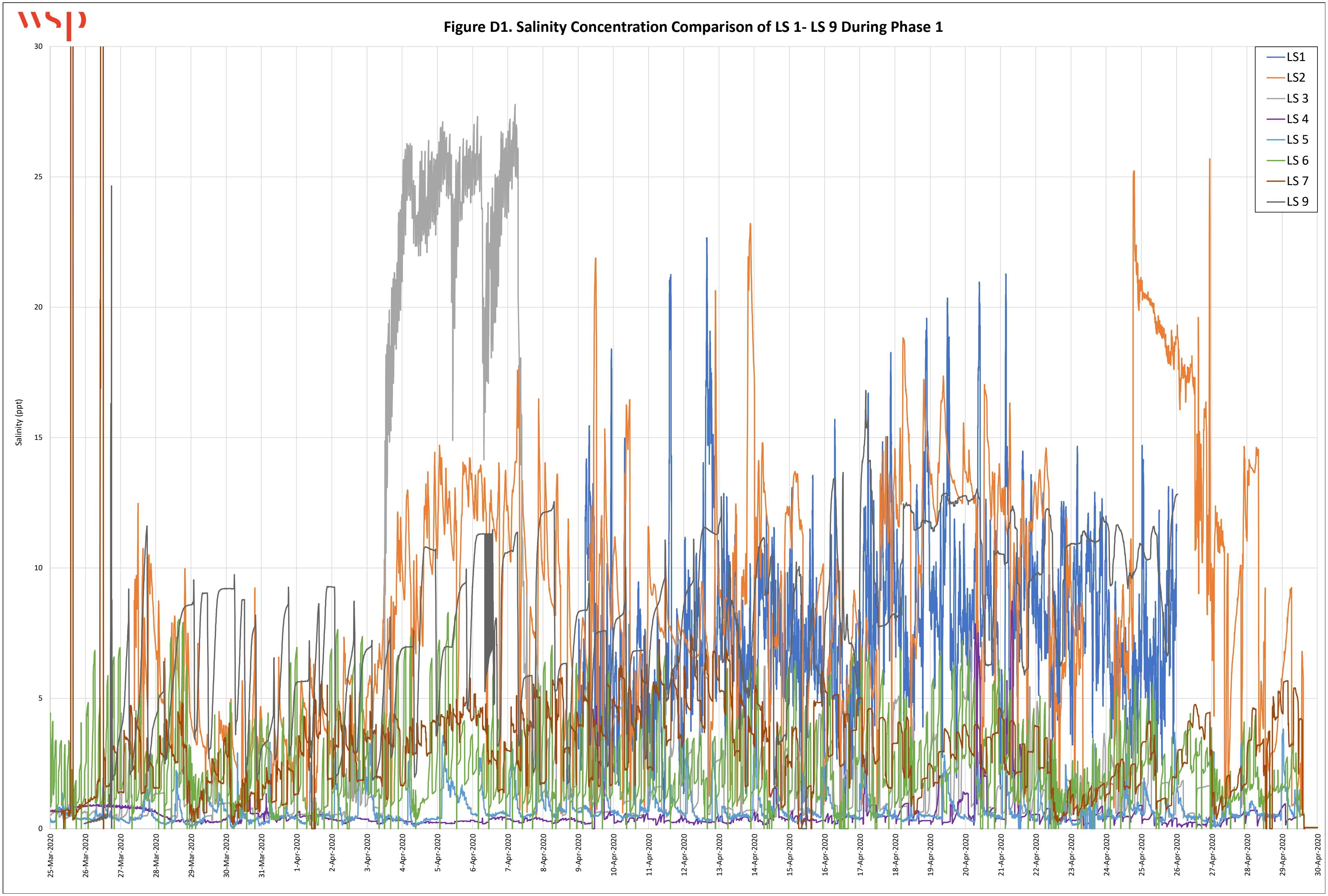
Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Figure C12. Salinity Loading Comparison of LS 9, MH 9-1, and MH 9-5 During Phase 3



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Appendix D
Salinity Concentration Comparison Data



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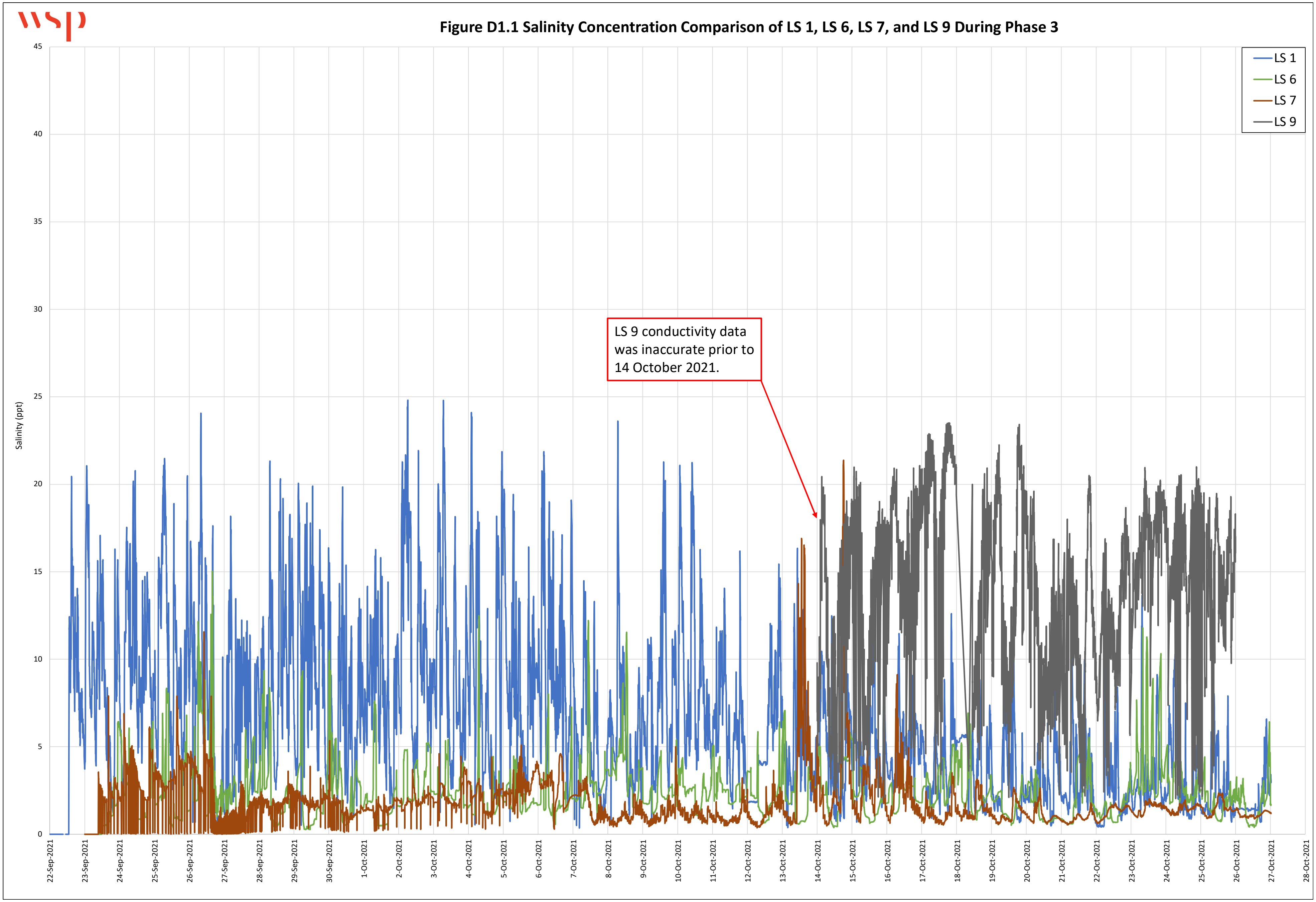
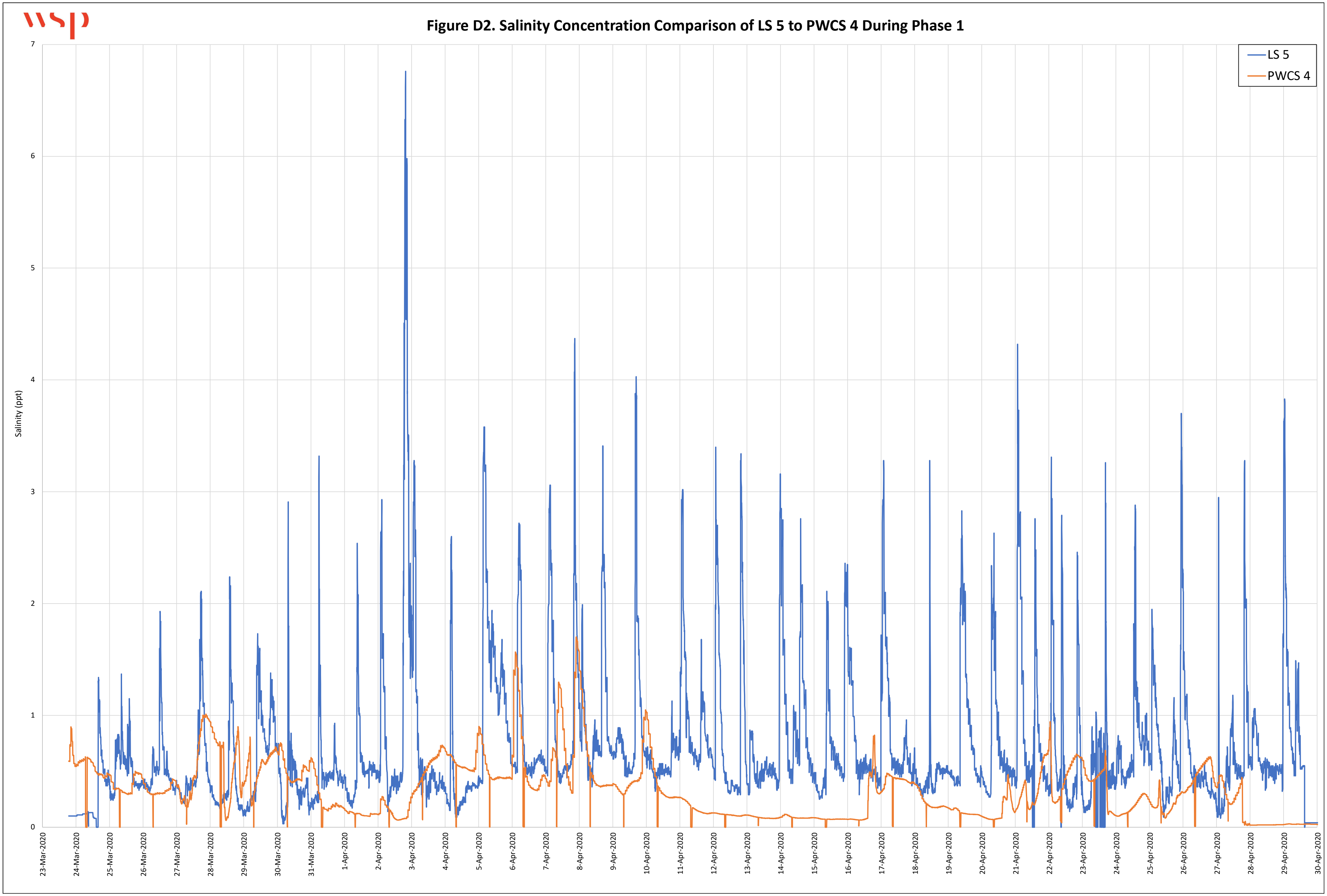


Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Approved for public release:
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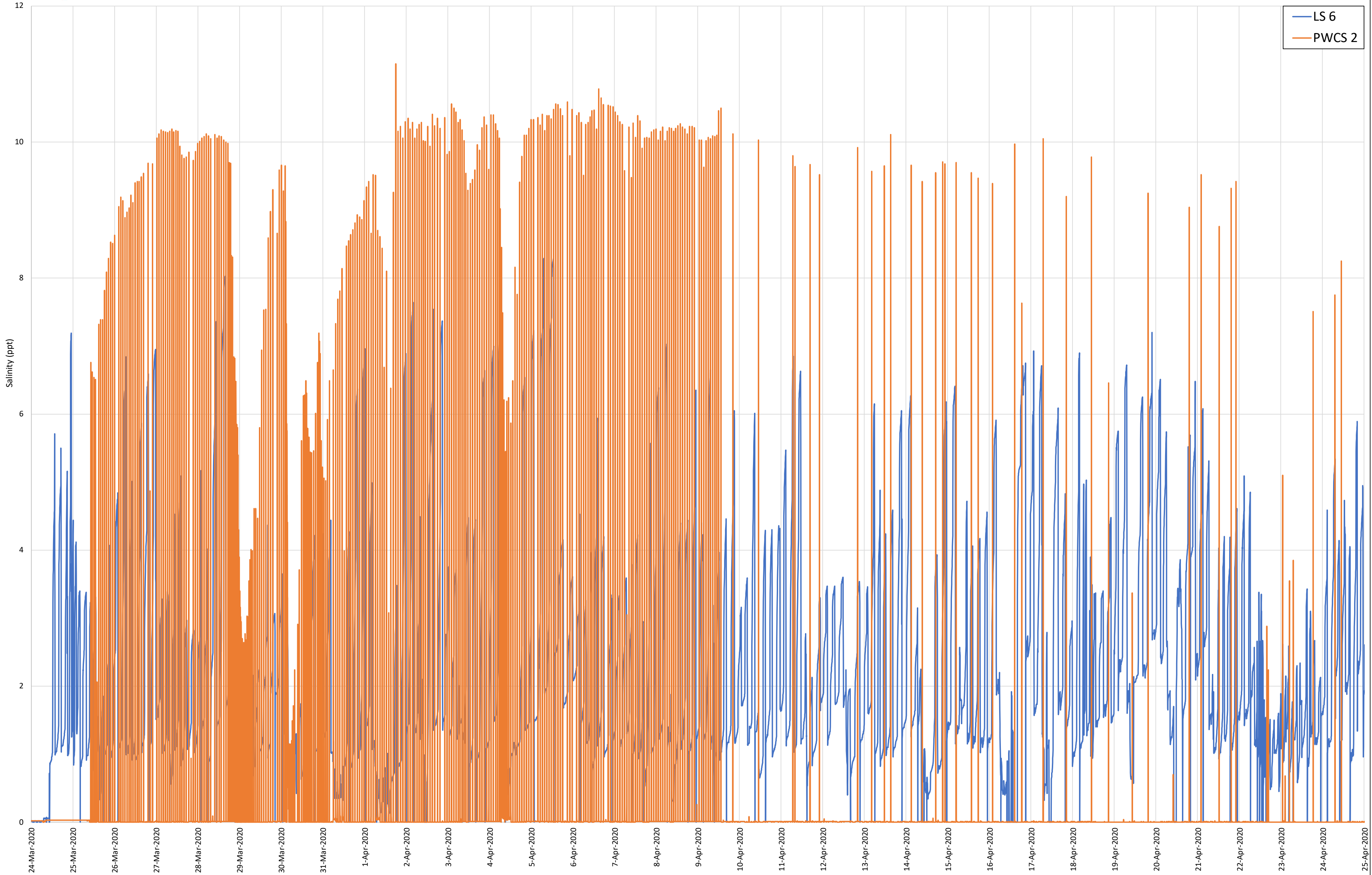
Figure D3. Salinity Concentration Comparison of LS 6 to PWCS 2 During Phase 1



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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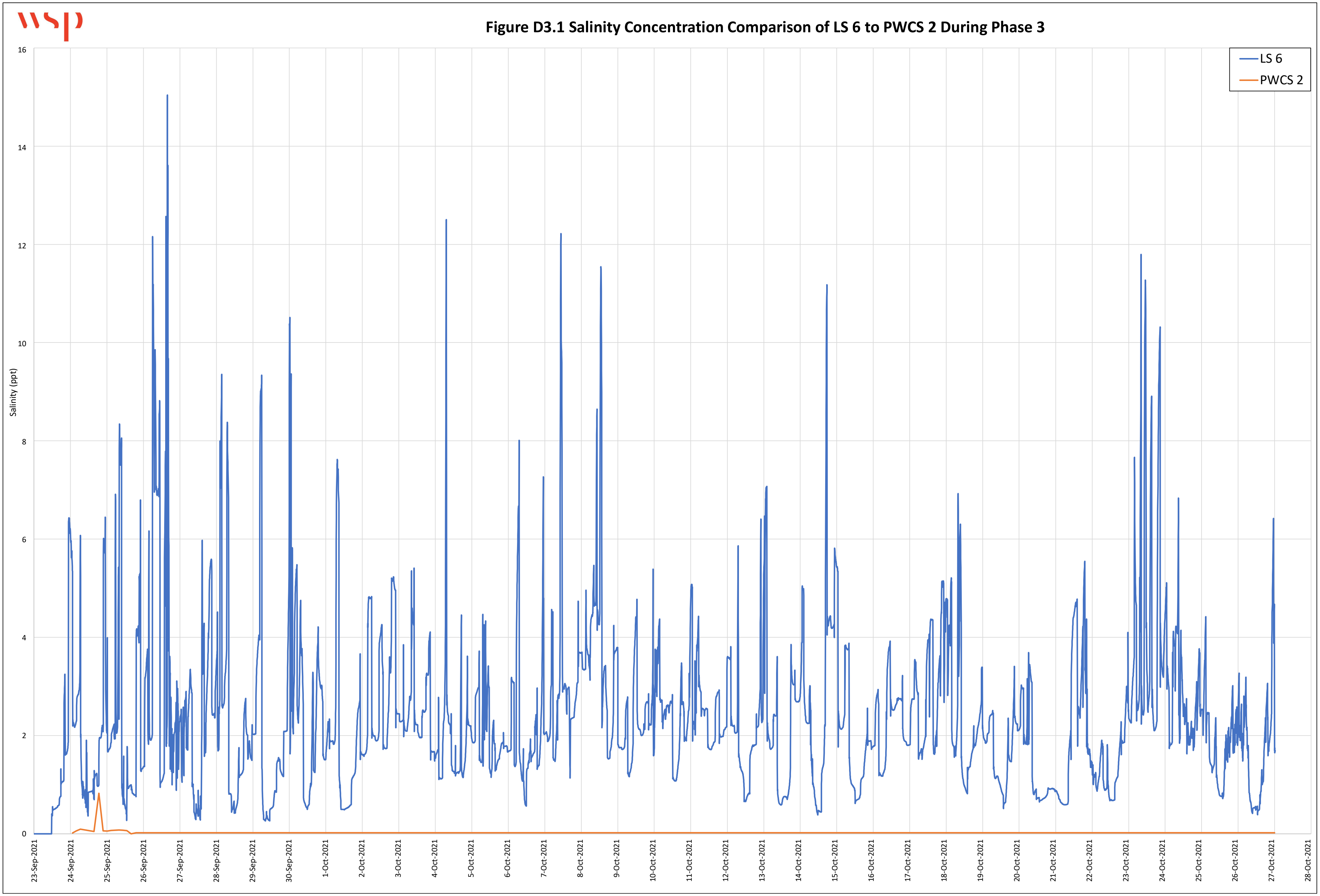
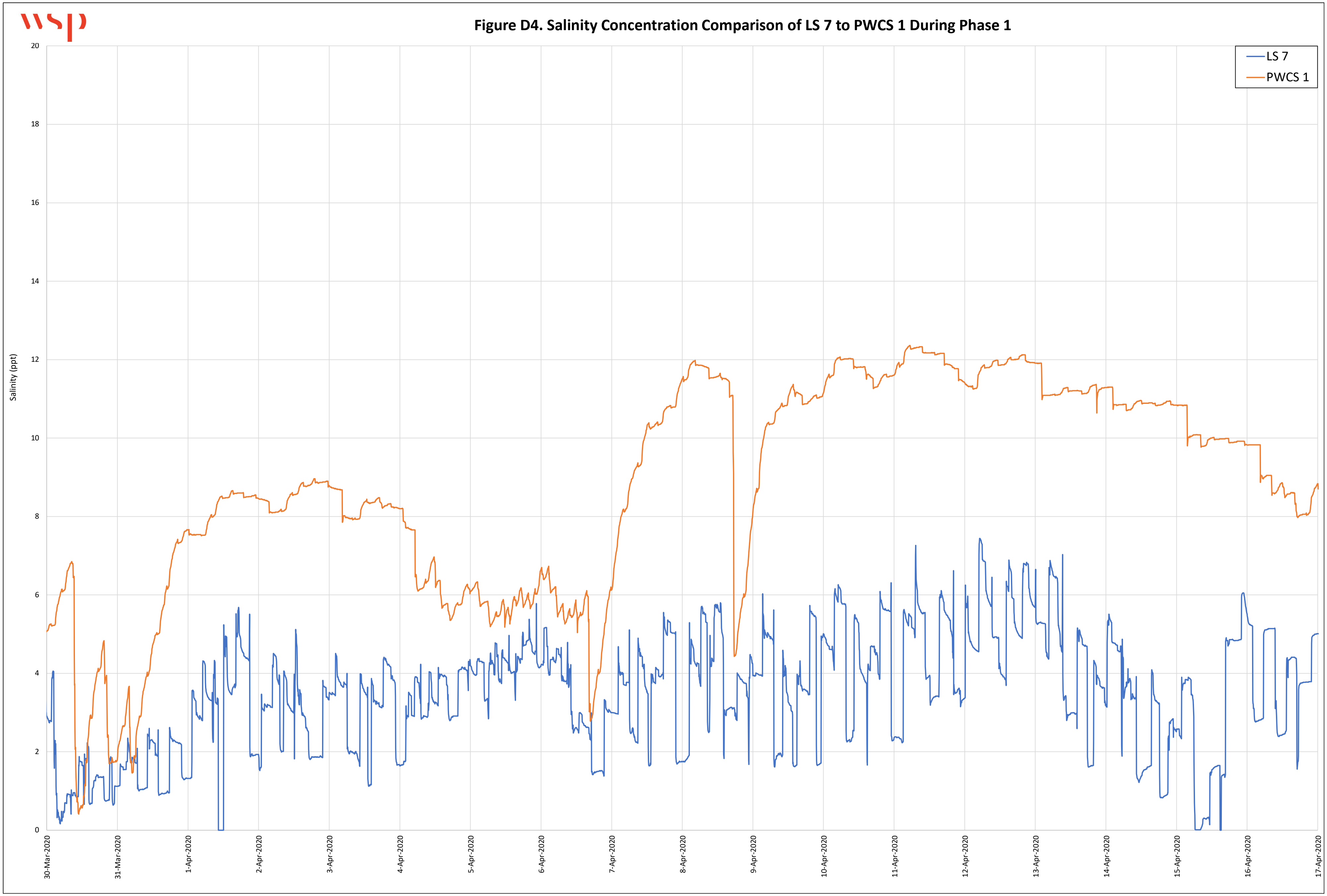


Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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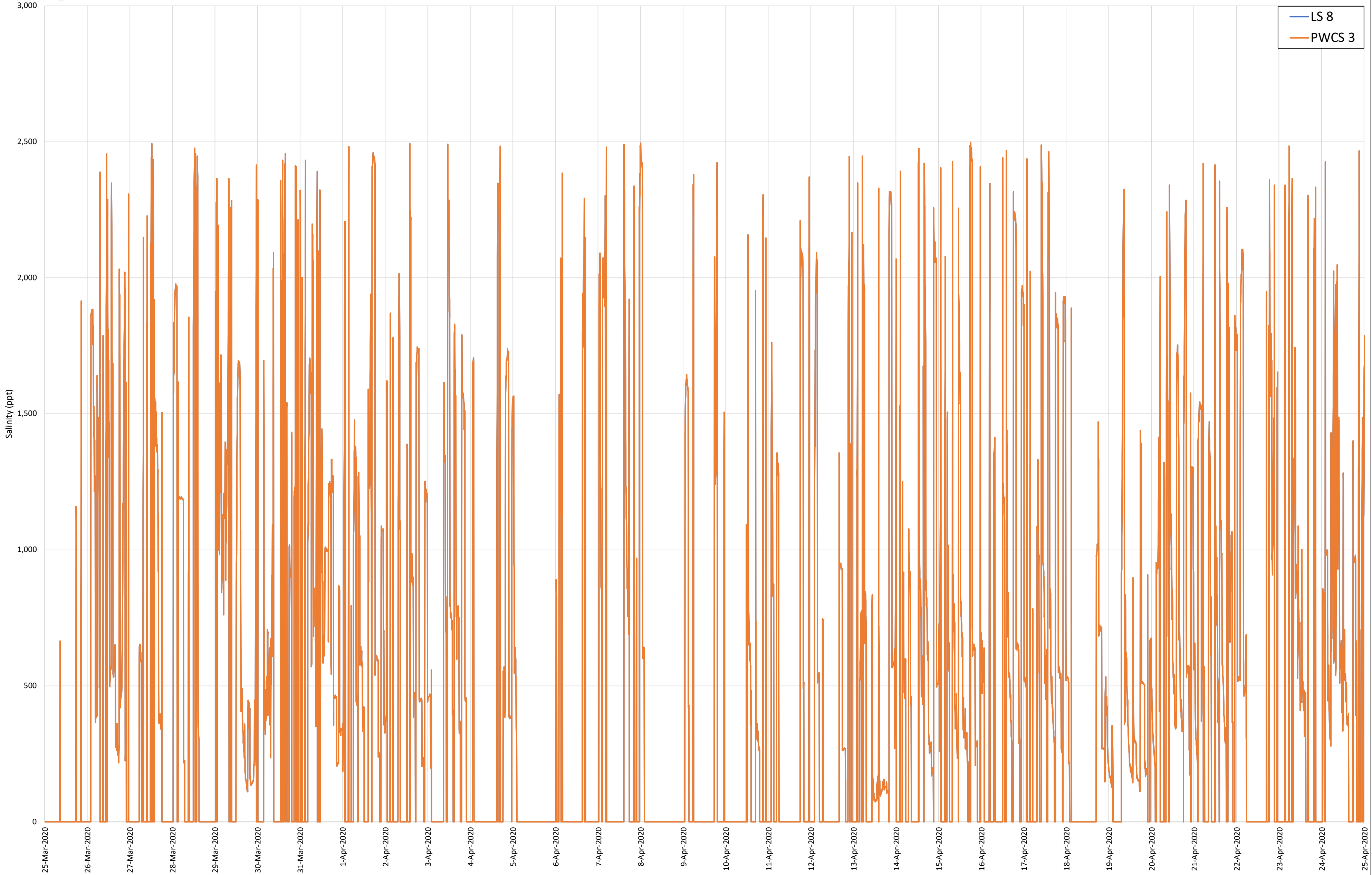
Figure D5. Salinity Concentration Comparison of LS 8 to PWCS 3 During Phase 1



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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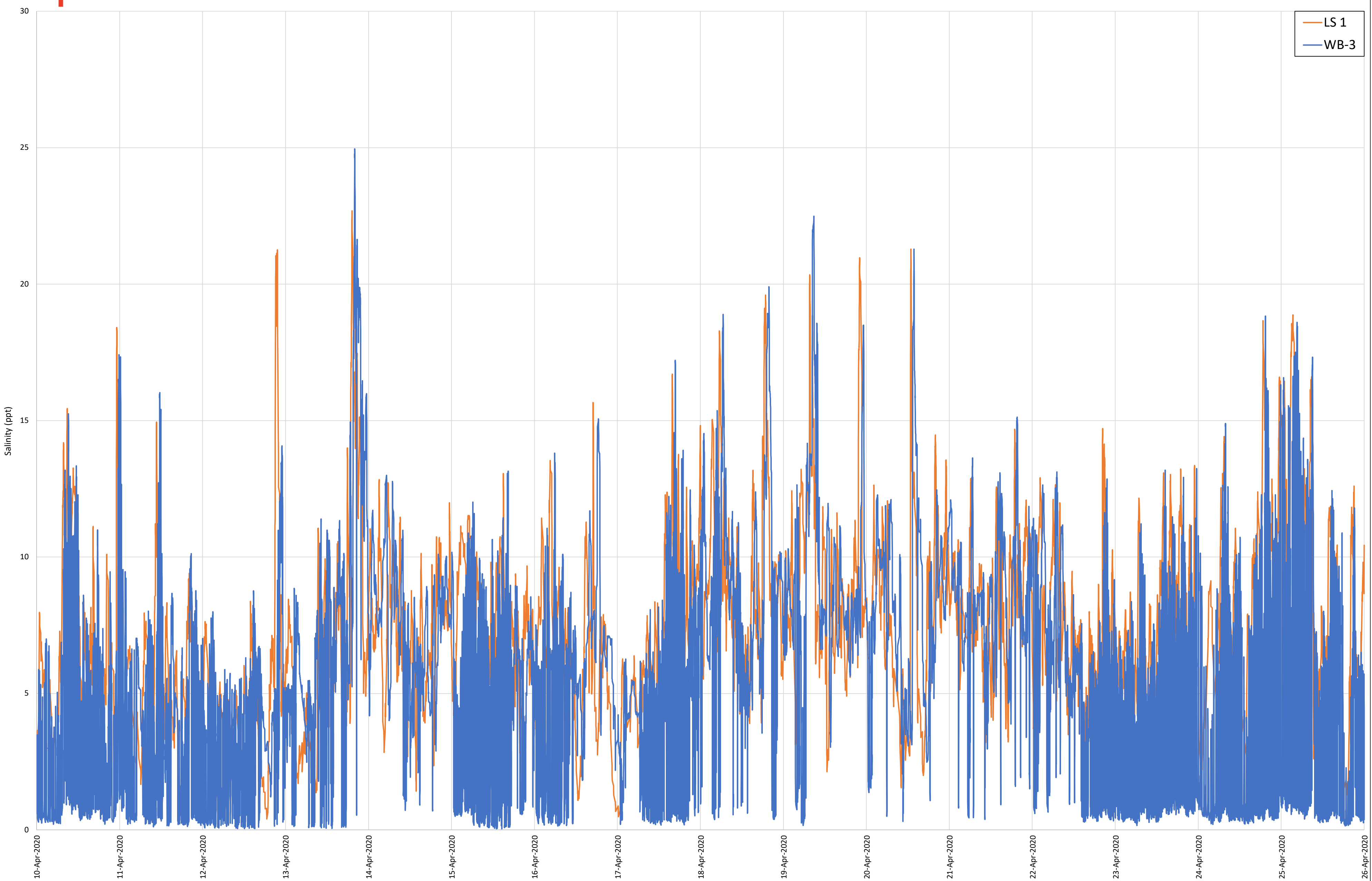
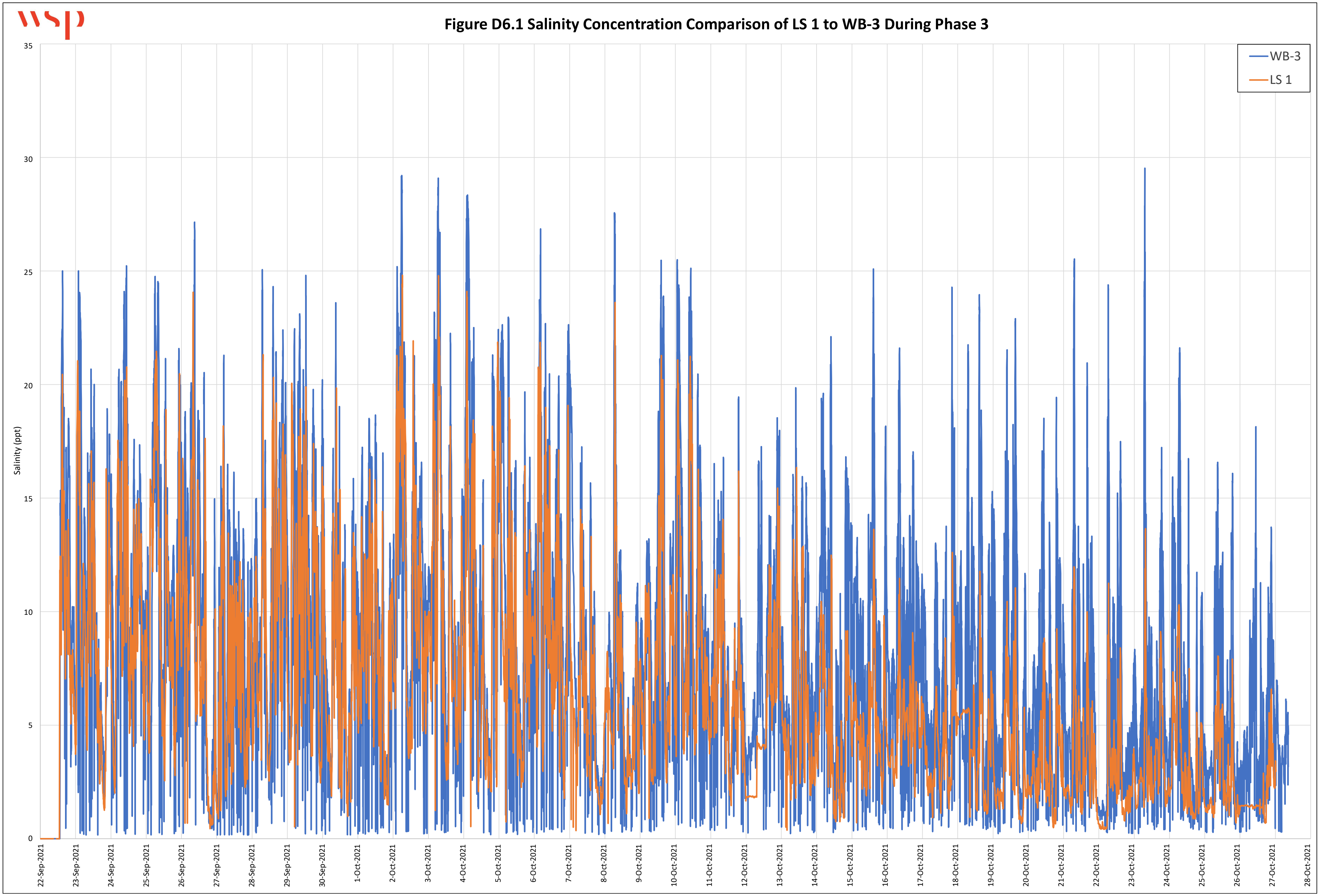
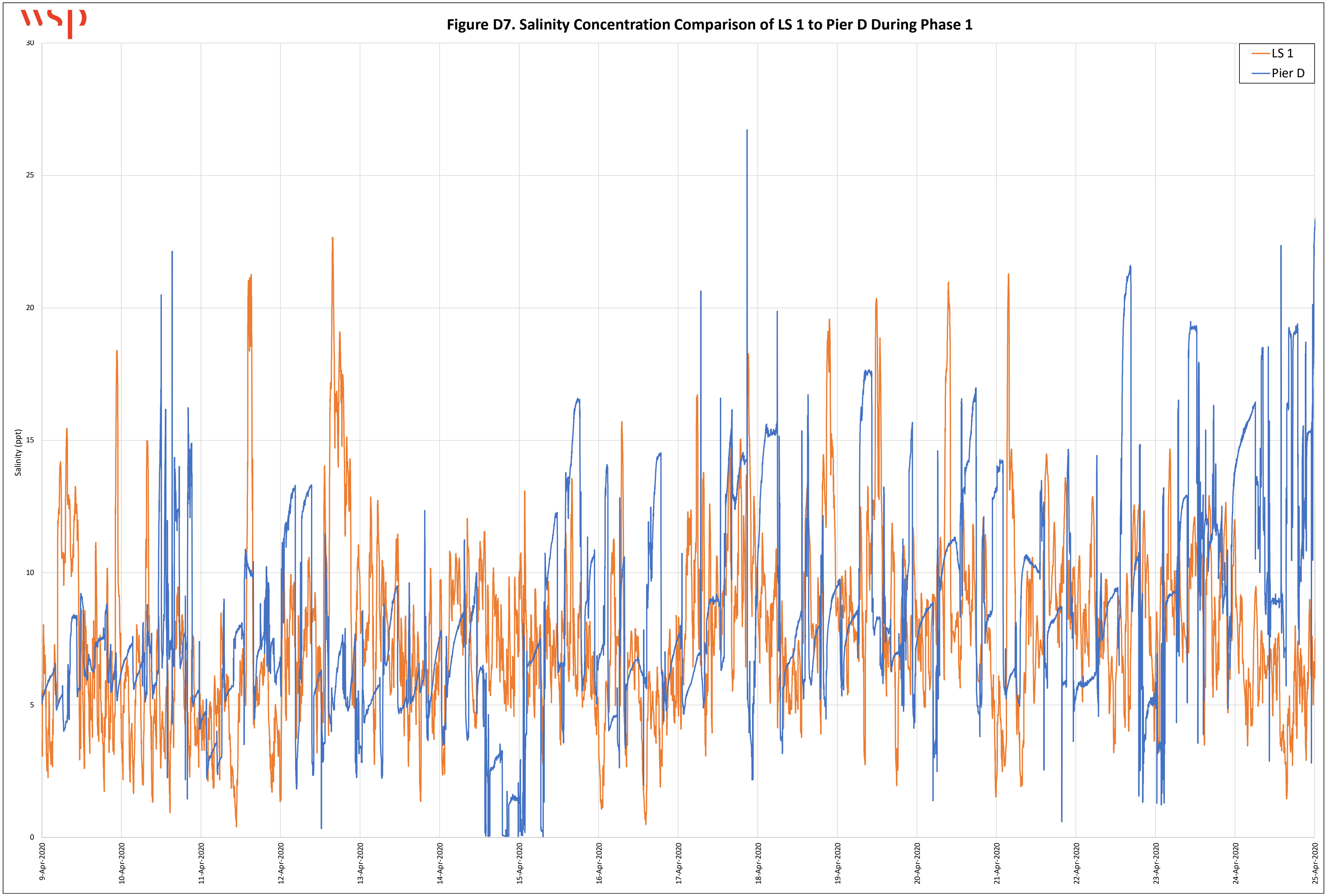
Figure D6. Salinity Concentration Comparison of LS 1 to WB-3 During Phase 1



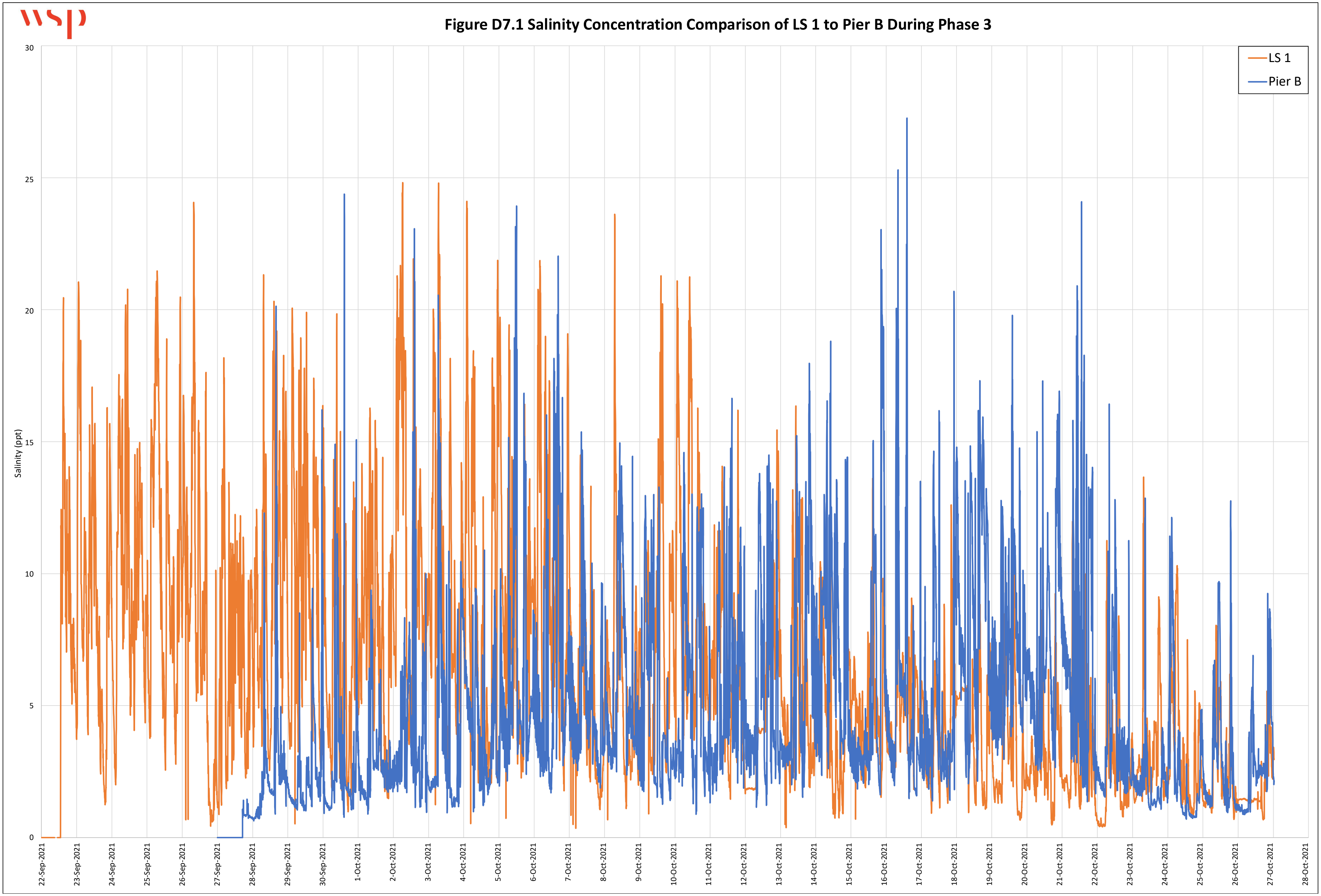
Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

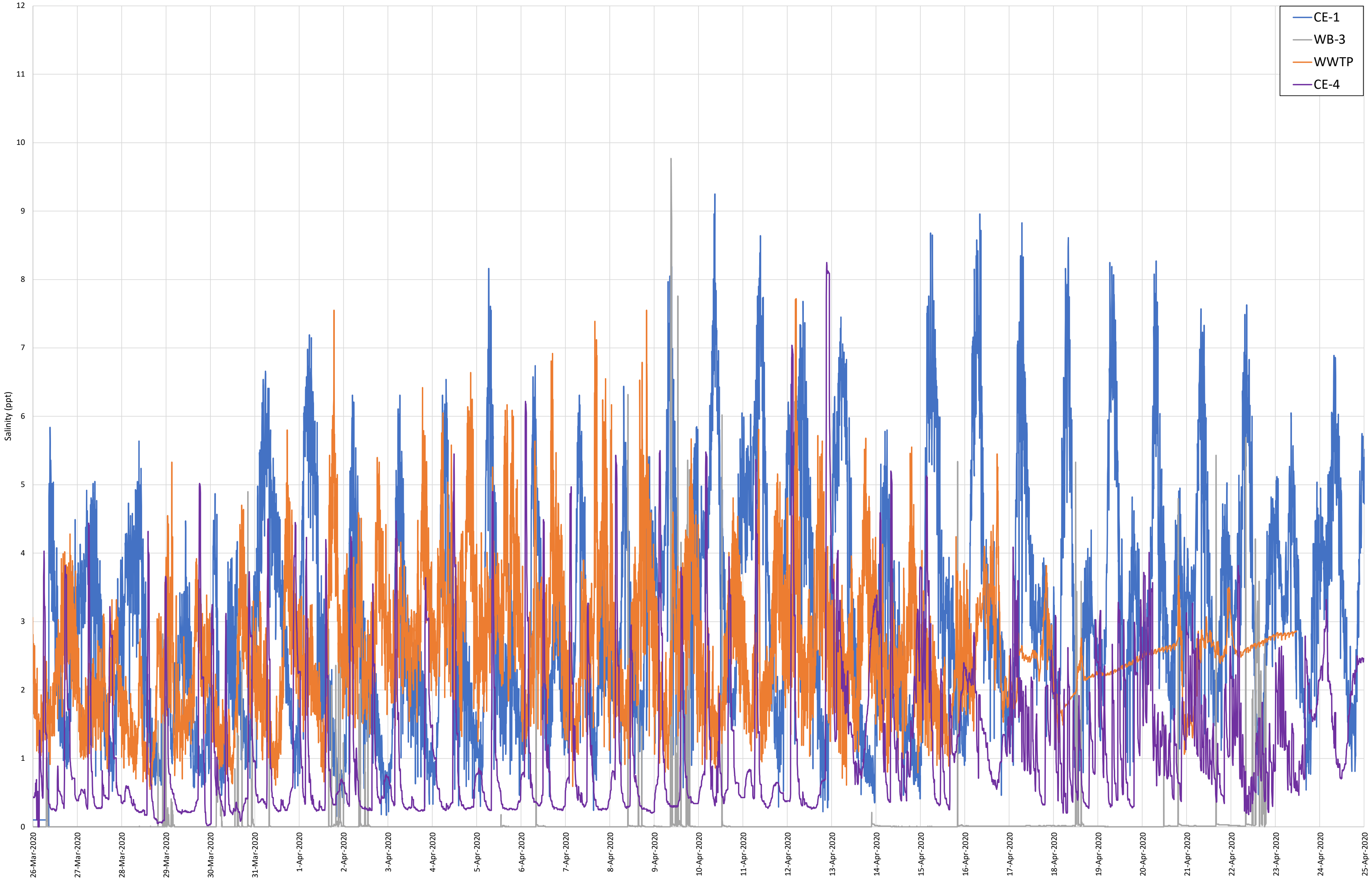


Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Figure D8. Salinity Concentration Comparison of WWTP to CE-1, CE-4, and WB-3 During Phase 1



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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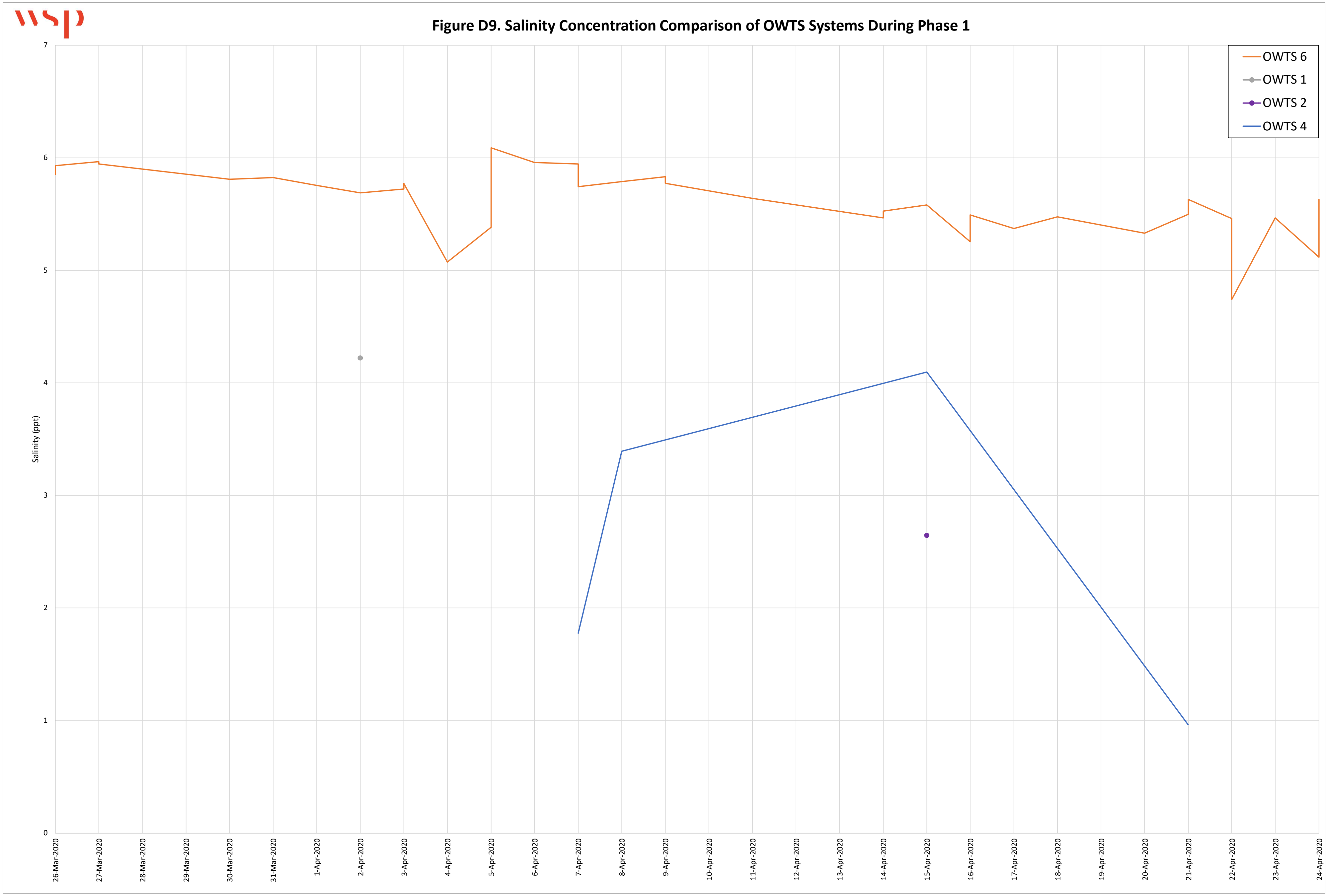
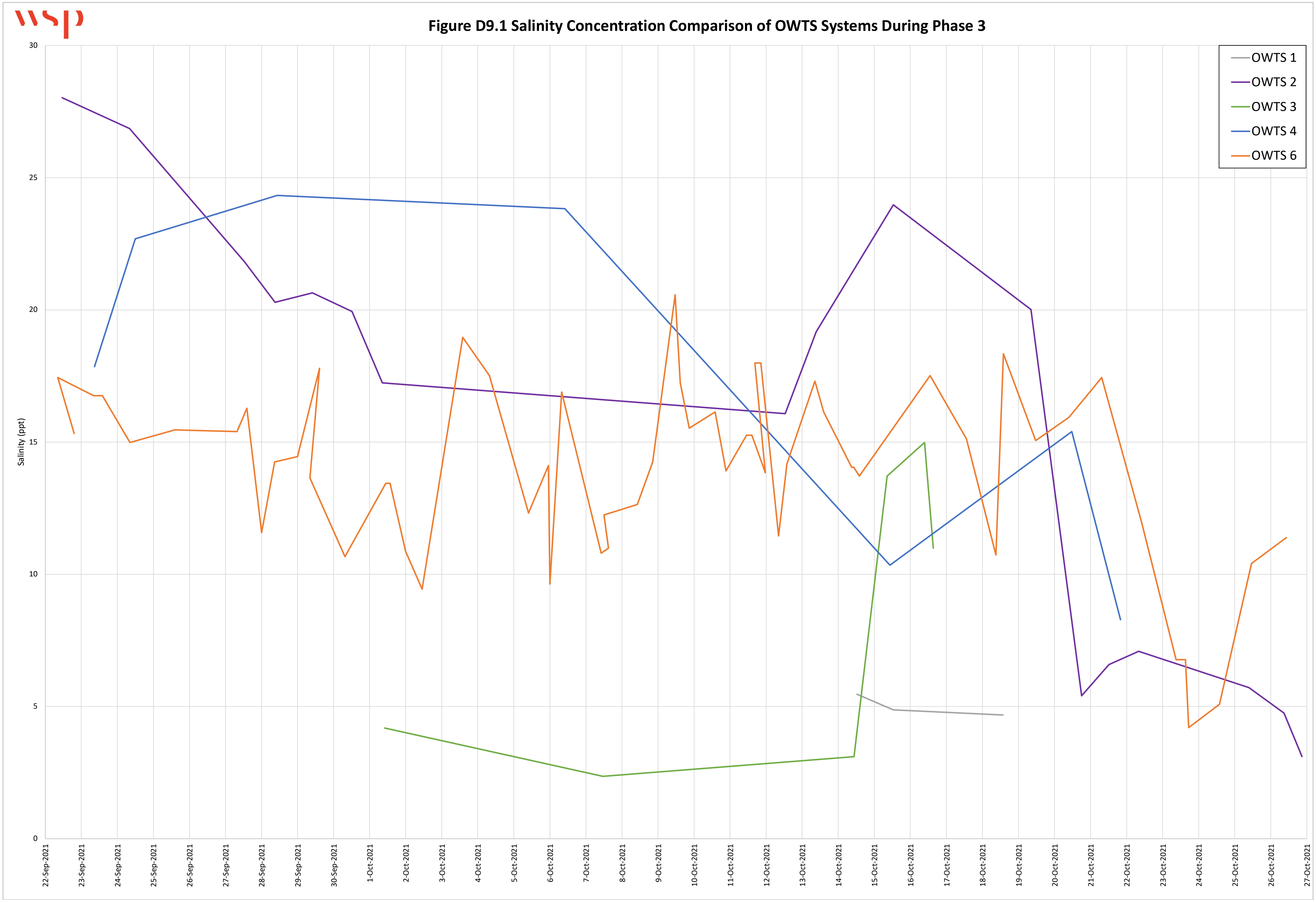
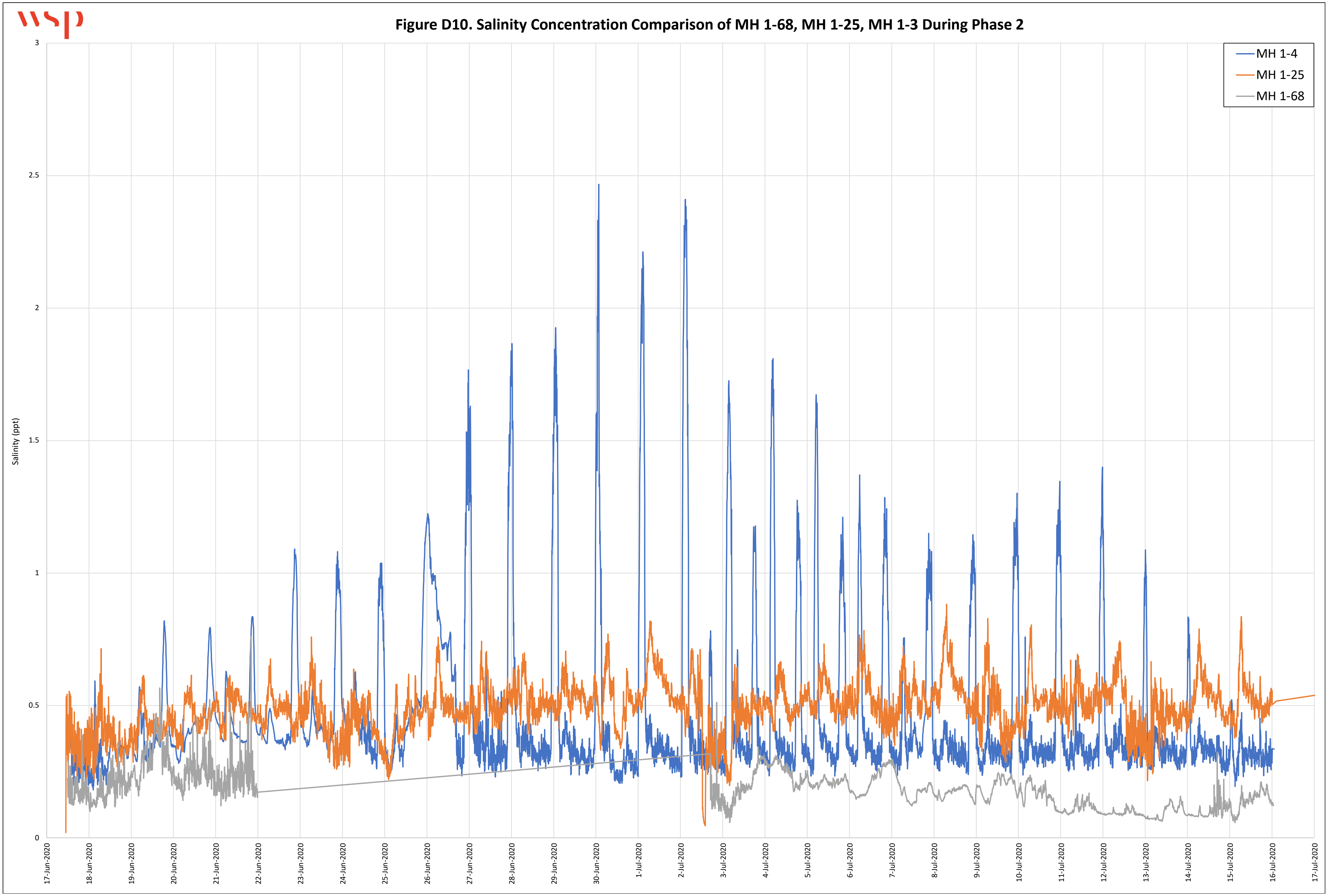


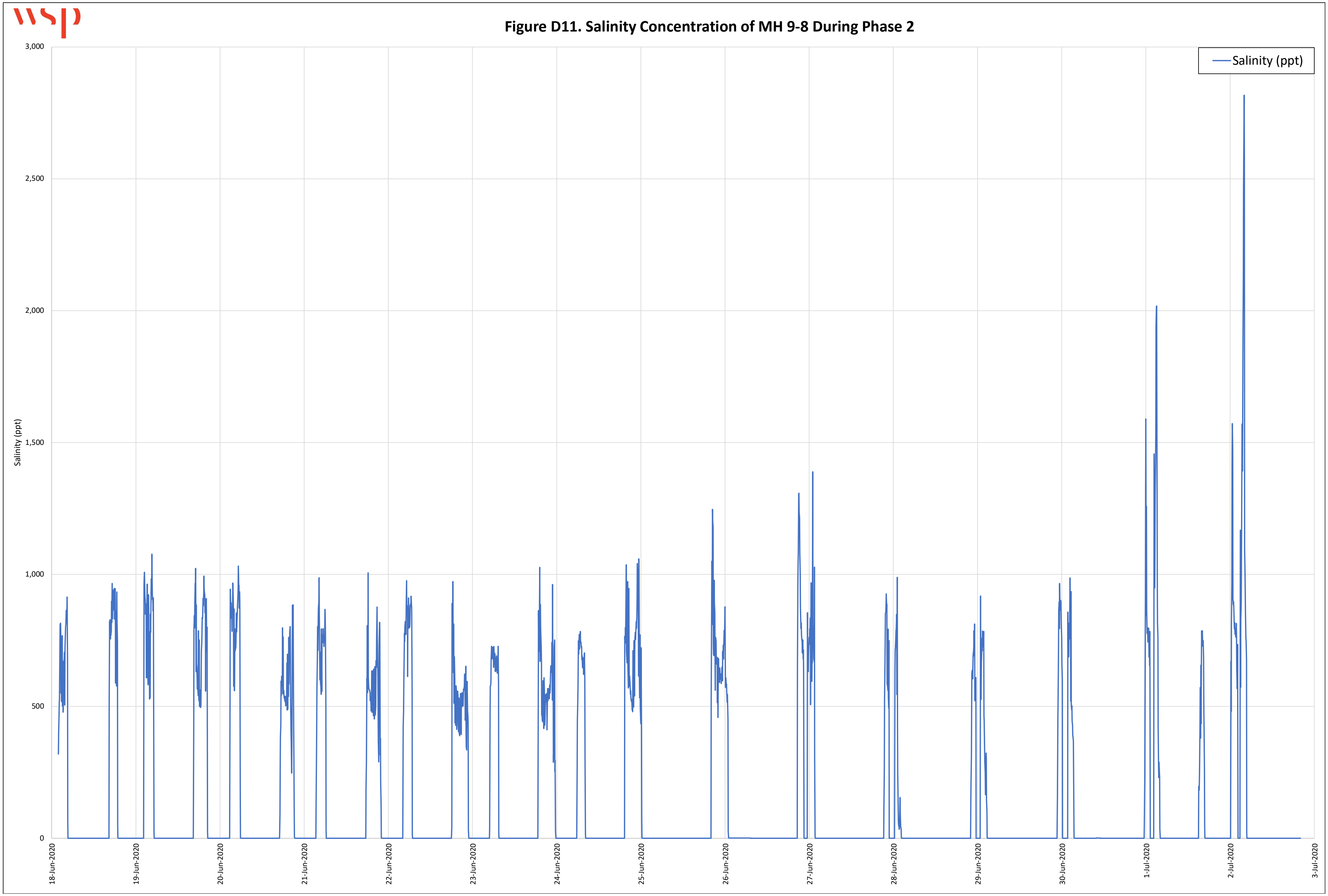
Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



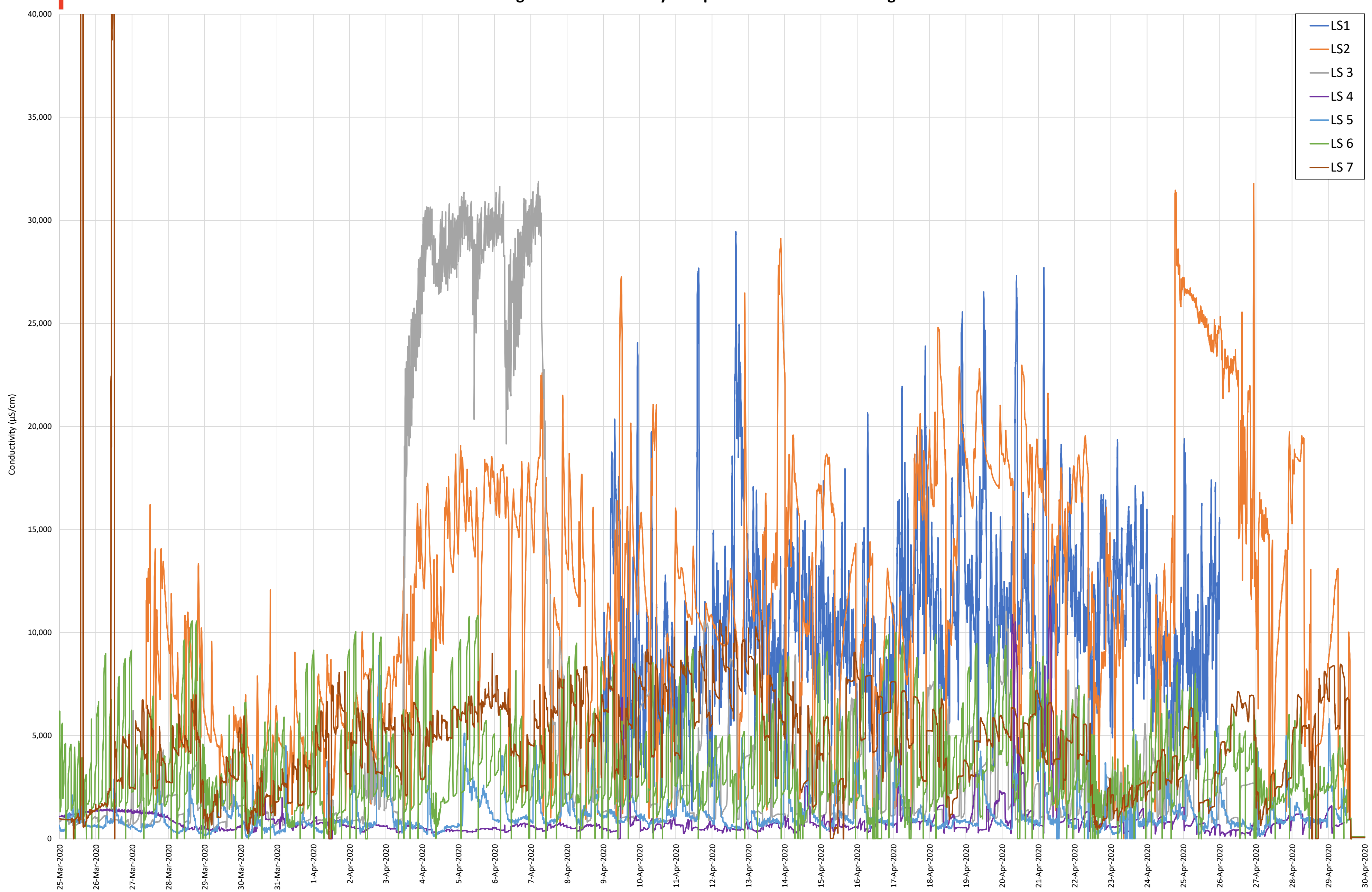
Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Approved for public release: distribution unlimited

Wastewater Salinity Follow-up Study
NBK-Bremerton, Washington
NAVFAC Northwest

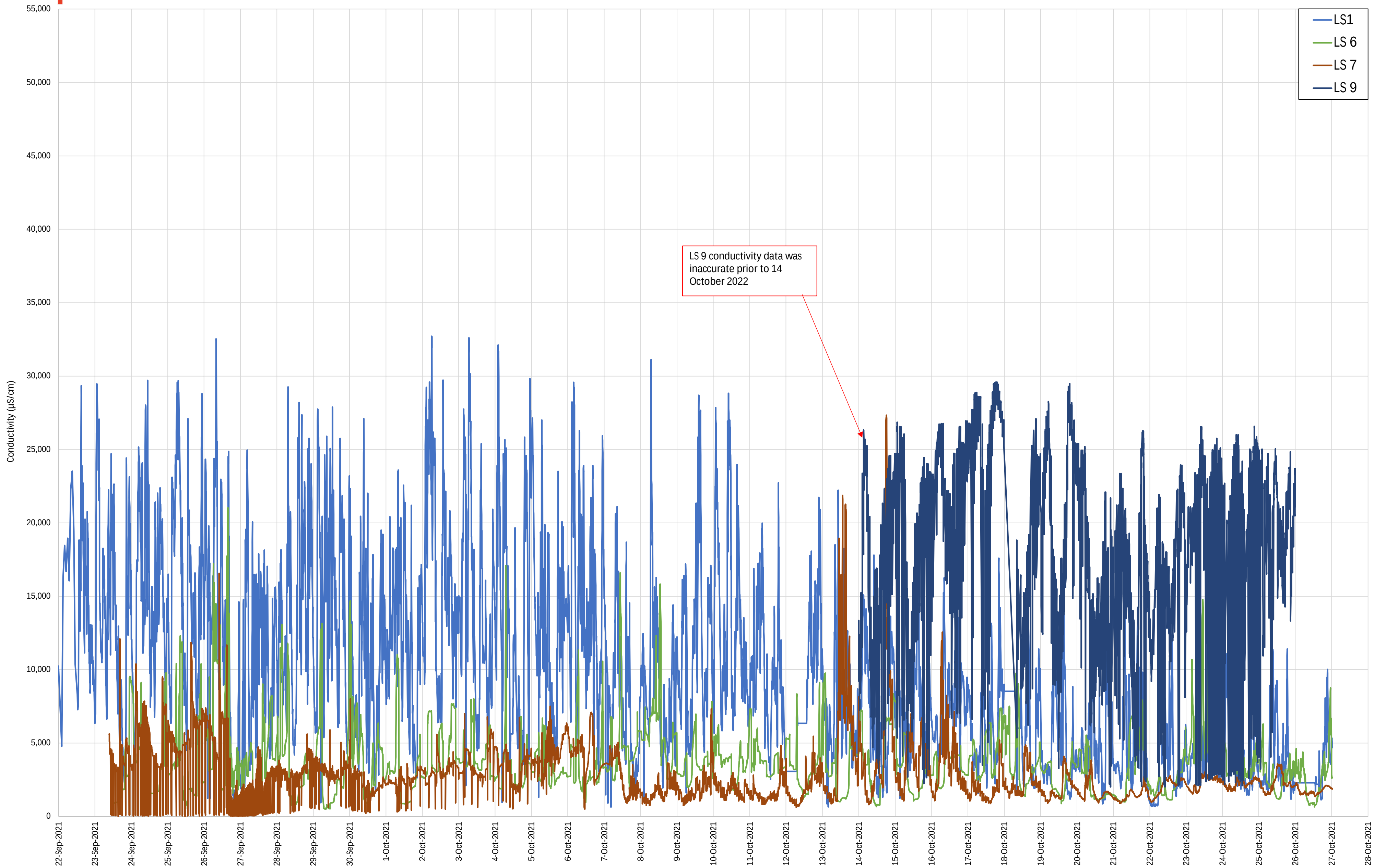
Appendix E
Conductivity Concentration Comparison Data

Figure E1. Conductivity Comparison of LS 1- LS 9 During Phase 1

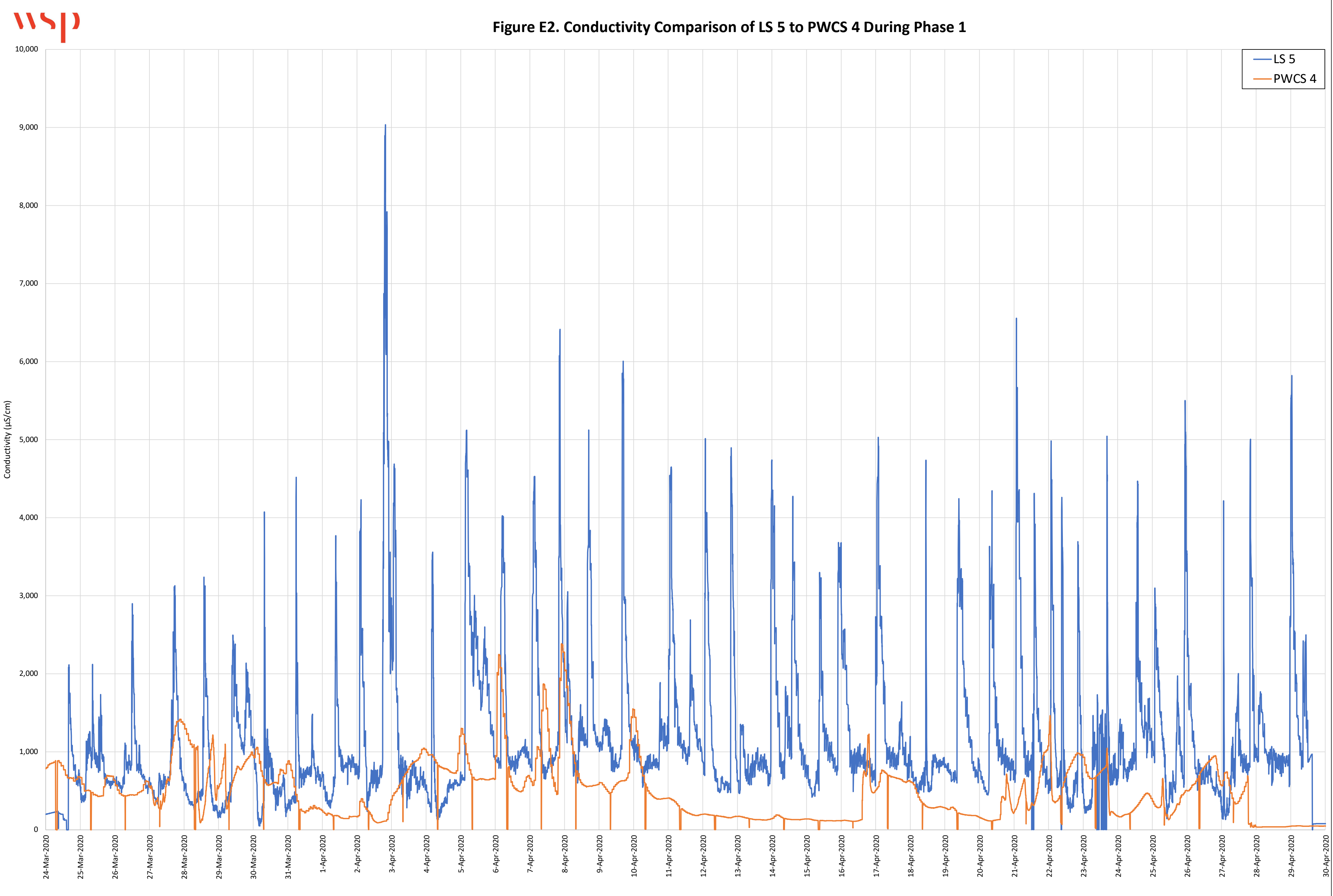


Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

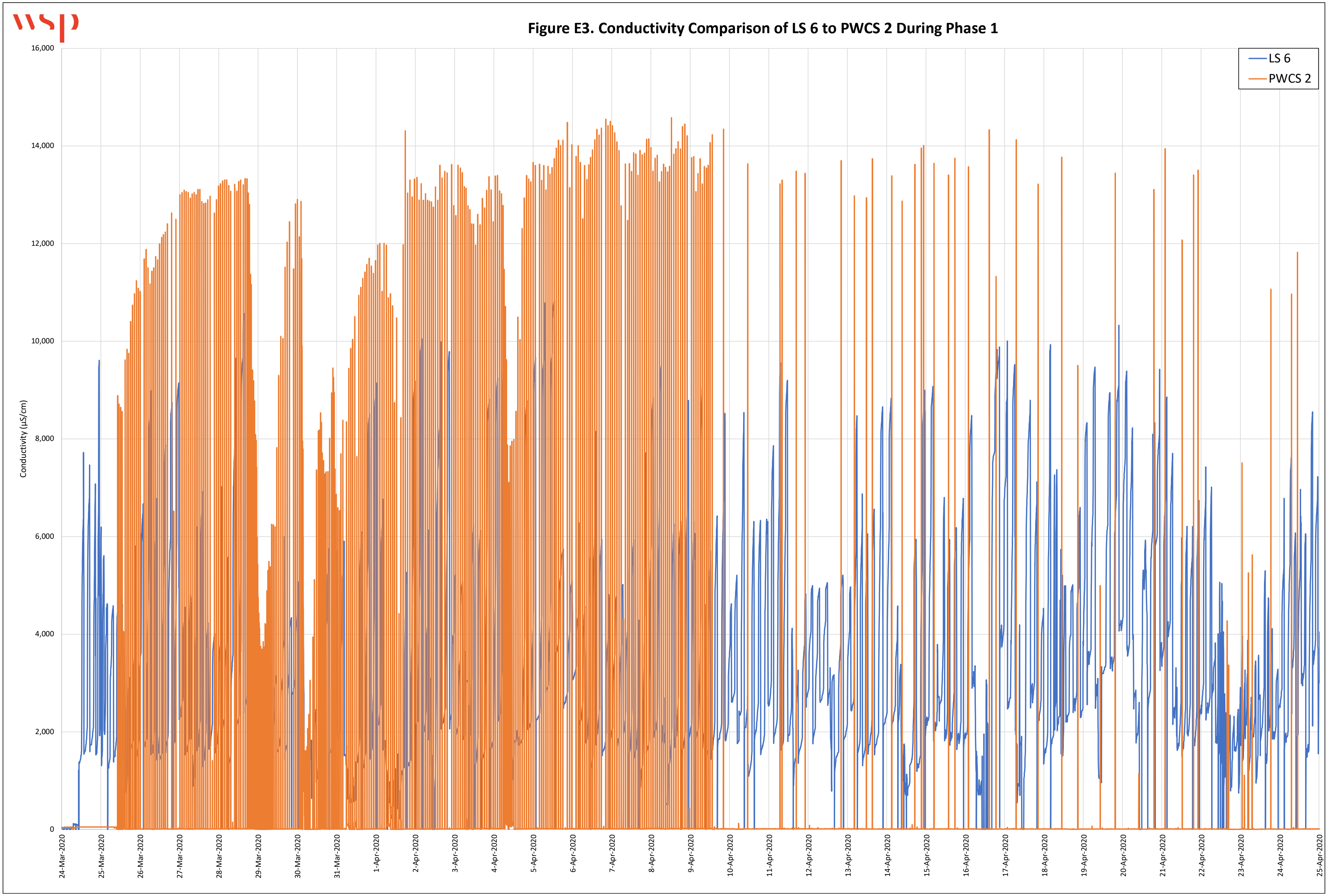
Figure E1.1 Conductivity Comparison of LS 1, LS 6, LS 7, and LS 9 During Phase 3



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

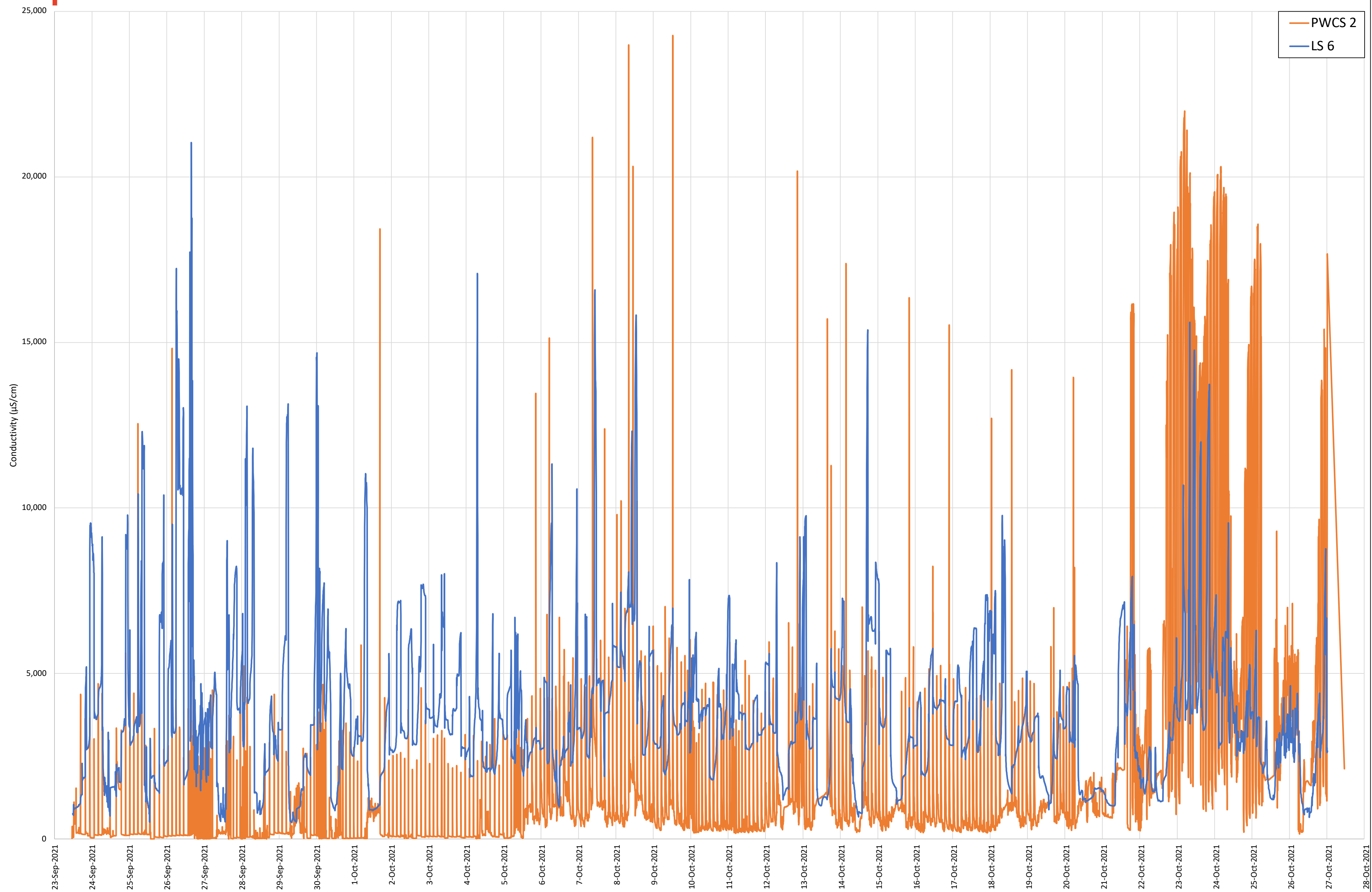


Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

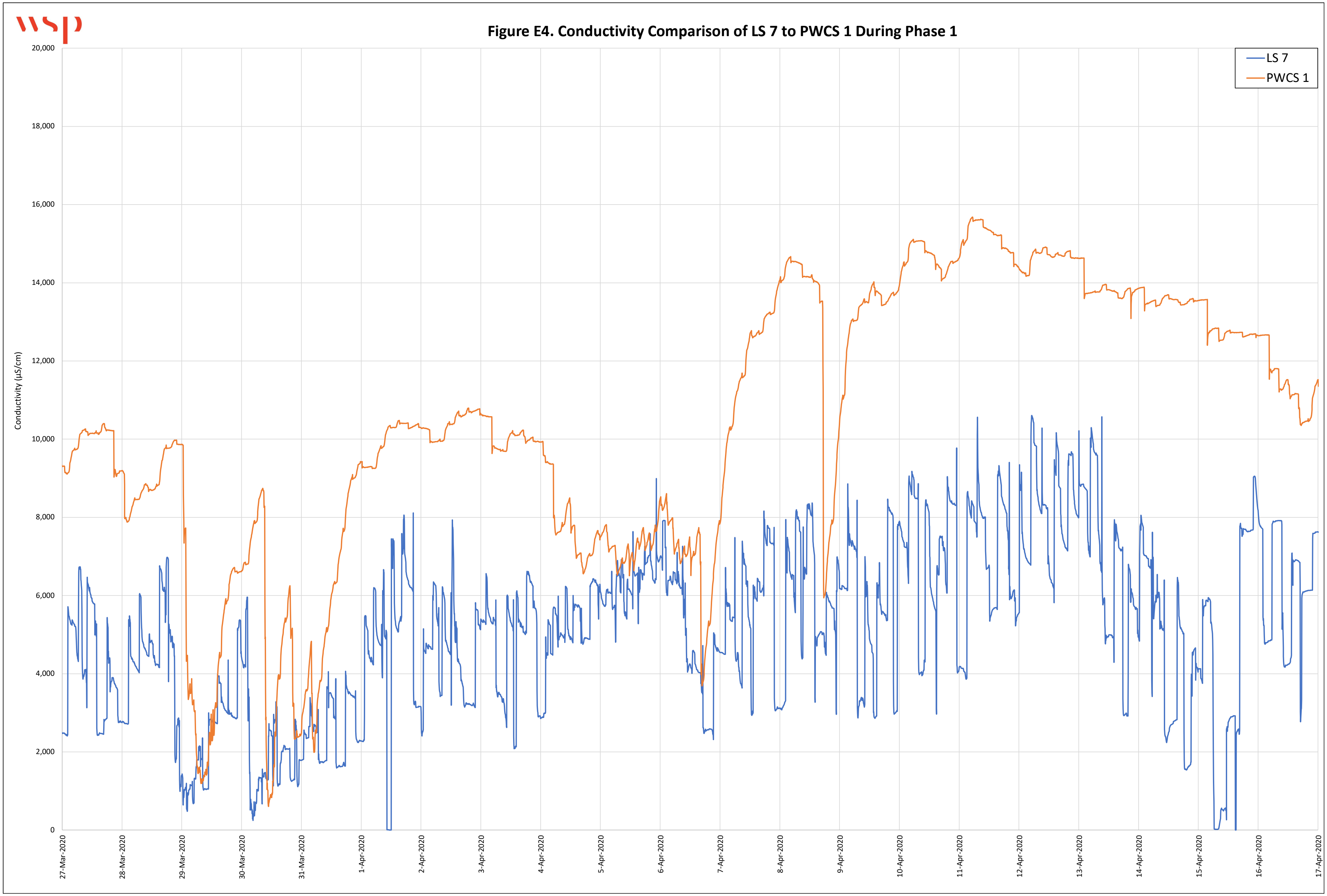


Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Figure E3.1 Conductivity Comparison of LS 6 to PWCS 2 During Phase 3

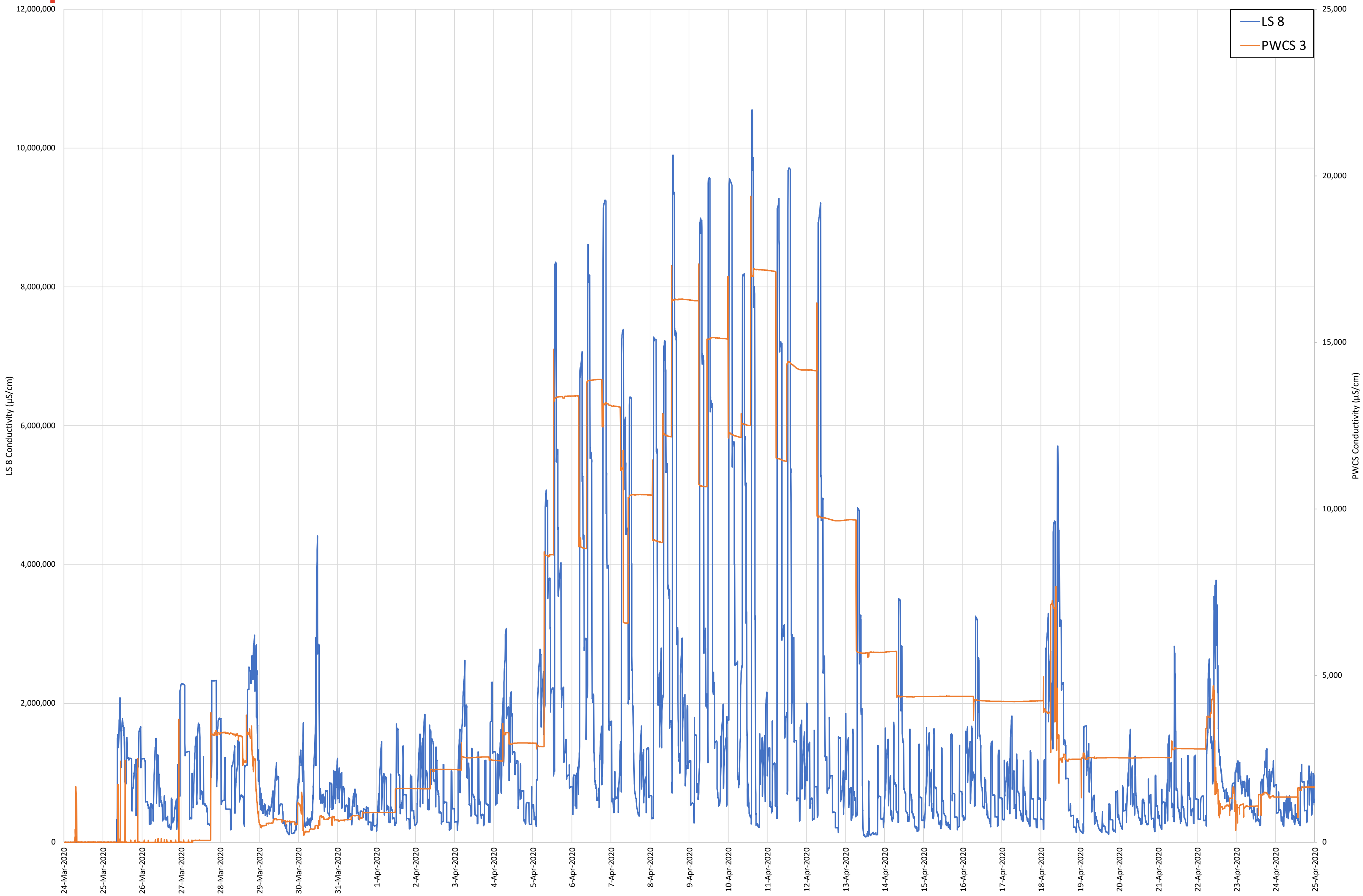


Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Figure E5. Conductivity Comparison of LS 8 to PWCS 3 During Phase 1



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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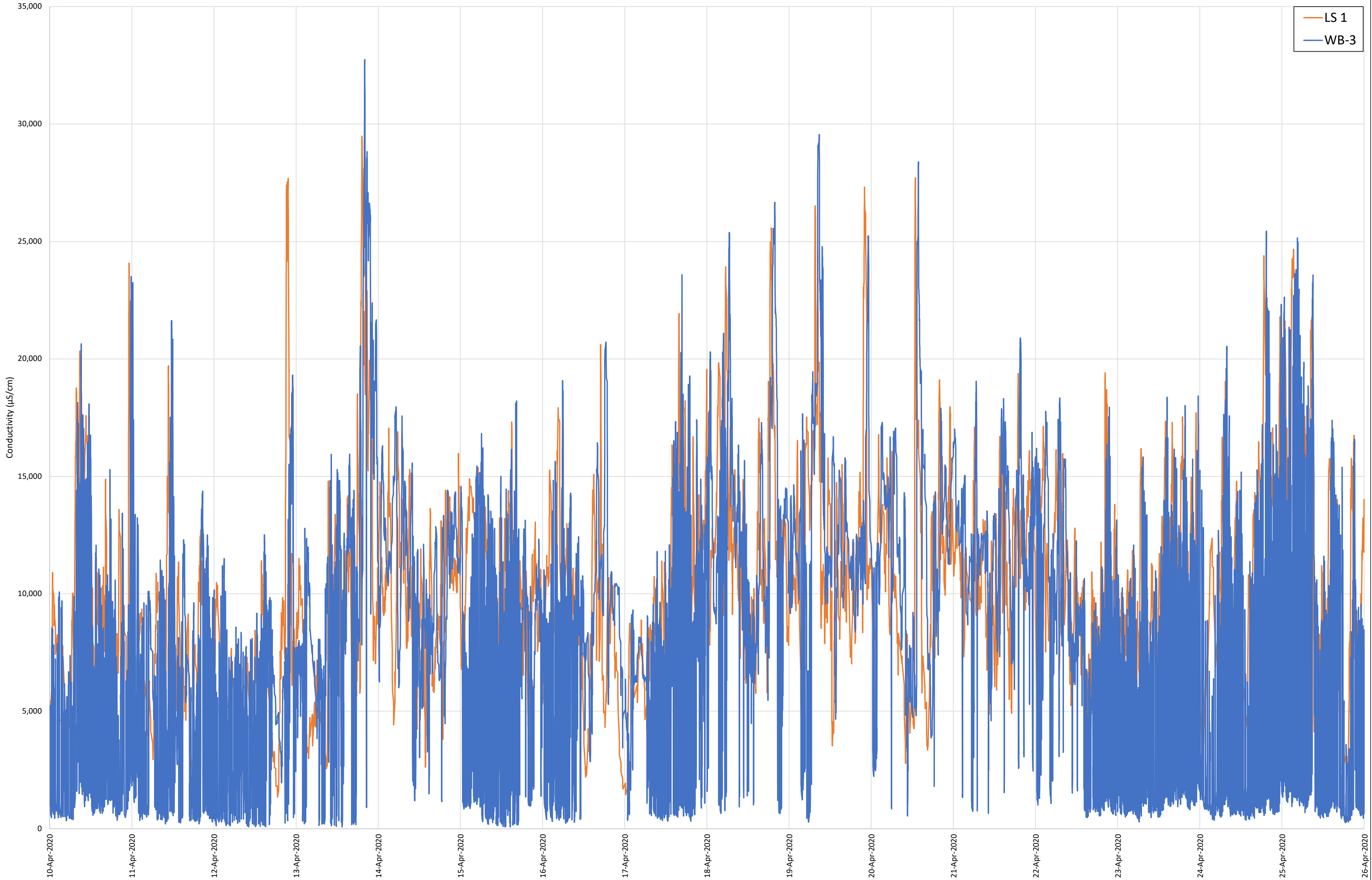
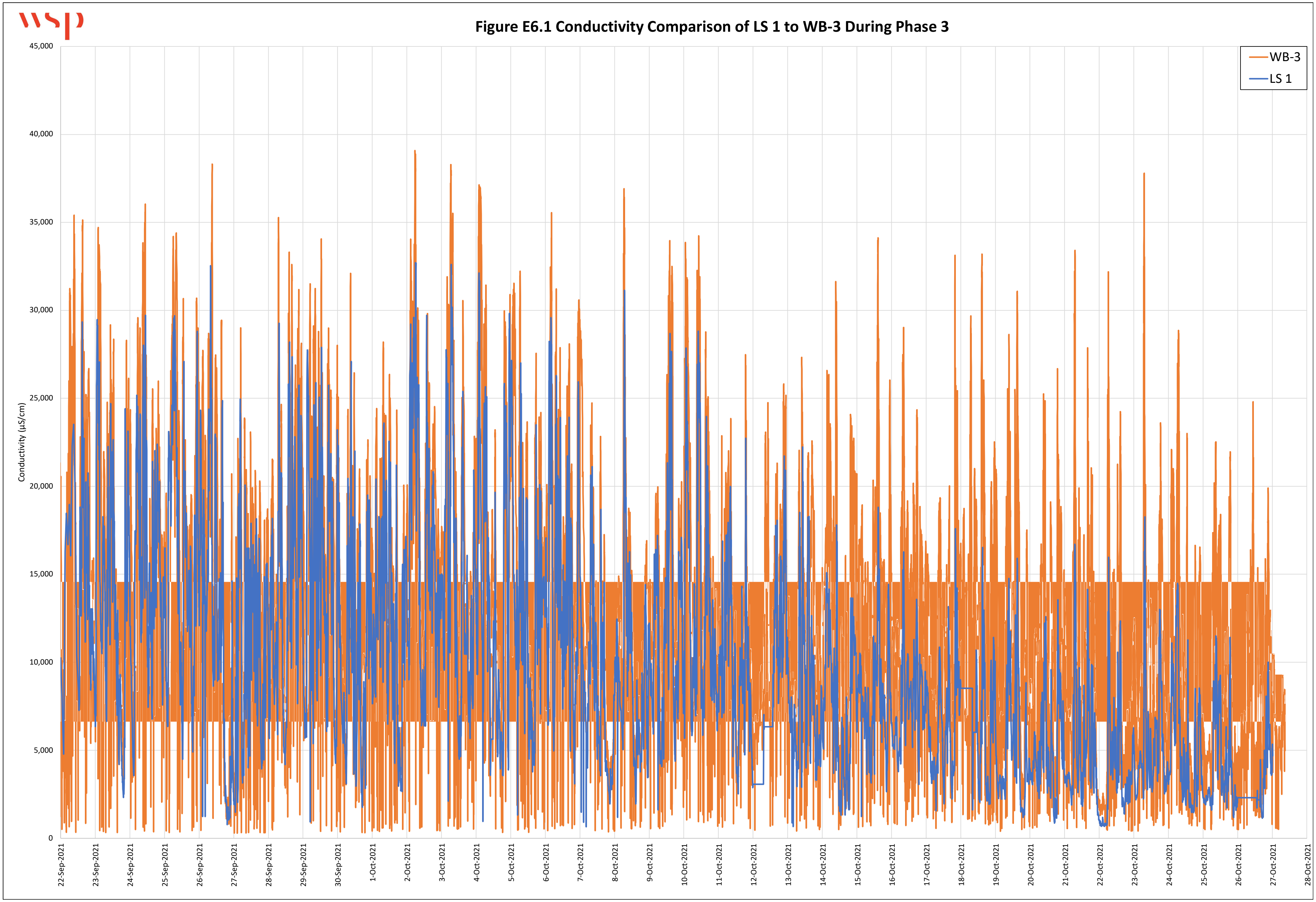
Figure E6. Conductivity Comparison of LS 1 to WB-3 During Phase 1



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



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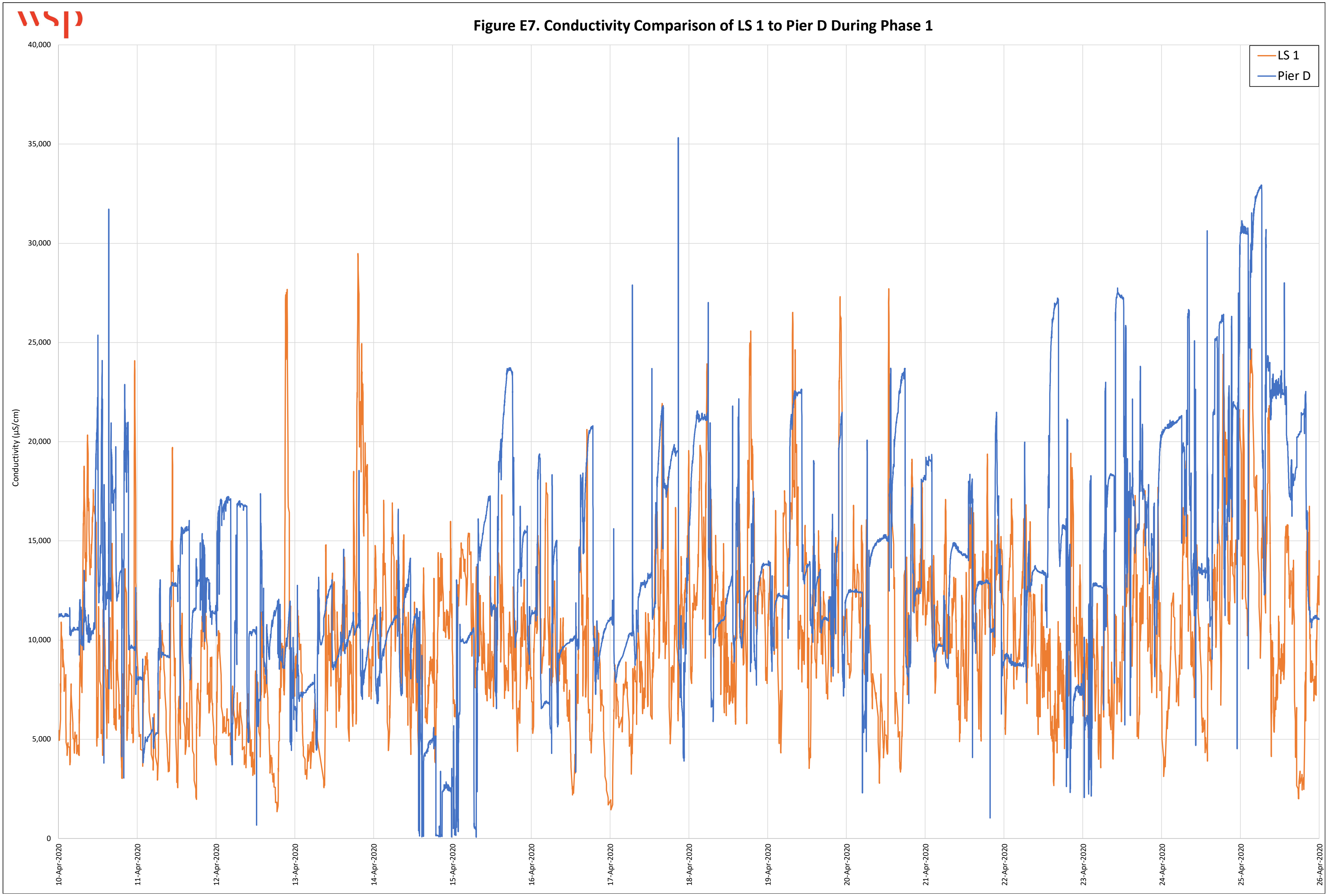
Project Number: WA16.0094.38



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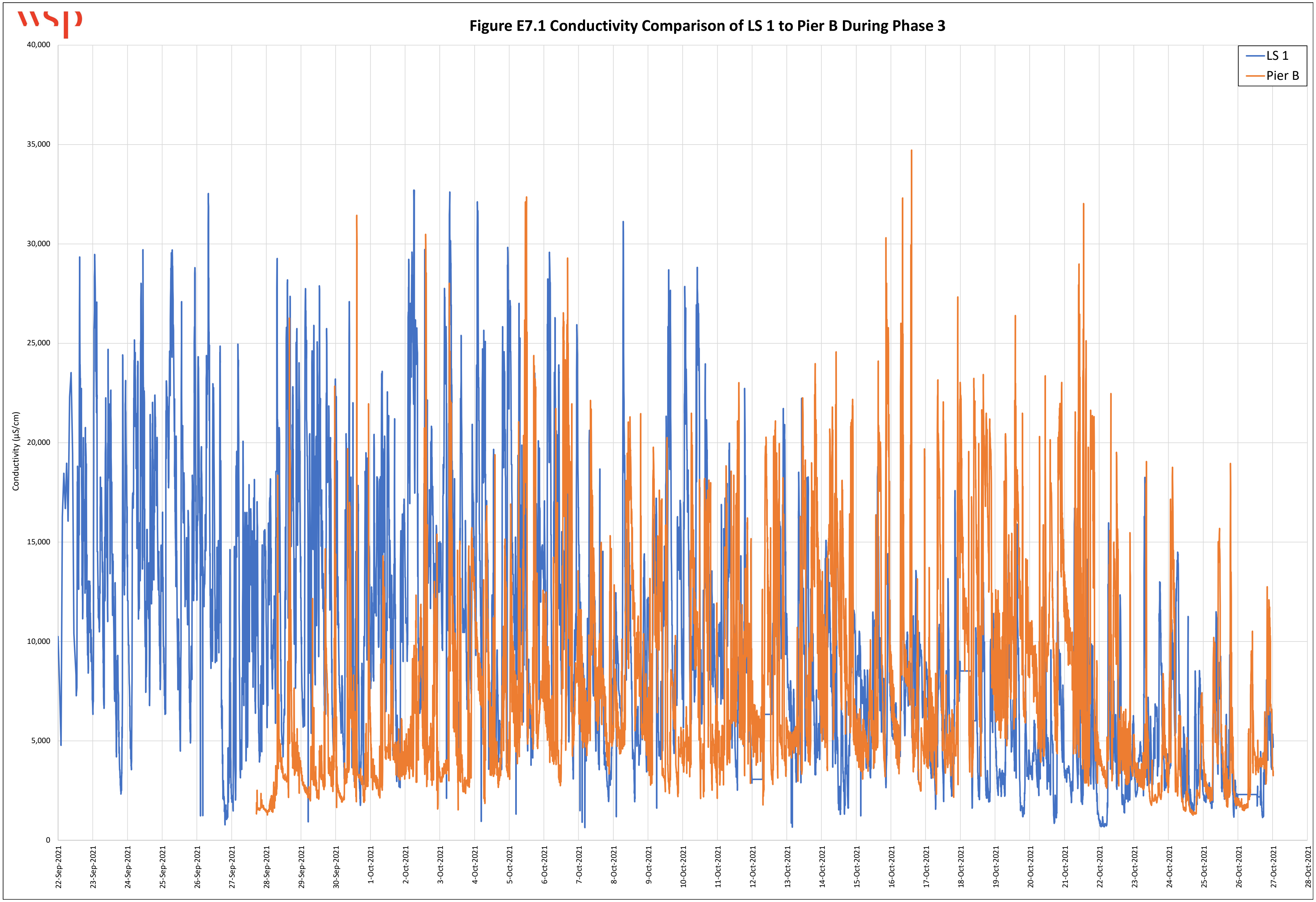

Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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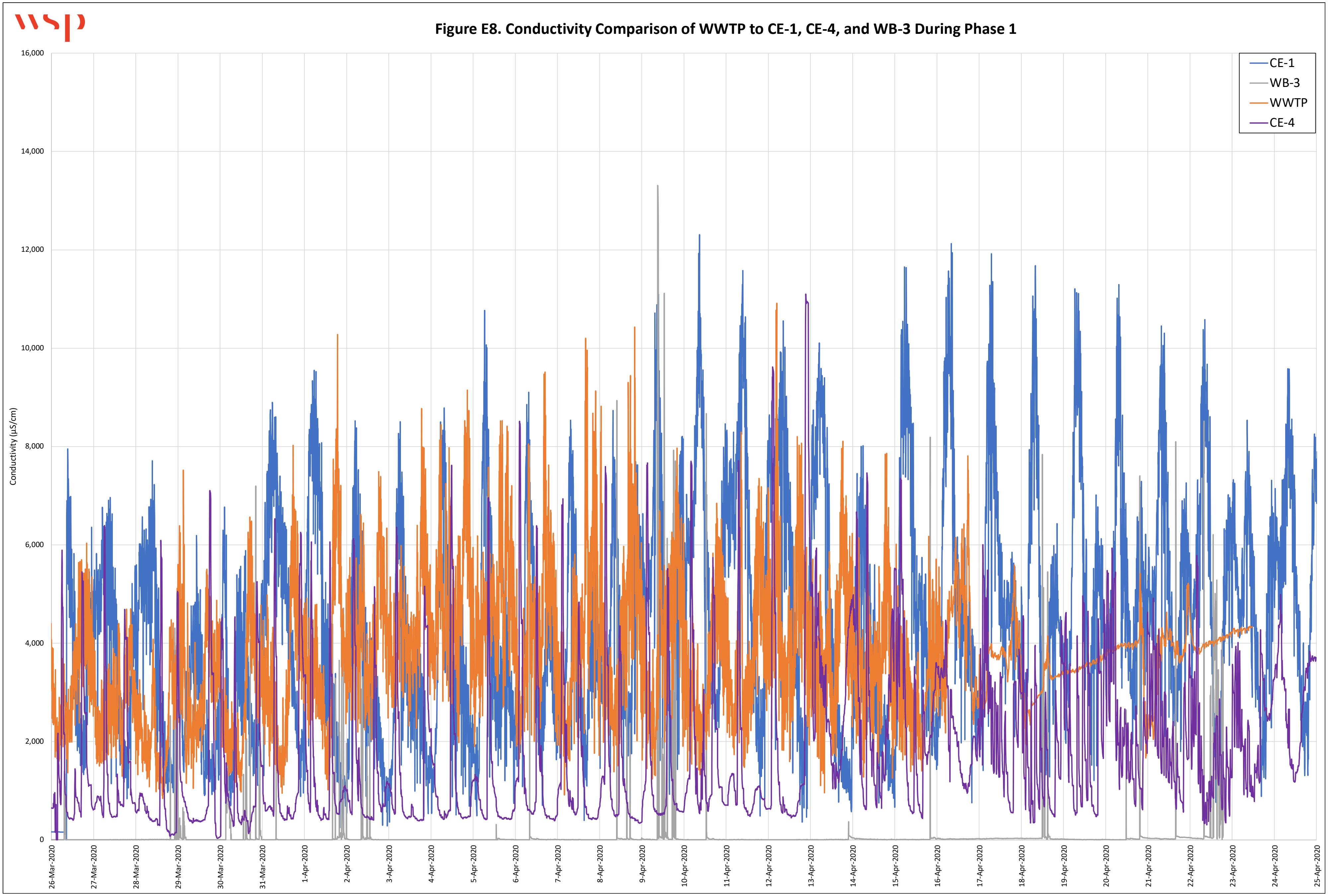

Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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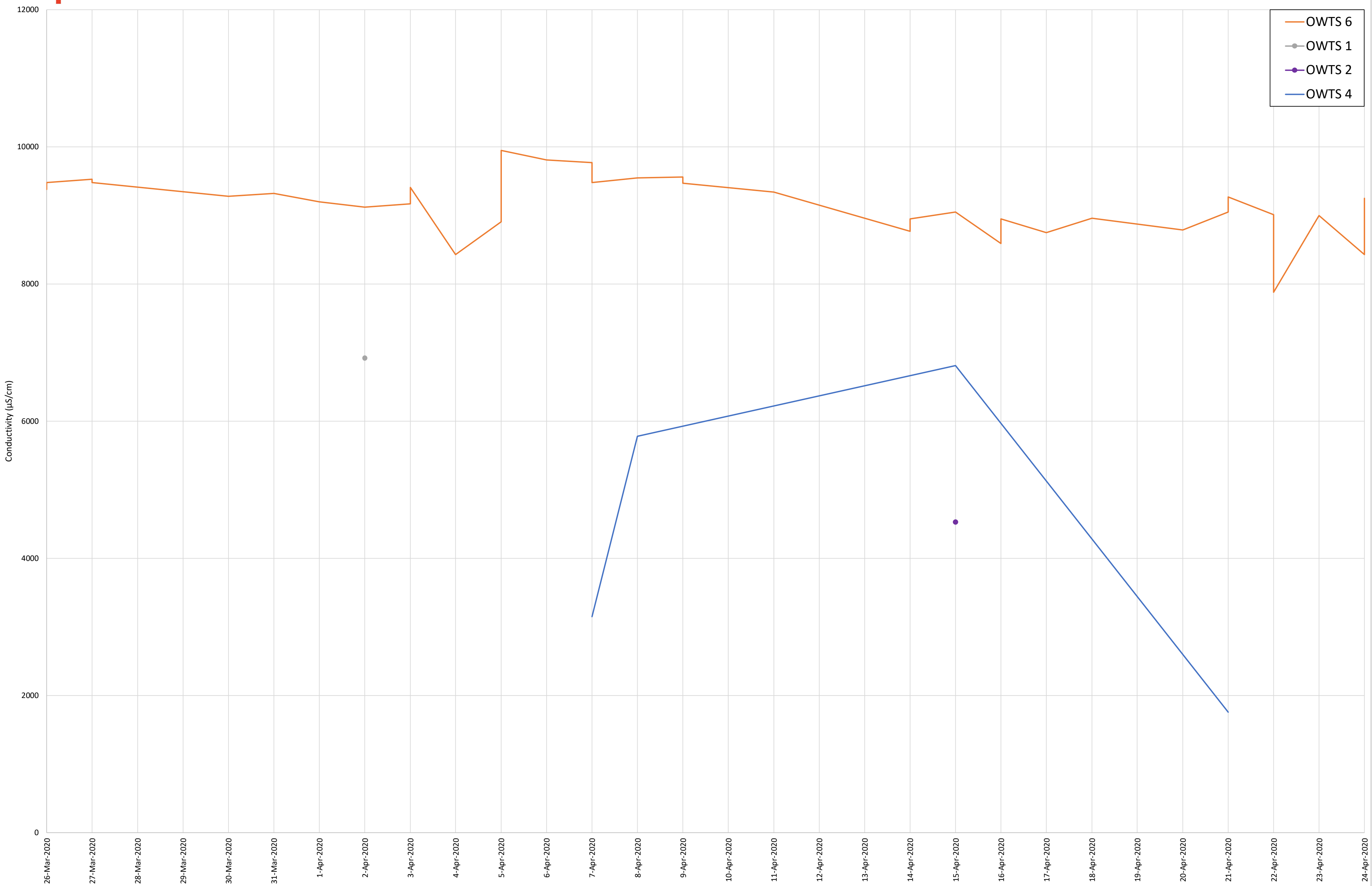
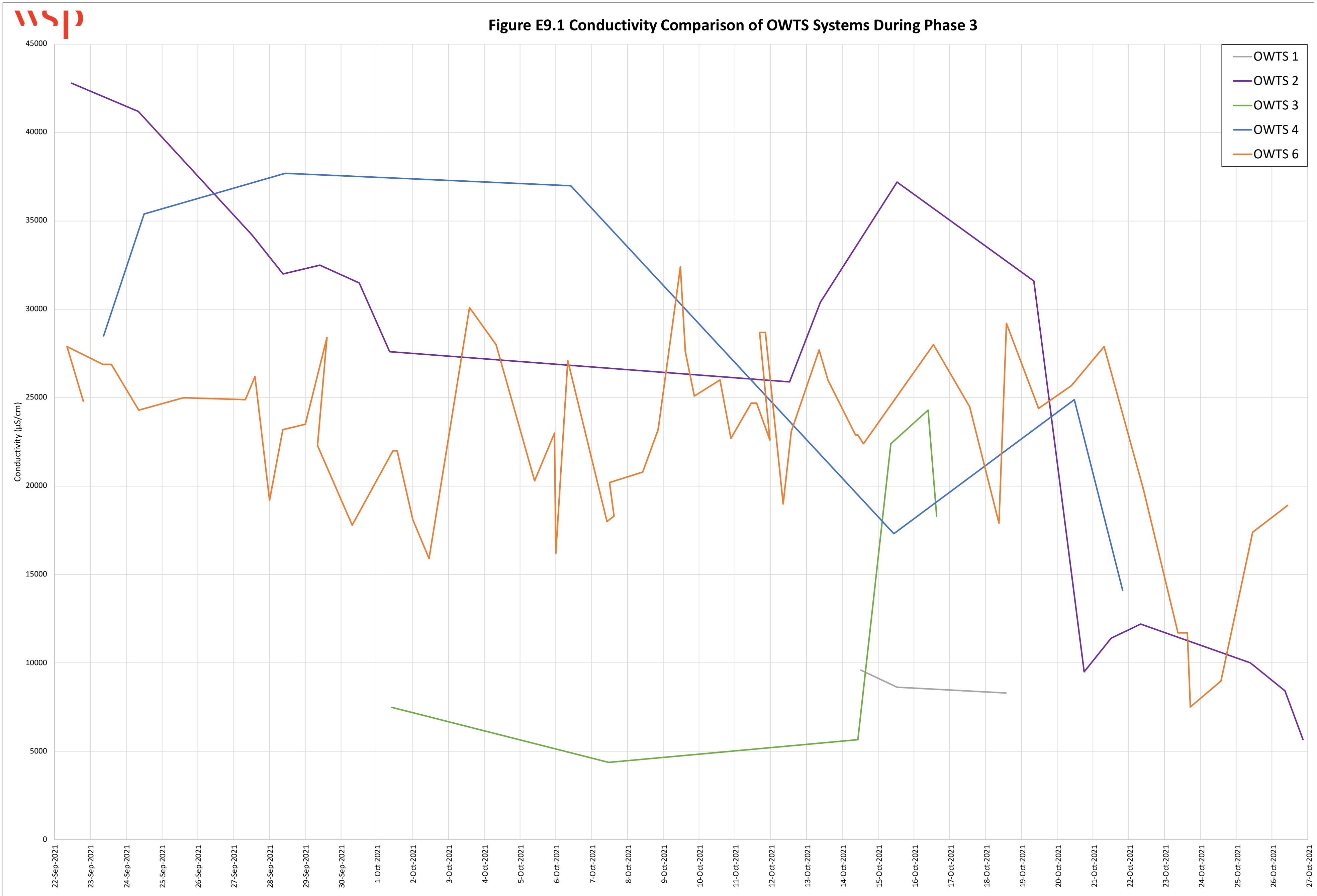
Figure E9. Conductivity Comparison of OWTS Systems During Phase 1



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

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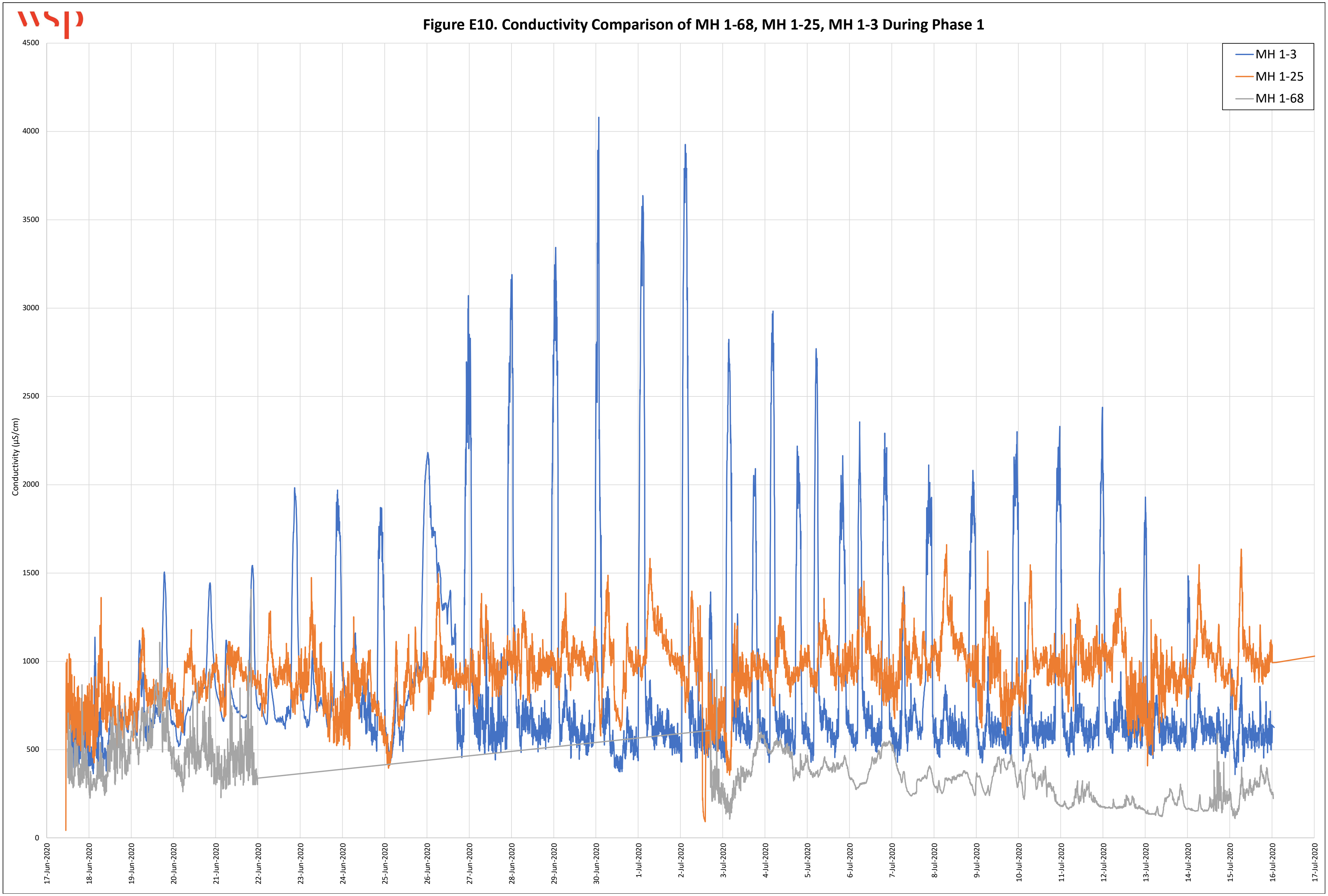
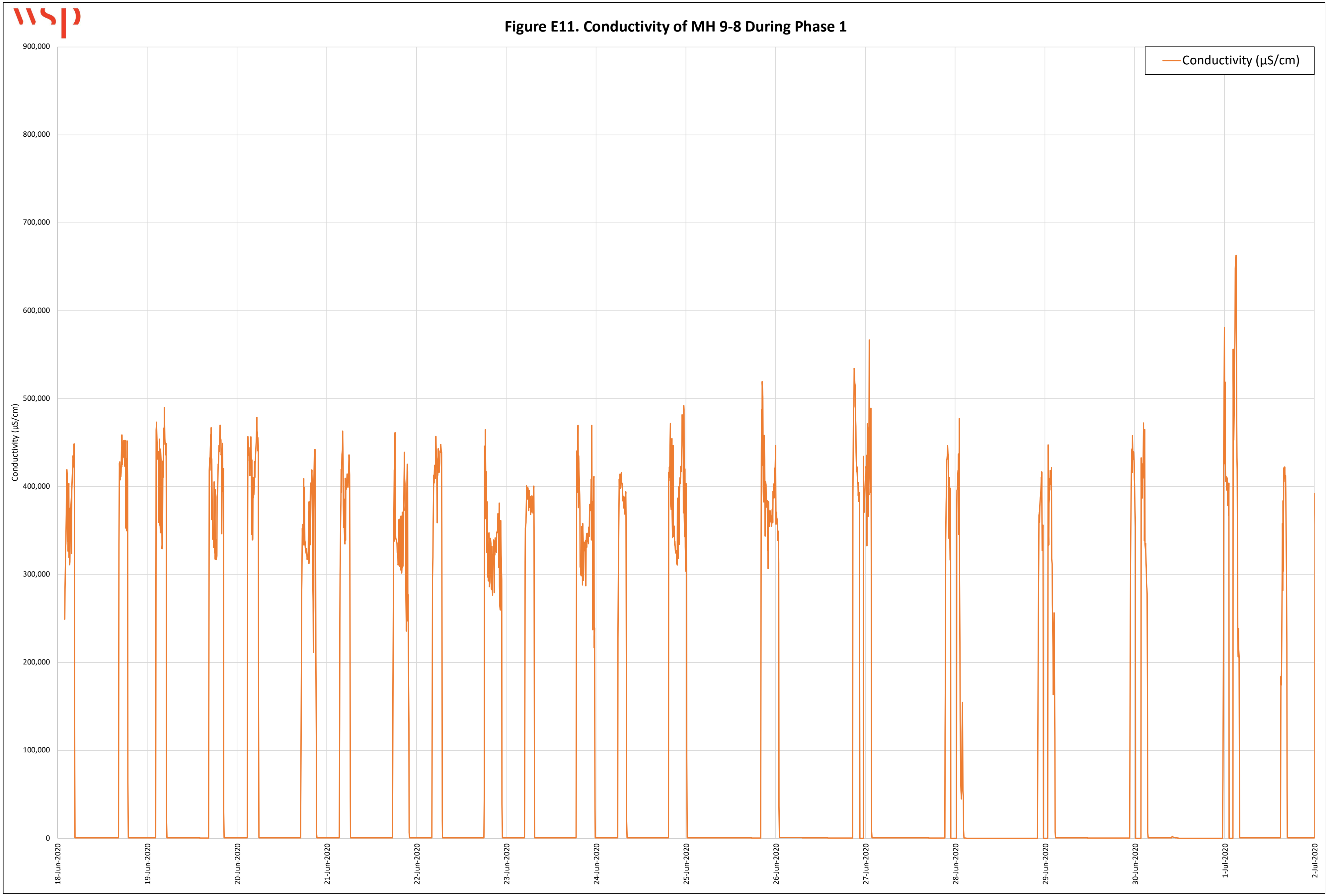


Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38



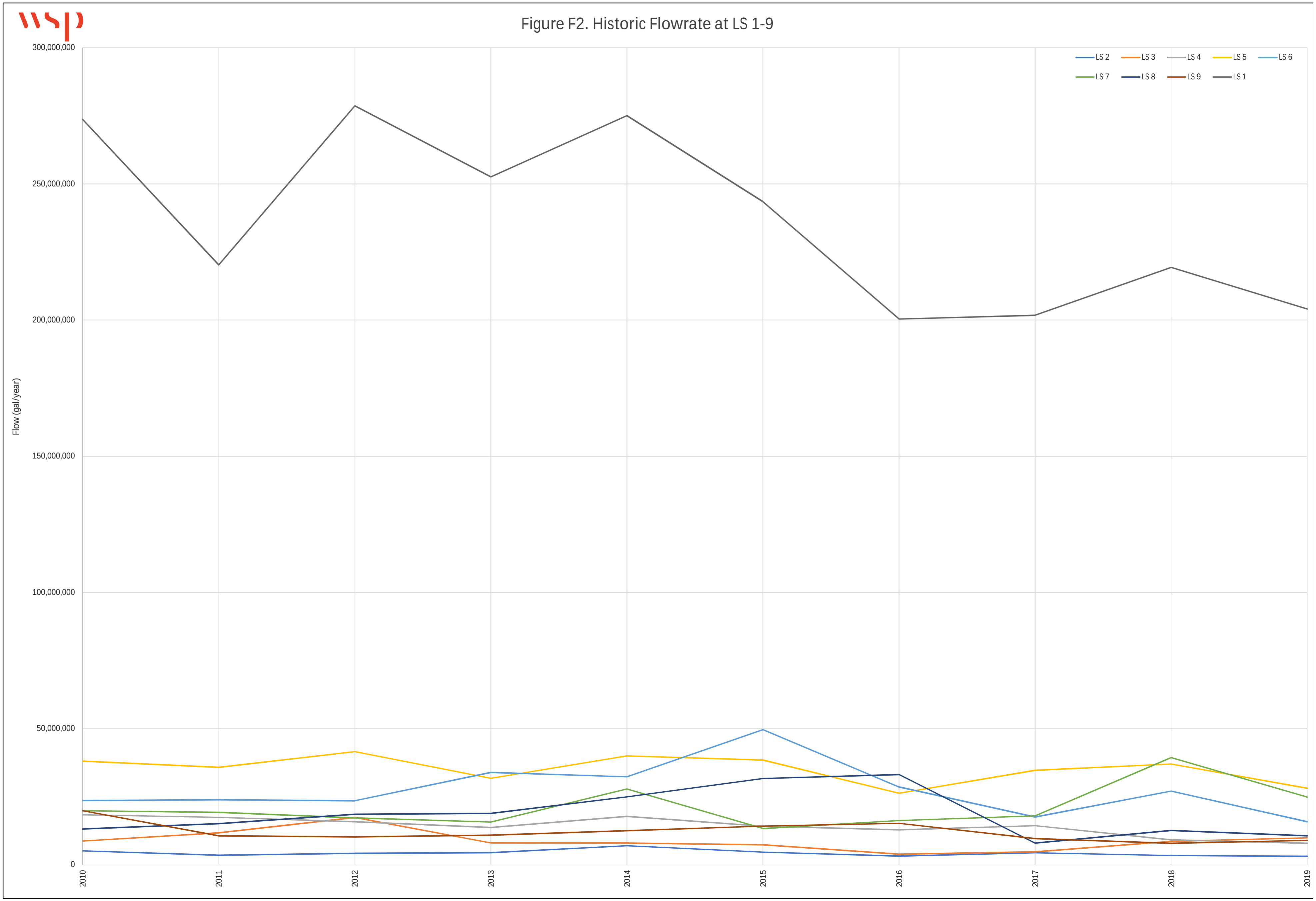
Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Appendix F
Groundwater and Historic Flowrate

Figure F1: Groundwater Sample Data

Date Sample Collected	Sample Location	Time Sample Collected	Time Sample Tested	pH	EC mS/cm	Temp °C	Chlorides mg/L	Salinity (Calculated, ppt)
4/7/2020	DD4 NE	935	1200	6.9	7.85	17.7	4250	5.15
4/7/2020	DD4 W	945	1203	7.2	9.01	17.7	4500	5.98
4/14/2020	DD6 NE	1015	1244	7.5	9.68	17.9	-	6.43
4/14/2020	DD6 SE	1018	1242	7.4	9.9	18.4	-	6.51
4/14/2020	DD4 NE	1039	1248	7.1	7.72	19.1	-	4.91
4/14/2020	DD4 SW	1037	1246	7.2	10.34	18.1	-	6.87
4/21/2020	DD6 SE	850	1120	7.2	8.92	17.1	7000	5.99
4/21/2020	DD6 W	856	1122	7.6	9.92	17	13000	6.73
4/21/2020	DD4 SW	910	1124	7.3	10.34	17.1	18400	7.03
4/21/2020	DD4 NE	917	1126	7.0	7.77	17	3850	5.18
9/11/2020	DD5*	953	09/16/20 at 0940	-	30.2	25	-	19.03
9/11/2020	DD4	1024	1130	7.0	6.92	16.9	-	4.58
9/11/2020	DD4	1024	1126	7.0	6.89	16.6	-	4.60
	DD4 Average Salinity:							5.54
	DD5 Average Salinity:							19.03
	DD6 Average Salinity:							6.42
	Total Average Salinity:							10.33

*Note that the DD 5 sample was collected and tested by NBK-Bremerton



Project Name: Bremerton Salinity Study
Project Number: WA16.0094.38

Approved for public release:
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Report Number: 2020PS05365

Laboratory Analysis Report

Laboratory Division

Puget Sound Naval Shipyard and IMF ,Code 134 , Bremerton, WA 98314-5001

Customer: Code 160.32
Date Submitted: 09-11-2020
Job Order: Mission Funding
Submitted by: Pham
Customer Ref Number: DD5GW DD4GW
Submitter's Phone:
Lab Code : 134.1
Lab Phone: 476-8090
Project/Program: OVERHEAD
Specification for Tests: ENVIRONMENTAL
Analysis/Service Requested: Customer Support Sample
RequestType: SAR
Sampling Procedure: Not Provided
Remarks: Sample and analysis may not meet method or sampling requirements and should not be used for regul compliance reporting.

Test Results

Sample Number: W001

Sampled Date/Time: 09-11-2020 09:53
Sample Description: DD5 Ground water

Test	Method	Result	Units	Test Date/Time
Specific Conductance	SM2510 B-2011	30200	uS/cm@25C	09-16-2020 09:40

Sample Number: W002

Sampled Date/Time: 09-11-2020 10:24
Sample Description: DD4 Ground water

Test	Method	Result	Units	Test Date/Time
Specific Conductance	SM2510 B-2011	8920	uS/cm@25C	09-16-2020 09:50

Results relate only to item(s) tested.

(1) Prepared By:	Date:	Authorized Representative.	Date:
AP · 196067	9/17/20	[signature]	11/7/20

(1) The person designated to sign for an action verifies based on personal observation or certified records, and certifies by signature that the action has been performed in accordance with the specified requirements.

Distribution: Code 160.32, Fax: 6-8810, Division Files

ENVIRONMENTAL SAMPLE ANALYSIS REQUEST AND CHAIN OF CUSTODY

Ref: PSNS&IMFINST 4730.54

SECTION I. CUSTOMER INFORMATION - REFER TO INSTRUCTIONS AND TERMS AND CONDITIONS ON THE BACK.

LABORATORY NUMBER: 2020PS05365

1a. SAMPLE SUBMITTED BY:	b. SHOP OR CODE:	c. MAIL STOP:	d. PHONE:	e. FAX:	2a. NAME (*FAX COPY ONLY*):	b. SHOP OR CODE:	c. FAX:
Duy Pham	106.32		6-0122	6-8880			

3. JOB ORDER: Mission Funded
4. SHIP OR PROJECT NO.: Overhead
5. CONTROLLING DOCUMENT OR SAMPLING PLAN:

6a. TURNAROUND TIME (TAT):
☑ ROUTINE (≤10 DAYS) ☐ RUSH* (3 TO 5 DAYS) ☐ OVERTIME (OT) * (CONTACT LAB SUPV.) **FOR RUSH OR OT WORK, FILL OUT BOX 6b. LAB SUPV. SIGNS BOX 6c.*

b. SHOP SUPV. APPROVING RUSH OR OT (SIGN & PHONE)
c. LAB SUPV. APPROVING SUPPORT (SIGN)

SECTION II. TESTING

7. ENVIRONMENTAL PROGRAM

- ☐ SWDP - SAMPLING POINT:
- ☐ NPDES - DRYDOCK
- ☐ NPDES - OUTFALL 021 {POWER PLANT}
- ☐ AHERA {ASBESTOS}
- ☐ RCRA
- ☐ TSCA {PCB}
- ☐ IPI 0505-903 {SWDP PRETREAT} (1)

Waste Stream No.:

- ☐ OTHER (SPECIFY):
- ☑ CUSTOMER SUPPORT (INFO) (2)

(1) For IPI 0505-903: Mark specific metals in box 8.
(2) Analysis of samples submitted for customer support purposes may not meet method or sampling requirements and should not be used for regulatory compliance reporting.

8. REQUESTED TESTS

RCRA TOTAL RECOVERABLE METALS (SW 846-6010)
☐ SOLID, OIL, OR GREASE ☐ AQUEOUS

SWDP OR NPDES TOTAL RECOVERABLE METALS
☐ AQUEOUS (EPA 200.7)

SPECIFIC METALS
☐ ARSENIC ☐ BARIUM ☐ CADMIUM ☐ CHROMIUM ☐ COPPER ☐ LEAD
☐ NICKEL ☐ SELENIUM ☐ SILVER ☐ TIN ☐ TITANIUM ☐ ZINC
☐ OTHER:

☐ TCLP METALS (EPA 1311) *(TCLP TAT: 7-10 DAYS)*

MERCURY
☐ SOLID (SW 846-7471) ☐ AQUEOUS (EPA 245.1, SW 846-7470)

ORGANIC COMPOUNDS
☐ VOLATILES (EPA 624.1)

PCB ANALYSIS (SW 846-8082)
☐ OIL ☐ SOLID OR SOIL ☐ SWIPE

OTHER
- ☐ ASBESTOS/PLM
- ☐ CYANIDE (ASTM D7511) ☐ TOTAL ☐ AMENABLE
- ☐ HEM AQUEOUS (OIL AND GREASE) (EPA 1664)
- ☐ HEM SGT AQUEOUS (TPH) (EPA 1664)
- ☐ TSS (SM 2540D)

WET CHEMISTRY
- ☐ pH AQUEOUS (SM 4500 H+)
- ☑ CONDUCTIVITY (SM 2510)
- ☐ OTHER-SPECIFY:

☐ OF021: pH (SM 4500 H+) AND TEMPERATURE (SM 2550) MEASUREMENTS PERFORMED IN THE FIELD.

SECTION III. SAMPLE INFORMATION

9. TRACE NO.	10. DATE	11. TIME	12. NO. OF CONTAINERS	13. DESCRIPTION	15. SAMPLE CONDITION ACCEPTABLE per ESRR?
DD5GW	9/11/20	0953	1	DD5 Groundwater	NO ☐
DD4GW	9/11/20	1024	1	DD4 Groundwater	NO ☐
					NO ☐
					NO ☐
					NO ☐
					NO ☐
					NO ☐
					NO ☐
					NO ☐
					NO ☐

14. ADDITIONAL INFORMATION: Both at NE corner

SECTION IV. CHAIN OF CUSTODY

SAMPLED BY (SIGNATURE):	BADGE NO.:	SHOP OR CODE:	PHONE:				
[signature]	166678	106.32	6-0122				
RELINQUISHED BY (SIGNATURE): [signature]	BADGE NO.: 166678	SHOP OR CODE: 106.32	DATE AND TIME: 9/11/20 1423	RECEIVED BY (SIGNATURE): [signature]	BADGE NO.: 185194	SHOP OR CODE: C/134.5	DATE AND TIME: 9-11-20 1423
RELINQUISHED BY (SIGNATURE):	BADGE NO.:	SHOP OR CODE:	DATE AND TIME:	RECEIVED BY (SIGNATURE):	BADGE NO.:	SHOP OR CODE:	DATE AND TIME:
RELINQUISHED BY (SIGNATURE):	BADGE NO.:	SHOP OR CODE:	DATE AND TIME:	RECEIVED BY (SIGNATURE):	BADGE NO.:	SHOP OR CODE:	DATE AND TIME:

Appendix G
Miscellaneous

Appendix G1. Sanitary Sewer Pipe Repair Project Drawings
Appendix G2. DD Mitigation of Groundwater Intrusion at Floor Drawings

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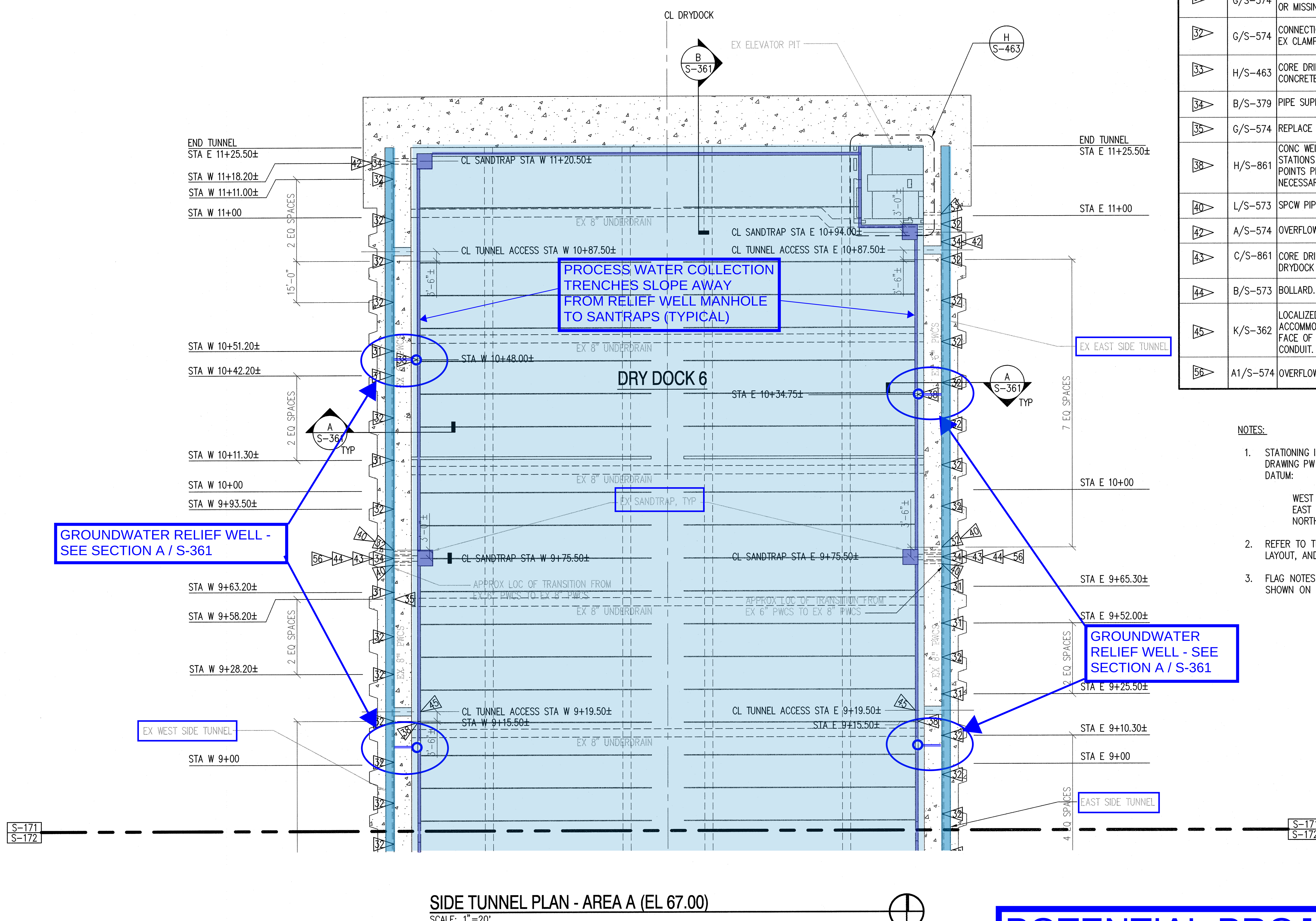


PRELIMINARY LAYOUT OF GROUNDWATER RELIEF WELLS

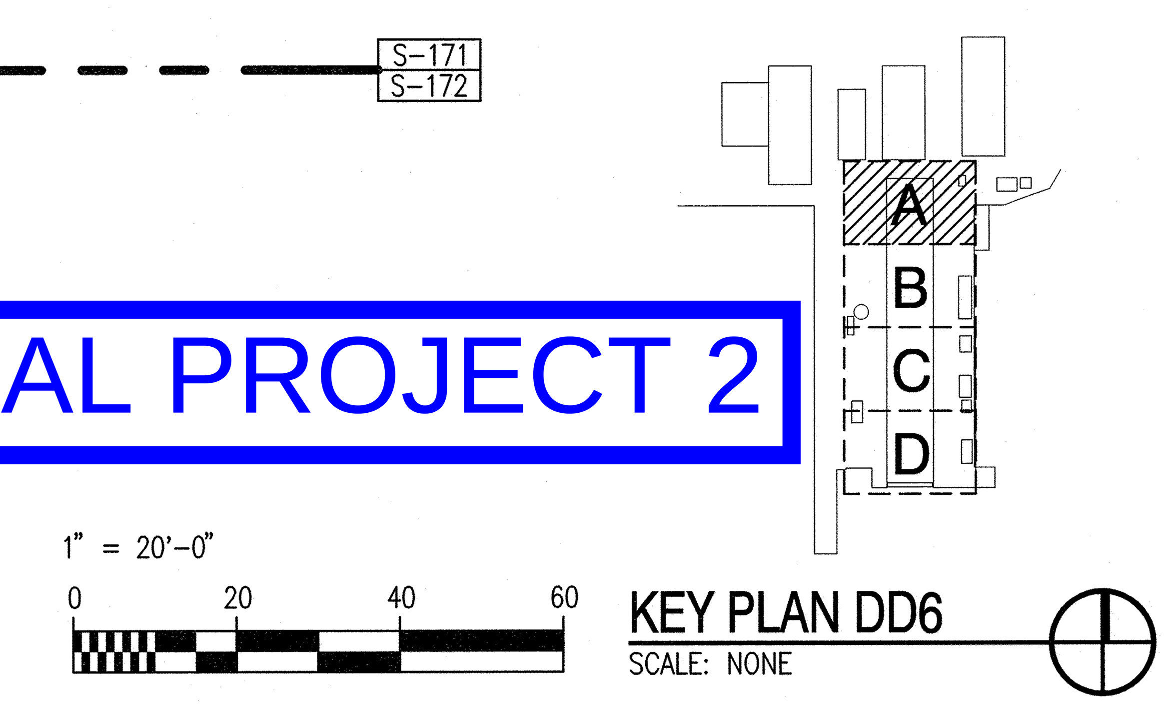
POTENTIAL PROJECT 2

FLAG NOTES:

ITEM	DETAIL	DESCRIPTION	QTY
31	G/S-574	CONNECTION WITHIN 1'-0" OF EXISTING CLAMP WITH LOOSE OR MISSING ANCHOR BOLT.	7
32	G/S-574	CONNECTION @ 15'-0" OC MAX. LOCATE MIN 1'-0" FROM EX CLAMPS	25
33	H/S-463	CORE DRILL 10"ø x 6'-7" LONG HOLE IN EX CONCRETE-FILLED OVERFLOW CHANNEL.	1
34	B/S-379	PIPE SUPPORT @ KNIFE PL VALVE.	4
35	G/S-574	REPLACE MISSING EX CLAMP WITH CONNECTION	1
38	H/S-861	CONC WEIR AT HIGH POINT IN SIDE TRENCHES. STATIONS GIVEN ARE APPROXIMATE, FIELD LOCATE HIGH POINTS PRIOR TO CONSTR AND ADJUST LOCATIONS AS NECESSARY.	4
40	L/S-573	SPCW PIPE SUPPORT TO WALL	4
42	A/S-574	OVERFLOW AND BAFFLE AT EXISTING SAND TRAP.	2
43	C/S-861	CORE DRILL (2) 12"ø x 6'-7" LONG HOLES THROUGH DRYDOCK SIDE WALL FOR SPCW MANIFOLD.	2
44	B/S-573	BOLLARD.	2
45	K/S-362	LOCALIZED DEMO OF TUNNEL ACCESS CEILING TO ACCOMMODATE CA PIPING AND CONDUIT. SHROUDS ON FACE OF DRYDOCK WALL TO PROTECT CA PIPING AND CONDUIT.	2
56	A1/S-574	OVERFLOW AND BAFFLE AT EXISTING SAND TRAP.	2

NOTES:

1. STATIONING IS BASED ON THE ORIGINAL CONSTRUCTION DOCUMENTS, DRAWING PW 40026, WHICH CORRESPONDS TO THE FOLLOWING PSNS DATUM:
   WEST TUNNEL: STA W 0.00' = PSNS N 442.50'
   EAST TUNNEL: STA E 0.00 = PSNS N 442.50'
   NORTH TUNNEL: STA N 0.00' = PSNS E 4570.75'
2. REFER TO THE MECHANICAL DRAWINGS FOR PIPING SIZES, TYPES, LAYOUT, AND INVERT ELEVATIONS.
3. FLAG NOTES ON SHOWN ON PLAN TAKE PRECEDENCE OVER THOSE SHOWN ON SECTIONS AND DETAILS.



kpff Consulting Engineers
1601 Fifth Avenue, Suite 1600
Seattle, Washington 98101
(206) 622-5822 Fax (206) 622-8130

NAVFAC

DES JEB | DRW JBB
REVIEWED BY GLV 01-19-12
PM/DM JMH
CHIEF ENG/ARCH GREG VARNEY

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING COMMAND - NORTHWEST
IPT NAVAL STATION - SILVERDALE, WASHINGTON
NAVAL BASE KITSAP - PSNS & IMF BREMERTON, WA
FY-12 MCON PROJECT P-419
INTEGRATED DRY DOCK WATER TREATMENT FACILITY
SIDE TUNNEL PLAN - AREA A (EL 67.00)

CODE ID. NO. 80091 | SIZE D
SCALE: AS NOTED
JOB ORDER NO. P-419
WORK ORDER NO. 865036
CONSTR. CONTR. NO. N44255- - -
NAVFAC DRAWING NO. 16012967
SHEET 10 OF 119
S-171

Path: T:\111000-111350\111215 (PSNS Dry Dock IWTF_Main)\111215.20 P419 (Dry Dock 6)\02 Plans\DRYD-P419-865036-S-171.dwg Plot date: Jan 19, 2012-11:35:40am CAD User: nathand.
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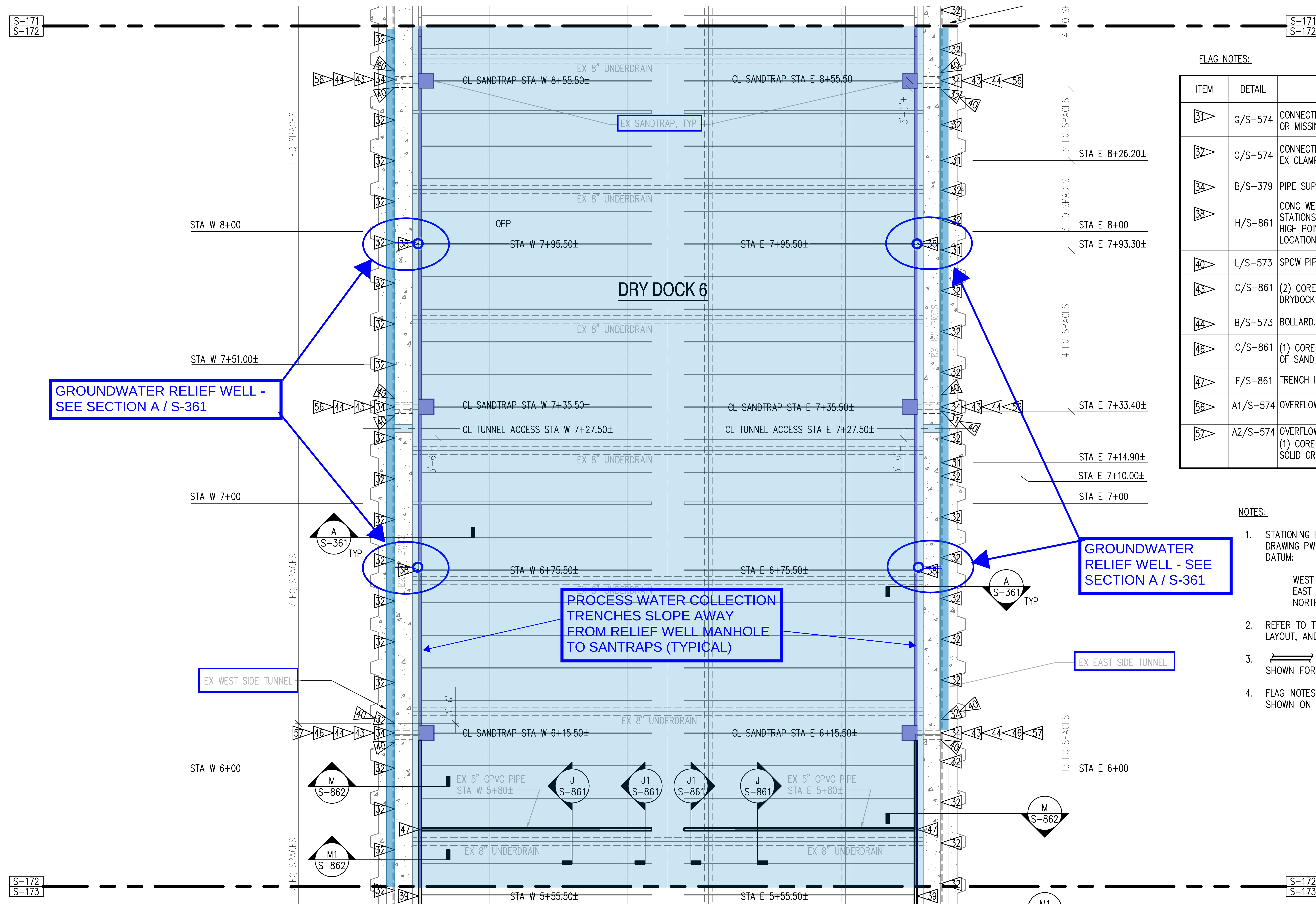


SIDE TUNNEL PLAN - AREA B (EL 67.00)

SCALE: 1"=20'

1" = 20'-0"

PRELIMINARY LAYOUT OF GROUNDWATER RELIEF WELLS

POTENTIAL PROJECT 2

FLAG NOTES:

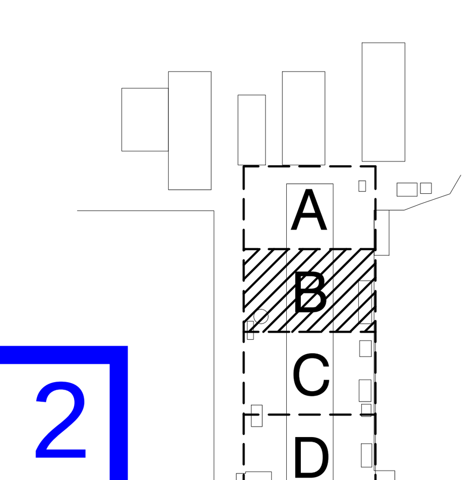
ITEM	DETAIL	DESCRIPTION	QTY
31	G/S-574	CONNECTION WITHIN 1'-0" OF EXISTING CLAMP WITH LOOSE OR MISSING ANCHOR BOLT.	4
32	G/S-574	CONNECTION @ 15'-0" OC MAX. LOCATE MIN 1'-0" FROM EX CLAMPS	39
34	B/S-379	PIPE SUPPORT PER B/S-379 @ KNIFE PL VALVE.	6
38	H/S-861	CONC WEIR AT HIGH POINT IN SIDE TRENCHES. STATIONS GIVEN ARE APPROXIMATE, FIELD LOCATE HIGH POINTS PRIOR TO CONSTR AND ADJUST LOCATIONS AS NECESSARY.	4
40	L/S-573	SPCW PIPE SUPPORT TO WALL	12
43	C/S-861	(2) CORE DRILLS 12"ø x 6'-7" LONG HOLE THROUGH DRYDOCK SIDE WALL FOR SPCW MANIFOLD.	6
44	B/S-573	BOLLARD.	6
46	C/S-861	(1) CORE DRILL 8"ø x 9'-4" LONG HOLE FROM NORTH SIDE OF SAND TRAP TO SIDE TUNNEL FOR GWR PIPING.	2
47	F/S-861	TRENCH INTERSECTION WITH GWR PIPING.	2
56	A1/S-574	OVERFLOW AND BAFFLE AT EXISTING SAND TRAP.	4
57	A2/S-574	OVERFLOW AND BAFFLE AT EXISTING SAND TRAP. INCLUDES (1) CORE DRILL 12"ø x 9'-4" LONG HOLE THROUGH EX SOLID GROUTED OVERFLOW.	2

NOTES:

1. STATIONING IS BASED ON THE ORIGINAL CONSTRUCTION DOCUMENTS, DRAWING PW 40026, WHICH CORRESPONDS TO THE FOLLOWING PSNS DATUM:

   WEST TUNNEL: STA W 0.00' = PSNS N 442.50'
   EAST TUNNEL: STA E 0.00 = PSNS N 442.50'
   NORTH TUNNEL: STA N 0.00' = PSNS E 4570.75'

2. REFER TO THE MECHANICAL DRAWINGS FOR PIPING SIZES, TYPES, LAYOUT, AND INVERT ELEVATIONS.
3. [symbol] DENOTES PARTIAL DEPTH TRENCH INFILL. SEE DETAILS SHOWN FOR ADDITIONAL INFORMATION.
4. FLAG NOTES SHOWN ON PLAN TAKE PRECEDENCE OVER THOSE SHOWN ON SECTIONS AND DETAILS.



KEY PLAN DD6

SCALE: NONE

NAVFAC

kpff Consulting Engineers
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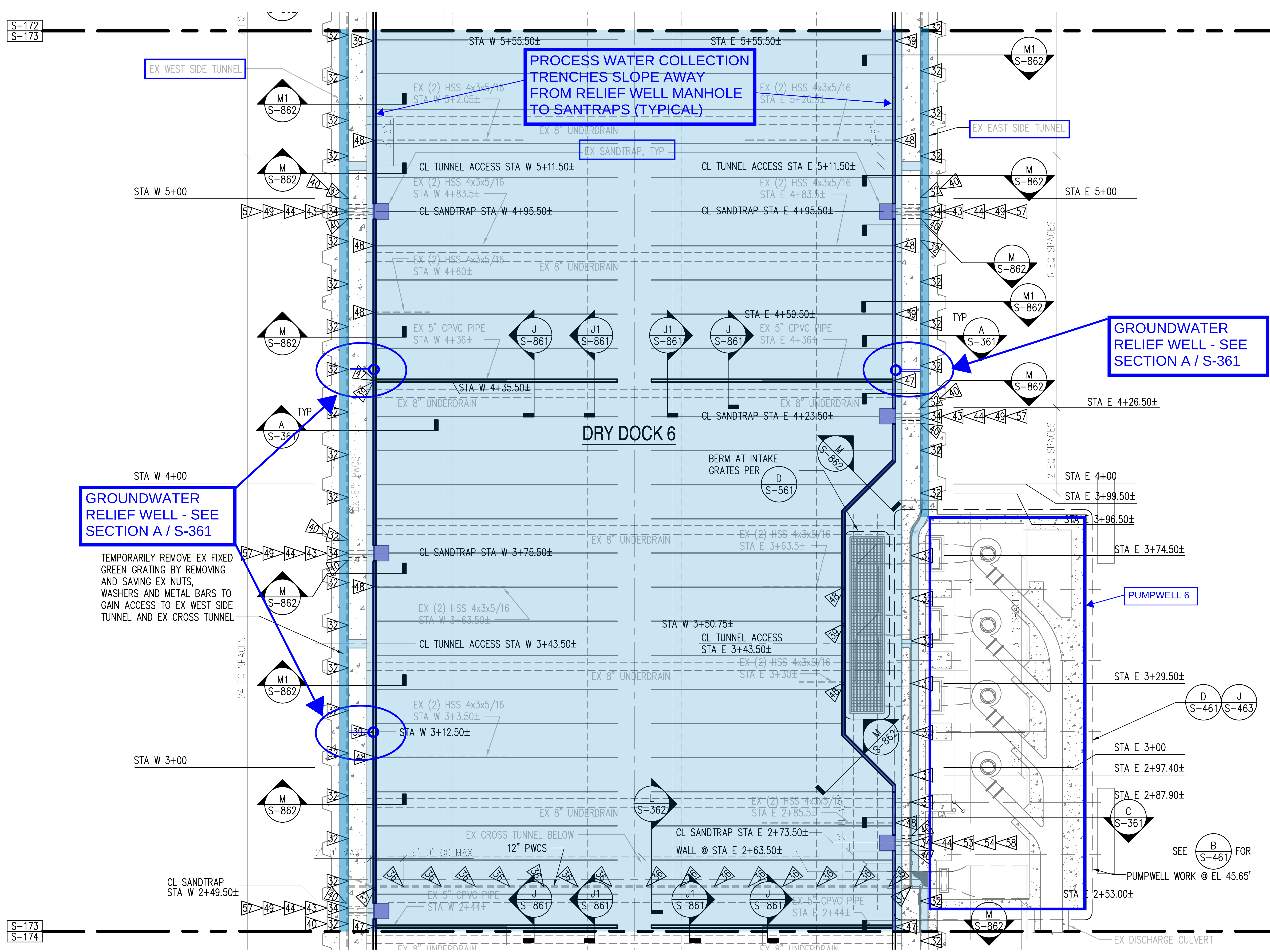
Seattle, Washington 98101
(206) 622-5822 Fax (206) 622-8130

DES JEB | DRW JBB | REVIEWED BY GLV 01-19-12 | PM/DM JMH | CHIEF ENG/ARCH GREG VARNEY

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING COMMAND – NORTHWEST
NAVAL STATION – SILVERDALE, WASHINGTON
NAVAL BASE KITSAP – PSNS & IMF BREMERTON, WA
FY-12 MCON PROJECT P-419
INTEGRATED DRY DOCK WATER TREATMENT FACILITY
SIDE TUNNEL PLAN – AREA B (EL 67.00)

SCALE: AS NOTED
JOB ORDER NO. P-419
WORK ORDER NO. 865036
CONSTR. CONTR. NO. N44255- – –
NAVFAC DRAWING NO. 16012968
SHEET 11 OF 119
S-172

Path: T:\111000-111350\111215 (PSNS Dry Dock IWTF_Main)\111215.20 P419 (Dry Dock 6)\02 Plans\DRYD-P419-865036-S-172.dwg Plot date: Jan 13, 2012-10:36:10am CAD User: byronr.
Xref Filename: | 3422 | NFM_SHEET_BORDER_P-419 | Symap_bw_08 | P356xSURV | DRYD-P419-865036-M-FP | PBxSF | DD6XMSP | DRYD-P419-865036-S-DD6 | VARNEY-NAVY |



SIDE TUNNEL PLAN - AREA C (EL 67.0)

SCALE: 1"=20'

PRELIMINARY LAYOUT OF GROUNDWATER RELIEF WELLS

POTENTIAL PROJECT 2

FLAG NOTES:

ITEM	DETAIL	DESCRIPTION	QTY
31	G/S-574	CONNECTION WITHIN 1'-0" OF EXISTING CLAMP WITH LOOSE OR MISSING ANCHOR BOLT.	3
32	G/S-574	CONNECTION @ 15'-0" OC MAX. LOCATE MIN 1'-0" FROM EX CLAMPS	38
34	B/S-379	PIPE SUPPORT PER B/S-379 @ KNIFE PL VALVE.	6
36	G/S-574	12" PWCS PIPE SUPPORT @ 12'-0" OC MAX.	14
37	E/S-574	12" PWCS PIPE SUPPORT.	2
39	M/S-861	CONC WEIR AT HIGH POINT IN SIDE TRENCHES. STATIONS GIVEN ARE APPROXIMATE, FIELD LOCATE HIGH POINTS PRIOR TO CONSTR AND ADJUST LOCATIONS AS NECESSARY.	6
40	L/S-573	SPCW PIPE SUPPORT TO WALL	12
43	C/S-861	(2) CORE DRILLS 12"ø x 6'-7" LONG HOLE THROUGH DRYDOCK SIDE WALL FOR SPCW MANIFOLD.	5
44	B/S-573	BOLLARD.	6
47	F/S-861	TRENCH INTERSECTION WITH GWR PIPING.	4
48	K/S-861	GWR PIPING CONNECTION.	10
49	C/S-861	(2) CORE DRILLS 8"ø x 9'-4" LONG HOLE FROM SAND TRAP TO SIDE TUNNEL FOR GWR PIPING.	5
53	C/S-861	(2) CORE DRILLS 12"øx3'-3" LONG THROUGH DRYDOCK SIDE WALL FOR SPCW MANIFOLD.	1
54	C/S-861	(2) CORE DRILLS 8"øx6'-0" LONG HOLE FROM SAND TRAP TO SIDE TUNNEL FOR GWR PIPING.	1
55	C/S-574	12" PWCS PIPE SUPPORT.	1
57	A2/S-574	OVERFLOW AND BAFFLE AT EXISTING SAND TRAP. INCLUDES (1) CORE DRILL 12"ø x 9'-4" LONG HOLE THROUGH EX SOLID GROUTED OVERFLOW.	5
58	A3/S-574	OVERFLOW AND BAFFLE AT EXISTING SAND TRAP. INCLUDES (1) CORE DRILL 12"ø x 6'-0" LONG HOLE THROUGH EX SOLID GROUTED OVERFLOW.	1

NOTES:

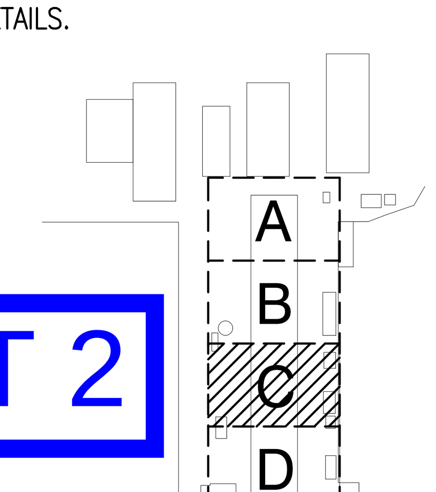
1. STATIONING IS BASED ON THE ORIGINAL CONSTRUCTION DOCUMENTS, DRAWING PW 40026, WHICH CORRESPONDS TO THE FOLLOWING PSNS DATUM:

   WEST TUNNEL: STA W 0.00' = PSNS N 442.50'
   EAST TUNNEL: STA E 0.00 = PSNS N 442.50'
   NORTH TUNNEL: STA N 0.00' = PSNS E 4570.75'

2. REFER TO THE MECHANICAL DRAWINGS FOR PIPING SIZES, TYPES, LAYOUT, AND INVERT ELEVATIONS.
3. DENOTES PARTIAL DEPTH TRENCH INFILL. SEE DETAILS SHOWN FOR ADDITIONAL INFORMATION.
4. FLAG NOTES SHOWN ON PLAN TAKE PRECEDENCE OVER THOSE SHOWN ON SECTIONS AND DETAILS.

1" = 20'-0"

0 20 40 60



KEY PLAN DD6

SCALE: NONE

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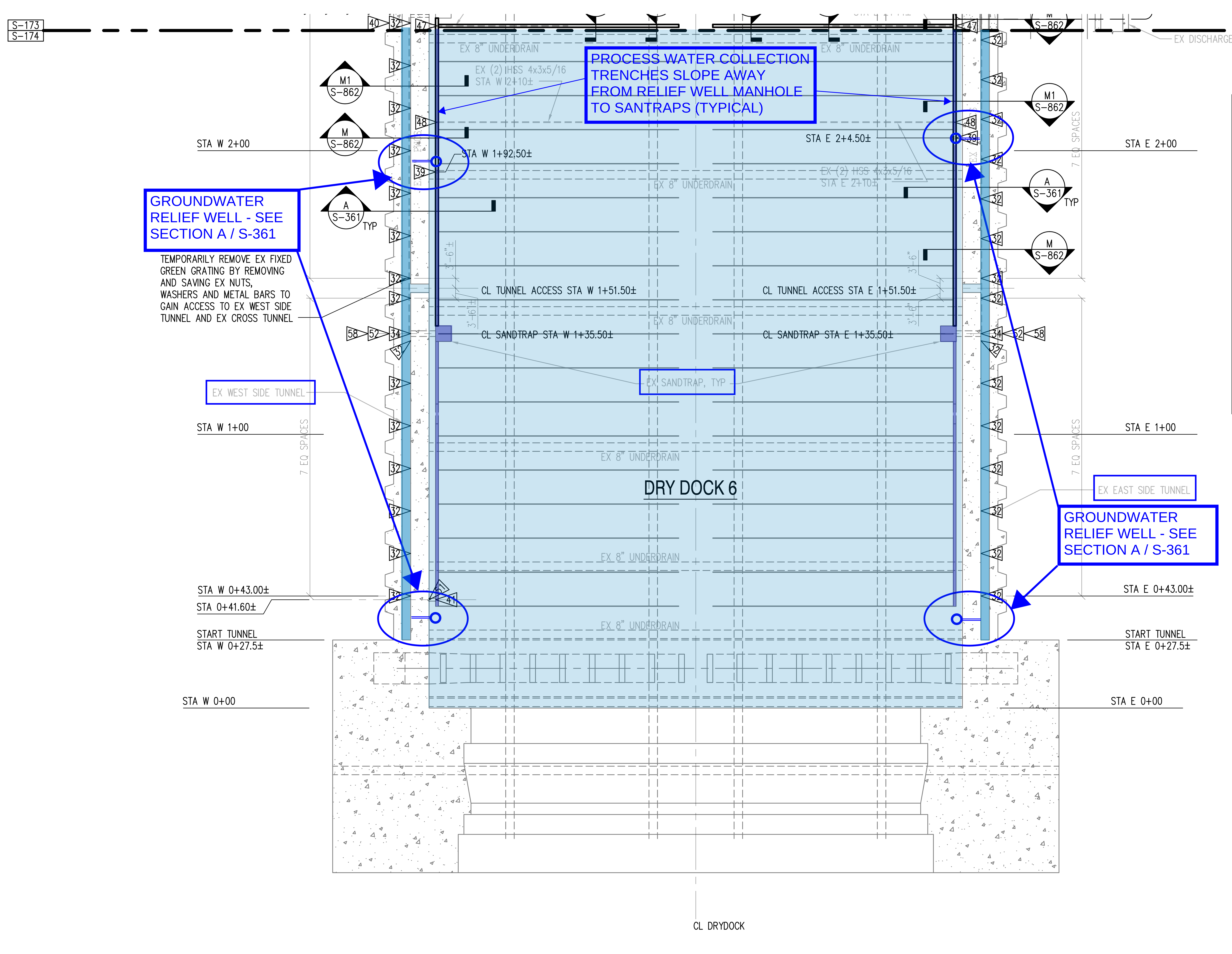
PM/DM JMH
CHIEF ENG/ARCH GREG VARNEY

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING COMMAND - NORTHWEST
NAVAL STATION - SILVERDALE, WASHINGTON
NAVAL BASE KITSAP - PSNS & IMF BREMERTON, WA
FY-12 MCON PROJECT P-419
INTEGRATED DRY DOCK WATER TREATMENT FACILITY
SIDE TUNNEL PLAN - AREA C (EL 67.00)

SCALE: AS NOTED
JOB ORDER NO. P-419
WORK ORDER NO. 865036
CONSTR. CONTR. NO. N44255- - -
NAVFAC DRAWING NO. 16012969
SHEET 12 OF 119

S-173



SIDE TUNNEL PLAN - AREA D (EL 67.00)

SCALE: 1"=20'

PRELIMINARY LAYOUT OF GROUNDWATER RELIEF WELLS

FLAG NOTES:

ITEM	DETAIL	DESCRIPTION	QTY
32	G/S-574	CONNECTION @ 15'-0" OC MAX. LOCATE MIN 1'-0" FROM EX CLAMPS	29
34	B/S-379	PIPE SUPPORT PER B/S-379 @ KNIFE PL VALVE.	2
39	M/S-861	CONC WEIR AT HIGH POINT IN SIDE TRENCHES. STATIONS GIVEN ARE APPROXIMATE, FIELD LOCATE HIGH POINTS PRIOR TO CONSTR AND ADJUST LOCATIONS AS NECESSARY.	2
41	D/S-862	TROUGH FOR DRAIN LINE.	1
48	K/S-861	GWR PIPING CONNECTION.	2
51	C/S-573	SHROUD FOR AND CONNECTORS FOR 1" DRAIN..	1
52	C/S-861	(1) CORE DRILL 8"ø x 9'-4" LONG HOLE FROM SOUTH SIDE OF SAND TRAP TO SIDE TUNNEL FOR GWR PIPING.	2
58	A3/S-574	OVERFLOW AND BAFFLE AT EXISTING SAND TRAP. INCLUDES (1) CORE DRILL 12"ø x 9'-4" LONG HOLE THROUGH EX SOLID GROUTED OVERFLOW.	2

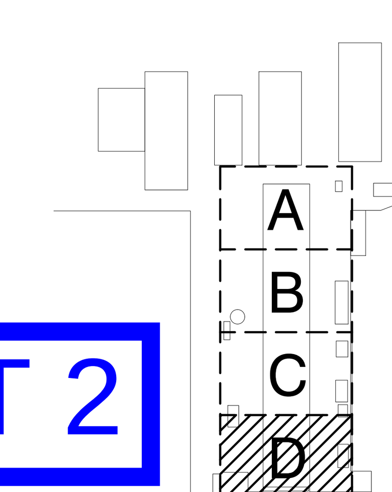
NOTES:

1. STATIONING IS BASED ON THE ORIGINAL CONSTRUCTION DOCUMENTS, DRAWING PW 40026, WHICH CORRESPONDS TO THE FOLLOWING PSNS DATUM:

   WEST TUNNEL: STA W 0.00' = PSNS N 442.50'
   EAST TUNNEL: STA E 0.00 = PSNS N 442.50'
   NORTH TUNNEL: STA N 0.00' = PSNS E 4570.75'

2. REFER TO THE MECHANICAL DRAWINGS FOR PIPING SIZES, TYPES, LAYOUT, AND INVERT ELEVATIONS.
3. DENOTES PARTIAL DEPTH TRENCH INFILL. SEE DETAILS SHOWN FOR ADDITIONAL INFORMATION.
4. FLAG NOTES SHOWN ON PLAN TAKE PRECEDENCE OVER THOSE SHOWN ON SECTIONS AND DETAILS.

POTENTIAL PROJECT 2



1" = 20'-0"   0 20 40 60

KEY PLAN DD6

SCALE: NONE

NAVFAC

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REVIEWED BY GLV 01-19-12
PM/DM JMH
CHIEF ENG/ARCH GREG VARNEY

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING COMMAND ~ NORTHWEST
NAVAL STATION - SILVERDALE, WASHINGTON
IPT
NAVAL BASE KITSAP - PSNS & IMF BREMERTON, WA
FY-12 MCON PROJECT P-419
INTEGRATED DRY DOCK WATER TREATMENT FACILITY
SIDE TUNNEL PLAN - AREA D (EL 67.00)

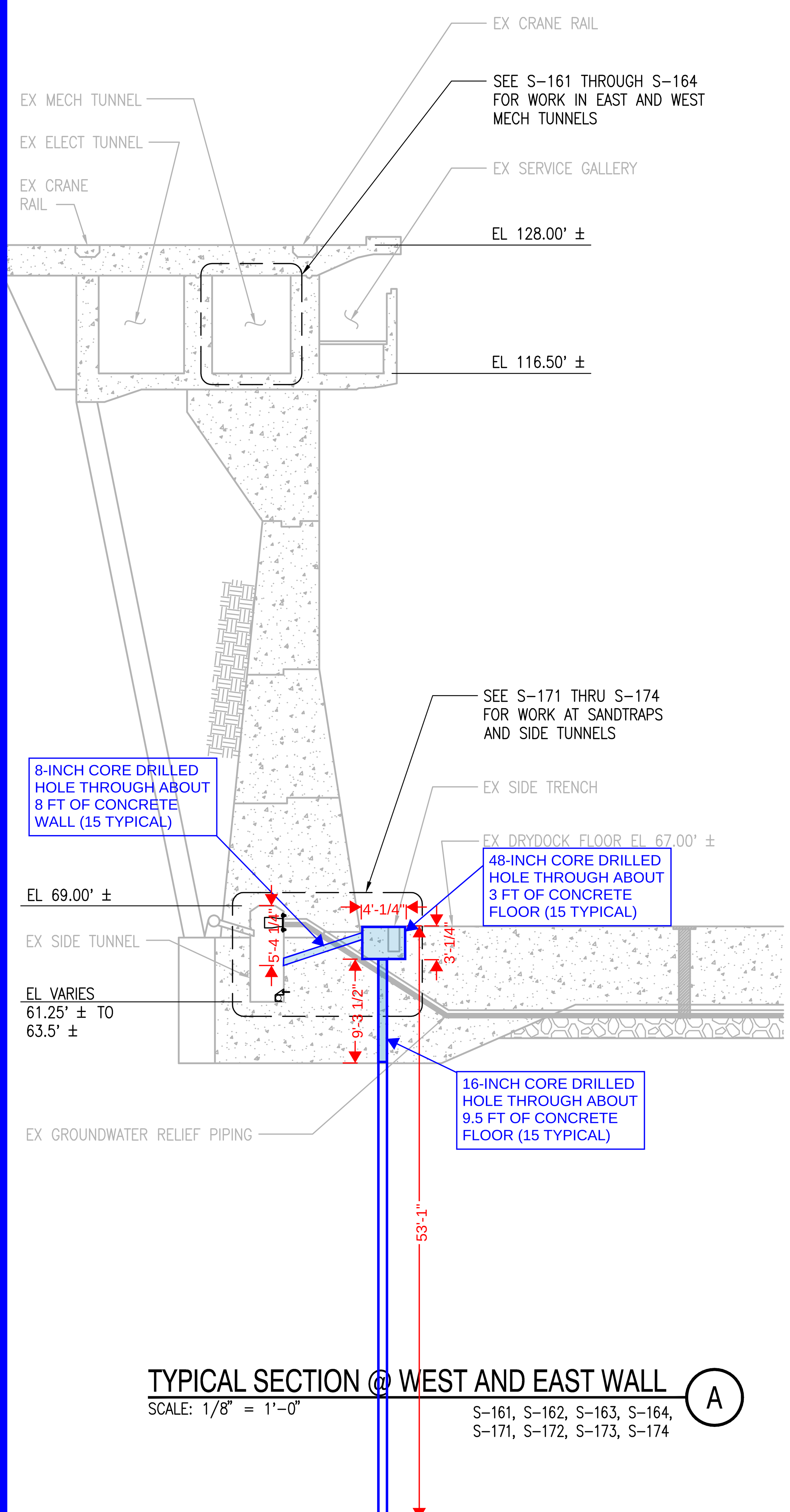
CODE ID. NO. 80091 SIZE D
SCALE: AS NOTED
MAXIMO NO.
JOB ORDER NO. P-419
WORK ORDER NO. 865036
CONSTR. CONTR. NO. N44255- - -
NAVFAC DRAWING NO. 16012970
SHEET 13 OF 119

S-174

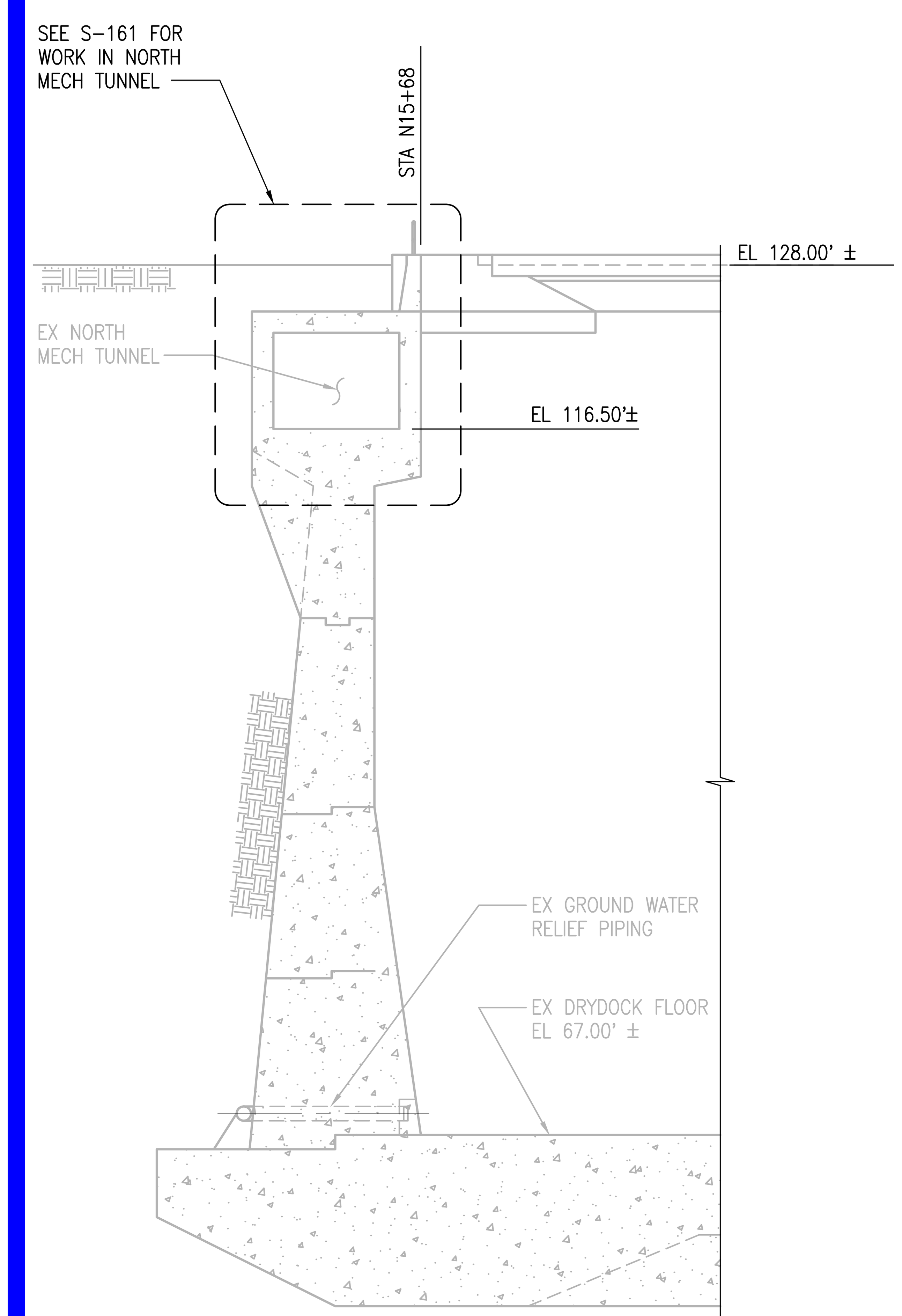
DRAWFORM REVISION: 01 MAY 2006

PRELIMINARY LAYOUT OF GROUNDWATER RELIEF WELLS

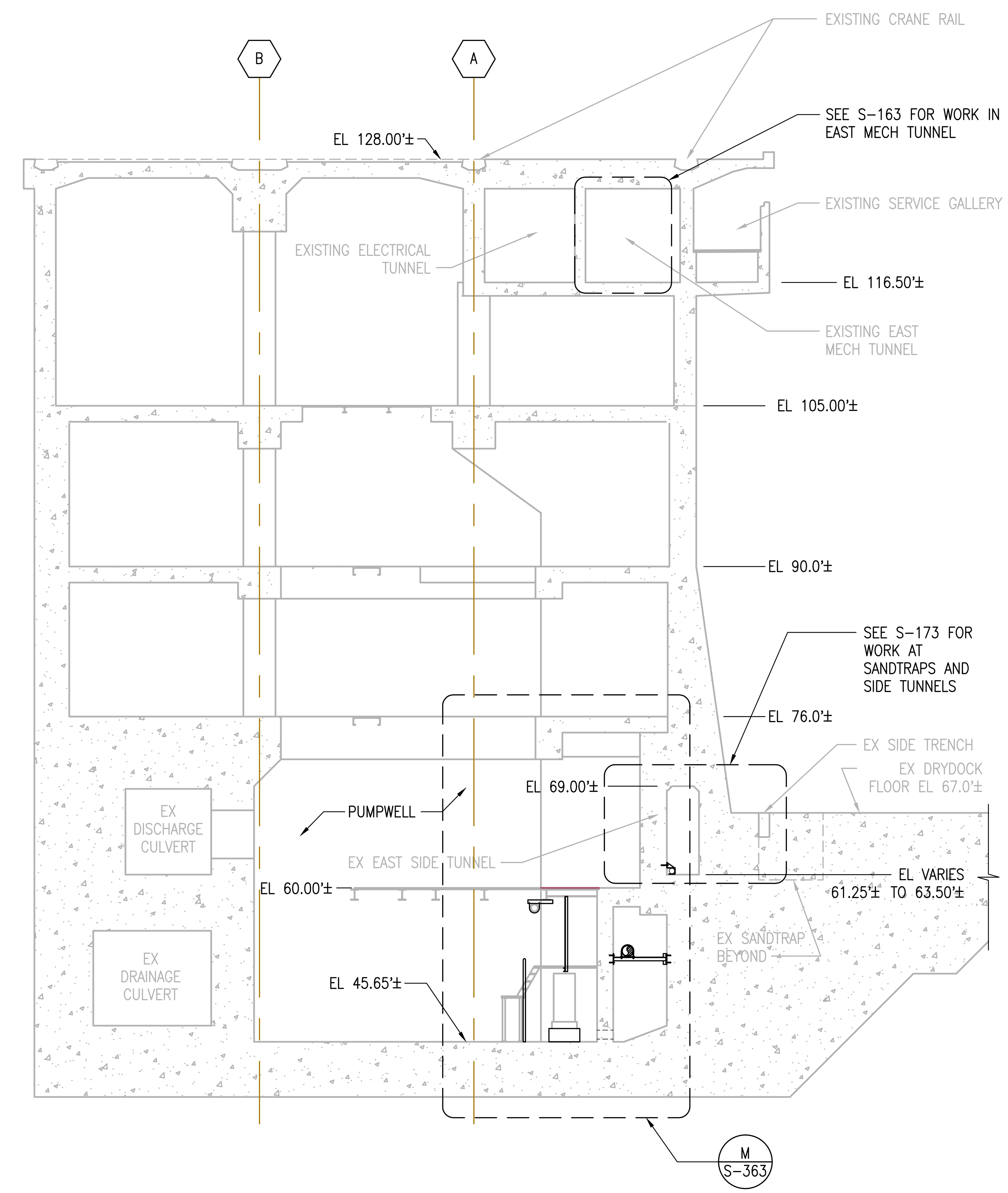
NOTE: CONFIRM ALL RELIEF WELL DIMENSIONS AND PIPE SIZES VIA GEOTECHNICAL REPORT



TYPICAL SECTION @ WEST AND EAST WALL (A)
SCALE: 1/8" = 1'-0"
S-161, S-162, S-163, S-164, S-171, S-172, S-173, S-174



TYP SECTION @ NORTH WALL (B)
SCALE: 1/8" = 1'-0"
S-161, S-171



TYP SECTION @ PUMP WELL 6 (STA E ~ 2 + 85) (C)
SCALE: 1/8" = 1'-0"
S-163, S-173, S-461

1/8" = 1'-0" 0 8 16 24 SCALE IN FEET

POTENTIAL PROJECT 2

NAVFAC

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1601 Fifth Avenue, Suite 1600
Seattle, Washington 98101
(206) 622-5822 Fax (206) 622-8130

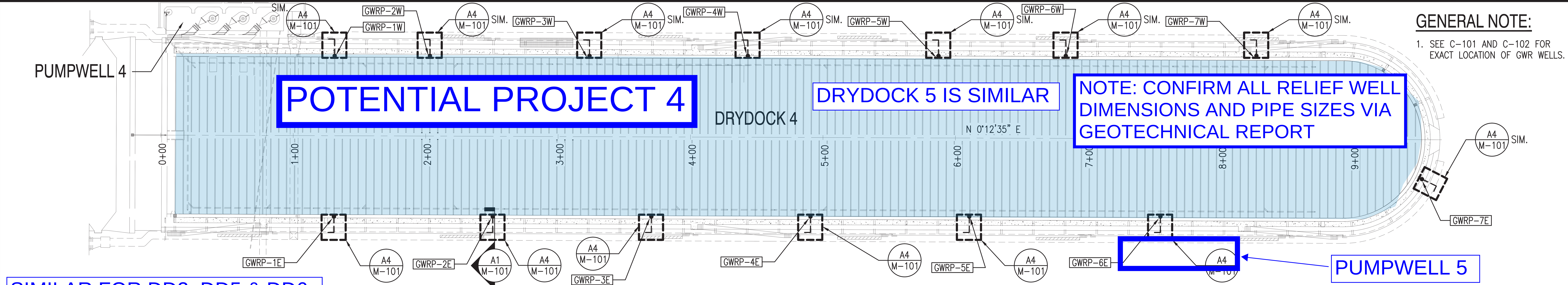
DES JEB | DRW JBB
REVIEWED BY GLV 01-19-12
PM/DM JMH
CHIEF ENG/ARCH GREG VARNEY

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING COMMAND – NORTHWEST
IPT NAVAL STATION – SILVERDALE, WASHINGTON
NAVAL BASE KITSAP – PSNS & IMF BREMERTON, WA
FY-12 MCON PROJECT P-419
INTEGRATED DRY DOCK WATER TREATMENT FACILITY
WALL SECTIONS

CODE ID. NO. 80091	SIZE D
SCALE:	AS NOTED
MAXIMO NO.	
JOB ORDER NO.	P-419
WORK ORDER NO.	865036
CONSTR. CONTR. NO.	N44255- – –
NAVFAC DRAWING NO.	16012971
SHEET 14	OF 119
	S-361

DRAWFORM REVISION: 01 MAY 2006

SYM | DESCRIPTION | DATE | APPR



MECHANICAL PLAN (C1)

SCALE: 1"=40'-0"

GENERAL NOTE:

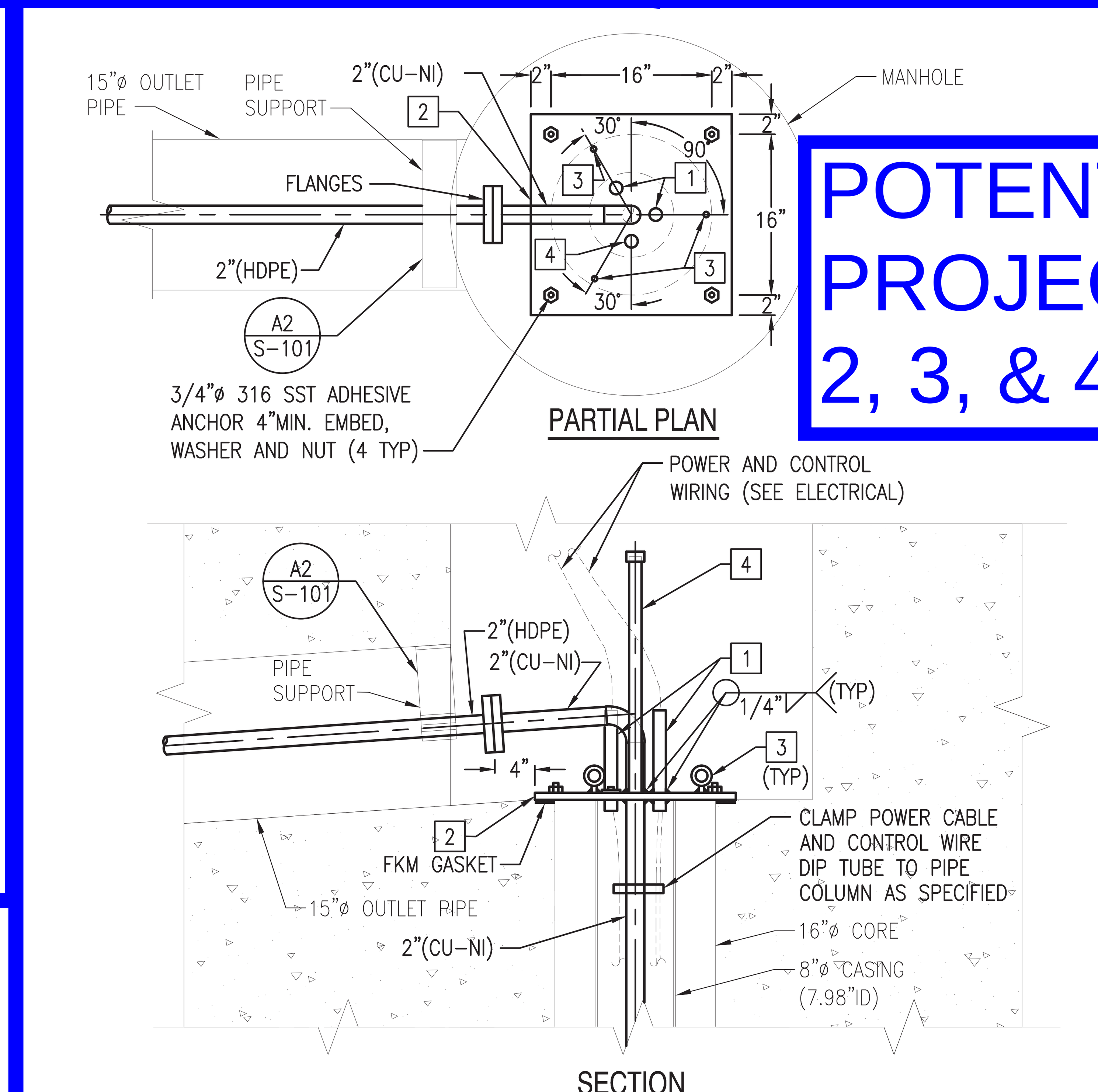
1. SEE C-101 AND C-102 FOR EXACT LOCATION OF GWR WELLS.

SIMILAR FOR DD2, DD5 & DD6

GWR PUMP SCHEDULE

MARK	SYSTEM	LOCATION	FLUID	FLOW (GPM)	TDH (FT)	MOTOR MAX HP	MOTOR VOLT	MOTOR PHASE	MOTOR RPM[4]	MIN CABLE LENGTH (FT)	NOTES	WEIGHT LBS
GWRP-1W	GWR DRAINAGE	GWR WELL 1W	SALTWATER	60	60	5	460	3	1750 OR 3450	200 [5]	[1][2][3]	150
GWRP-2W	GWR DRAINAGE	GWR WELL 2W	SALTWATER	60	60	5	460	3	1750 OR 3450	250 [5]	[1][2][3]	150
GWRP-3W	GWR DRAINAGE	GWR WELL 3W	SALTWATER	60	60	5	460	3	1750 OR 3450	250 [5]	[1][2][3]	150
GWRP-4W	GWR DRAINAGE	GWR WELL 4W	SALTWATER	60	60	5	460	3	1750 OR 3450	250 [5]	[1][2][3]	150
GWRP-5W	GWR DRAINAGE	GWR WELL 5W	SALTWATER	60	60	5	460	3	1750 OR 3450	250 [5]	[1][2][3]	150
GWRP-6W	GWR DRAINAGE	GWR WELL 6W	SALTWATER	60	60	5	460	3	1750 OR 3450	200 [5]	[1][2][3]	150
GWRP-7W	GWR DRAINAGE	GWR WELL 7W	SALTWATER	60	60	5	460	3	1750 OR 3450	200 [5]	[1][2][3]	150
GWRP-1E	GWR DRAINAGE	GWR WELL 1E	SALTWATER	60	60	5	460	3	1750 OR 3450	250 [5]	[1][2][3]	150
GWRP-2E	GWR DRAINAGE	GWR WELL 2E	SALTWATER	60	60	5	460	3	1750 OR 3450	200 [5]	[1][2][3]	150
GWRP-3E	GWR DRAINAGE	GWR WELL 3E	SALTWATER	60	60	5	460	3	1750 OR 3450	200 [5]	[1][2][3]	150
GWRP-4E	GWR DRAINAGE	GWR WELL 4E	SALTWATER	60	60	5	460	3	1750 OR 3450	200 [5]	[1][2][3]	150
GWRP-5E	GWR DRAINAGE	GWR WELL 5E	SALTWATER	60	60	5	460	3	1750 OR 3450	200 [5]	[1][2][3]	150
GWRP-6E	GWR DRAINAGE	GWR WELL 6E	SALTWATER	60	60	5	460	3	1750 OR 3450	250 [5]	[1][2][3]	150
GWRP-7E	GWR DRAINAGE	GWR WELL 7E	SALTWATER	60	60	5	460	3	1750 OR 3450	300 [5]	[1][2][3]	150

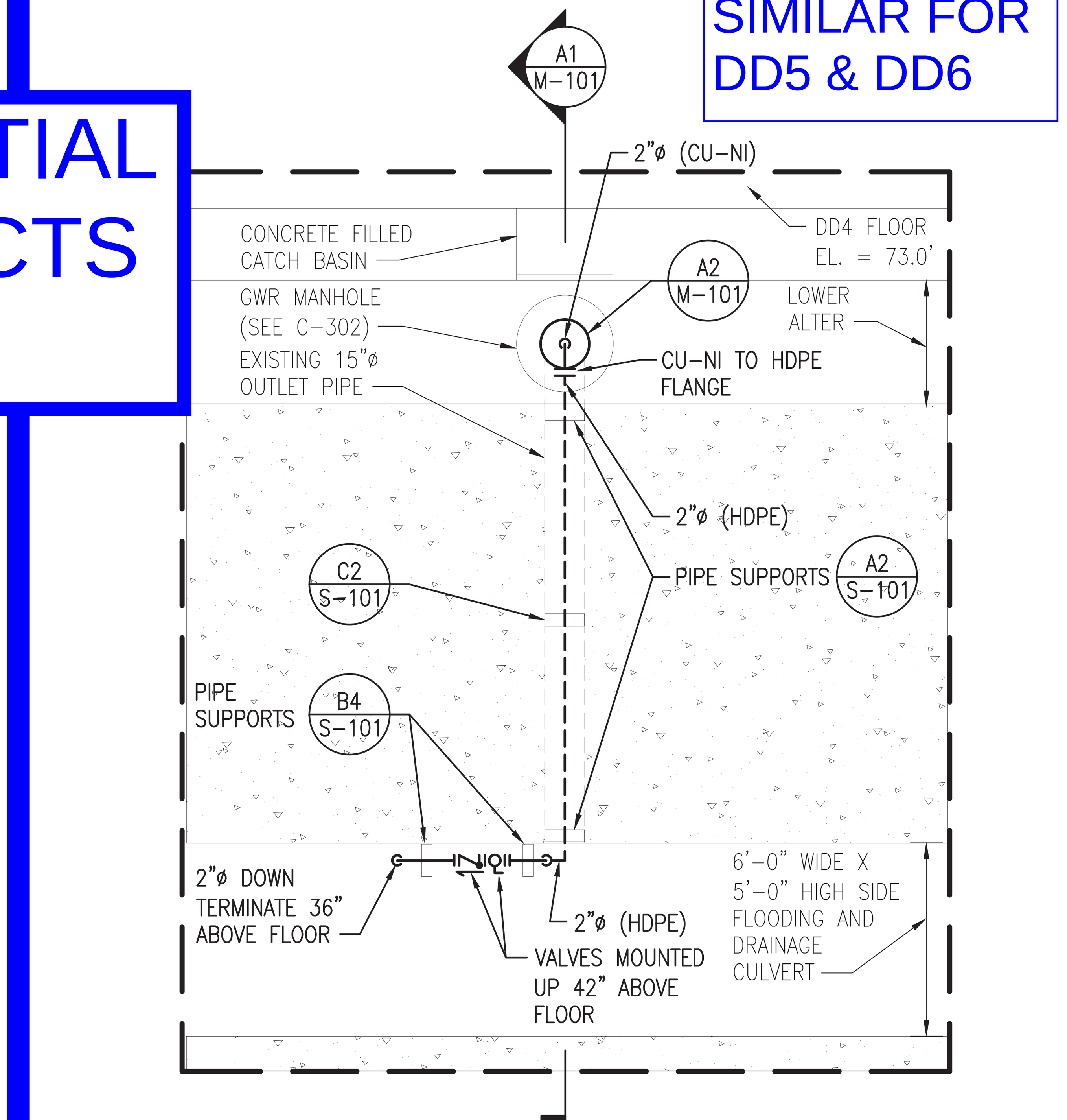
NOTES:
[1] PUMP IMPELLER, BOWL, SHAFT, & MOTOR MUST BE CONSTRUCTED OF TYPE 316 STAINLESS STEEL MATERIAL WITH MINIMUM (MIN) WORKING PRESSURE = 150 PSI
[2] PROVIDE FULLY SUBMERSIBLE CONTINUOUS DUTY WELL PUMP TO WITHSTAND 100 FEET SUBMERGENCE UNDER SALTWATER.
[3] VARIABLE FREQUENCY DRIVE (VFD) APPLICATION (SEE ELECTRICAL DRAWINGS), PROVIDE INVERTOR DUTY MOTOR.
[4] 2600 RPM IS THE MAXIMUM PUMP RPM ALLOWED AT THE SPECIFIED PUMP OPERATING POINT. IF PROVIDING A 3450 RPM MOTOR THE VFD WILL BE USED TO LIMIT THE RPM TO 2600.
[5] CONTRACTOR TO CONFIRM MIN. CABLE LENGTH PRIOR TO SHOP DWG SUBMITTAL. PROVIDE CONTINUOUS UN-SPLICED POWER CABLE FROM PUMP MOTOR (EL+30.0') IN WELL CASING TO ASSOCIATED MOTOR POWER DISCONNECT (SEE ELECTRICAL DRAWINGS FOR DISCONNECT LOCATIONS), INCLUDING 40 FEET OF CABLE TO BE COILED IN MANHOLE AT TOP OF WELL CASING. THE CABLE COILED IN MANHOLE IS INTENDED TO ALLOW REMOVAL OF PUMP/MOTOR ASSEMBLY WITHOUT DISCONNECTING OR CUTTING THE POWER CABLE.



CASING SEAL PLATE DETAIL (A2)

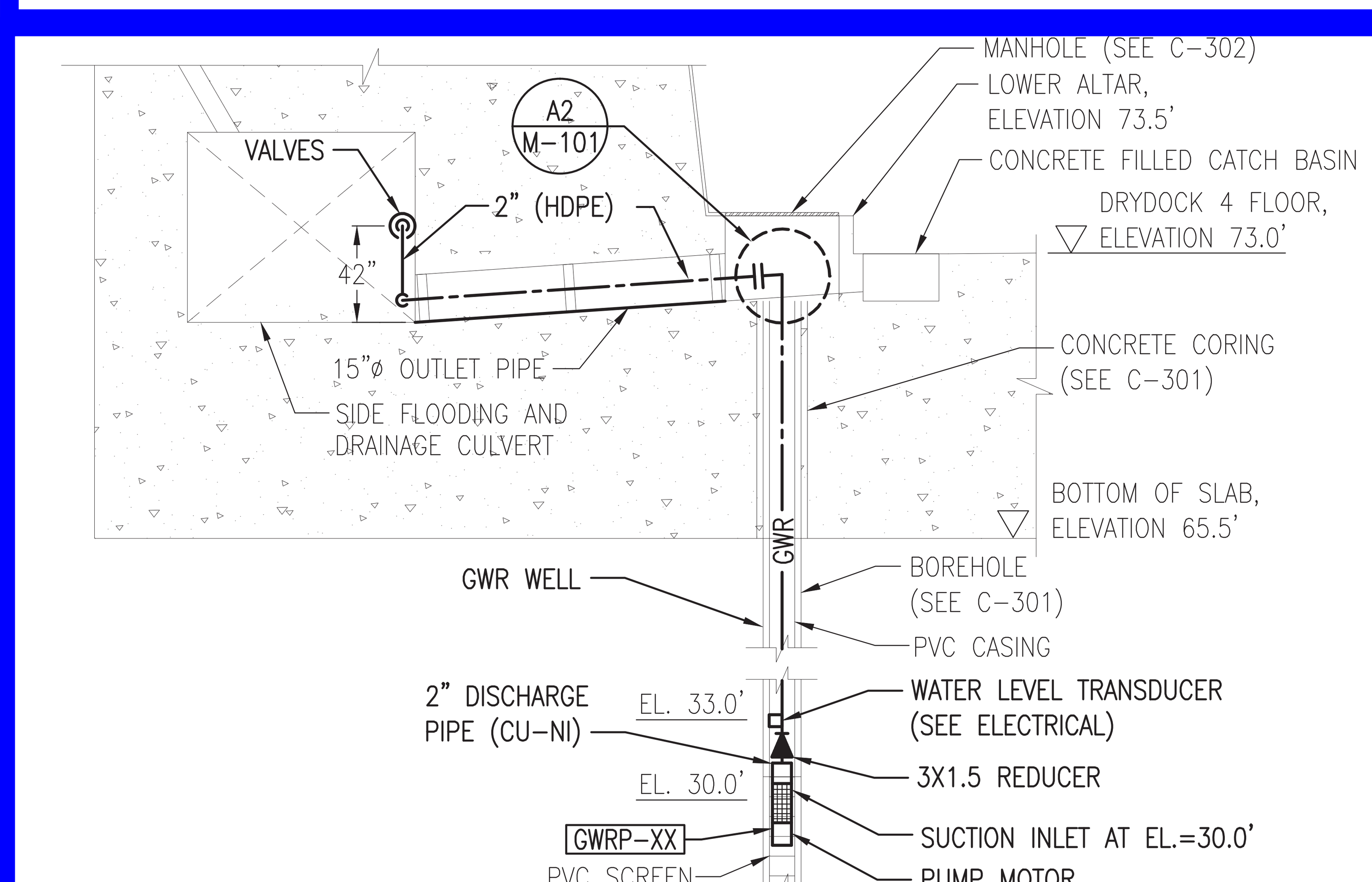
SCALE: 1" = 1'-0" M-101

SIMILAR FOR DD5 & DD6



TYPICAL ENLARGE PLAN (A4)

SCALE: 1/4" = 1'-0" M-101



TYPICAL SECTION (A1)

SCALE: 1/4" = 1'-0" M-101

SIMILAR FOR DD5 & DD6

LEGEND

SYMBOL	DESCRIPTION
—GWR—	GROUNDWATER RELIEF PIPING
	CONCENTRIC REDUCER
	FLANGED CHECK VALVE
	FLANGE
	FLANGED THROTTLING BALL VALVE OR THROTTLING GLOBE VALVE

ABBREVIATIONS

ABBREVIATION	DESCRIPTION	ABBREVIATION	DESCRIPTION
CU-NI	COPPER-NICKEL	MAX.	MAXIMUM
DWG	DRAWING	MIN.	MINIMUM
FKM	ASTM D1418 FLUOROELASTOMER	OD	OUTSIDE DIAMETER
GPM	GALLONS PER MINUTE	RPM	REVOLUTIONS PER MINUTE
GWR	GROUNDWATER RELIEF	PSI	POUNDS PER SQUARE INCH
GWRP	GROUNDWATER RELIEF PUMP	SIM.	SIMILAR
HP	HORSEPOWER	SST	STAINLESS STEEL
HDPE	HIGH DENSITY POLYETHYLENE	TDH	TOTAL DISCHARGE HEAD
ID	INSIDE DIAMETER	ø	DIAMETER
LBS	POUNDS	VFD	VARIABLE FREQUENCY DRIVE

SHEET KEY NOTES:

1. PROVIDE 1.25"ø X 10"L. CU-NI SLEEVE WELDED TO SEAL PLATE. SEAL WATER TIGHT BETWEEN WIRING AND SLEEVE.
2. PROVIDE 3/4" X 20" X 20" SEAL PLATE (CU-NI) WITH 1/4" THICK FKM GASKET UNDER PLATE EXCEPT AT 16"ø CORE.
3. PROVIDE LIFTING EYES (CU-NI) WELDED TO SEAL PLATE (3 TYP). 1000 LBS. MIN. LIFTING CAPACITY EACH.
4. PROVIDE 1.25"øX24" LONG STANDPIPE (CU-NI) WITH THREADED CAP FOR MEASURING WATER DEPTH IN WELL.

1" = 1'-0" (0, 1, 2, 3)
1/4" = 1'-0" (0, 2, 4, 8, 12)
1" = 40'-0" (0, 40, 80, 120)

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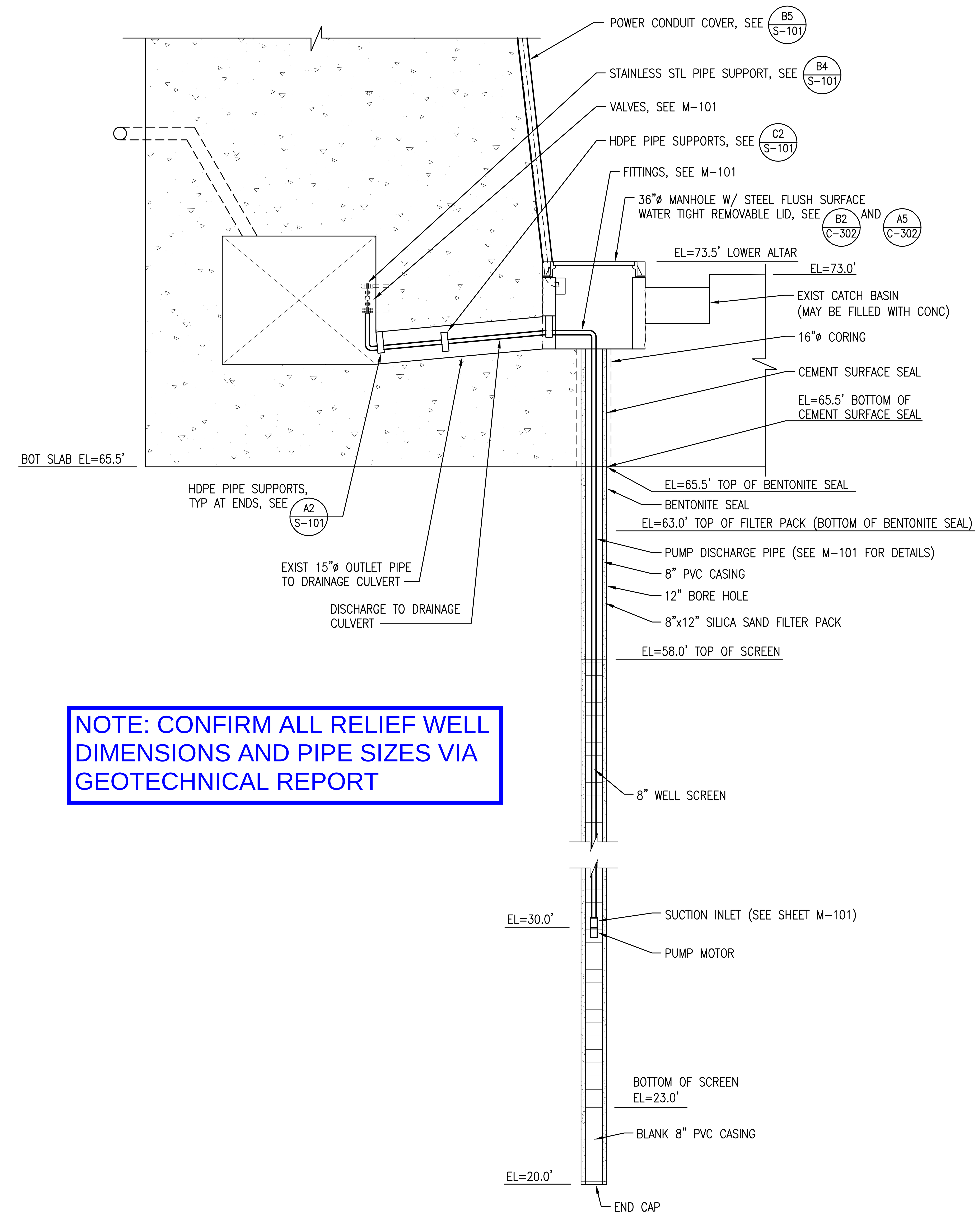
NAVFAC

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL BASE KITSAP - BREMERTON, WA
NBK BREMERTON, WA
REPAIR GROUNDWATER INTRUSION, PSNS DRY DOCK #4
MECHANICAL PLAN AND DETAILS

DES DB/JH · DRW JML · CHK LDS · DATE 02-13-15
SCALE: AS NOTED · WORK ORDER NO. B2L4TP
NAVFAC DRAWING NO. 16027310/80122 · SHEET 14 OF 22
M-101

CAD FILENAME: 80122_M-101.DWG

SIMILAR FOR DD5 & DD6



NOTE: CONFIRM ALL RELIEF WELL DIMENSIONS AND PIPE SIZES VIA GEOTECHNICAL REPORT

GROUNDWATER RELIEF WELL

SCALE: 3/8"=1'-0" C-101 A5

PRELIMINARY LAYOUT OF GROUNDWATER RELIEF WELLS

POTENTIAL PROJECTS 2, 3, & 4

SYM	DESCRIPTION	DATE	APPR

NAVFAC

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www.reidmiddleton.com
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APPROVED
FOR COMMANDER NAVFAC
ACTIVITY
SATISFACTORY TO DATE: 02-13-15
DES SMK DRW DJO CHK HNK
<<PM/DM>>
BRANCH MANAGER
CHIEF ENG/ARCH
FIRE PROTECTION

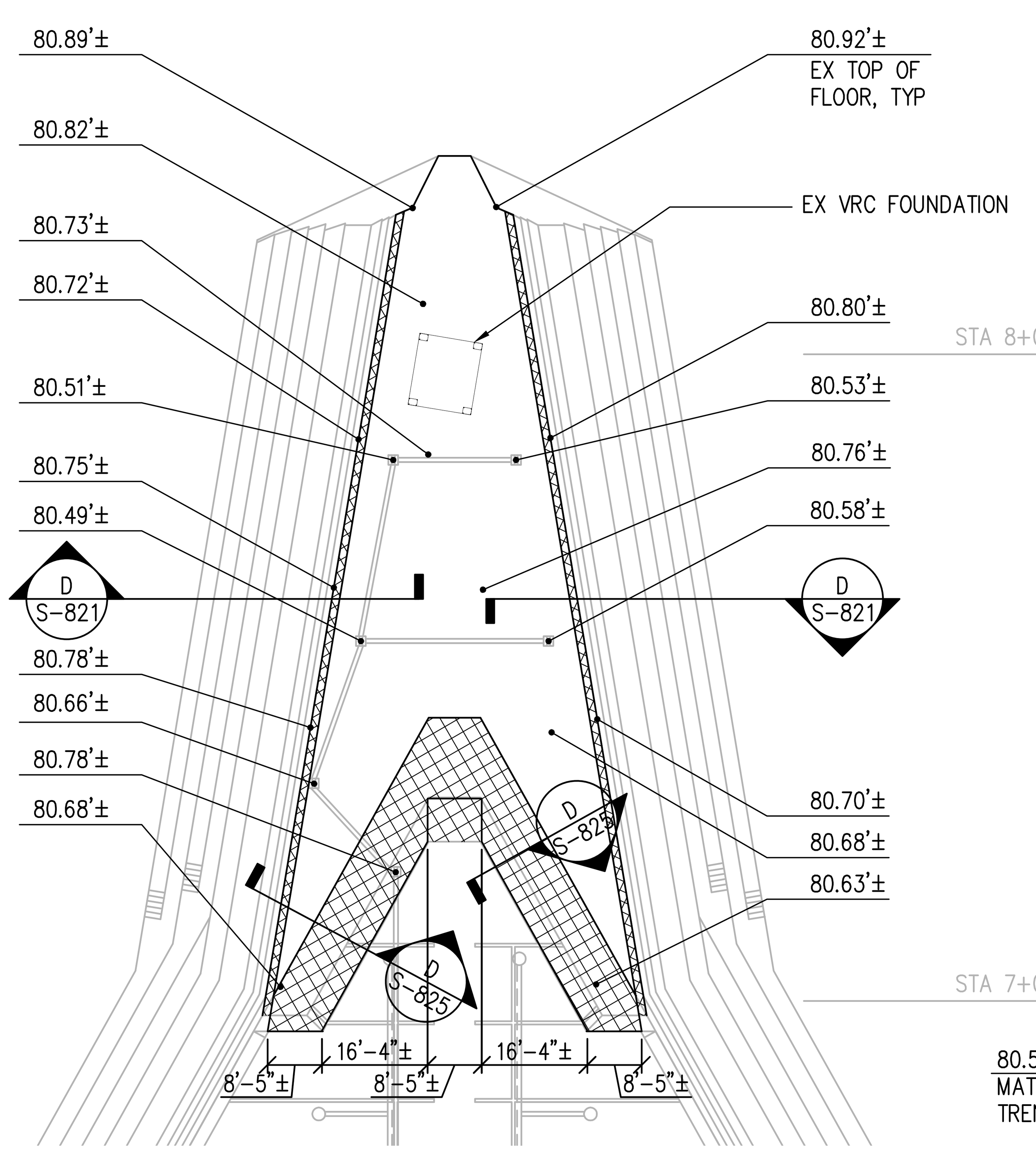
DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL BASE KITSAP - BREMERTON, WA
DEPARTMENT OF THE NAVY
NAVY NORTHWEST
PSNS & IMF
NBK BREMERTON, WA

REPAIR GROUNDWATER INTRUSION, PSNS, DRY DOCK #4

SECTIONS AND DETAILS

SCALE: AS NOTED
EPROJECT NO.: B2L4TP
CONSTR. CONTR. NO. --
NAVFAC DRAWING NO./PWD NO. 16027307/80119
SHEET 11 OF 43
C-301

DRAWFORM REVISION: 10 MARCH 2009



PARTIAL DEMOLITION PLAN (1, S-121)

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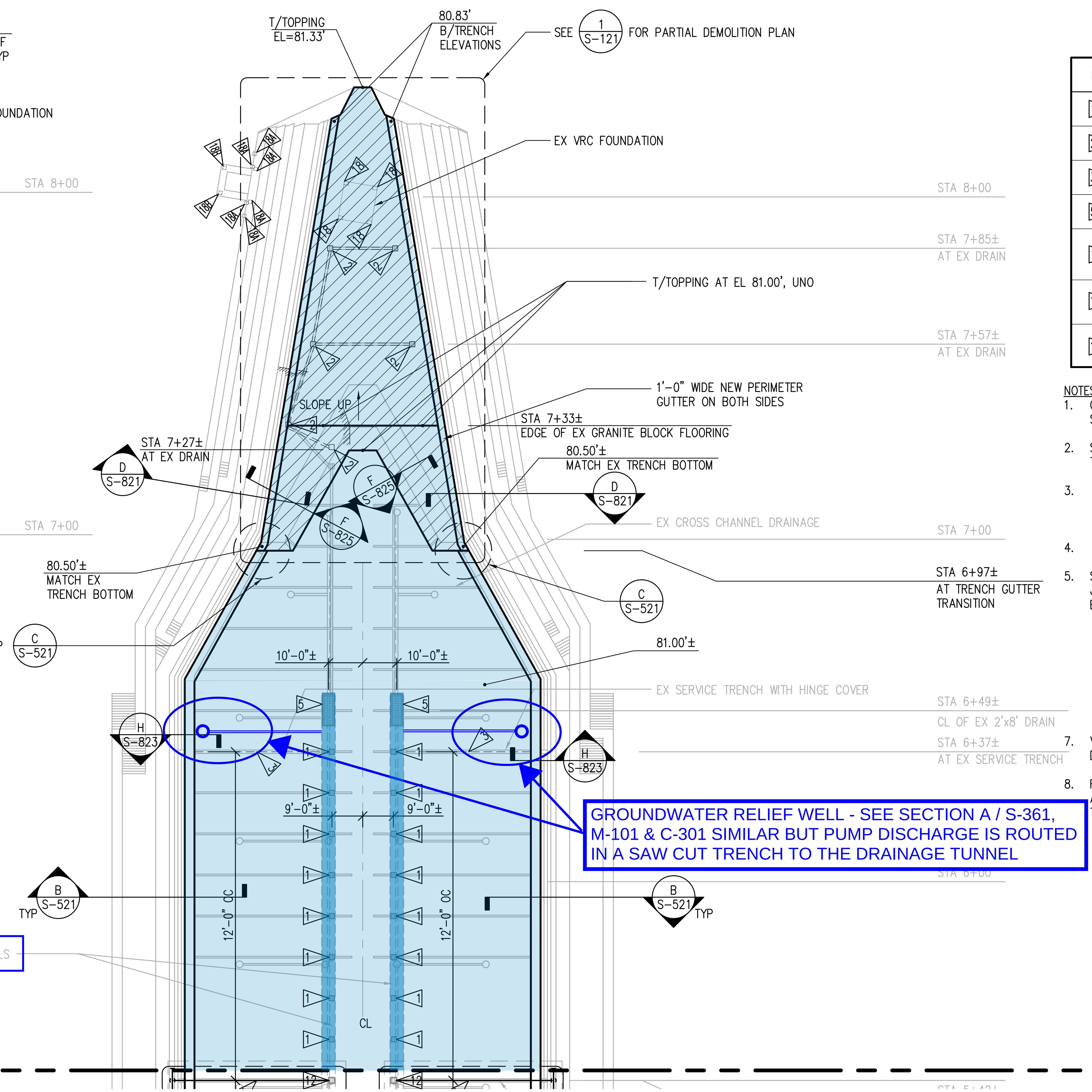


FLOOR PLAN - AREA 2A - DD2

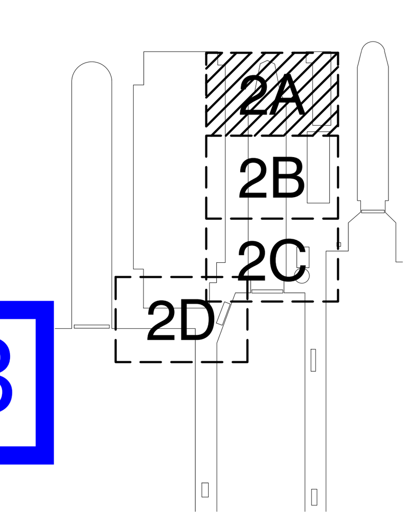
SCALE: 1"=20'-0"

FLAG NOTES:

ITEM	SEE SECTION, ELEVATION, OR DETAIL	DESCRIPTION	QUANTITY
1	F/S-821	FILL IN DRAINS	16
2	L/S-823	PLUG INLETS AT NORTH END OF DOCK	6
3	K/S-821	FILL IN SERVICE TRENCH	2
5	H/S-821	PLUG 8'x2' DRAIN OPENINGS	2
18	G/S-825	MODIFICATION AT EX VRC BASE ANCHORAGE	4
18A	H1/S-825	MODIFICATION AT EX VRC BRIDGE BASE ANCHORAGE	6
18B	H2/S-825	MODIFICATION AT EX VRC BRIDGE BASE ANCHORAGE	2

NOTES:

1. QUANTITIES SHOWN ARE FOR ITEMS WITHIN THE MATCH LINE SHOWN FOR THIS SHEET ONLY.
2. STATIONING IS BASED OFF OF DWG PW35015 WHICH DEFINES STA 0+00 AT THE NORTH FACE OF THE ABUTMENT.
3. (hatch) INDICATES DRY DOCK FLOOR TO BE RESURFACED PER B S-821
4. (crosshatch) INDICATES EX DRY DOCK CONCRETE FLOOR TO BE DEMOLISHED.
5. SURVEY NOTES: SPOT ELEVATIONS NOTED ± ARE BASED ON THE SURVEY IN JULY & AUGUST OF 2011 PERFORMED BY PACIFIC SURVEYING AND ENGINEERING INC USING THE FOLLOWING DATUM:
   HORIZONTAL DATUM: PUGET SOUND NAVAL SHIPYARD (LOCAL GROUND) BASIS OF BEARINGS: PSNS NO. F 35, NORTHING: 3819.627, EASTING: 3956.058, EL = 220.15 TO PSNS NO. L 39, NORTHING: 2706.840, EASTING: 4716.860, EL = 196.28 S34°21'36"E, 1348.00' (CALC. & MEASURED)
   VERTICAL DATUM: PUGET SOUND NAVAL SHIPYARD (LOCAL) (SUBTRACT 109.40' FROM ELEVATIONS TO MLLW TIDAL DATUM)
7. VERIFY TRENCH INVERT ELEVATIONS PER CIVIL DRAWINGS.
8. REFER TO HAZARDOUS MATERIALS DRAWINGS AND SPECIFICATIONS FOR REMOVAL AND DISPOSAL OF ASBESTOS AND HAZARDOUS METALS IN CONJUNCTION WITH THE PLANNED DEMOLITION.



1" = 20'-0"

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KEY PLAN DD2

SCALE: NONE

POTENTIAL PROJECT 3

11/12/2013

NAVFAC

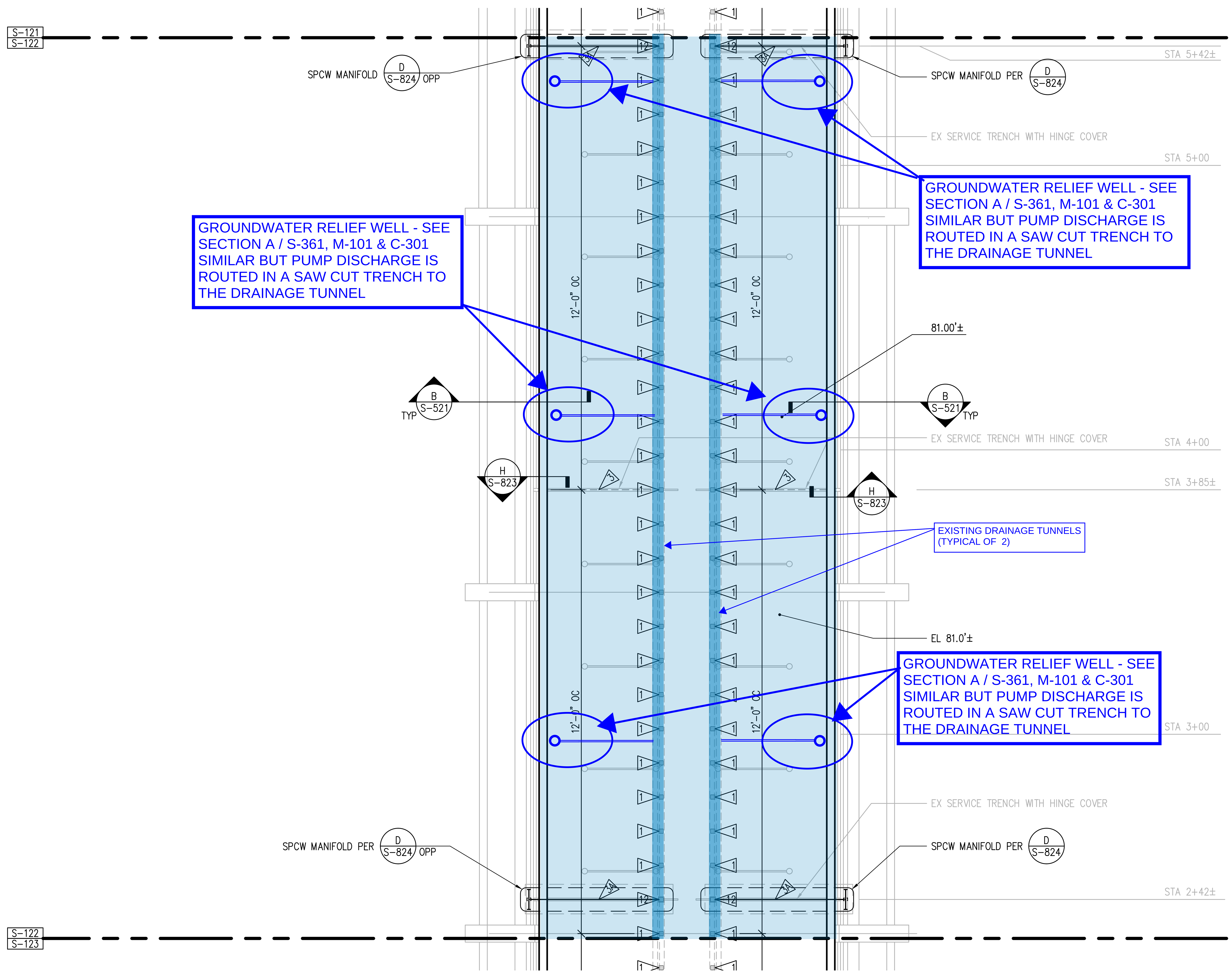
kpff Consulting Engineers
1601 Fifth Avenue, Suite 1600
Seattle, Washington 98101
(206) 622-5822 Fax (206) 622-8130

GREGORY L. VARNEY, STATE OF WASHINGTON, REGISTERED PROFESSIONAL ENGINEER 25842, 4Nov13

DES JGC | DRW JBB
REVIEWED BY GLV 11-12-13
PM/DM C. HICKLE, S. KEATING
CHIEF ENG/ARCH GREG VARNEY

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING COMMAND – NORTHWEST
NAVAL STATION – SILVERDALE, WASHINGTON
IPT
NAVAL BASE KITSAP – PSNS & IMF BREMERTON, WA
FY-15 MCON PROJECT P-422
INTEGRATED DRYDOCK WATER TREATMENT FACILITY
FLOOR PLAN – AREA 2A – DD2

CODE ID. NO. 80091 | SIZE D
SCALE: AS NOTED
JOB ORDER NO. P-422
WORK ORDER NO. 1107669
CONSTR. CONTR. NO. N44255- - -
NAVFAC DRAWING NO. 16018615
SHEET 69 OF 186
S-121



FLOOR PLAN - AREA 2B - DD2
SCALE: 1"=20'-0"

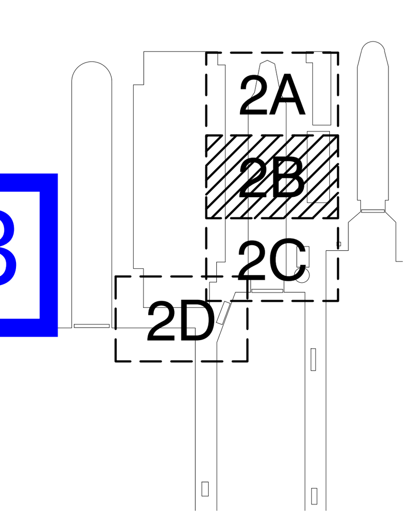
POTENTIAL PROJECT 3

FLAG NOTES:

ITEM	SEE SECTION, ELEVATION OR, DETAIL	DESCRIPTION	QTY
1	F/S-821	FILL IN DRAINS	50
3	K/S-821	FILL IN SERVICE TRENCH	2
3A	A/S-825	FILL IN EX SERVICE TRENCH W/ SPCW MANIFOLD	4
6	G/S-523	SPCW MANIFOLD SUPPORT	4
12	C/S-825	REPLACE EX DRAIN COVER AND FRAME	4

NOTES:

1. QUANTITIES SHOWN ARE FOR ITEMS WITHIN THE MATCH LINE SHOWN FOR THIS SHEET ONLY.
2. STATIONING IS BASED OFF PW35015 WHICH DEFINES STA 0.00 AT THE NORTH FACE OF THE ABUTMENT.
5. SURVEY NOTES: SPOT ELEVATIONS SHOWN ARE BASED ON THE SURVEY IN JULY & AUGUST OF 2011 PERFORMED BY PACIFIC SURVEYING AND ENGINEERING INC USING THE FOLLOWING DATUM:
   HORIZONTAL DATUM: PUGET SOUND NAVAL SHIPYARD (LOCAL GROUND) BASIS OF BEARINGS: PSNS NO. F 35, NORTHING: 3819.627, EASTING: 3956.058, EL = 220.15 TO PSNS NO. L 39, NORTHING: 2706.840, EASTING: 4716.860, EL = 196.28 S34°21'36"E, 1348.00' (CALC. & MEASURED)
   VERTICAL DATUM: PUGET SOUND NAVAL SHIPYARD (LOCAL) (SUBTRACT 109.40' FROM ELEVATIONS TO MLLW TIDAL DATUM)
5. REFER TO HAZARDOUS MATERIALS DRAWINGS AND SPECIFICATIONS FOR REMOVAL AND DISPOSAL OF ASBESTOS AND HAZARDOUS METALS IN CONJUNCTION WITH THE PLANNED DEMOLITION.



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KEY PLAN DD2
SCALE: NONE

11/12/2013

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GREGORY L. VARNEY STATE OF WASHINGTON 25842 REGISTERED PROFESSIONAL ENGINEER 4 Nov 13

DES JGC | DRW JBB
REVIEWED BY GLV 11-12-13
PM/DM C. HICKLE, S. KEATING
CHIEF ENG/ARCH GREG VARNEY

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL FACILITIES ENGINEERING COMMAND – NORTHWEST
NAVAL STATION – SILVERDALE, WASHINGTON
IPT NAVAL BASE KITSAP – PSNS & IMF BREMERTON, WA
FY-15 MCON PROJECT P-422
INTEGRATED DRYDOCK WATER TREATMENT FACILITY
FLOOR PLAN – AREA 2B – DD2

SCALE: AS NOTED
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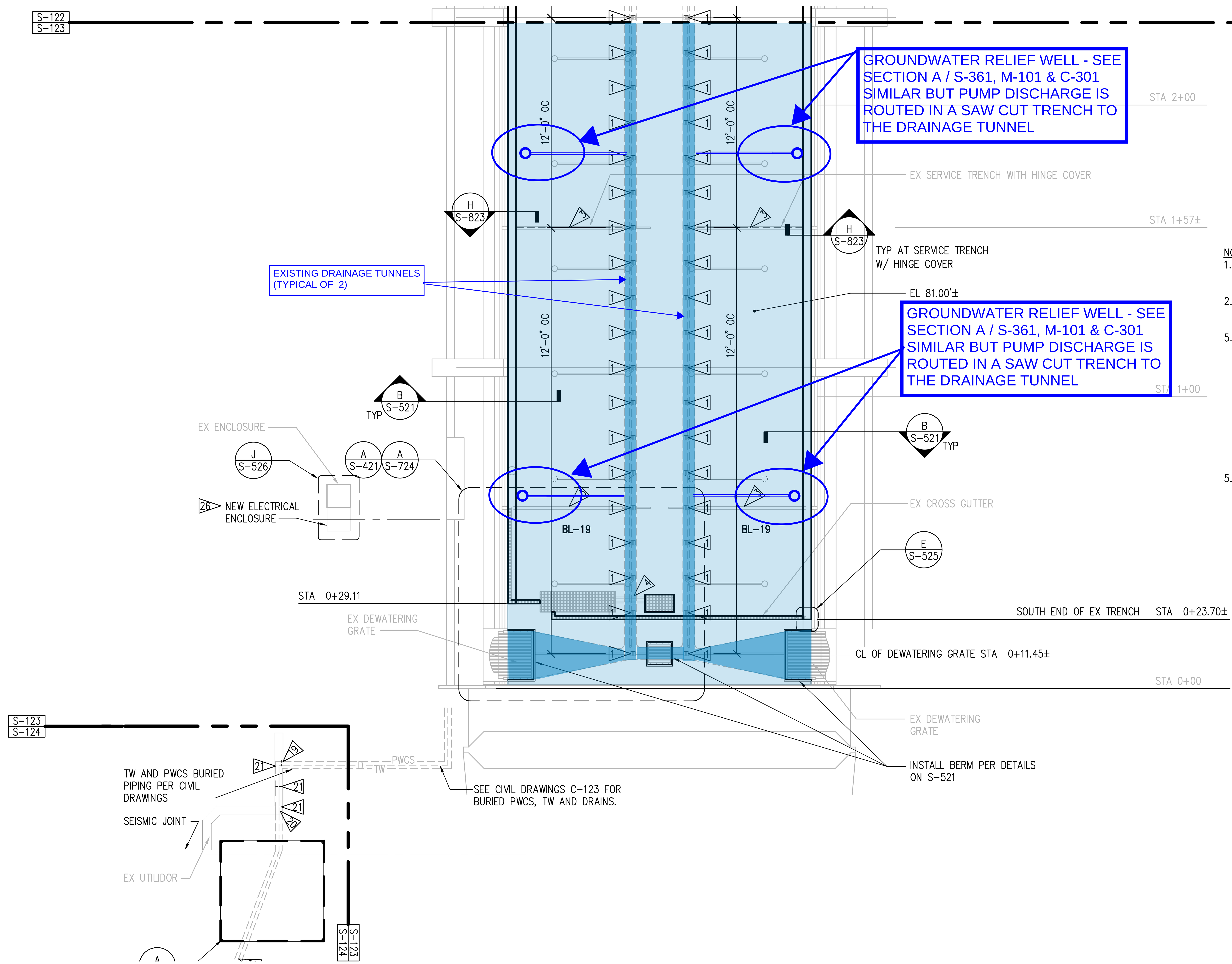
WORK ORDER NO. 1107669
CONSTR. CONTR. NO. N44255– – –
NAVFAC DRAWING NO. 16018616
SHEET 70 OF 186
S-122



FLOOR PLAN - AREA 2C - DD2
SCALE: 1"=20'-0"

FLAG NOTES:

ITEM	SEE SECTION, ELEVATION, OR DETAIL	DESCRIPTION	QTY
1	F/S-821	FILL IN DRAINS	36
3	K/S-821	FILL IN SERVICE TRENCH	4
4	J/S-823	WALL PENETRATION FOR 8" PIPE	1
26	J/S-526	ELECTRICAL ENCLOSURE PAD	1

NOTES:

1. QUANTITIES SHOWN ARE FOR ITEMS WITHIN THE MATCH LINE SHOWN FOR THIS SHEET ONLY.
2. STATIONING IS BASED OFF PW35015 WHICH DEFINES STA 0.00 AT THE NORTH FACE OF THE ABUTMENT.
5. SURVEY NOTES: SPOT ELEVATIONS SHOWN ARE BASED ON THE SURVEY IN JULY & AUGUST OF 2011 PERFORMED BY PACIFIC SURVEYING AND ENGINEERING INC USING THE FOLLOWING DATUM:
   HORIZONTAL DATUM: PUGET SOUND NAVAL SHIPYARD (LOCAL GROUND)
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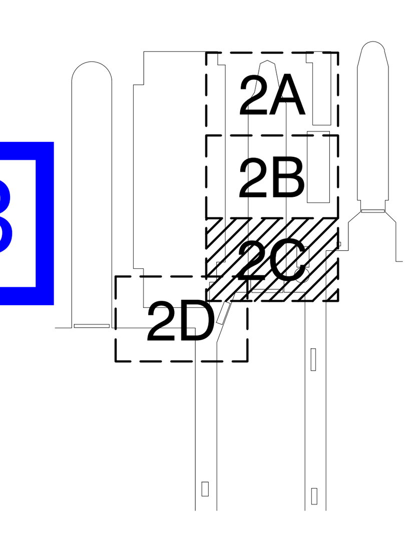
   VERTICAL DATUM: PUGET SOUND NAVAL SHIPYARD (LOCAL)
   (SUBTRACT 109.40' FROM ELEVATIONS TO MLLW TIDAL DATUM)
5. REFER TO HAZARDOUS MATERIALS DRAWINGS AND SPECIFICATIONS FOR REMOVAL AND DISPOSAL OF ASBESTOS AND HAZARDOUS METALS IN CONJUNCTION WITH THE PLANNED DEMOLITION.

POTENTIAL PROJECT 3



1" = 20'-0"
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KEY PLAN DD2
SCALE: NONE

11/12/2013

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NAVAL BASE KITSAP – PSNS & IMF BREMERTON, WA
FY-15 MCON PROJECT P-422
INTEGRATED DRYDOCK WATER TREATMENT FACILITY
FLOOR PLAN – AREA 2C – DD2

SCALE: AS NOTED
JOB ORDER NO. P-422
WORK ORDER NO. 1107669
CONSTR. CONTR. NO. N44255- - -
NAVFAC DRAWING NO. 16018617
SHEET 71 OF 186
S-123

Wastewater Salinity Follow-up Study
NBK-Bremerton, Washington
NAVFAC Northwest

Appendix H
Krayer Report

April 2017

Salinity Impacts on Coastal Wastewater Treatment Facilities

Amy Seymour Krayer
Worcester Polytechnic Institute

Matthew I. Michaels
Worcester Polytechnic Institute

Talia Pearl Solomon
Worcester Polytechnic Institute

Salinity Impacts on Coastal Wastewater Treatment Facilities

A Major Qualifying Project Report:

Submitted to the Faculty

Of

WORCESTER POLYTECHNIC INSTITUTE

In fulfillment of the requirements for the

Degree of Bachelor of Science

By

____

Amy S. Krayer

____

Matthew I. Michaels

____

Talia P. Solomon

April 24th, 2017

Approved:

____

Professor John A. Bergendahl

Abstract

Global warming is an ever-present problem resulting in increasing sea level rise and surge flooding. This water misplacement can infiltrate coastal wastewater treatment collection systems and interfere with treatment processes. Many coastal facilities have already experienced problems relating to higher concentrations of seawater in their wastewater influent. The specific effects of salinity on the sedimentation and aeration activated sludge processes were analyzed to determine what mitigation techniques could be employed. Bench-scale experimental results suggested that at concentrations of salinity between 2.63 and 5.24 percent by weight, the traditional sedimentation and aeration processes could no longer operate effectively. A salinity monitoring system, which includes isolated reseeding and reverse sedimentation tanks, was designed to trigger a process control response during high salinity events.

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Authorship

PE Licensure and Design Statement .... Amy Krayer

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Chapter 2: Background .... Matthew Michaels, Amy Krayer, Talia Solomon

Chapter 3: Methodology .... Matthew Michaels, Talia Solomon, Amy Krayer

Chapter 4: Results .... Talia Solomon, Matthew Michaels

Chapter 5: Design .... Matthew Michaels, Talia Solomon

PE Licensure

There is a process every engineer must undergo to obtain his or her Professional Engineering (PE) Licensure. The first step in the process is to pass the Fundamentals of Engineering (FE) Exam and become an Engineer in Training (EIT). After this, the engineer must complete a minimum of four years of qualifying engineering experience, under the supervision of a PE. After an EIT has completed the minimum qualifying period, he or she must submit an application for registration to become a PE. The Board of Registration will then review the applicant's education, work experience, character and experience references. Once the board has determined that the applicant has met all requirements, he or she will be scheduled to sit for the Principles and Practice of Engineering (PE) Exam. Upon completion of these requirements, the applicant will be issued a license to practice as a PE. The licensure is state specific, therefore, engineers wishing to practice in multiple states must register their license with each state's board and gain approval before being permitted to practice.

Procurement of a PE illustrates that an engineer has not only obtained an engineering degree, but has also gained valuable experience in the work force. PE's are seen to have a full understanding of the components of their profession and are the only people certified to sign, seal, and submit engineering plans and drawings on behalf of their clients. This ability makes them more desirable as employees, especially in the consulting industry. Licensure is also essential for moving up in responsibility and authority in many companies and PEs generally earn higher wages as compared to non-licensed engineers.

Due to the high level of responsibility, PEs must also adhere to a stringent code of ethics. PE's must act morally and ethically in all professional situations, always keeping in mind the well-being of the public before making decisions. The prestige that comes with the PE title is an advantage that opens many doors for engineers who obtain it.

Design Statement

This project incorporates design by including experimental design and a full-scale process modification, and fulfills ABET's requirement for capstone design experience.

The goal of the project was to determine how increased salinity levels affected biological and chemical wastewater treatment processes, such as activated sludge, aeration and sedimentation. Experimental procedures were researched and designed to test how increased salinity levels affect sedimentation, oxygen solubility, and aeration. To mitigate the effects of salinity on the aeration and sedimentation processes, new treatment processes and protocols were designed. These included an evaluation system to measure salinity with a control that is to be activated once salinity has reached a critical level, a reseeding tank to culture activated sludge in the case of a high salinity disturbance event, and a system to remove flocs from the top of a sedimentation basin as opposed to the bottom.

Chapter 1: Introduction

Wastewater is defined as the water supply of a community after it has been used in domestic, institutional, commercial or industrial applications. It is typically composed of microorganisms, biodegradable organic materials, non-biodegradable organic materials – such as detergents, pesticides, fats, oils, and grease – nutrients, metals, and other inorganic materials. Table 2.1 shows the typical composition of domestic wastewater before treatment.

Table 1.1: Typical Composition of Untreated Domestic Wastewater

Adapted from: Crittenden, 2012

Contaminants	Unit	Concentration[a]
Solids, total (TS)	mg/L	390-1230
Dissolved solids, total (TDS)	mg/L	270-860
Suspended solids, total (TSS)	mg/L	120-400
5-day Biochemical Oxygen Demand (BOD_5,	mg/L	110-350
Total Organic Carbon (TOC)	mg/L	80-260
Chemical Oxygen Demand (COD)	mg/L	250-800
Nitrogen	mg/L	20-70
Phosphorus	mg/L	4-12
Chlorides	mg/L	30-90
Sulfate	mg/L	20-50
Oil and grease	mg/L	50-100
Volatile Organic Compounds (VOCs)	mg/L	<100 - >400
Coliform, total	No./100 mL	10^6-10^{10}
Fecal coliform	No./100 mL	10^3-10^8
Cryptosporidium oocysts	No./100 mL	10^1-10^2
Giardia lamblia cysts	No./100 mL	10^1-10^3

*[a]Low range is based on an approximate wastewater flowrate of 200 gal/capita*day. High range is based on wastewater flowrate of 60 gal/capita*day*

Proper wastewater treatment is important for protecting public health. If untreated, fecal coliform, cryptosporidium, and giardia can cause disease outbreaks and contaminate drinking water sources. In addition, nutrients, such as nitrogen and phosphorus, can damage the discharging bodies of water, as well as any organisms living within them.

Wastewater treatment dates back to the Romans, who used stone channels to send wastewater to the Tiber River (Nathanson, 2016). Throughout most of the 1800's there was no running water or modern toilets in homes. Instead, both industry and local residents dumped their waste directly into cesspools, privy vaults, and surface waters, which leached into groundwater. Water companies often utilized source water directly from these surface waters and the groundwater was tapped for drinking water. Due to the high concentration of microorganisms in raw wastewater, epidemic outbreaks of cholera, typhoid, and giardia were common. Between 1831 and 1854, tens of thousands of people in England died of cholera (Tuthill, 2003). One British scientist, John Snow, tracked down cases of cholera throughout his neighborhood and was able to prove that the outbreak was stemming from the consumption of water at a single infected pump on Broad Street. This breakthrough discovery lead to the construction of specific facilities for wastewater treatment and the establishment of stringent water treatment regulations, many of which are still intact today.

By 1948, the United States government implemented the Water Pollution Control Act to restore the nation's water to conditions that were suitable for public use. This was later expanded and renamed the Clean Water Act (CWA) of 1972, which set the first regulations on pollutants discharged from wastewater treatment facilities (WWTFs) into nearby waters. The law requires a permit for discharging and sets maximum contaminant levels for various pollutants. WWTFs must comply with the Environmental Protection Agency's CWA Monitoring Program, including annual quality reporting and on-site compliance evaluations (EPA, 2016).

According to the census, there were 16,024 WWTFs operating in the United States by the middle of the 1990's. These facilities combine to provide an overall design capacity of 42,225 million gallons per day (mgd) of wastewater treatment, which serves over 180 million Americans (US Census, 2006). WWTFs must be equipped to handle water from both domestic and industrial sources, as well as inflow and infiltration (I/I). Infiltration occurs when groundwater enters the collection system through defective or broken pipes. Groundwater gains access when a system lies beneath a water table or the soil above has become overly saturated. Inflow refers to water entering a system at connection or access points, and tends to spike during precipitation events. Both inflow and infiltration add water to the system, which alters the composition of the wastewater and causes volumes to exceed capacity, affecting treatment efficiency. Coastal communities are at an especially high risk for I/I as high tides, rising sea levels, and oceanic flooding can cause saltwater to enter the system on a regular basis.

Globally, eight out of ten of the world's largest cities are near a coast and approximately 40 percent of the United States' population lives in relatively high-density coastal areas (National Oceanic and Atmospheric Association, 2016). This means a vast majority of wastewater treatment occurs near the ocean and is susceptible to saltwater intrusion. As sea levels increase and extreme weather events occur more frequently every year due to global climate change, the threat of saltwater inflow becomes more imminent.

Global climate change refers to the ongoing increase in the temperature near the Earth's surface. It is a result of high concentrations of greenhouse gases in the atmosphere. Greenhouse gases (GHGs) – such as water vapor, carbon dioxide, and methane – absorb energy released by the Earth, which slows or prevents the release of heat to space, effectively warming the Earth. This process is often called the "greenhouse effect", as a greenhouse traps heat inside a structure to warm the air. Some of these GHGs are released by natural processes, however much of it is a direct result of human activities that burn fossil fuels. The main GHGs emitted by humans include carbon dioxide, methane, and nitrous oxide. For example, the graph below shows atmospheric carbon dioxide concentrations over time.

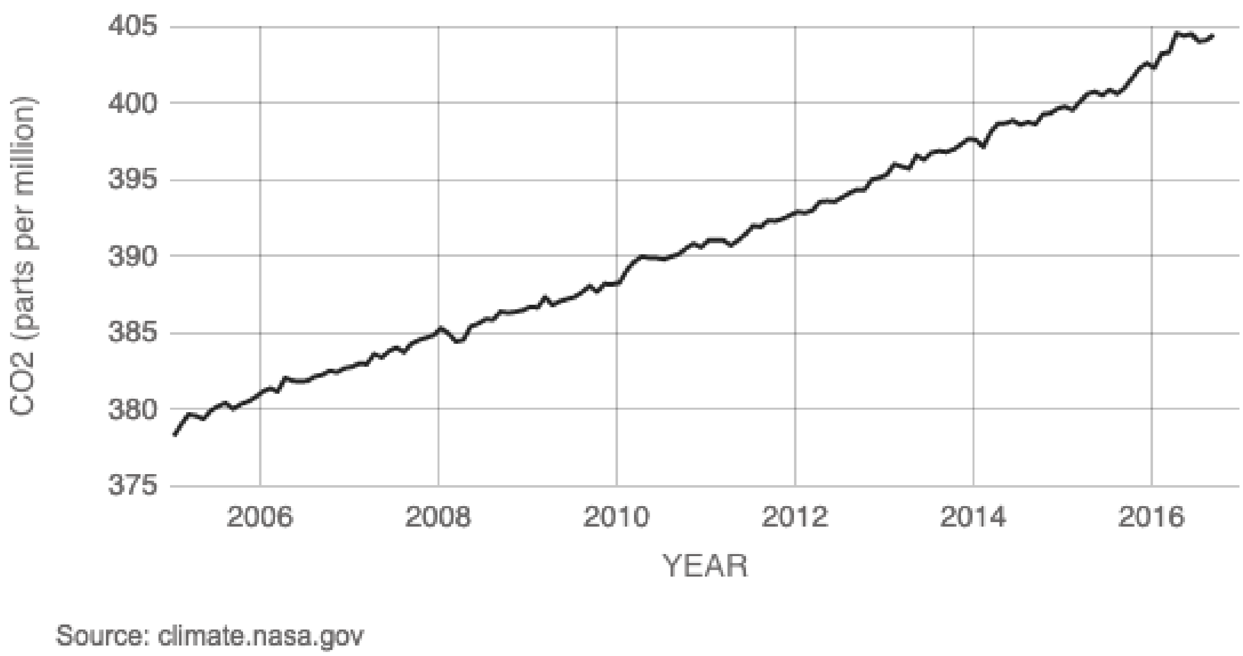


Figure 1.1: Atmospheric Carbon Concentrations 2005-Present

Source: NASA, 2016

Over the last ten years alone, carbon dioxide has increased by over 100 parts per million (ppm) and does not seem to be subsiding any time soon. This has been a substantial escalation since the 1950 concentration level, which was considered a peak in the history of carbon dioxide concentrations over the last three glacial cycles, as shown in the graph below.

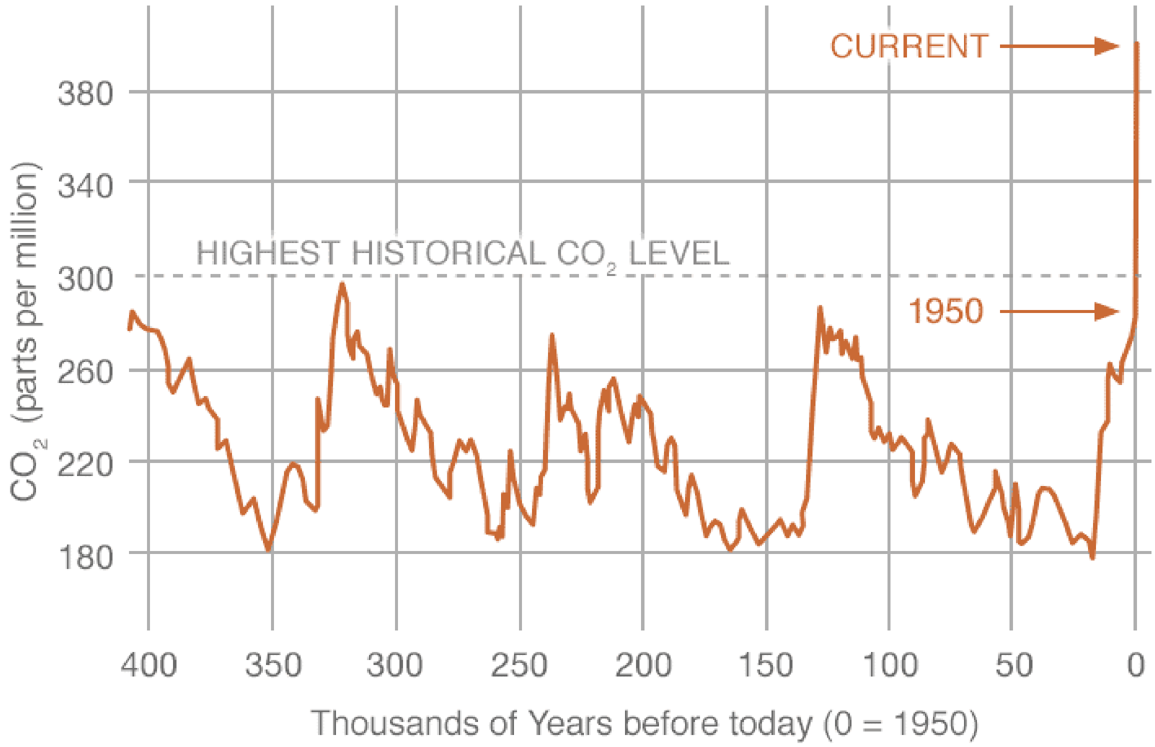


Figure 1.2: Atmospheric Carbon Dioxide Concentrations Over Three Glacial Cycles

Source: NASA, 2016

Both carbon dioxide concentrations and temperature have risen in approximately the same time frame. In a similar trend to the graph above, as depicted in Figure 1.3 below, the average global temperature has increased approximately 1.4 degrees Fahrenheit since 1880, of which two-thirds has occurred since 1975 (Carlowicz, 2014).

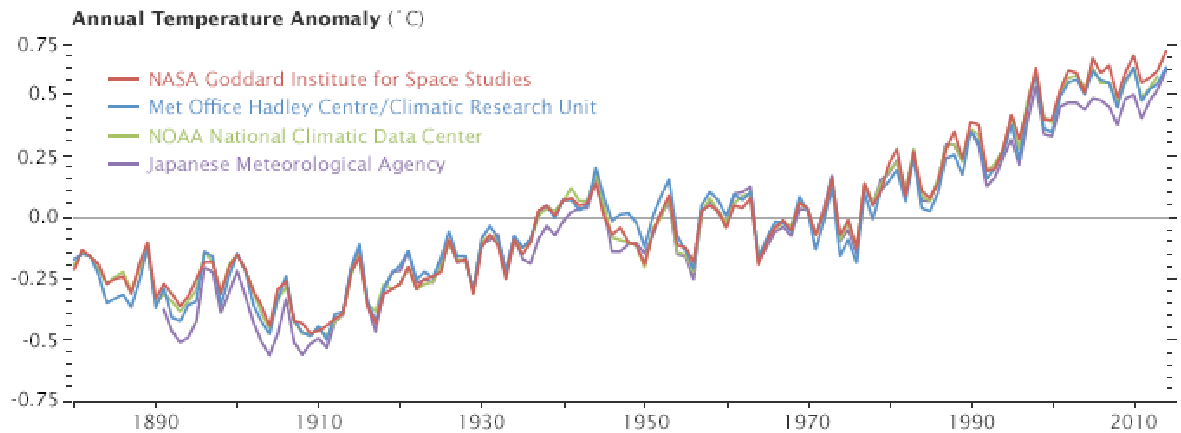


Figure 1.3: Global Average Annual Temperature Change

Source: Carlowicz, 2014

Although this 1.4 degree Celsius change may seem insignificant, the ice age was caused by a mere two-to-three degree drop (Carlowicz, 2014). As seen in the Figure 1.4, sea-levels have also risen proportionally with temperature change, an average of 3.4 millimeters per year (mm/year) over the past 20 years.

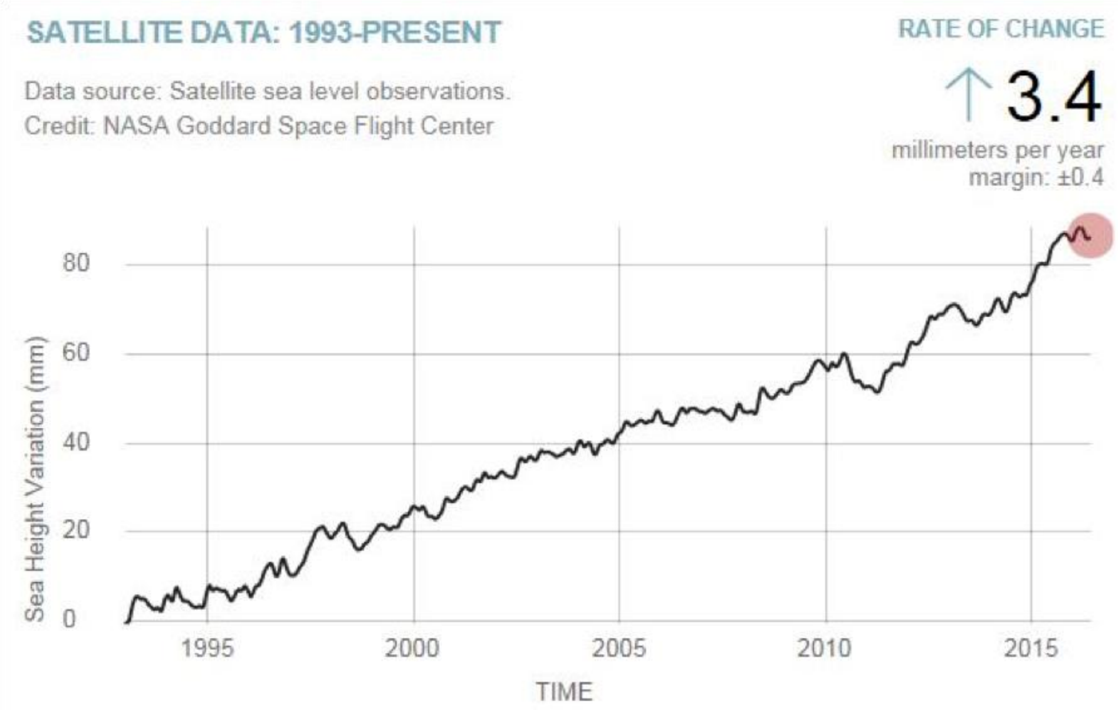


Figure 1.4: Sea Level Changes 1993-Present

Source: NASA, 2016

This is double the average increase that occurred throughout the twentieth century. In Boston alone, sea levels have risen 0.92 feet over the past 100 years (National Oceanic and Atmospheric Association, 2016).

Scientists attribute both of the major causes of sea-level rise (SLR) to global climate change. The first is thermal expansion, when the ocean expands as the temperature rises due to global climate change. Oceans are absorbing approximately 90 percent of the increased atmospheric heat, and expanding rapidly as a result (National Oceanic and Atmospheric Administration, 2016). A 2010 study on the impact of SLR on coastal areas estimated that thermal expansion has contributed between 25-50 percent to global mean SLR since 1960 (Nicholls, 2010). The second major cause is the loss of land-based ice, when glaciers and ice sheets melt due to elevated temperatures. Atlantic ice loss has quadrupled since 1992 and the

Greenland ice sheets have decreased in mass six-fold (Carlowicz, 2014). Land-based water storage changes are suspected to contribute approximately 30 percent to SLR (Nicholls, 2010).

The primary way, however, that most people experience global climate change is through changes in extreme weather events. Additional water from thermal expansion and ice melt has caused more periodic nuisance flooding. Storm surges inland are 300 to 900 percent more frequent within United States coastal communities than 50 years ago (National Oceanic and Atmospheric Association, 2016). North Atlantic hurricanes have also increased substantially in intensity, frequency, and duration since the early 1980s. Increases in activity are linked to higher average oceanic temperatures (USGCRP, 2014). A study on the risk of climate change to coastal wastewater collection systems found that Hurricane Ophelia in 2005 and El Niño-associated rain events during 2006 had "impressive effects" on total flow. For example, Ophelia caused influent flow at a WWTF in Wilmington, North Carolina to be as high as 17.0 mgd at a facility that typically experiences a mean flow rate of 8.18 mgd and is only designed for a capacity of 12.0 mgd (Flood, 2011). Not only does saltwater intrusion exhibit problems in terms of a high saline content, but the excess water consumes system capacity needed during critical overflow periods.

Overloaded systems are at risk for inefficient treatment, as well as sanitary and combined sewer overflows (Flood, 2011). A sanitary sewer overflow spills raw sewage into basements or out of manholes into the streets before it can reach the WWTF due to excess I/I. A combined sewer overflow discharges surplus wastewater directly into surface waters during heavy rainfall or snowmelt. Both overflow events can ensue as a direct result of global climate change, causing more frequent rainfall and other extreme weather events, as well as higher mean sea levels.

Manchester-by-the-Sea (MBTS) is one of many coastal communities already noticing the effects of climate change associated SLR. Large amounts of seawater are entering the system through manholes, contributing approximately 10 percent of the flow for the entire community. A report completed by CDR Maguire showed 273,000 gpd enters the system at peak infiltration. This report also estimated approximately 1,473,000 gallons of inflow during a typical storm event (CDR Maguire, 2016). The high salinity concentration has become enough of a problem that the Massachusetts Department of Public Works issued the town an Administrative Consent Order, mandating them to address I/I problems within their wastewater collection system.

King County in Seattle, Washington has also experienced similar I/I complications. Since 2003, the county's Wastewater Treatment Division has been monitoring locations in the combined sewer and found that between three and six million gallons of saltwater enter the system each day. This amounts to be between one and two billion gallons per year (Phillips, 2011). During periods of high tide, seawater enters through gates, overflow weirs, and groundwater infiltration. Operators noticed spikes in conductivity, a measure of salinity, during or after tides greater than 10 feet, which occurs approximately 250 times per year in that area. Typical wastewater has a conductivity of 0.65 milli-Siemens per centimeter (mS/cm) and readings over 2 mS/cm indicate saltwater intrusion. In some areas of the collection system, King County wastewater averages 3.2 mS/cm, indicating that the flow is about 10 percent saltwater (Phillips, 2011). This prompted the county to raise the level of its waterfront weirs by six inches as a short-term solution and undertake a more comprehensive study in order to develop strategies to stop the sources of intrusion.

Elevated levels of salinity within the wastewater process present a number of challenges to the treatment plant. Increased salinity negatively affect the organisms responsible for removing pollutants, such as colloids, and elemental nutrients, like nitrogen, sulfur, and phosphorus. Population size and diversity of these organisms decrease with increasing salinity.

The amounts of dissolved oxygen, required by these organisms to grow, within the process stream also decreases as salinity within the system increases. This leaves the activated sludge less effective at removing pollutants from the wastewater. Aside from the impact of salinity on activated sludge, research shows that increased salt contents in wastewater may also reduce the effectiveness of the sedimentation process.

The purpose of this project was to determine the impact of increased salinity on the biological and chemical treatment processes used for wastewater treatment. To do so, laboratory experiments were conducted to determine a ‘critical salinity level’ at which point treatment processes would need to be modified in order to continue to operate appropriately, as well as recommendations on how these issues can be mitigated. The results produced from this study will be increasingly pertinent as more coastal WWTFs face problems related to global climate change and SLR.

Chapter 2: Background

Section 2.1: Pre-Treatment

Large debris can potentially damage or clog pumps, pipes, and channels, therefore raw sewage must undergo pre-treatment to ensure these are removed upon reaching the WWTF. In order to do so, screens and bar racks are utilized. Spacing of bars ranges from coarse (50-150 mm openings) to fine (10 mm opening), and screens are typically arranged from largest (in opening size) to smallest to act as a sieve. Particles must be maintained at a velocity of at least 0.6 meters per second (m/s) in order to prevent settling before water enters the primary treatment.

Section 2.2: Sedimentation

Sedimentation is the use of gravity to physically separate suspended material from water. When water enters the sedimentation basin, it contains small, negatively charged particles. Particles with the same charge repel each other, which hinders combination of these particles into a settled form. To combine them, the velocity in the sedimentation basins is decreased to a calm, quiescent flow so that particle suspension is no longer supported.

There are four types of sedimentation commonly used in WWTFs. Type I sedimentation is referred to as discrete particle settling. As such, the particle's size, shape, and specific gravity do not change with time — these particles settle independently of each other. Type II sedimentation is called flocculant settling. Particles in this type aggregate as they settle meaning that they change in size, shape, and specific gravity with each contact. Type III settling is known as zone settling. There is a concentration of particles in this type, but not enough to cause substantial displacement of water. Lastly, Type IV sedimentation is compression settling, in which particles are in such high concentration that they constantly touch each other. Settling, therefore, can only occur by compression of the mass.

Sedimentation is typically separated into two stages: primary and secondary. The goal of primary sedimentation is to remove settleable solids and a portion of the BOD. Approximately 35 percent BOD and 60 percent-suspended solids are removed during this step in the treatment process (Henze, 2011). Colloidal and dissolved constituents, however, are not affected at this stage. Primary settling basins are either circular or rectangular, typically three to five meters in depth, with a hydraulic retention time of about two hours. Settled solids, also known as primary sludge, are removed from the bottom of the basin via scrapers and sent to further sludge processing. Solids that float to the top, also known as scum, are removed by water jets or mechanical arms and sent to further sludge processing as well.

The goal of secondary sedimentation is to remove the residual organics and suspended solids not removed in primary treatment. Wastewater enters the secondary sedimentation basin after going through the aeration and activated sludge process. Suspended solids will either settle to the bottom of the basin and be recycled into the activated sludge process, or be sent for further sludge treatment processes further downstream. BOD is typically reduced to 80 percent of influent levels at this stage (Henze, 2011).

Section 2.2.1: Effect of Salinity on Sedimentation

Previous studies on the effects of salinity on the sedimentation process have produced mixed results. Some research suggests that higher salinity makes it more difficult for suspended solids to settle. One such study, published in the *Journal of Environmental Progress*, attributed this to salinity's effect on water density (Smythe, 1997). The more salt present in a given amount of water, the more mass per unit volume the solution will contain. The volume of the water does not increase as the salt dissolves into solution, thus the density of the mixture increases with salinity (Moussa, 2006). Higher density wastewater could pose problems during sedimentation as the difference in density between the water and flocs decreases, which inhibits settling. This results in a large number of suspended solids and bacteria remaining in the effluent wastewater stream (Smythe, 1997).

Not all research, however, supports these conclusions. The sludge volume index (SVI), a measurement of the settled sludge volume over the mixed liquor suspended solids, can loosely reflect the performance of sedimentation:

$$SVI\left(\frac{mL}{g}\right) = (Settled\ Sludge\ Volume/Mixed\ Liquor\ Suspended\ Solids) * 1000$$

High SVI values can be attributed to sludge bulking. A study published in *Water, Science, and Technology* compared the activity and settling of microbes in the activated sludge process at various levels of salinity. The study found that wastewater with increased levels of salinity showed reduced SVIs, and settlement occurred more quickly. Reductions in SVI, however, as the Smythe study concluded, have also been attributed with increased amounts of suspended solids in effluent (Zhao, 2014). It appears that the supernatant of certain sludge becomes rather turbid at salinity above five percent (Tan, 2016). Increased turbidity, however, can result in quicker settling and SVI decrease. Low SVI values are characteristic of poor sludge activity due to a lack of nutrition for the microorganisms. Debate on whether increased salinity improves or degrades SVI is ongoing.

Section 2.3: Biological Wastewater Treatment

Activated sludge is defined as an aerobic process utilizing increased concentrations of microorganisms, both living and dead, that are suspended in wastewater that break down contaminants. These microorganisms require oxygen to grow cell mass. Aeration is the primary process used to supply the activated sludge with oxygen. The ideal range of dissolved oxygen (DO) content for microbial survival ranges between two to five mg/L (Michigan Water Resources Division; Wilén 2010). If DO levels drop below 2 mg/L, not only will the desired microorganisms die, but filamentous microorganisms, those that adversely affect the settleability of sludge, will increase (Wilén, 2010).

When microorganisms are mixed with raw sewage and oxygen, the organics are metabolized into new biomass. Thorough mixing is required to combine the sewage, microorganisms, oxygen and nutrients before clarification can take place. Contents in the aeration basin are commonly referred to as mixed liquor. After aeration, the biomass and suspended solids must be separated from the wastewater. To do so, a clarifying tank is used. Sludge is discharged from the bottom of the clarifying tank, while particles that float to the surface of the water, known as scum, are collected in a trough. Excess sludge is either returned to the aeration basin, discarded as waste, or sent for further processing. Aeration is a resource intensive process because oxygen needs to be constantly supplied to the aeration basin. Sludge processing and disposal are also major operational expenses.

Aeration is also useful for other important tasks, such as carbon dioxide (CO_2) removal. High levels of carbon dioxide can cause operational issues, such as increases in the acidity of water, increases in the amounts of lime needed to soften water, and more difficulty removing iron. Aeration is used to lower CO_2 values if concentrations are higher than 10 mg/L. When oxygen is added to the wastewater, it forces CO_2 out of solution, as it is more readily soluble. Aeration is also useful for iron (Fe) and manganese (Mn) precipitation. Aeration reduces Fe and Mn into less soluble forms, which in turn allows them to precipitate out of solution to be removed later in the treatment process.

Section 2.3.1: Effect of Salinity on the Activated Sludge Process

Increased levels of salinity in wastewater inhibit the effectiveness of the activated sludge process. In particular, population size and diversity of the microbes vital to the process are hindered. A study conducted by the United Nations Educational, Scientific, and Cultural Organization-Institute for Water Education (UNESCO) found that at salt contents of one percent, populations of key organisms responsible for the removal of nitrogen, phosphorus, and organic compounds are affected. The nitrification process, which is carried out by ammonium and nitrite oxidizing bacteria, was decreased by 20 to 30 percent. In addition, phosphate accumulating organism populations, responsible for the removal of phosphorus, were found to decrease 70 percent at salinity of one percent (Welles, 2012).

This data is in agreement with an older study from 1966, published in the *Water Pollution Control Federation Journal*, which examined the effects of salinity on activated sludge. The study compared volatile solid production and average oxygen demand in samples of wastewater at various levels of salinity. Results showed significant reduction in solid production and oxygen demand at levels of 45 g/L of NaCl, as shown in Figure 2.1 below (Kincannon, 1966).

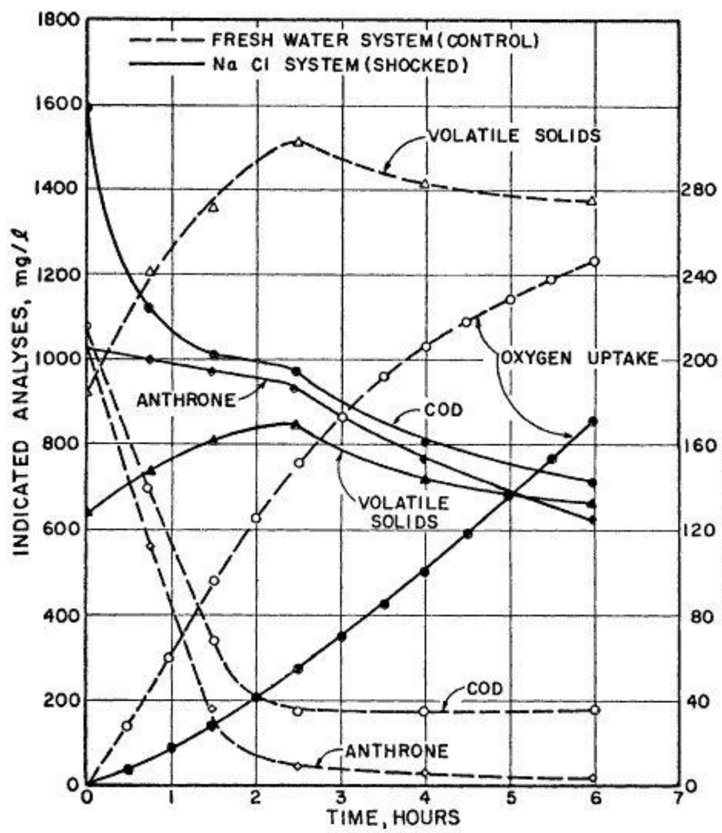


Figure 2.1: Solid Production and Oxygen Demand of Wastewater at 45 g/L NaCl

Source: Kincannon, 1966

These results, along with the findings of UNESCO, support the conclusion that microbe populations and diversity within activated sludge decrease as salinity increases.

Several studies have been completed to determine if activated sludge made with halophilic bacteria were able to withstand higher salt concentrations. High salinity results in loss of cell activity in activated sludge. Bacteria can thrive in water with up to two percent salinity before serious degradation of cell ability occurs (Zhang, 2014). To increase the cellular activity of activated sludge, halophilic bacteria are utilized. Halophilic bacteria thrive in high salt concentrations, unlike regular bacteria found in activated sludge. Studies have shown the use of salt tolerant bacteria that are able to yield high COD removal rates. One study done by the Pathology Department at Harbin Medical University in China found a bacterium called NY6 that can withstand salinity up to six percent, with optimal conditions being at two percent salinity (Zhang, 2014). NY6 is characterized as slightly halophilic. It was utilized because of its strong ability to be salt-resistant and its high rate of COD removal. A study done by Harbin Engineering University yielded similar results from observations on the microorganisms in a sequencing batch reactor (SBR) for 300 days with salinity varying from zero to three weight percent. The results of the study determined the SBR could maintain good performance below two percent salinity with a COD and BOD removal rate of 95 percent (Zhao, 2016).

Harbin Institute of Technology tested the effects of varying levels of salinity on three modified types of activated sludge. Type I activated sludge, called Marine Activated Sludge (MAS), was cultivated in a reactor for 60 days using seawater and sea mud. The strains of bacteria that reside in the sea ecosystem need certain levels of salinity to grow. The optimal range for MAS was between two and four percent (Tan, 2016). A second type of sludge, Domesticated Activated Sludge (DAS), was cultivated for 60 days using activated sludge from a treatment plant and continuously mixing it with seawater. This sludge performed best in the range of three to ten percent salinity. Although DAS showed similar trends to MAS, MAS performed better in terms of maintaining biodiversity of the microorganisms (Tan, 2016). The third type of activated sludge was cultured similarly to DAS, but saline water was used instead of seawater. This was called Conventional Activated Sludge (CAS). CAS performed best at a salinity of one percent. Above two percent, there was a severe loss of biodiversity and a reduction in the ability to treat (Tan, 2016). Although MAS and DAS performed well in increased salinity, neither could withstand salinity over ten percent.

Salt-resistant bacteria, as well as reverse osmosis through membrane bioreactors (MBRs), are both proven solutions to address salinity issues in wastewater, however, given their constraints, were deemed unfeasible as solutions for this project. Halophilic bacteria used to treat wastewater containing between three and five percent salinity by weight, resulted in higher COD removal efficiency and lower COD concentrations. Unfortunately, these bacteria are not available widespread, the organisms require a minimum 10 day cultivation period, and the cultivation media must be replaced every three days (Kargi, 2000). This is simply impractical and too costly for wastewater treatment plants that only experience occasional spikes in salinity. There is also evidence that MBRs are capable of removing salt from wastewater and can produce high quality effluent. However there are some negative considerations that may deem them a poor choice for some applications. MBRs are expensive, unsuitable for large-scale facilities, and high maintenance. Furthermore, coastal WWTFs that experience saltwater intrusion may need an emergency solution, whereas recommending a MBR is practically equivalent to asking these communities to build new WWTFs.

Section 2.4: Effect of Salinity on Oxygen Solubility

In addition to the effect of salt concentration on the organisms within sludge, higher levels of salinity cause oxygen’s solubility in wastewater to decrease. The Virginia Institute of

Marine Science studied the effects of increased salinity on oxygen solubility, particularly in estuaries, and found that as salinity increases in a body of water, oxygen solubility decreases. According to data published by the Fondriest Environmental Group, oxygen solubility in seawater is 20 percent less than that of fresh water at the same temperature and pressure (FEG, 2014). On a molecular level, this is due to the fact that water is made up of polar molecules. When salt ions are added, they attract the water molecules better than the non-polar oxygen molecules, leading to less oxygen being able to remain dissolved in the solution.

Furthermore, the diffusivity of oxygen through water may also be affected by increased salinity. A study published in the *Journal of Experimental Marine Biology and Ecology* found that the diffusivity of oxygen in water decreases as salinity levels are increased. The authors attributed this to salt's effect on the activity coefficient, a measure of how much a solution deviates from thermodynamically expected behavior (Cao, 2015).

The effects of salinity on oxygen solubility and diffusion are of importance to wastewater treatment because of the impacts to the activated sludge process. The bacteria and protozoa in activated sludge are aerobic, meaning that they require oxygen to grow and reproduce. Decreases in soluble oxygen available in the wastewater spurs competition amongst the organisms, hindering overall population size and growth rate. Fewer organisms decrease the effectiveness of the sludge to remove soluble organics from the wastewater process stream.

Chapter 3: Methodology

The main objective of this project was to gain a better understanding of the impacts of increased salinity on the biological and chemical processes within WWTFs. The goal was to determine a critical salinity threshold, at which the amount of salt would no longer allow a facility to operate normally. Salinity management and mitigation techniques were then developed from this threshold. In order to do so, the following experimentation was performed as outlined in the sections below.

Section 3.1: Artificial Seawater

Components were added to wastewater samples in order to artificially reproduce saltwater intrusion on a WWTF in accordance with ASTM D1141 - 98 (2013): Standard Practice for the Preparation of Substitute Ocean Water. The procedure, as shown in Appendix A, gives quantities to create a one-liter, 3.5 percent salinity by weight solution. Quantities were manipulated using these standard ratios to create solutions of lower and higher salinity and scaled to provide the required amount of seawater.

Section 3.2: Respirometry

Respirometry tests were run on wastewater to determine BOD removal at varying levels of salinity. The wastewater was diluted with artificial seawater, as well as deionized water, to produce 500 mL of solution at a desired salinity level. Each sample was then placed in a respirometer reaction vessel along with a headspace vial containing 5 mL of 30 percent potassium hydroxide by weight to absorb any carbon dioxide produced. The sample was mixed at 700 rotations per minute (rpm) for the duration of the test. Each vessel was tightly sealed and connected via a tube and needle to the respirometer flow-cell base. The base, which sourced oxygen from a tank, added oxygen to the sample in order to maintain a constant oxygen content in the reaction vessel. A computer attached to the base measured and recorded the amount of oxygen added over time. Each sample was tested for a period of 48 hours. The full experimental procedure can be found in Appendix B.

Section 3.3: Sedimentation

Sedimentation tests were run to determine the impact of varying levels of salinity on the sedimentation process. To achieve differing salinity levels, wastewater samples were diluted with an artificial seawater solution and deionized water to a total of 500 mL. Initial turbidity readings were taken for each sample using the Hach 2100N Turbidimeter. Samples were placed on a paddle mixer and set at a rapid mix rate between 150 and 200 rpm for approximately two minutes. After this time, paddle speed was reduced to approximately 30 rpm for 20 minutes to allow for the formation of flocs. Next, the paddles were turned off and the flocs were left to settle for another 20 minutes. After settling, approximately 3 mL of supernatant were pipetted from each solution and diluted to a factor of 3/28 using deionized water before measuring the final turbidity. A full experimental procedure can be found in Appendix C.

Section 3.4: Oxygen Solubility

Oxygen solubility experiments were run on samples of wastewater to determine how salinity affects the amount of soluble oxygen in wastewater. To do so, samples of wastewater were diluted using artificial seawater and deionized water to make 250 mL of solution at a desired salt concentration. Each sample was placed into a flat bottom flask connected to an oxygen source. Oxygen was bubbled through until the system reached steady state. A dissolved oxygen probe was used to measure the amount of oxygen dissolved in the wastewater sample. A full experimental procedure can be found in Appendix D.

Chapter 4: Results and Analysis

Section 4.1: Salinity and Sedimentation

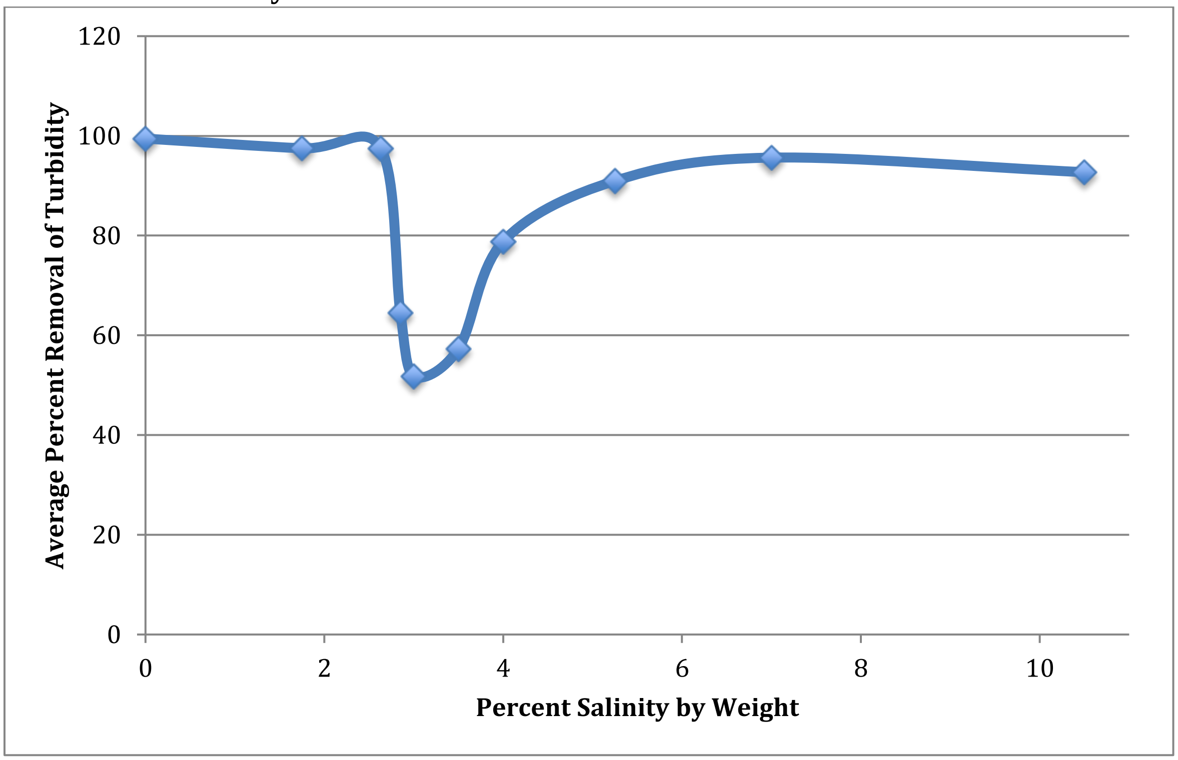


Figure 4.1: Average Percent Turbidity Reduction

The data presented above represents the average removal of turbidity found during sedimentation experimentation. During the tests, saline solutions were added prior to taking initial turbidity values. For this reason, the data is shown as percent changes from initial to final turbidity levels in the samples after sedimentation occurred. Trends in the data show that turbidity removal decreased as the salinity levels in the samples increased. However, once the salinity within the sample reached four percent, turbidity removal increased. Although the 10.5 percent sample does not follow this trend, it is attributed to the fact that excess salt particles contributed to a more turbid solution. Seven percent salinity by weight represents a sample that is entirely composed of seawater; therefore 10.5 percent salinity represents an extremely salty solution, in which the particles have trouble dissolving entirely. This is in accordance with research published on the *Fresenius Environmental Bulletin*, which stated that the supernatant of certain sludge becomes rather turbid at salinity above five percent (Tan, 2016).

While high salinity solutions exhibited almost as much turbidity removal as the baseline samples, the suspended solids in these samples floated to the top as opposed to settling to the bottom, as shown in Figure 4.2 below.

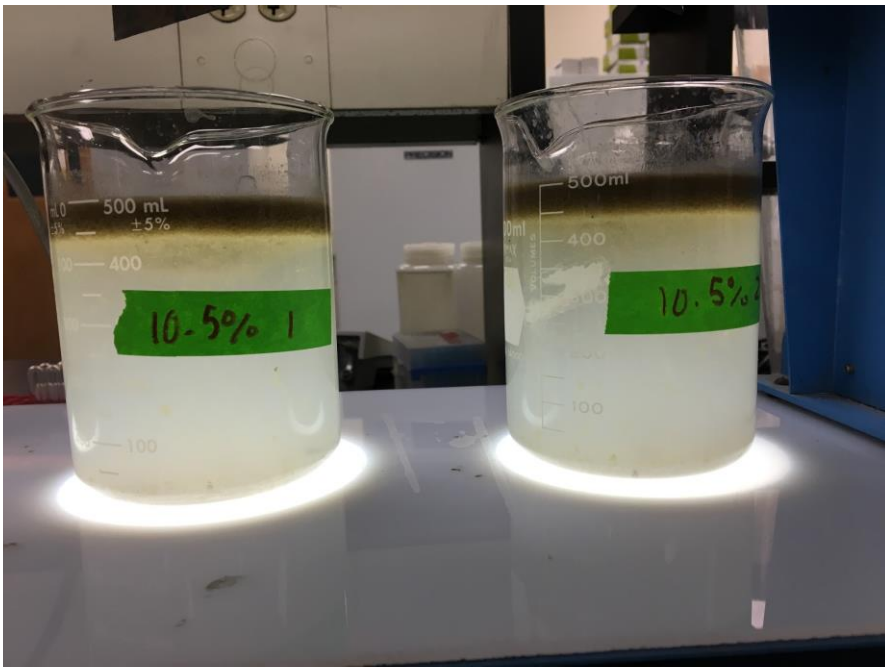


Figure 4.2: High Salinity Sedimentation

This phenomenon is due to the fact that the added salt in these samples increased the density of the water above that of the suspended solids, causing them to float. This may prove ineffective in commercial and industrial settings where equipment is typically designed to remove sludge from the bottom of a tank rather than the top.

The critical salinity threshold is then twofold: at salinity percentages above 2.63, there is a significant decrease in turbidity removal and at salinity percentages above three, flocs begin floating to the top.

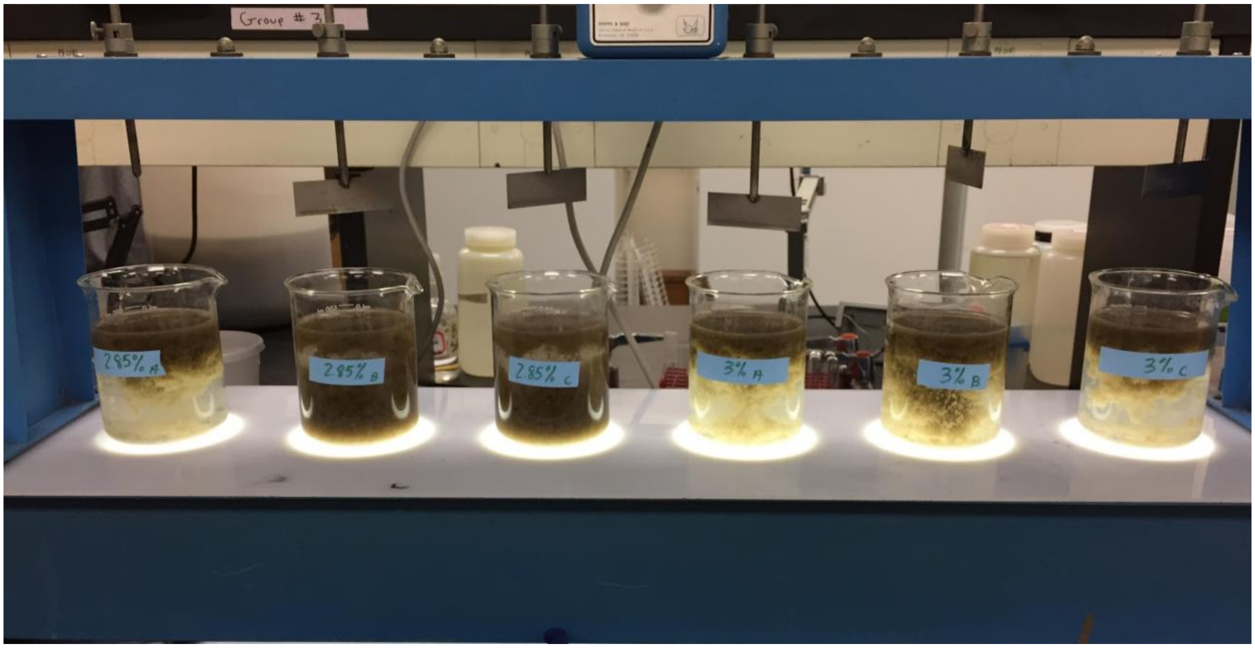


Figure 4.3: Sedimentation Experimentation Results

As shown in Figure 4.3 above, at 2.85 percent salinity by weight, separation is weak and flocs both settle to the bottom and float to the top. Furthermore, the results are inconsistent, which would make treatment difficult for a facility. This means typical sedimentation processes would no longer be effective with influent composed of 40 percent seawater. At salinity levels above three percent, separation is still weak, however flocs float entirely to the top rather than settle to the bottom, indicating that I/I resulting in 43 percent seawater would require skimming sludge from the top of the tank rather than the bottom.

These results confirm previous studies of salinity's effect on sedimentation. The 1997 study by Smythe published in the *Journal of Environmental Progress* attributed salinity with decreased efficacy of sedimentation due to changes in water density. Smythe argued that his data showed that as water density became closer to that of the suspended solids, the separation of the two was hindered. These findings confirm this as turbidity removal was found to decrease around 2.85 percent salinity, but increase above levels of 3.5 percent salinity by weight.

Also confirmed by these results is the theory that high levels of salinity cause quicker separation of water and suspended solids. Separation in samples greater than or equal to seven percent salinity was observed to occur significantly quicker than samples with lower salinity. For example, samples containing 10.5 percent salinity were observed to separate within a few minutes of the saline solution being placed in the wastewater, and would require mixing prior to taking the initial turbidity measurement. These high salinity samples would again separate almost to completion within 30 seconds of the settling period after flocculation. Given, however, that the suspended solids in these samples floated to the surface, the more rapid rate of separation may not be beneficial for commercial and industrial uses.

Section 4.2: Salinity and Dissolved Oxygen

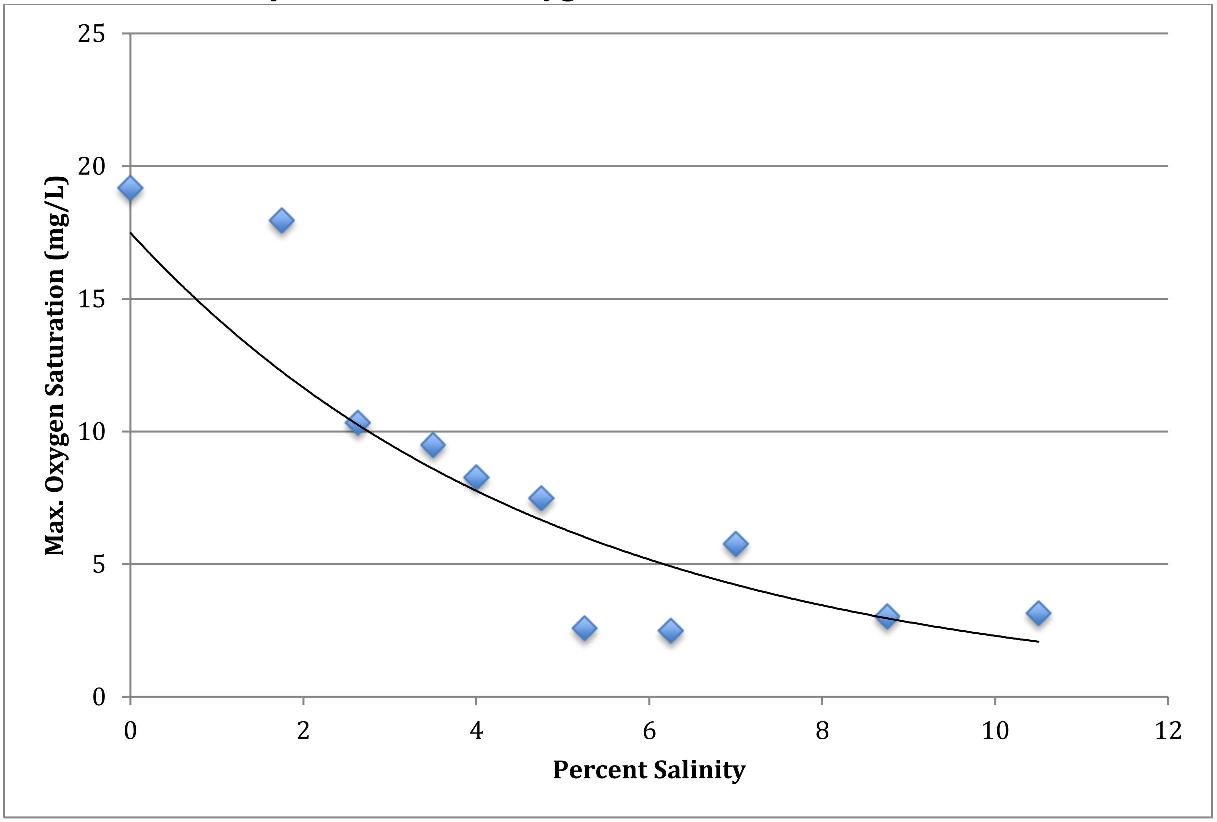


Figure 4.4: Maximum Oxygen Saturation vs. Percent Salinity

The graph above shows the maximum oxygen saturation of wastewater between 15 and 17°C at varying salinity levels. Factors had to be closely monitored as the solubility of oxygen varies greatly based on temperature, pressure, and salinity. Only data within a specific temperature range is presented in Figure 4.4, as the dissolution of oxygen in water is an exothermal process, therefore, colder temperatures shift the equilibrium towards the dissolved form.

The maximum dissolved oxygen concentration of water between 15 and 17°C is between 9.65 and 10.07 mg/L (EPA, 2012). It is clear, therefore, that the wastewater solutions used in this experiment were supersaturated most likely due to rapid aeration and the excess of organic material in the water. This is not surprising as organic materials retain more soluble oxygen in solution, and the oxygen was bubbled directly into the samples minimizing mass diffusion limitations. The baseline sample was approximately 194 percent saturated, whereas the sample with 4.75 percent salinity by weight was only about 78 percent saturated, indicating that the ability of the microorganisms to intake oxygen decreases as salinity increases.

Trends in the data align with previous studies, such as that of the Virginia Institute of Marine Science, in that dissolved oxygen decreases as salinity increases. The average DO of a baseline sample of wastewater containing no salinity was measured to be 19.18 mg/L. Once salinity was increased to just 2.63 percent by weight, the average DO decreased to 10.33 mg/L – a 46 percent drop in DO within a salinity change of less than 3 percent. Furthermore, the data also reaffirms a study published in 2014 by the Fondriest Environmental Group, which claimed that oxygen solubility in seawater is 20 percent less than that of fresh water. DO at seven percent salinity by weight, the concentration of seawater, was 5.77 mg/L, which is 30 percent of the baseline DO of 19.18 mg/L. The excess organic material in wastewater can account for the 10 percent difference in oxygen solubility.

Oxygen solubility less than 2 mg/L has been shown to have significant effects on water quality. Below 2 mg/L, the wastewater is at risk of dead zones, which will promote anaerobic conditions (Wilén, 2010). It is typical to design between 25 and 75 percent of the minimum operating values; therefore WWTFs require a maximum oxygen saturation of at least 8 mg/L (Turton, 2008). At four percent salinity by weight, the average DO was measured to be 8.28 mg/L, but at 4.75 percent salinity by weight, the average DO was 7.49 mg/L, below the critical threshold. Using the trend line equation, $y = 17.484e^{-0.232x}$, it was calculated that the critical salinity threshold sits at 3.85 percent salinity by weight, meaning that wastewater containing more than 55 percent seawater will not meet DO requirements, potentially rendering the aeration process insufficient. Although 55 percent seawater would indicate a larger I/I event, respirometry data provides evidence of microbial inhibition at lower salinity levels, which also greatly affect the aeration process. For a more detailed discussion regarding respirometry, refer to Section 4.3 below.

It is interesting to note that for both DO and sedimentation experimentation, the critical salinity threshold lies between two and four percent salinity by weight. Additionally, in both, 3.5 percent salinity by weight represents a turning point in the data. For oxygen solubility, salinity around 3.5 percent marks the beginning of the downfall of DO towards a dangerous level, whereas, in sedimentation, it marks the beginning of increasing average percent removal of turbidity. Clearly, when wastewater is comprised of 50 percent seawater, it substantially alters the chemical and biological composition of the solution wherein it no longer behaves as anticipated.

Section 4.3: Salinity and Respirometry

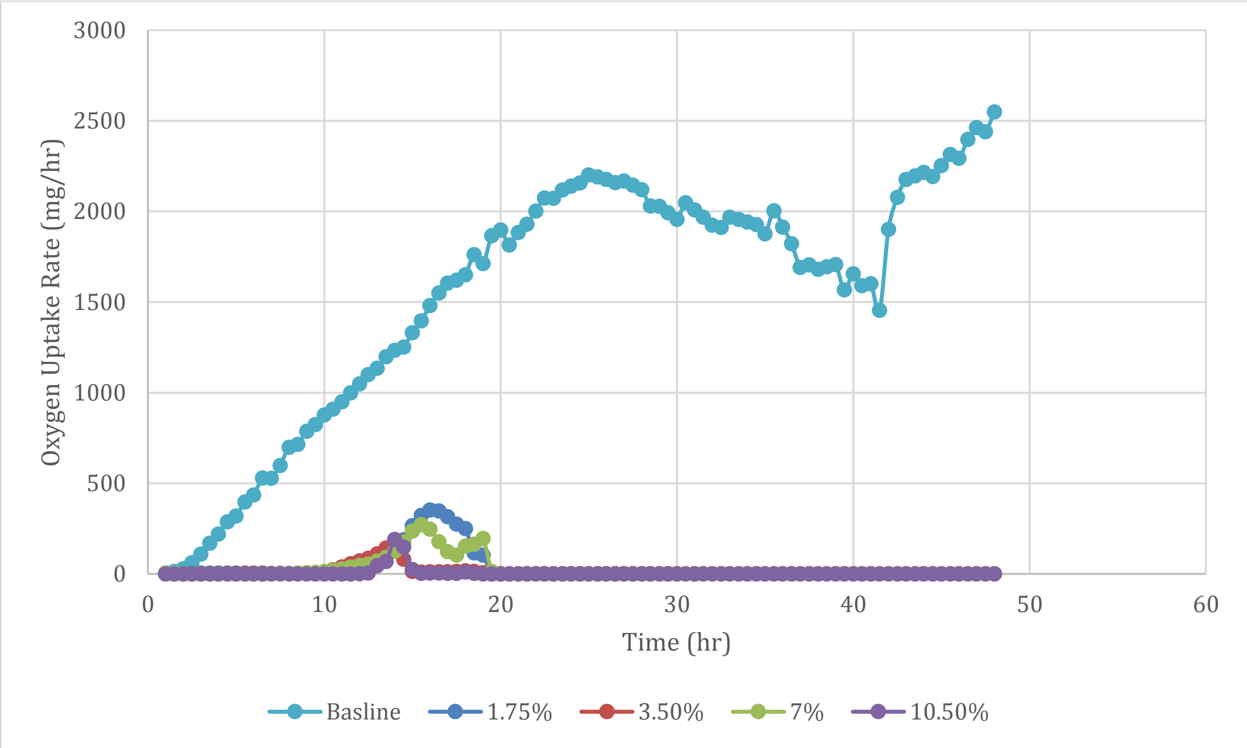


Figure 4.5: Oxygen Uptake Rates vs. Time

The data shown in the graph above represents the Oxygen Uptake Rate (OUR) found during the respirometry experimentation over a period of 48 hours at various levels of salinity. For each level of salinity, the respirometry experiment was run on three duplicate samples and the resulting data was averaged to create the trends shown above. Baseline samples containing no added salt exhibited the largest OUR, far exceeding the rates produced by samples at higher salinity concentrations. As discussed previously, the microorganism populations within samples require oxygen to consume soluble organics, therefore OUR is a direct indicator of cell growth and BOD removal.

As expected, in the samples in which no salt was added, the OUR was highest but as the salinity level increased, the OUR dropped considerably. The significant decrease in OUR between the baseline samples and those at salinity levels of 1.75 percent confirms the finding of the Tan study conducted at the Harbin Institute of Technology, which found that Conventional Activated Sludge exhibited a severe loss of bioactivity and diversity at concentrations around two percent.

Also supported by this data are Tan's findings that organisms could be cultured in solutions with elevated salt concentrations in an effort to adapt them to higher salinity. Figure 4.6 below shows a subset of the OUR graph in Figure 4.5 above.

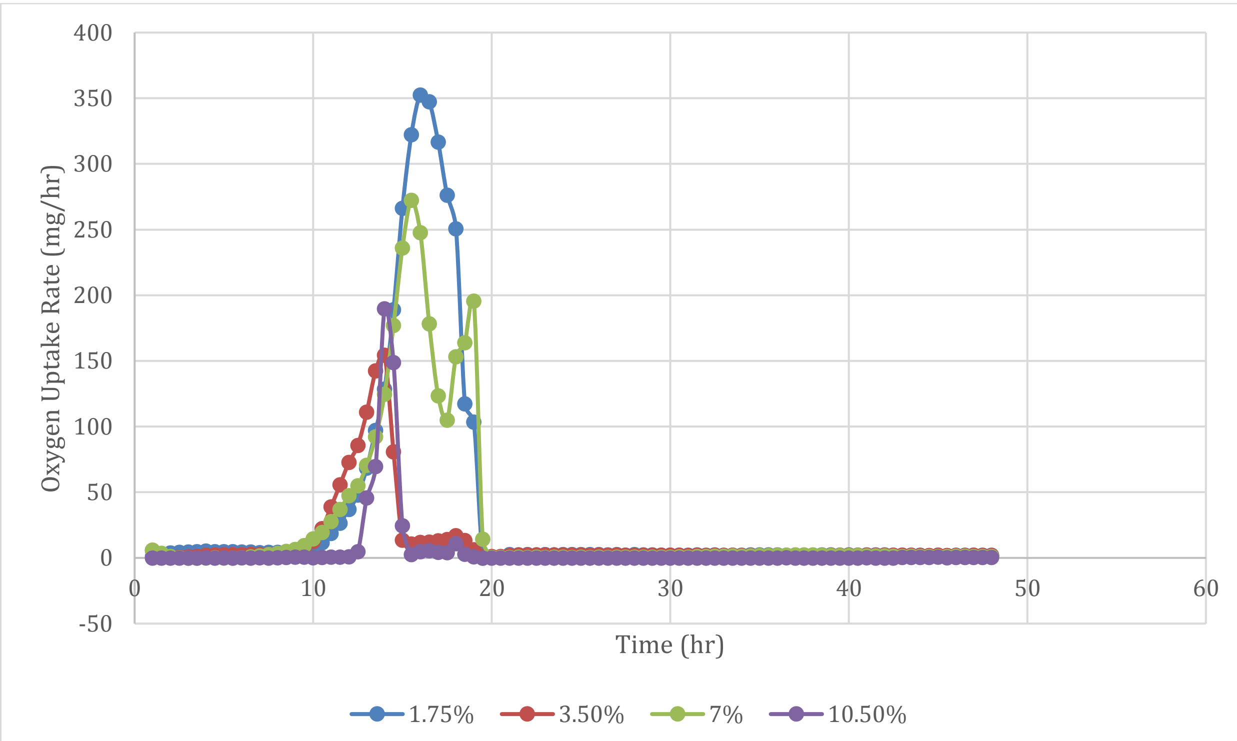


Figure 4.6: Enlarged Oxygen Uptake Rate vs. Time

In the samples with added salt, OUR did not begin to increase until 10 to 13 hours into the experimentation. This phenomenon, known as lag time, is indicative that the microbes within the sample required time to adapt to their saline shocked environment. Following the lag phase, the microbes began to consume oxygen, indicating adaption to the additional salinity. OURs within these samples, however, recovered only to a small fraction of the baseline OUR.

Trends in the data show that samples with higher salinity will experience a significant decrease in OUR and increase in lag time, illustrating that salinity negatively effects the microorganism populations within activated sludge crucial to BOD removal. At salinity levels as low as 1.75 percent by weight, the aeration processes of wastewater treatment are expected to be greatly hindered. While some level of aeration will continue to occur at any salinity level, the 'critical threshold' is anything above zero percent salinity by weight, as the extreme reduction in BOD removal will disrupt downstream treatment processing and overall water effluent quality. These findings were used to develop and design methods by which WWTFs can respond to disturbances in salinity within wastewater to minimize the effects on aeration processes.

Chapter 5: Design

Through bench-scale experimentation, it was identified that increased levels of salinity greatly affect the sedimentation and activated sludge processes in WWTFs. Salinity ranging between 2.63 to 5.24 percent by weight exhibited poor floc separation and, therefore, the sedimentation processes cannot be sufficiently completed. At 5.25 percent salinity by weight and above, flocs aggregate and float to the top of the water. When activated sludge comes into contact with wastewater containing salinity over 2.63 percent by weight, there is a longer acclimation period for microorganisms and BOD removal is diminished. To mitigate both of these issues, a salinity monitoring system was designed to be put into place before primary settling. During salinity disturbance events, the evaluation system will trigger newly-designed technologies that address the issues salt imposes on the activated sludge and sedimentation processes. The details of each design are discussed below, and derivatives and example calculations can be found in Appendix F-J.

Section 5.1: Activated Sludge Reseeding System Design

In order to address the negative effects of salinity on the microorganism populations within the activated sludge used in the activated sludge process, it is recommended that a sample of activated sludge be maintained in a reseeding tank separate from the processing stream. This sample, which can be isolated from the system in the event of a spike in salinity, would be used to reseed the activated sludge process in an effort to restore the system following salinity levels returning to normal operating conditions.

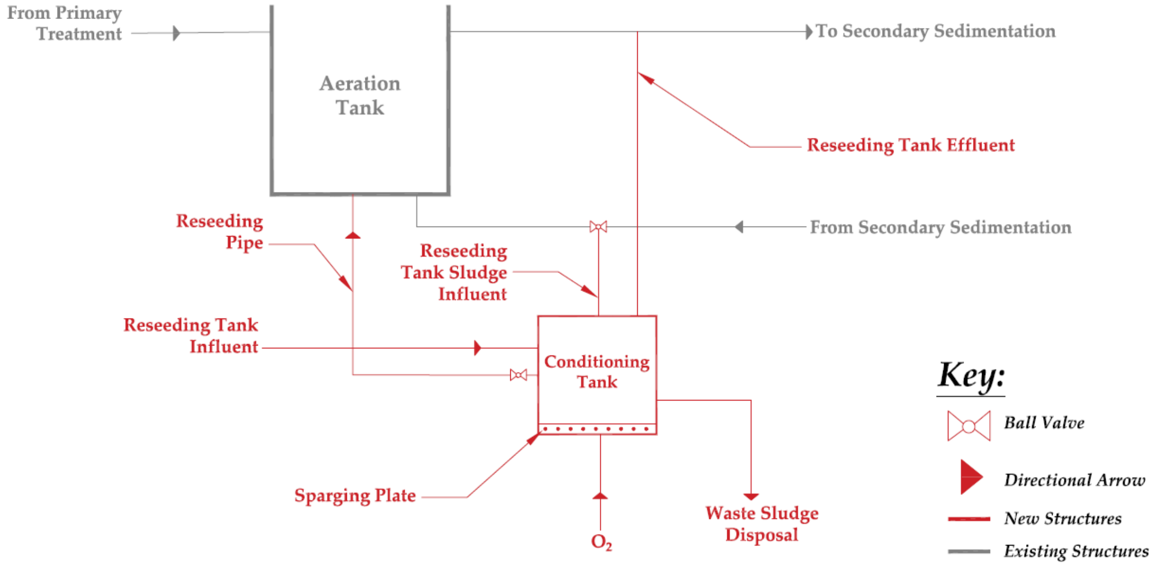


Figure 5.1: Activated Sludge Reseeding System Schematic

As shown in Figure 5.1 above, the reseeding tank is placed in parallel to the aeration tank. Sludge for the reseeding tank is pumped from the secondary sedimentation tank via the reseeding sludge influent pipe on the sludge recycle stream. Wastewater is taken from the influent stream into the plant to provide the necessary organic matter for microbial growth within the reseeding tank. Oxygen, a requisite nutrient, is sparged at the bottom of the tank. This not only maintains required DO levels, but also provides the system with low shear mixing. Once wastewater is stripped of its organic materials within the reseeding tank, it is pumped via the reseeding effluent pipe into the secondary sedimentation tank. The concentration of activated sludge within the reseeding tank should be equivalent to the concentration within the main aeration tank. For details on sizing of the pipes and reseeding tank, refer to Section 5.3 below.

Section 5.2: Sedimentation Process Design

Findings show that wastewater containing salinity concentrations between 2.64 and 5.24 percent salinity by weight does not flocculate, and therefore the clarification process will not be effective. To address this issue, it is recommended to redesign the secondary sedimentation system to input ocean water to increase the salinity to a level where flocs will float and, in essence, flip the tank to skim sludge from the top and dispel clean water from the bottom.

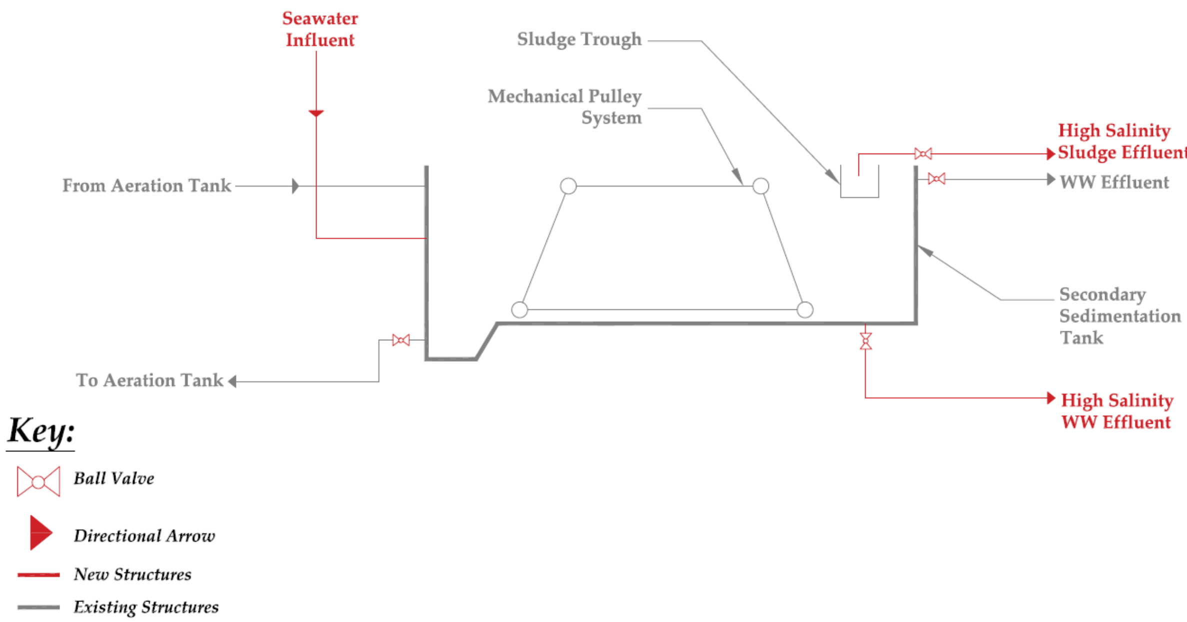


Figure 5.2: Sedimentation System Schematic

In order to flip the tank, as shown in the Figure 5.2 above, both sludge and effluent pipes are placed on both exits of the tank. Clean water is piped from the bottom of the tank directly to the next stage of the treatment process via a chlorinated polyvinyl chloride (CPVC) pipe and continues on normally. CPVC is recommended as it is a cheaper, lighter weight, and easier to install alternative to metallic piping. Additionally, the extra chlorination of the polyvinyl chloride resin makes it resistant to degradation and bacteria formation, which is especially advantageous in the handling of ocean water and sludge.

Sludge is collected in the trough typically designated for skimmings and floated debris, and piped out via a CPVC pipe. The new sludge pipe is larger than the existing to account for the high flow rate needed to ensure that flocs to do not overflow from the trough. For sizing specifications, refer to Section 5.3 below. Due to the fact that the trough is traditionally intended for small amounts of organic material, it may be beneficial to also resize it to be larger if the WWTF experiences frequent disturbances. In addition, the mechanical sludge scraper system must be turned off during a disturbance to keep flocs afloat and ensure proper flow. Ball valves are placed on all existing and new effluent and sludge pipes to control the flow of sludge and clean water as needed.

A pump transfers seawater into the sedimentation tank via a CPVC pipe. The pump contains a screen to ensure aquatic plants and animals do not enter the system. For pump specifications, refer to Section 5.3 below. Seawater is added to the tank according to the following equation:

$$Q_s = 3Q_w - \left(\frac{x_w}{0.0175}\right) Q_w$$

where Q_s is the volumetric flow rate of seawater to be added, Q_w is the volumetric flow rate of wastewater present, and x_w is the concentration of salinity present in the wastewater. For detailed calculations, refer to Appendix E. The flow rate of wastewater from the existing influent must be slowed to account for the additional volume of seawater to the tank.

Considering that seawater contains approximately seven percent salinity by weight, depending on the frequency of disturbances, the sedimentation tank may degrade as a result of the salt. It is recommended that operators inspect tanks post-disturbance to evaluate the degree of rehabilitation required. If necessary, a polyurethane or polyurea resin spray coating can be applied to the concrete.

Section 5.3: Sizing Calculations

Section 5.3.1: High Salinity WW Effluent and Seawater Influent Pipe Sizing

The following equations may be used to calculate the proper pipe diameter for the Salinity Effluent Pipe and Seawater Influent Pipe (schematic 5.3):

$$D_{we} = 656.98 \times Q_{we}$$

$$D_{si} = 166.7 \times Q_{si}$$

Where:

$D_{we} = Diameter\ of\ Disturbance\ WW\ Effluent\ Pipe$ (m)

$D_{si} = Diameter\ of\ Seawater\ Influent\ Pipe$ (m)

$Q_{we} = flowrate\ through\ Disturbance\ WW\ Effluent\ Pipe$ (m^3/s)

$Q_{si} = flowrate\ through\ Seawater\ Influent\ Pipe$ (m^3/s)

These values are based on a laminar flow profile for the wastewater (Re = 1900) and turbulent flow (Re = 7500). They are a function of volumetric flow rate, Q (m^3/s), through each pipe. Derivations and physical fluid properties used to develop these equations can be found in Appendix F.

Section 5.3.2: High Salinity WW Effluent and Seawater Influent Pump Sizing

In order to calculate the pump power, U (kW), required per unit length (m) for the High Salinity WW Effluent and Seawater Influent Pipes (schematic 5.3), the following equations may be used:

$$U_{we} = \frac{7.97 \times 10^{-17}}{Q_{we}^2}$$

$$U_{si} = \frac{9.53 \times 10^{-17}}{Q_{si}^2}$$

Where:

$$U_{we} = \frac{Disturbance\ WW\ Effluent\ Pump\ Energy}{Meter\ of\ Pipe}\left(\frac{kW}{m}\right)$$

$$U_{si} = \frac{Seawater\ Influent\ Pump\ Energy}{Meter\ of\ Pipe}\left(\frac{kW}{m}\right)$$

These equations rely on pressure drop calculations based on a laminar flow profile (Re=1900). Pump energy efficiency is assumed to be 70 percent and the equations are presented as a function of the anticipated flow rate, Q (m^3/s), through each pipe. Derivations of the pump power equations, pressure drop values, and physical fluid properties used can be found in Appendix G.

Section 5.3.3: High Salinity Sludge Effluent Pipe Sizing

The following equation may be used to calculate the required pipe diameter of the Salinity Sludge Removal Pipe (Schematic 5.3) based on the flowrate through the pipe (Q_{sr}):

$$D_{se} = \frac{12.85 \times Q_{se}}{Z}$$

Where:

$D_{se} = Diameter\ of\ Disturbance\ Sludge\ Effluent\ Pipe$ (m)

$Q_{se} = flowrate\ through\ Disturbance\ Sludge\ Effluent\ Pipe$ (m^3/s)

$Z = \frac{V_T}{V_S} = Sludge\ collection\ ratio$

$V_T = Volume\ of\ Sludge\ Trough$

$V_S = Volume\ of\ Sedimentation\ Tank$

And

$Q_{se} \geq 0.0856$ (m^3/s)

The values were calculated based on a semi-turbulent flow profile (Re=3500). Based on specifications outlined in the 2014 edition of *Recommended Standards for Wastewater Facilities* published by the Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, a minimum flow rate of Q = 0.0856 m^3/s is required to prevent blockage of sludge removal piping.

In most WWTFs, the volume of the sludge collection trough situated at the top of the sedimentation tank is significantly smaller than the volume of the sedimentation tank. In order to ensure the diameter of the pipe is sufficient to prevent overflow of the trough, a sizing factor, Z, relating the two volumes, is utilized. Derivations and physical fluid properties used to develop this equation can be found in Appendix H.

Section 5.3.4: High Salinity Sludge Effluent Pump Sizing

In order to calculate the pump power, U (kW), required per unit length (m) for the High Salinity Sludge Effluent Pipe, the following equation may be used:

$$U_{se} = \lambda \frac{3.5 \times 10^{-6}}{Q_{se}^2}$$

Where:

$$U_{se} = \frac{Disturbance\ Sludge\ Effluent\ Pump\ Energy}{Meter\ of\ Pipe} \left(\frac{kW}{m}\right)$$

$$\lambda = Darcy - Weisbach\ Friction\ Coefficient$$

This equation relies on pressure drop calculations based on a turbulent flow profile (Re=3500). Pump energy efficiency is assumed to be 70 percent and the equations are presented as a function of the anticipated flow rate, Q (m^3/s), and the Darcy-Weisbach friction coefficient, λ.

The friction coefficient is a function of the Reynolds number (Re), as well as the relative roughness of the piping, defined as the ratio of the absolute roughness to the diameter of the pipe (ε/D). For the recommended CPVC pipe material, the absolute roughness is $\varepsilon = 1.5 \times 10^{-6}$ (m). Once the desired diameter of the High Salinity Sludge Effluent Pipe is determined, the relative roughness can be calculated. This value can be used along with the design Reynolds number (Re=3500) to determine the Darcy-Weisbach friction coefficient using a Moody Chart. The derivation of this equation and physical fluid properties used can be found in Appendix I.

Section 5.3.5: Sizing of Reseeding Tank

The amount of sludge required to reseed the aeration tank following a salinity disturbance is the main determining factor in the sizing of the reseeding tank. According to the EPA's 1973 published guide *Start-Up of Municipal Wastewater Treatment Facilities*, the maximum effective reseeding size for an activated sludge process is ten percent of the total sludge population. Accordingly, the amount of reseeding activated sludge recommended to be retained in the reseeding tank is ten percent of the overall sludge volume in the aeration tank. As such, the volume of the reseeding tank (V_c) must be one-tenth the volume of the aeration tank (V_{aer}).

$$V_c = \frac{V_{aer}}{10}$$

Furthermore, it is assumed that all flows entering and exiting the reseeding tank are ten percent of their analogous flows entering and leaving the aeration tank. As such, the diameter of the pipes connected to the reseeding tank should be designed with diameters ten percent of their existing counterparts. The table below correlates the pipes leading to and from the reseeding tank to their existing system counterparts as labeled in Figure 5.3.

Table 5.1: Pipe Correlation Table

Reseeding System	**Existing System**
Reseeding Tank Influent	Aeration Influent
Reseeding Pipe	Sludge Recycle Pipe
Reseeding Tank Sludge Influent	Sludge Recycle Pipe
Reseeding Tank Effluent	Aeration Effluent

Section 5.4: System Controls and Process Response

A salinity monitoring system must be installed to measure the salinity of wastewater before and primary settling and trigger the control system response. Conductivity is measured to evaluate the salinity concentration. Conductivity is the measurement of water's ability to pass an electrical flow. This is directly related to the concentration of ions in the water -- the more ions present in the water, the higher the conductivity. Waters containing high levels of salinity will, therefore, have high conductivity. The meter uses a probe to measure the conductivity. An electrical current flows between two electrodes within the probe that are set at various distances from each other. The strength of the electrical current measured is directly related to the concentration of ions present, which is a measure of salinity. Readings should be continually taken before primary settling to determine salinity before the next step of the treatment process. If the salinity of the wastewater is above 2.63 percent by weight, systematic changes to both the activated sludge and secondary sedimentation processes will be triggered as shown in Figure 5.3 below.

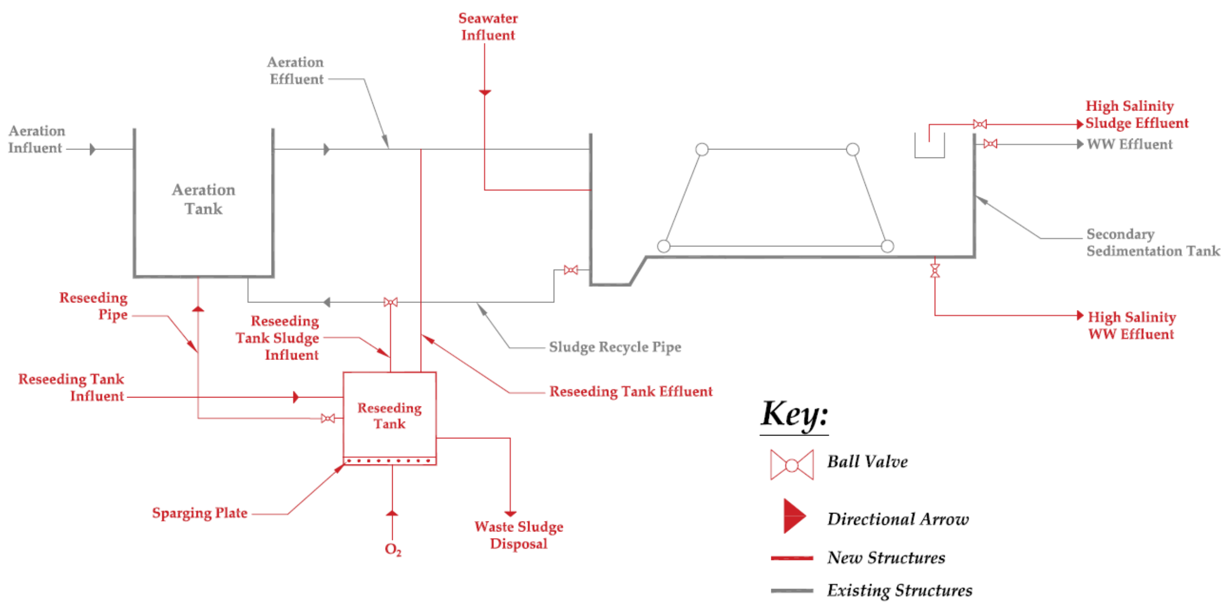


Figure 5.3: Overall System Schematic

Following a measured disturbance in the level of salinity above 2.63 percent, the process response will be triggered by the control system in the following order:

1. Wastewater entering the reseeding tank via the WW Influent Pipe will be stopped.
2. Sludge entering the reseeding tank via the Reseeding Tank Influent Pipe will be stopped.
3. Existing WW Effluent Pipe and Sludge Recycle Pipe will be closed.
4. High Salinity Sludge Effluent and High Salinity WW Effluent Pipes will be opened.
5. The sludge scraper will be turned off.
6. Seawater will be pumped into the sedimentation tank via the Seawater Influent Pipe.
7. Once the disturbance is observed to have ended and salinity levels return to normal operating conditions, the process response will occur in the following order:
8. All piping will return to its pre-disturbance state.
9. The sludge scraper will be turned on.
10. Reseeding sludge from the reseeding tank will be pumped into the aeration tank.

Conclusion

Through bench scale experimentation which replicated the chemical and biological processes related to wastewater treatment, the impacts of salinity on WWTF was successfully studied. Critical salinity thresholds for activated sludge aeration, sedimentation, and dissolved oxygen levels were determined. Above these thresholds, the treatment processes would need to be modified in order to effectively continue to treat the wastewater. Additionally, design recommendations, which detail how a coastal WWTF could address salinity issues was included.

Prior to this study, little research had been conducted as to the effect salinity has on wastewater treatment. With global warming continuing to raise sea levels and adverse storm events and flooding becomes more common and frequent, the results of this study will become increasingly relevant. The knowledge and data collected over the course of this study can be used to further design salinity mitigation techniques to be used by coastal WWTFs.

Appendix A: Artificial Seawater Generation Procedure

The procedure to create one liter (L) of 3.5 percent salinity by weight artificial seawater as adapted from ASTM D1141 - 98 (2013) is as follows:

1. Label a container *Stock Solution No. 1*
2. Add 555.6 grams (g) $MgCl_2 \cdot 6H_2O$, 57.9 g $CaCl_2$ (anhydrous), and 2.1 g $SrCl_2 \cdot 6H_2O$
3. Dilute to a total volume of 1 L. Store in a well-stoppered glass container.
4. Label a second container *Stock Solution No. 2*
5. Add 69.5 g KCl, 20.1 g $NaHCO_3$, 10.0 g KBr, 2.7 g H_3BO_3, and 0.3 g NaF
6. Dilute to a total volume of 1 L. Store in a well stoppered amber glass container.
7. Pour approximately 0.75 L of wastewater into a separate container.
8. Dissolve 24.53 g sodium chloride (NaCl) and 4.09 g anhydrous sodium sulfate (Na_2SO_4) in the wastewater.
9. Slowly add 20 mL of Stock Solution No. 1 while stirring vigorously.
10. Next add 10 mL of Stock Solution No. 2
11. Dilute to a total volume of 1 L.

Appendix B: Respirometry Testing Procedure

1. Using the Challenge Technology Respirometer, insert a Teflon-coated magnetic stirring bar in each reactor vessel.
2. Connect the clear tubing to the large luer of the manifold on the flow-cell base. Connect the other end to the oxygen cylinder. The open end of the yellow tubing should be attached to the connectors on the top of the manifold, while the end with the luer fitting should be inserted into the matching fitting on the inlet side of the flow-cell. One end of the long pieces (~0.5m) of yellow tubing should be attached to the outside fitting of the flow cells. The other end of the tubing will be attached to a 20-gage needle for connection to each respirometer reaction vessel. Open the oxygen tank and adjust the airflow so that an air bubble is observed in the regulator bottle but not in the manifold cells.
3. Add test waste, or desired volume of test solution to each 500 mL vessel.
4. The volume of the vessel should be at 500 mL. If necessary, add dilution water to make this volume. *Note: the temperature of the water should be around room temperature.*
5. Add 5 mL of 30 percent potassium hydroxide solution to the carbon dioxide absorption tube.
6. Place a KOH absorption tube into each reactor vessel. Add screw cap with inserted butyl rubber septum to each reactor vessel. Tighten to seal.
7. Place reactor vessels on the Challenge MS-304 magnetic stirrer and adjust the stirring to at least 700 rpm.
8. Vent the reactor vessel by momentarily inserting a clean 20-gage needle through the septum. This action equalizes the pressure, prior to the beginning of the test.
9. Attach the flow-cell base to the reactor vessel by inserting the 20 gauge needle in the septum of the vessel. For best results, insert the needle at a 45 degree angle.
10. Start the flow of oxygen into the reactor vessel using a 20 mL syringe and 20-gage needle. Withdraw the headspace gas from each reactor vessel, until one or two counts occur in the flow-cell base. Visual confirmation of gas bubbling through the flow-cell manifold should be made. Check to make sure the counts are registered on the computer.

Appendix C: Sedimentation Testing Procedure

The procedure to measure the turbidity of a sample is as follows:

1. Pour 500 mL of sample at the desired salinity contents in the six beakers.
2. Pipette 3mL of the sample into a turbidity vial. Fill the vial the rest of the way (25mL) with reagent grade water.
3. Gently invert the vial to mix the sample evenly. Be careful not to create air bubbles.
4. Clean the vial with a Kimwipe to ensure there are no scratches or marks. Rinse with reagent grade water if necessary.
5. Place the vial in the turbidimeter with the arrow on the vial facing the line on the inside of the turbidimeter.
6. After 10 seconds has passed, watch the reading closely for another 10-20 seconds. Wait until the results begin to hover over a central value and record that value as initial turbidity.

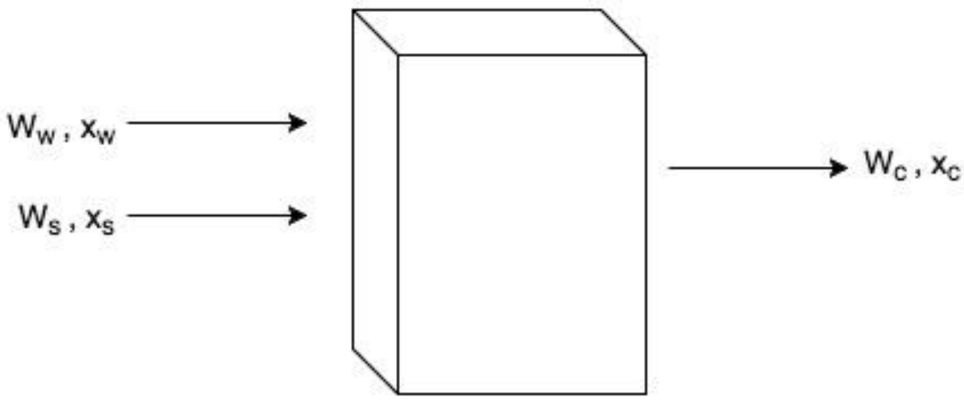
The procedure to test sedimentation and flocculation is as follows;

1. Place beakers onto the Phipps & Bird stirrer and lower paddles into each beaker.
2. Take an initial turbidity measurement from each sample as outlined in the procedure above.
3. Set the paddle speed between 150-200 rpm and mix for two minutes.
4. After two minutes, reduce the speed to 30 rpm and flocculate for 20 minutes. Turn the paddles off and allow the floc to settle for 20 minutes.
5. After the samples have been allowed to settle, take a final turbidity measurement. The samples should be pipetted out of the beaker at a distance of 2/3 of the height of the beaker.

Appendix D: Oxygen Solubility Testing Procedure

1. Charge the beaker with 250 mL of the wastewater sample at the desired salinity level.
2. Place the dissolved oxygen probe into the beaker, ensuring adequate space for effluent gas.
3. Place open tubing connected to an oxygen tank into the wastewater sample and bubble oxygen into the beaker.
4. Allow the system to run until the oxygen level in the sample converges to a steady value.

Appendix E: Seawater Addition Calculation



where W_W = volume of wastewater

x_w = concentration of salinity in the wastewater

W_s = amount of seawater

x_s = concentration of salinity in the sweater = 7 percent

W_c = amount of combined (waste and sea) water

x_c = concentration of salinity in the combined water = 5.25 percent

$$W_c = W_W + W_s$$

$$x_w W_W + x_s W_s = x_c W_s$$

$$x_w W_W + x_s W_s = x_c (W_W + W_s)$$

$$x_w W_W + 0.07 W_s = 0.0525 (W_W + W_s)$$

$$W_s = 3W_W - \left(\frac{x_w}{0.0175}\right) W_W$$

Appendix F: Equations and Physical Properties for Pipe Sizing: High Salinity WW Effluent and Seawater Influent Pipe

$$D = \frac{Re \times \mu}{\rho \times v}$$

$$v = \frac{Q}{A_c}$$

$$A_c = \frac{\pi \times D^2}{4}$$

Where:

D = Diameter of the pipe

Re = Reynolds Number

μ = Fluid Kinematic Viscosity

ρ = Fluid Density

v = Fluid Kinematic Velocity

Q = Volumetric Flowrate

A_c = Pipe cross-sectional area

Fluid Physical Properties:

Wastewater	
Kinematic Viscosity (μ)	1.02×10^{-3} (Pa s)
Density (ρ)	1000 (Kg/m^3)
Reynold's Number* (Re)	1900
Seawater	
Kinematic Viscosity (μ)	1.08×10^{-3} (Pa s)
Density (ρ)	1027 (Kg/m^3)
Reynold's Number* (Re)	7500

** Reynold's number was selected based on desired laminar flow profile*

Appendix G: Equations and Physical Properties for Pump Sizing: High Salinity WW Effluent and Seawater Influent Pipe

$$P_h = \frac{Q \times \Delta p}{700}$$

$$\Delta p = \frac{\lambda \rho L v^2}{2D}$$

$$v = \frac{Q}{A_c}$$

$$A_c = \frac{\pi \times D^2}{4}$$

Where:

Δp = pressure drop along pipe

ρ = Fluid Density

λ = Darcy-Weisbach Friction Coefficient

D = Pipe Diameter

L = length of pipe

v = Fluid Kinematic Velocity

Q = Volumetric Flowrate

A_c = Pipe cross-sectional area

Fluid Physical Properties:

Wastewater	
Friction Factor* (λ)	8.42×10^{-3}
Density (ρ)	1000 (Kg/m^3)
Reynold’s Number** (Re)	1900
Seawater	
Friction Factor* (λ)	8.42×10^{-3}
Density (ρ)	1027 (Kg/m^3)
Reynold’s Number** (Re)	1900

**Friction factor found using moody chart relating relative roughness of piping and Re*

*** Reynold’s number was selected based on desired laminar flow profile*

Appendix H: Equations and Physical Properties for Pipe Sizing: Sludge Effluent Pipe

$$D = \frac{Re \times \mu}{\rho \times v}$$

$$v = \frac{Q}{A_c}$$

$$A_c = \frac{\pi \times D^2}{4}$$

Where:

D = Diameter of the pipe

Re = Reynolds Number

μ = Fluid Kinematic Viscosity

ρ = Fluid Density

v = Fluid Kinematic Velocity

Q = Volumetric Flowrate

A_c = Pipe cross-sectional area

Fluid Physical Properties:

Activated Sludge	
Kinematic Viscosity (μ)	3×10^{-2} (Pa s)
Density (ρ)	1060 (Kg/m^3)
Reynold's Number* (Re)	3500

** Reynold's number was selected based on desired turbulent flow profile*

Appendix I: Equations and Physical Properties for Pump Sizing: High Salinity Sludge Effluent Pipe

$$P_h = \frac{Q \times \Delta p}{700}$$

$$\Delta p = \frac{\lambda \rho L v^2}{2D}$$

$$v = \frac{Q}{A_c}$$

$$A_c = \frac{\pi \times D^2}{4}$$

Where:

Δp = pressure drop along pipe

ρ = Fluid Density

λ = Darcy-Weisbach Friction Coefficient

D = Pipe Diameter

L = length of pipe

v = Fluid Kinematic Velocity

Q = Volumetric Flowrate

A_c = Pipe cross-sectional area

Fluid Physical Properties:

Activated Sludge	
Density (ρ)	1060 (Kg/m^3)
Reynold's Number* (Re)	3500

** Reynold's number was selected based on desired turbulent flow profile*

Appendix J: Example Pipe Sizing

Assumptions:

- The total flow to the plant is 1MGD
- The salinity in the wastewater was measured at 3 percent by weight
- 20 percent of the total flow into the plant passes through the piping at any given time
- Sludge travels through the piping at 0.0856 cubic meters per second
- The sludge collection ratio is 0.5
- The aeration tank is 350 cubic meters

Calculations:

Seawater addition:

$$Q_s = 3Q_w - \left(\frac{x_w}{0.0175}\right) Q_w = 3(0.05) - \frac{0.03}{0.0175} \times 0.05 = 0.64 \left(\frac{m^3}{s}\right)$$

High Salinity WW Effluent and Seawater Influent Pipe Sizing:

$$D_{we} = 656.98 \times Q_{we} = 656.98 \times 0.01 = 6.57\ (m)$$

$$D_{si} = 166.7 \times Q_{si} = 166.7 \times 0.06 = 10(m)$$

High Salinity WW Effluent and Seawater Influent Pump Sizing:

$$U_{we} = \frac{7.97 \times 10^{-17}}{Q_{we}^2} = \frac{7.97 \times 10^{-17}}{0.01^2} = 7.97 \times 10^{-13} \left(\frac{Kw}{m}\right)$$

$$U_{si} = \frac{9.53 \times 10^{-17}}{Q_{si}^2} = \frac{9.53 \times 10^{-17}}{0.06^2} = 2.65 \times 10^{-14} \left(\frac{Kw}{m}\right)$$

High Salinity Sludge Effluent Pipe Sizing:

$$D_{se} = \frac{12.85 \times Q_{se}}{Z} = \frac{12.85 \times 0.0856}{0.5} = 2.19\ (m)$$

Reseeding Tank Sizing:

$$V_c = \frac{V_{aer}}{10} = \frac{350}{10} = 35\ (m^3)$$

Appendix K: list of abbreviations

PE	Professional Engineering
FE	Fundamentals of Engineering
EIT	Engineer in Training
CWA	Clean Water Act
WWTF	Wastewater Treatment Facility
EPA	Environmental Protection Agency
MGD	million gallons per day
I/I	inflow and infiltration
GHGs	greenhouse gases
ppm	parts per million
SLR	sea level rise
MBTS	Manchester by the Sea
SVI	sludge volume index
DO	dissolved oxygen
SBR	sequencing batch reactor
MAS	marine activated sludge
DAS	domesticated activated sludge
CAS	conventional activated sludge
MBR	membrane bioreactor
RPM	rotations per minute
OUR	oxygen uptake rate
CPVC	chlorinated polyvinyl chloride

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