Revised Level Three Response Engineering Report
Boat Haven Boatyard
2790 Washington Street
Port Townsend, Washington

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Prepared for

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1.0 INTRODUCTION

This document presents an Engineering Report as part of the Level Three Response for the Port of Port Townsend (Port) in accordance with the conditions of the Boatyard General Permit (Boatyard Permit) issued by the Washington State Department of Ecology (Ecology). The Port Townsend Boat Haven Boatyard (Boatyard) is located at 2790 Washington Street in Port Townsend, Washington. A vicinity map is provided on Figure 1. An overview of the Port's facility and the storm drain system is shown on Figure 2.

The current Boatyard Permit was issued by Ecology on March 2, 2011 in accordance with the National Pollutant Discharge Elimination System (NPDES) and went into effect on June 1, 2011. It requires that water quality sampling of qualifying storm events be conducted during 5 months of the year at the point of discharge. The Boatyard Permit also establishes "benchmark" concentrations for various parameters, including zinc, with increasing levels of response actions (i.e., Level One, Level Two, and Level Three) being required based on the number of times the benchmarks are exceeded. A Level Three response action was triggered at the Boatyard due to six exceedances of the zinc benchmarks at Outfall A since June 1, 2011, the effective date of the current Permit.

This Level Three Response Engineering Report has been prepared in accordance with the Boatyard Permit, and to meet the applicable requirements of Washington Administrative Code (WAC) 173-240, *Submission of Plans and Reports for Construction of Wastewater Facilities* and Ecology Publication No. 05-10-014, *State Requirements for Submission of Engineering Reports and Plans for Industrial Wastewater Treatment Facilities*. In addition, although this facility is covered under the Boatyard General Permit, not the Industrial Stormwater General Permit, the relevant portions of the February 2013 Ecology document, *Guidelines for the Preparation of Industrial Stormwater General Permit Engineering Reports* (Ecology 2013), were considered.

2.0 BACKGROUND

The Boatyard covers more than 20 acres of land, and activity at the Boatyard includes marine vessel repairs and new marine vessel construction conducted by both boat owners and by marine trade industries, which falls under the Standard Industrial Code (SIC) No. 3732, Boat Building and Repairing. The Boatyard also includes marine supply and equipment businesses and small restaurants. Stormwater at the Boatyard is collected in a stormwater system consisting of catch basins, vaults, and underground pipelines, and is discharged to Puget Sound (Port Townsend Bay). A portion of the stormwater from the Boatyard is treated in four perimeter sand filters and in two StormwateRx® Aquip® adsorptive media filtration systems. The stormwater drainage system, treatment facilities, and outfall points of discharge are shown on Figures 2 through 6. Stormwater runoff from areas where boat hull work is performed drains to Outfall A. The area that drains to Outfall B is limited to buildings and roadways where boats are not stored and where boat maintenance activities are not conducted. Boat repairs, construction, cleaning, and maintenance are conducted in all six of the main Boatyard drainage areas identified as Vault 1, 2, 3, and 4, West Sims, and East Sims on Figure 2. Figure 3 shows a more detailed view of the storm drain conveyance system for the eastern portion of the Boatyard and Figure 4 shows a more detailed view of the storm drain conveyance system for the western portion of the boatyard.

2.1 POTENTIAL SOURCES OF ZINC

Potential sources of zinc at the Boatyard include boat bottom paint and particulates generated during boat bottom maintenance and repair (which is also the primary potential source of copper at the Boatyard), galvanized roofs and fencing, leaks or spills of motor oil or hydraulic fluid, and wear of vehicle and boat travel lift tires. It is also possible that solids accumulated in surface soil, in storm drain structures, and possibly in the four perimeter sand filters at the Boatyard are sources of zinc and copper through re-entrainment into stormwater.

An effective way to reduce zinc concentrations at Outfall A would be to eliminate zinc sources through education and enforcement actions, in addition to the stormwater treatment best management practices (BMPs) described in this report. Source control efforts at the Boatyard are discussed further in Section 3.0.

2.2 EXISTING STORMWATER TREATMENT

The Port installed a stormwater collection and conveyance system in 1996 that included stormwater treatment elements including oil/water separator vaults (which also allow settling and removal of suspended solids) and sand filters. Additional stormwater treatment features were installed in 2011 as part of a stormwater improvement project partly funded by Ecology. A description of the current stormwater treatment elements at the Boatyard is provided below.

2.2.1 StormwateRx Aquip Systems

The Port is treating stormwater from a large portion of the Boatyard using two StormwateRx Aquip treatment units. These systems are passive adsorptive media filtration systems specifically designed for treatment of stormwater pollutants such as suspended solids and metals from industrial sites, including boatyards. In the Aquip system, stormwater first passes through a pretreatment chamber for pH buffering and gravity-settling of sediment (and associated pollutants), and then into a treatment chamber that contains a series of inert and adsorptive filtration media. The filtration media trap pollutants and remove total, dissolved, and ionized pollutants by chemical precipitation, adsorption, microsedimentation, and filtration. A StormwateRx Aquip model 210SBE unit was placed adjacent to Vault 1, and a model 160SBE unit was placed adjacent to Vault 4. The Port referred to the 210SBE system at Vault 1 as the "Boatyard" Aquip and the 160SBE system at Vault 4 as the "West End" Aquip. The systems were placed above ground on level concrete pads, in the locations shown on Figures 5 and 6. Stormwater is pumped out of the effluent chambers of the vaults by dual sump pump systems in each vault and pumped to the StormwateRx Aquip inlets. The treated stormwater then discharges by gravity to catch basins CB-22 and CB-65 for the Boatyard and West End Aquip units, respectively.

A Stormwater Treatment Results and Project Completion Report (Completion Report, Landau Associates 2011) was issued in 2011 and summarizes a previous investigation into available and applicable BMPs implemented in 2007 and the subsequent actions taken, including installation of the two Aquip treatment units. The Completion Report also states that it was financially infeasible to provide enhanced treatment for all stormwater runoff at the Boatyard, and the Vault 1 and Vault 4 drainage basins were chosen for implementation of the Aquip units, based primarily on levels of boat repair activity and sampling results for copper concentrations from all boatyard drainage areas that drain to Outfall A. Zinc concentrations from prior monitoring were not taken into account, although zinc concentrations tend to be elevated at the same locations as elevated copper concentrations. The Aquip units were installed with the option of relocating them if it is determined that stormwater treatment in a different drainage basin would increase overall treatment effectiveness.

Ecology's own analysis of BMPs for boatyards (Ecology 2010a) identified the StormwateRx Aquip treatment units as demonstrating the best performance at the lowest cost among three treatment technologies tested in the Boatyard Stormwater Treatment Technology Study (Taylor Associates 2008). The Aquip units employed at the Boatyard have not achieved the same level of metals removal effectiveness as indicated by data presented by Ecology in the Permit Fact Sheet (Ecology 2010b), which had supported Ecology's selection of the copper and zinc benchmark values as technologically achievable.

The metals adsorption media in the Aquip unit that treats stormwater from Vault 1 was determined to have become spent and was replaced with new media in October 2012 provided by the treatment system vendor, StormwateRx. In addition, a broken weir in an upstream flow splitter (CB 58) was previously identified as a potential cause of stormwater bypassing the Aquip unit that treats stormwater from Vault 4. The weir was repaired in August 2012. Since then, concentrations of metals in the influent to the Aquip unit and the effluent from the Aquip unit have increased, indicating the repaired weir appears to have fixed the bypass issue, but that metals concentrations in stormwater from this drainage area are higher than were previously thought. However, the Aquip unit treating stormwater from Vault 4 is now removing a higher percentage of the metals load from Outfall A. Stormwater sampling results from Outfall A after these two maintenance activities show a decrease in metals concentrations compared to the April 2012 sampling event, but sampling results from the influent and effluent of both Aquip units in November 2012 and of the Vault 1 Boatyard Aquip in February 2013 indicate that they are not performing optimally. The less-than-design level of zinc and copper removal by the Aquip units is of special concern at Vault 1 in light of the media replacement in October 2012.

Tide Gate 2, as shown on Figure 4, is located to prevent the backflow of marine water from Outfall A into the storm drain system during high tides. Until recently, it was believed that this tide gate did not provide full backflow prevention, as some marine water was detected in the upstream storm drain system, specifically at Vault 1. The performance of the Aquip unit at that location was likely negatively affected from treatment of marine water, which may partially explain that system's poorer than expected removal of metals. An investigation revealed that a City of Port Townsend stormwater outfall at the eastern edge of the Boatyard did not have a backflow prevention device, and during high tides marine water was briefly ponding in an area near the northeastern corner of the Boatyard, and from there the marine water entered the Boatyard storm drain system through catch basin CB 29C. At the Port's request, the City installed a backflow prevention device at the aforementioned outfall in March 2013.

2.2.2 PERIMETER SAND FILTERS

There are four existing perimeter sand filters at the Boatyard, one filter in each of the East Sims and West Sims drainage areas as shown on Figure 3, and filters B5 and B6 in the Vault 4 drainage area as shown on Figure 4. These four sand filters provide capacity to filter some of the stormwater runoff from these drainage basins. In 2009, it was determined that the sand filters were very conservatively designed with respect to allowable flow, and the Port enlarged the flow control orifices in the upstream structures to enable higher flow rates to the filters prior to bypass as was described in the Stormwater Treatment

Improvements Design Report (Landau Associates 2010). However, visual observation of the sand filters since 2010 indicates the orifice sizing is still conservative, as no stormwater ponding or flooding has been observed at the surface of any of the four sand filters. The existing sand filters could provide additional removal of metals from stormwater if further flow control improvements are made.

2.2.3 Sand Filters in Traffic Area of Vault 1 Drainage Basin

The Vault 1 drainage basin includes sand filters, which were designed to collect runoff from traffic areas and provide some filtration prior to draining to Vault 1 and discharging to Outfall A. The locations of the Vault 1 drainage basin traffic area sand filters are shown on Figure 3. However, Boatyard personnel have reported that these filters became clogged not very long after installation in 1996, and stormwater runoff from these areas is currently draining by surface flow to catch basins without filtration. Because it was believed that this area would be subject to too much traffic and plugging with solids, rehabilitation and maintenance of the existing Vault 1 area sand filters was not previously identified as an option in the Level 2 Source Control Report (Landau Associates 2013). However, the Port has recently concluded that rehabilitation and maintenance of the existing Vault 1 area sand filters could be a viable alternative to reduce the solids loading to Vault 1 and the subsequent Aquip unit, as the Port has determined a way to reroute and block heavy traffic over the sand filters in this area.

2.3 EVALUATION OF APPLICABLE STORMWATER TREATMENT BEST MANAGEMENT PRACTICES

Applicable stormwater treatment BMPs were evaluated in a Level 2 Source Control Report (Landau Associates 2013). The stormwater source control and treatment BMPs that were identified and evaluated as potential solutions to reduce Port stormwater zinc levels to below Permit benchmark values include: Re-bedding the existing sand filters, optimizing the existing StormwateRx Aquip units, installing downspout filters or seal-coating roofs, adding or replacing a tide gate, electrocoagulation, infiltration, adding an additional Aquip unit, discharging stormwater to the sanitary sewer, and installing roofing over hull preparation areas. The Level 2 Report evaluated the effectiveness, implementability, and cost of each of the reasonable and applicable BMPs listed above and provided a relative ranking for each BMP. As stated in the Level 2 Report, zero stormwater discharge (through discharge to the sanitary sewers or infiltration) is not a feasible option, and installation of roofing over all active areas of the Boatyard is also infeasible from both an implementability and cost perspective. Hence, a combination of stormwater treatment methods will be required to achieve zinc benchmarks at the Boatyard. Since the Level 2 Report was written, two additional applicable BMPs were identified for consideration: Rehabilitating and maintaining the existing sand filters in the Vault 1 basin, as discussed in Section 2.2.3, and adding crushed oyster shell to selected storm drain structures for metals adsorption and ion exchange. These stormwater treatment methods are discussed in Section 4.0.

2.4 BOATYARD STORMWATER SAMPLING RESULTS

Concentrations of zinc in Boatyard stormwater samples collected from Outfall A in April, May, and October 2012, and January and April 2013, were above the maximum daily benchmark value of 90 micrograms per liter (µg/L), and the seasonal average zinc concentration for the 2011-2012 sampling period was above the seasonal average benchmark of 85 µg/L. Since the Level Three Response was triggered, an additional exceedance was recorded for the 2012-2013 seasonal zinc average. In addition, copper benchmarks have been exceeded five times since the effective date of the current Permit. Although a separate Level Two Response (triggered at four or more exceedances) is not required for copper at this time according to Section S7.A of the Permit, it should be noted that the investigation and planned actions summarized in both the Level Two Source Control Report for zinc (Landau Associates 2013) and this report related to the reduction of zinc concentrations in stormwater are also applicable to the reduction of copper concentrations in stormwater. A summary of stormwater sampling results for both zinc and copper at the boatyard under the current Permit is provided in Table 1. Also included in Table 1 are monitoring results from the influent and effluent of the two StormwateRx Aquip systems that treat stormwater from the Vault 1 and Vault 4 drainage basins.

As part of the Level 2 Source Control Report (Landau Associates 2013), additional monitoring for zinc and copper was recommended in February 2013 in order to provide data to help identify the actions most likely to provide the greatest removal of zinc and copper from stormwater. However, much less precipitation than normal in spring and summer limited the amount of monitoring that could be completed prior to the preparation of this report. For the recommended additional source control monitoring, the Port collected split samples for laboratory analysis as well as field analysis with a Hach DR/890 meter. Both the laboratory and field data are shown in Table 2.

Of the eight source control samples collected, five samples differed by 50 percent or more between the laboratory and field meter results. There does not appear to be any correlation between the laboratory and field meter results, as the field meter sometimes indicated higher and sometimes lower concentrations than the laboratory. As the field meter does not appear to be providing accurate data, the Port plans to use laboratory analysis for further source control monitoring, and only the laboratory results for the eight samples already collected were evaluated for source control purposes.

Zinc (283 µg/L) and copper (173 µg/L) concentrations from the pipe entering CB81 (shown on Figure 4) from the north indicate that roof runoff is a likely source of zinc and copper in stormwater at concentrations above the benchmarks. There are multiple buildings with roofs that drain to CB81, and further investigation is necessary in order to prioritize roof runoff for treatment and identify any physical constraints from installing treatment features.

Results from CB46 (part of the Vault 3 drainage basin, as shown on Figure 4) indicated elevated concentrations of zinc (861 µg/L) and copper (1,510 µg/L). The potential source has been attributed to a nearby tenant where a large amount of exposed metal and metal shavings was observed in the vicinity of CB46. The Port has communicated the importance of appropriate housekeeping procedures to the tenant, and the Port plans to perform additional sampling at this location in the future to verify the elimination of the pollutant source.

Stormwater samples were also collected from Vault 1 where stormwater is pumped to the corresponding Aquip system, and from the treated effluent from the Aquip system. The Vault 1 sample result was intended to be compared against Vault 2, 3, and 4 sample results to determine if the Aquip systems were optimally placed at the Boatyard, but since samples from the other vaults were not able to be collected, these results could only be used to determine the effectiveness of the Vault 1 Boatyard Aquip. Again, the results show that the Aquip unit is not performing optimally and is not meeting the original design basis for anticipated metals removal effectiveness.

Additional steps were taken to evaluate potential reasons why the Aquip unit was not performing well and to evaluate potential stormwater treatment improvements. In November 2012, one sample of influent to the Vault 1 Boatyard Aquip was analyzed for grain size (i.e., particle size distribution). The results indicated that 99 percent of the solids entering the Aquip unit were smaller than 62.5 micrometers (µm). The relatively small size of the solids entering the Aquip indicate that certain treatment improvement options (such as pre-filtration with an automated backflushing sand filter vessel) will likely not provide a measurable increase in solids and metals removal.

3.0 SOURCE CONTROL EFFORTS

Although a Level Three Response Engineering Report is required to identify and describe treatment BMPs, source control is always the most cost-effective method of reducing pollutant concentrations in stormwater and bringing concentrations down below Boatyard Permit benchmark values. Therefore, source control efforts at the Boatyard are discussed in this section. Source control efforts described here include both existing BMPs and new policies and procedures put into place since the Level Three Response was triggered to help ensure that tenants and customers adhere to existing source control BMPs. Data for Boatyard stormwater influent to the existing StormwateRx Aquip treatment systems show that metals concentrations in stormwater runoff can fluctuate considerably. Increased source control will reduce spikes in metals concentrations and better enable treatment BMPs to consistently reduce metals concentrations to below benchmark levels.

The Boatyard Stormwater Pollution Prevention Plan includes source control BMPs, as required by the Permit, in order to meet Permit benchmarks in stormwater discharge. BMPs in place at the Boatyard include (this is a partial list):

- Requirement to use a vacuum sander (meeting minimum requirements) for paint removal
- Prohibition of in-water vessel hull cleaning, repair, modification, surface preparation, or coating
- Management and collection of solids (from stripping, sanding, etc.) to prevent release into the environment, including specific procedures for tarping, sweeping, double-bagging, and disposal of solids
- Management of paints and solvents to prevent release into the environment
- Prohibition of bilge water discharge to waters of the state, and provision of intermediate bulk containers for bilge water storage and appropriate disposal
- Management of sacrificial anodes (zincs) to prevent release into the environment
- Prohibition and elimination of illicit discharges, including sump isolation and cleanout when Port personnel suspect contaminants have entered a washdown sump
- Providing tenants/customers a waste facility to bring paint, solvents, oils, wastewater, other hazardous materials, and recyclable materials for appropriate disposal
- Regular removal of oils, debris, sludge, etc., from storm drain structures
- Requirement to store solid wastes contaminated with potential pollutants under cover
- Requirement to prevent the spread of wind-blown materials from sanding, sandblasting, and spray-painting
- Requirement to store hazardous materials in secondary containment

However, given the size of the Boatyard, the large number of people conducting boat maintenance, turnover of personnel, the potential for boat repair activity to occur 24 hours a day, 7 days a week, and the variety of marine trades on site, ensuring these BMPs are followed is a challenging task. The Port has taken recent steps to effectively direct limited staff resources toward this goal. Since the Level Three Response was triggered, additional policies and procedures have been instituted at the Boatyard, including:

- Additional facility monitoring for BMP compliance, including Saturday and Sunday patrols
- Development of a “full-court press” approach to monitoring Boatyard and marina activities by having Yard and Hoist staff and Maintenance and Moorage staff work in concert with the Environmental Compliance Officer
- Development of a simple tri-fold BMP handout for haul-out customers based on feedback from the Port Townsend Marine Trades Association (PTMTA) and customers
- Development of a team approach with the PTMTA regarding BMP development, implementation, and monitoring
- Using various media outlets to educate customers about BMPs, including the quarterly Port newsletter (the November issue featured a piece on the work of the Environmental Compliance Officer) and the local newspaper (the November 6 issue of the Port Townsend Leader featured an article on the Port’s Level Three Response)
- Institution of a process, with Port Commissioner support, whereby vessel owners and contractors are notified of BMP non-compliance verbally, followed with a written warning if the non-compliance continues, and finally a stop work order and/or eviction notice
- Additional staffing of up to one full-time employee for BMP administration and enforcement, pending future availability of funds.

These increased source control efforts are intended to reduce the concentrations of zinc and copper in stormwater that enter the treatment BMPs described in Sections 2.2 and 4.0, and thereby help ensure that metals concentrations in stormwater discharge are consistently brought below Permit benchmark levels.

The Port has also collected approximately eight soil samples this past year from graveled areas of the Boatyard in order to identify areas of surface soil that contain elevated levels of copper and zinc from historical boat repair activities. As shown to Ecology staff during a November 6, 2013 meeting at the Boatyard, those results have been posted on a facility map that is maintained in the office of the Environmental Compliance Officer. Pending future availability of funds, soil excavation and disposal will be performed to remove those potential pollutant sources, which would act to further limit the load placed on facility stormwater treatment systems.

4.0 STORMWATER TREATMENT IMPROVEMENTS

The additional monitoring recommended in the Level 2 Source Control Report was intended to provide more data to aid in choosing the most effective treatment alternatives. Because only a portion of the desired data was able to be obtained in the period between the Level Two and Level Three Responses, no one particular metals pollutant source could be identified to remove or treat in order to consistently meet the zinc and copper benchmark values. Therefore, a combination of stormwater treatment actions is planned for the Boatyard.

Using a combination of past stormwater sampling source evaluation testing results and estimated reductions in stormwater zinc concentrations that would be expected for implementing various stormwater treatment options, a worksheet was developed to estimate stormwater treatment improvements that would be necessary to achieve the benchmark value for zinc at Outfall A. This analysis is presented in Table 3.

As indicated in Table 3, the applicable stormwater treatment BMPs identified for implementation as part of the Level Three Response include making improvements to the existing sand filters to maximize the volume of treated stormwater and increase the effectiveness of metals removal. The other planned method of stormwater treatment is to improve the performance of the four existing sedimentation vaults through removal of existing orifice restrictions and/or addition of oyster shell filtration media. As noted in Table 3, in the event that any unexpected logistical issues arise that prohibit any of the planned BMPs, then contingent BMPs (Section 4.5) with an equal zinc load removal will be implemented in place of the currently planned BMP.

4.1 USE OF OYSTER SHELL FOR METALS REMOVAL

A number of the proposed improvements in this report make use of crushed oyster shells. The use of crushed oyster shells for stormwater treatment has been tested and shown to reduce the concentration of zinc and copper in stormwater. In a 2008 study at the Port of Seattle's Sea-Tac Airport conducted by Taylor Associates, field-scale testing indicated that filtration through oyster shell media improved overall water quality in stormwater runoff, including a decrease in acidity, a decrease in TSS and turbidity, an increase in calcium and magnesium concentrations and hardness and alkalinity, and a reduction of zinc and copper concentrations by up to 59 and 64 percent, respectively, with no decrease in removal efficiency throughout the course of the 9-month study (see Appendix A). In addition, Landau Associates has worked with a Snohomish County boatyard on stormwater treatment improvements that included placing crushed oyster shell directly in storm drain structures. Results have shown a reduction of zinc and copper concentrations by 80 and 50 percent, respectively.

The metals removal mechanisms of oyster shell are believed to include filtration and sedimentation of suspended solids (which contain zinc, copper, and other pollutants). The shells also likely act to physically trap and reduce re-suspension of solids (e.g., paint chips, dirt, and other small particles generated from boat repair work). Oyster shell can provide pH buffering from low to more neutral or slightly above neutral pH, which creates preferred aqueous conditions for precipitation or adsorption of dissolved metals. Furthermore, the zinc and copper appear to undergo an ion exchange process with the calcium in the oyster shell and become chemically adsorbed to the oyster shell surface as zinc carbonate and copper carbonate.

4.2 SAND FILTER IMPROVEMENTS

As discussed in this report, there are existing sand filters at the Boatyard, including sand filters in the more central traffic area of the Boatyard and four sand filters at the perimeter of the Boatyard. Improvements are planned to both sets of these sand filters to reduce the loading of both zinc and copper to Outfall A.

4.2.1 REHABILITATE VAULT 1 AREA SAND FILTERS

To rehabilitate the traffic area sand filters in the Vault 1 drainage basin, all the media components of the currently plugged sand filter (the top layer of crushed surfacing, filter fabric, filter sand, and drain rock) will be removed and disposed of. The retainer grate and perforated pipe will be salvaged for reuse. The bottom impermeable membrane may have to be replaced if damaged during excavation. The spent crushed surfacing, filter sand, and drain rock will be tested and disposed of per applicable laws and regulations, as described in Section 5.1.

After inspecting the drain pipe and repairing any sections as necessary, the sand filter trenches will be reconstructed with a 14-inch underdrain layer of partially broken oyster shells, a minimum 18-inch-deep filter bed media mix of approximately 70 percent sandy loam soil, 15 percent compost, and 15 percent crushed oyster shell. Additionally, the Port will take steps as necessary to visually delineate the perimeter of the Vault 1 area sand filters so that people do not unnecessarily disturb the function of the sand filters.

Landau Associates has worked with a Whatcom County industrial facility on stormwater treatment improvements as part of a Level Three Response, which included stormwater treatment at eight locations using the same filtration media mix described above. Filtration was in the form of downspout filter units instead of an at-grade sand filter trench, but results consistently showed near complete removal of zinc (97 to more than 99 percent reduction) at all locations for over a year. It is conservatively estimated that the Port can expect to see a 90 percent reduction in metals concentrations exiting the Vault 1 traffic area sand filters using this media mix.

4.2.2 PERIMETER SAND FILTER IMPROVEMENTS

Since 2009, when the upstream flow control orifices were enlarged, very little flow has been observed ponding at or exiting any of the four perimeter sand filters. This could be due to inaccurate drainage basin delineation, higher infiltration rates in unpaved areas than anticipated, low estimation of hydraulic conductivity of the sand filter, or other conservative design factors of safety. Rather than repeating the design calculations to determine optimal orifice size, the Port will completely remove the flow control orifices in catch basins CB 26, CB 34, CB57A, and CB60. Removal of the inlet flow control orifices will allow stormwater to flow freely through the 6-inch pipes to the four perimeter sand filters, which will provide increased metals removal from the East Sims, West Sims, and Vault 4 drainage basins. Additionally, bypass flow around the filters will be attenuated, allowing increased treatment of stormwater from the Vault 4 drainage basin at the Vault 4 West End Aquip system.

The orifices may be enlarged and reattached in the future if the increased flow causes levels to rise in the sand filters to an extent where flooding or discharge to the surrounding areas occurs. As a precautionary measure, the Port will initially monitor weather forecasts and observe the water levels in the filters if the forecast calls for 0.5-inches or more of precipitation in any 24-hour period. Barriers, plugs, or other means of quickly halting flow to the sand filters will be kept on hand in case of flooding or offsite stormwater discharge. If storm events with precipitation of 0.5 inches or more do not cause flooding or offsite discharge, monitoring may be reserved for just the larger forecast storm events.

After removing the flow control orifices and evaluating subsequent sand filter effluent sampling results, the East Sims and West Sims sand filters will be either amended with crushed oyster shell or completely rehabilitated in a similar manner to the traffic area sand filters, with an underdrain layer of whole oyster shells and a filter media mix of sandy loam soil, compost, and crushed oyster shell (Section 4.1). The Port is also currently investigating the use of biochar as a filtration medium. Biochar is charcoal created by pyrolysis of biomass, and studies have indicated that this material may be effective at removing pollutants including metals. The Port may decide to incorporate biochar into one or more of the perimeter sand filters. Using biochar in one of the filters would have the added benefit of providing a side-by-side, real-world comparison of the efficacy of metals reduction of biochar and oyster shell in the two Sims sand filters.

After removing the flow control orifices but prior to rehabilitating the East Sims and West Sims sand filters, samples of the influent to and effluent from all four sand filters will be collected during at least one storm event (preferably on the same date as sampling from Outfall A), and analyzed for total zinc and copper by U.S. Environmental Protection Agency (EPA) Method 200.7. The results from the East and West Sims filters will be used to determine the level of rehabilitation of those filters. After they are rehabilitated, treated stormwater from at least one storm event will be sampled at all four perimeter sand filters. If increasing the flow to sand filters B5 and B6 by removing the upstream flow control orifices alone does not bring zinc concentrations exiting B5 and B6 to below benchmarks, and the combined result of the BMPs described in this report does not bring zinc concentrations at Outfall A to below benchmarks, the Port will rehabilitate sand filters B5 and B6 as well.

4.3 IMPROVED TREATMENT AT VAULTS 1 & 4 USING OYSTER SHELL

The less-than-expected metals removal at the Vault 1 Aquip could be attributable to the loss of adsorption capacity in Aquip media due to marine water intrusion into the Vault 1 storm drain system. However, the less-than-expected metals removal at the Vault 4 Aquip where marine water intrusion was not previously observed suggests that there may be other reasons for the less-than-expected metals removal. Nevertheless, to confirm that marine water is no longer entering the storm drain system, the Port will monitor stormwater in Vault 1 and Vault 4 to determine if further investigation into possible marine water intrusion is necessary. One way to detect the presence of marine water would be with a conductivity meter that can be easily lowered into storm drain structures.

To increase metals removal, crushed oyster shell will be added to Vaults 1 and 4 to remove some metals prior to treatment at the Aquip units. The vaults receive most of the stormwater runoff from their respective drainage basins. Pretreatment in the vaults is ideal due to the large volume of stormwater available that will allow for a long contact time with the oyster shell. In addition, the underflow and overflow baffles in these oil/water separator vaults will help to force flow through the shell media and will allow an empty effluent chamber to be maintained for the pump inlets that deliver flow to the Aquip treatment unit. If placing, maintaining, and removing oyster shell in the vaults is for some reason found to be infeasible due to site constraints, the crushed oyster shell could alternatively be added directly on the top of the Aquip system media beds.

The dimensions of the four vaults vary slightly (see original 1996 design plan set from Reid Middleton), but have a length of roughly 30 feet (ft) and a width of 9 to 10 ft. The inlet chamber and central chambers of the oil/water separator vaults will be filled to a depth of at least 3 ft, and to a height of at least 1 ft above the underflow baffle, to ensure that stormwater flows through the crushed or broken shell media rather than just flows over the top of the shell media bed. Alternatively, a 1-ft-thick layer of broken or crushed and washed oyster shell can be placed on top of the Vault 1 or Vault 4 Aquip filter media bed.

A minimum of two stormwater samples, upstream and downstream of the newly added oyster shell, will be collected during storm events and analyzed by EPA Method 200.7 for zinc and copper to measure metals removal due to the oyster shell. These results, when compared with historical data from Vaults 1 and 4, will also be used to determine if the Aquip systems are properly located at the Boatyard. The option exists to move one or more Aquip units to Vault 2 or 3 if the data suggest that this would provide increased zinc mass loading removal.

4.4 OYSTER SHELL IN OTHER STORM DRAIN STRUCTURES

Existing storm drain flow-splitting structures upstream of Vaults 2 and 3 allow bypass of stormwater from larger storm events. The outlet from each flow splitter to the vault was originally installed with a flow-restricting orifice. The orifices at the inlets to Vault 1 and Vault 4 (at catch basins CB 27 and CB 58) were removed in 2010 when the StormwateRx Aquip units were installed at these two vaults. The intent at the time was to also remove the orifices at CB 37 and CB 41, which restrict flow to Vault 2 and Vault 3. It was recently determined that those two orifice flow restrictors were not removed, and so they will be removed as part of this Level 3 Response.

The removal of the Vault 2 and Vault 3 flow-restricting orifices will reduce the amount of stormwater that bypasses these vaults and should act to increase the amount of settling and removal of suspended solids (and associated metals). The overflow bypass structure will still be retained to allow overflow of stormwater from extreme storm events and to help reduce the re-suspension of settled solids.

There is currently no stormwater treatment in the Vault 2 and Vault 3 drainage basins (other than solids settling). After removal of the flow-restricting orifices upstream of Vaults 2 and 3, the vast majority of stormwater runoff from their respective drainage basins will flow through the vault. To increase the amount of stormwater treated in this area, crushed oyster shell will be added to Vault 3 (as was described for Vaults 1 and 4 in Section 4.3). Vault 2 has a relatively smaller drainage basin area, and past sampling results indicate a lower concentration of zinc in stormwater at Vault 2. Therefore, installation of oyster shell in Vault 2 is not currently planned but may be considered as a potential future contingent action depending on future Outfall A sampling results.

A minimum of two samples of the influent to and effluent from Vault 3 will be collected during storm events and analyzed by EPA Method 200.7 for zinc and copper to measure metals removal after installation of the oyster shell. At Vault 2 and at CB 80 (the roof drain Vault 3 bypass storm drain line), a minimum of two stormwater samples will be collected during storm events and analyzed by EPA Method 200.7 for zinc and copper to obtain more data on pollutant loading at these locations in case benchmarks are not met at Outfall A and it is determined that additional stormwater treatment is needed.

4.5 CONTINGENT FUTURE STORMWATER TREATMENT

Following implementation of the stormwater treatment improvements described above, if stormwater monitoring results continue to show that concentrations of zinc or copper exceed their respective benchmark values then additional stormwater treatment improvements will be implemented. The following sections outline those additional expected contingent stormwater treatment methods that would be most effective for additional stormwater quality improvements.

4.5.1 DOWNSPOUT FILTERS

Roof drain downspout filters are containers (such as converted 275-gallon liquid totes) that are filled with a filtration media mix and that can act to remove metals such as zinc and copper that may be present due to the roofing materials present. Results from installations by Landau Associates (using a mix of sandy loam soil, crushed oyster shell, and compost) and some public ports (using a sand/compost mix) indicate that these types of filters can be very effective for metals removal and at relatively low cost.

Due to access needs or other physical constraints at the Boatyard, downspout filters are not feasible at most buildings. However, the Port has identified buildings 10 and 13 as feasible candidates for downspout filters. Downspout filters can achieve a near 100 percent reduction in zinc and copper concentrations in roof runoff. However, each filter would treat a relatively small area of the entire Boatyard. To target the downspouts with the highest concentrations of zinc, stormwater samples will be collected from individual downspouts of buildings 10 and 13 from at least one storm event and analyzed for zinc and copper by EPA Method 200.7. If stormwater runoff from those roofs are found to be sources of zinc and if zinc benchmarks are not met at Outfall A after the initial round of treatment BMPs has been implemented, downspout filters will be installed at these buildings.

4.6 SCHEDULE AND EXPECTATION OF BENCHMARK ACHIEVEMENT

As required by Section S7.A of the Boatyard Permit, implementation of the preferred option will occur within 12 months of the time Ecology accepts the engineering report. The following items will be completed within that timeframe:

- Remove flow-restricting orifices at the inlet of the four perimeter sand filters and at the inlet of Vaults 2 and 3
- Add oyster shell filter media in Vaults 1, 3, and 4
- Rehabilitate the East Sims and West Sims sand filters
- Rehabilitate the Vault 1 traffic area sand filters.

Contingent actions following completion of the above stormwater treatment steps and if sampling at Outfall A still indicates zinc or copper at concentrations exceeding benchmark values will be to add oyster shell in Vault 2, install downspout filters at buildings 10 and 13, or rehabilitate the B5 and B6 sand filters. Those contingent treatment BMPs would be implemented in a sequential manner, as necessary, within 90 days of receiving the analytical results from Outfall A sampling.

The schedule for monitoring is as follows, given adequate precipitation:

- Monitor for signs of continued marine water intrusion (especially at Vault 1) as soon as possible. Monitoring can be conducted using a conductivity meter.
- Sample at the four perimeter sand filters as soon as possible after orifice removal but prior to rehabilitating the East Sims and West Sims sand filter, and again after rehabilitation.
- Sample at Vault 2 as soon as possible, and sample at Vaults 1, 3, and 4 after addition of oyster shell.
- Sample at CB 80 and at the building 10 and 13 downspouts as soon as possible for source control evaluation, related to potential future contingency actions.

Zinc benchmarks are expected to be met at Outfall A as a result of the BMPs identified in this report. The estimated zinc concentration in stormwater and loading reductions at Outfall A and for each drainage basin are shown in Table 3.

5.0 SITE-WIDE MONITORING AND MAINTENANCE

In addition to the monitoring described in Section 4.0, which will be used to determine which contingent actions may be appropriate, stormwater quality monitoring as required by the Boatyard Permit will continue to allow evaluation of the overall effectiveness of the various actions described in this report in reducing zinc concentrations below the benchmark values established in the Permit.

Proper procedures need to be established for testing and disposal of stormwater treatment filtration media and any associated filtered or settled solids, and those procedures are discussed in this section. The Port will maintain the proposed treatment improvements described in this report, and details on the frequency and specifics of maintenance activities are also described in this section.

5.1 DISPOSAL OF SPENT FILTRATION MEDIA AND FILTERED SOLIDS

With the use of sand filter media and chipped or crushed oyster shell, there will be a periodic need to dispose of that material. Given the known presence of metals at the Boatyard, it is recommended that a composite sample of the material be analyzed by EPA Method 6010 for a standard suite of total metals (e.g., RCRA 8 metals[1]), as well as for zinc and copper, to determine if the material would be characterized as hazardous or state dangerous waste. Depending on the results of the analysis for total metals, toxicity characteristic leaching procedure (TCLP) testing for metals by EPA Method 1311 might also be necessary to determine if the material needs to be disposed of as hazardous waste.

5.2 MONITORING AND MAINTENANCE OF STORMWATER TREATMENT FEATURES

Applicable monitoring and maintenance procedures for the planned stormwater treatment features are provided in this section.

5.2.1 VAULT 1 AREA SAND FILTERS

Part of the monthly Boatyard inspections will be to visually inspect the Vault 1 area sand filters for ponded water or other signs of filter media plugging. If signs of plugging are observed, then it may be necessary to use a shovel to remove accumulated surface sediment from the top of the media. Or it may be necessary to rake the filter media bed (a rake for the Aquip system media could be used) in order to break up solidified solids and re-establish the necessary infiltration rate.

[1] The Resource Conservation and Recovery Act 8 metals are: Arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver.

5.2.2 PERIMETER SAND FILTERS

For the perimeter sand filters, the same monitoring and maintenance practices should be followed as described above for the Vault 1 area sand filters.

In addition (as noted above in Section 4.2.2), visual inspections are needed during storm events to determine if the increased flow to the sand filters from the removal of the flow-restricting orifices causes stormwater levels to rise in the sand filters to an extent where flooding or discharge to the surrounding areas occurs. The Port will initially monitor weather forecasts and observe the water levels in the filters if the forecast calls for 0.5 inches or more of precipitation in any 24-hour period. Barriers, plugs, or other means of quickly halting flow to the sand filters will be kept on hand in case of flooding or offsite stormwater discharge. If storm events with precipitation of 0.5 inches or more do not cause flooding or offsite discharge, monitoring may be reserved for just the larger forecast storm events.

5.2.3 STORM DRAIN STRUCTURES WITH OYSTER SHELL

The flow-restricting orifices to Vault 1 and Vault 4 were previously removed to maximize flow through the vaults and into the two Aquip treatment units. As stated above, the flow-restricting orifices to Vault 2 and Vault 3 will also be removed. However, with the oyster shell to be added to Vaults 1, 3, and 4, it is possible that stormwater flow will be reduced over time to below optimum levels if solids accumulate within the shell media and flow is thereby restricted. To verify that the shell media has not become plugged and is restricting flow by an undesirable amount, the flow splitters at the inlet manholes to each of these vaults should be visually monitored during significant rainfall events. If flow is observed to be overflowing and bypassing the vault structure for a storm with precipitation of 0.5 inches or less, then that may be a sign that accumulated solids need to be removed from the top of the oyster shell media bed or that vactor truck servicing is needed to remove some or all of the shell and associated filtered solids.

For the large volume of oyster shell media to be installed in these vaults relative to the expected annual flow volumes, it is expected that the oyster shell will last longer than a year before needing to be serviced or replaced. The actual duration between change-out events will depend on various factors including facility erosion control measures and the size of the broken or crushed oyster shell. More finely crushed oyster shell will offer more treatment surface area per unit of volume and will last longer relative to coarser (broken, chipped) oyster shell.

6.0 USE OF THIS REPORT

This Level 3 Engineering Design Report has been prepared for the exclusive use of the Port of Port Townsend and applicable regulatory agencies for specific application to stormwater system improvements at the Port of Port Townsend Boat Haven Boatyard. No other party is entitled to rely on the information, conclusions, and recommendations included in this document without the express written consent of Landau Associates. Further, the reuse of information, conclusions, and recommendations provided herein for extensions of the project or for any other project, without review and authorization by Landau Associates, shall be at the user's sole risk. Landau Associates warrants that within the limitations of scope, schedule, and budget, our services have been provided in a manner consistent with that level of care and skill ordinarily exercised by members of the profession currently practicing in the same locality under similar conditions as this project. We make no other warranty, either express or implied.

This document has been prepared under the supervision and direction of the following key staff.

LANDAU ASSOCIATES, INC.

Martin C. Valeri
Project Engineer, E.I.T.

Joseph A. Kalmar, P.E.
Principal

JOSEPH A. KALMAR
STATE OF WASHINGTON
0034611
REGISTERED
PROFESSIONAL ENGINEER
12/18/2013

MCV/JAK/ccy

7.0 REFERENCES

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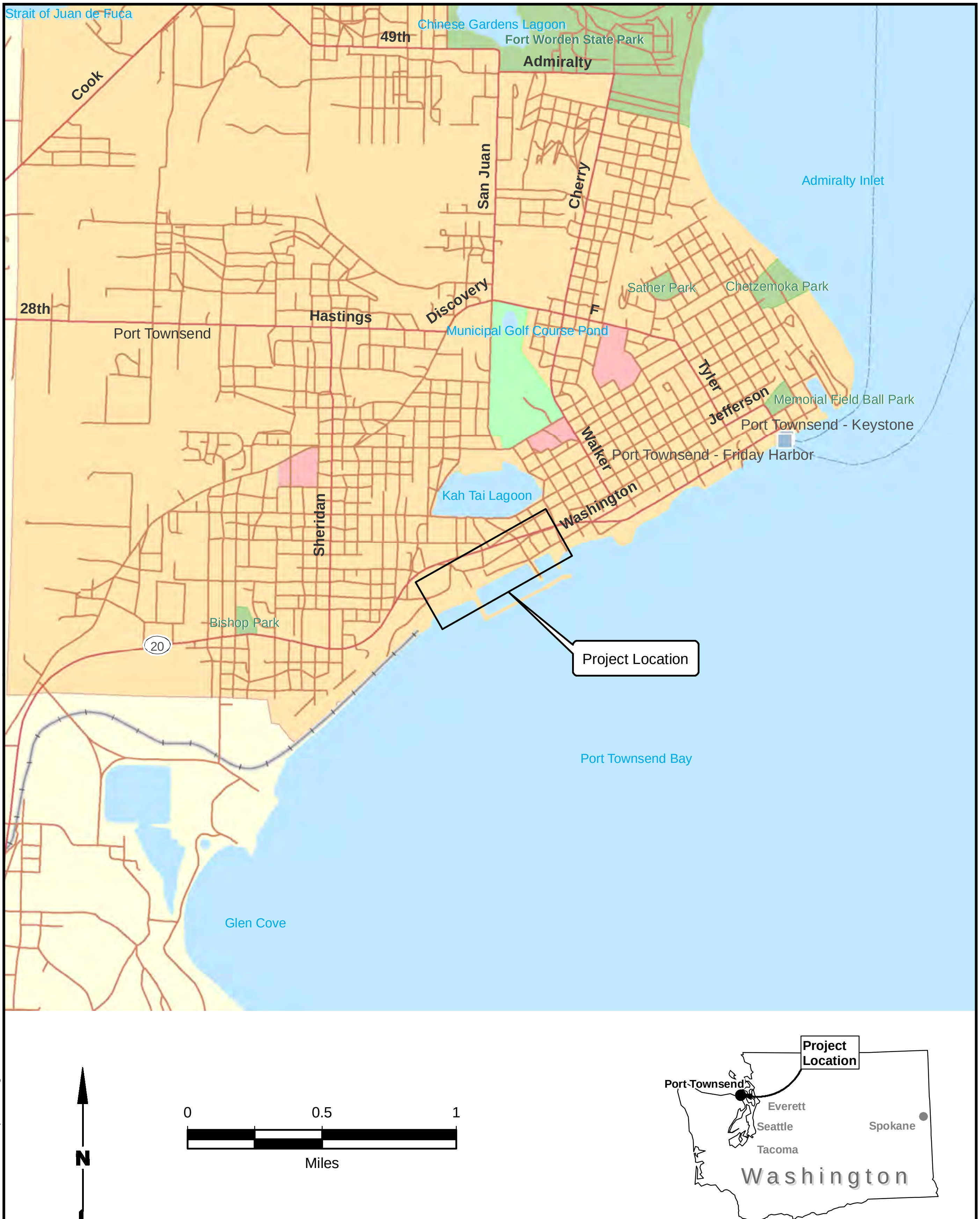
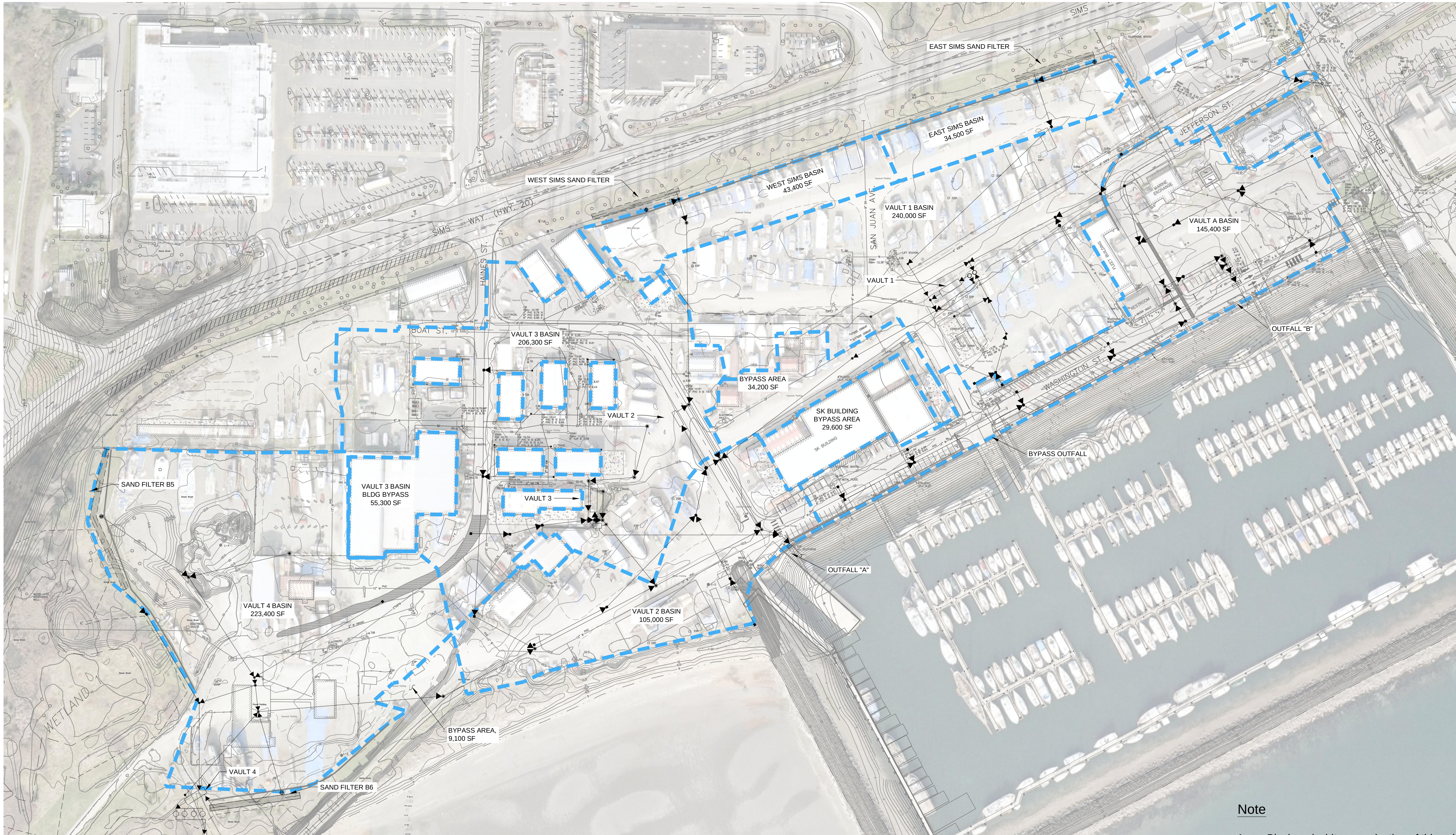


Data Source: ESRI 2008

LANDAU ASSOCIATES	Port Townsend Boatyard Port Townsend, Washington	**Vicinity Map**	Figure 1

Y:\Projects\304006\030\034\Mapdocs\Fig1.mxd 2/16/2010



Note

1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

LANDAU ASSOCIATES, INC. | V:\1304\006\030.033\SDT\Figure 2_5_6.dwg (A) "Figure 2" 5/31/2011

NOTE

1. LOCATION OF STORM DRAIN UTILITIES AND BASIN BOUNDARIES PROVIDED BY REID MIDDLETON 1996; THE AERIAL PHOTO WAS PROVIDED BY GOOGLE EARTH PROFESSIONAL 2010.

LEGEND

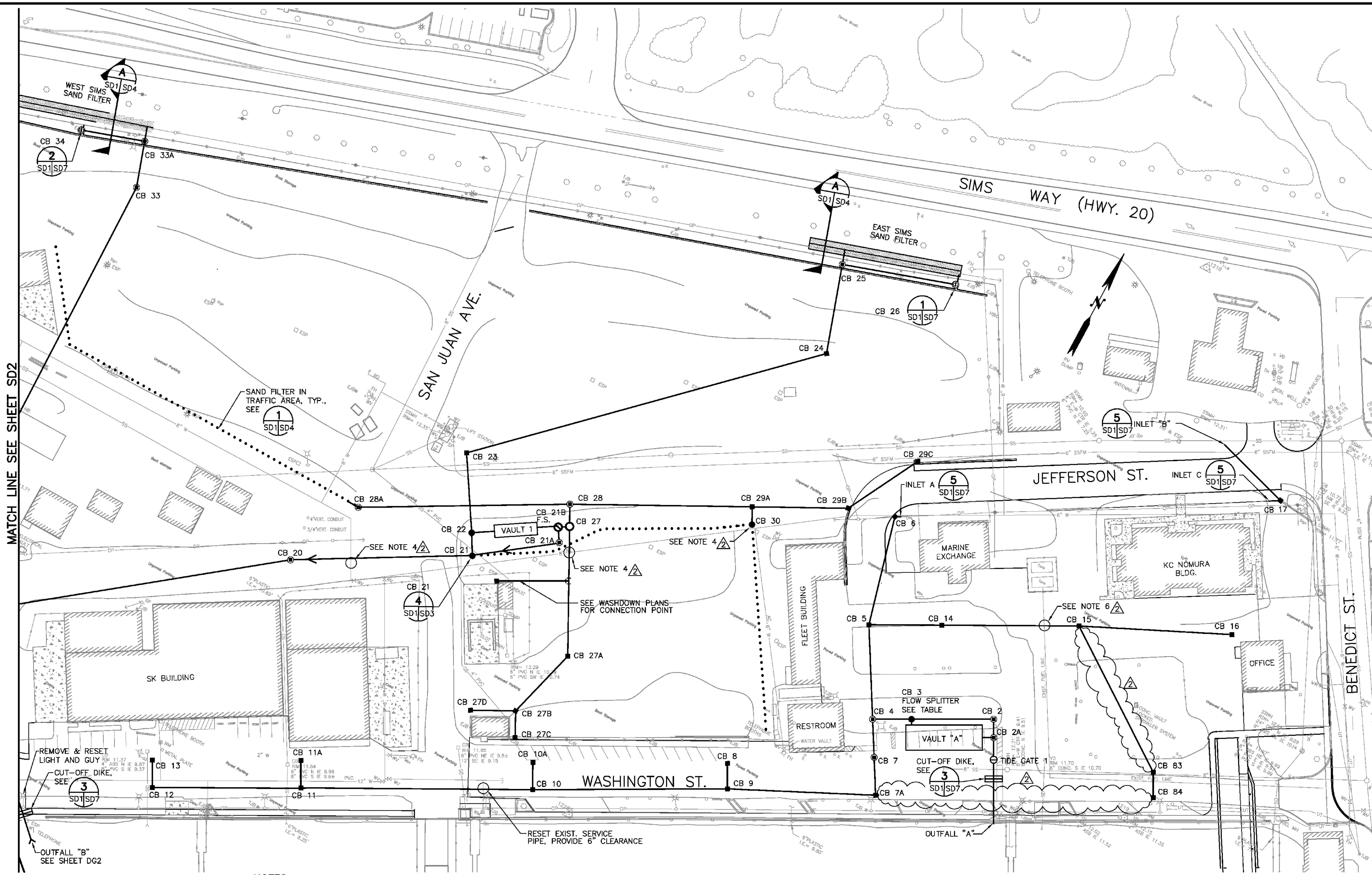
- DRAINAGE BASIN BOUNDARY (APPROXIMATE)
- STORM DRAIN LINE

0 160 320

Scale in Feet

LANDAU ASSOCIATES

Port Townsend Boatyard Port Townsend, Washington	**Site Plan and Drainage Basin Map**	Figure 2



NOTES:

1. FOR PIPE AND STRUCTURE TYPE AND LOCATION SEE SHEETS SD8 AND SD9.
2. FOR LEGEND SEE SHEET T3.
3. ROOF DRAIN COLLECTION PIPE: 6" PVC, UNLESS NOTED OTHERWISE.
4. REVISE EXISTING WATER LINE PROFILE TO AVOID CONFLICT WITH STORM DRAIN, SEE 3 SD1 U5 2
5. REVISE EXISTING SANITARY SEWER FORCE MAIN PROFILE TO AVOID CONFLICT WITH STORM DRAIN, SEE 3 SD1 U5 2
6. REVISE EXISTING FUEL LINE PROFILE TO AVOID CONFLICT WITH STORM DRAIN. 2

SCALE IN FEET
40 0 40 80

CALL 48 HOURS
BEFORE YOU DIG
1-800-424-5555

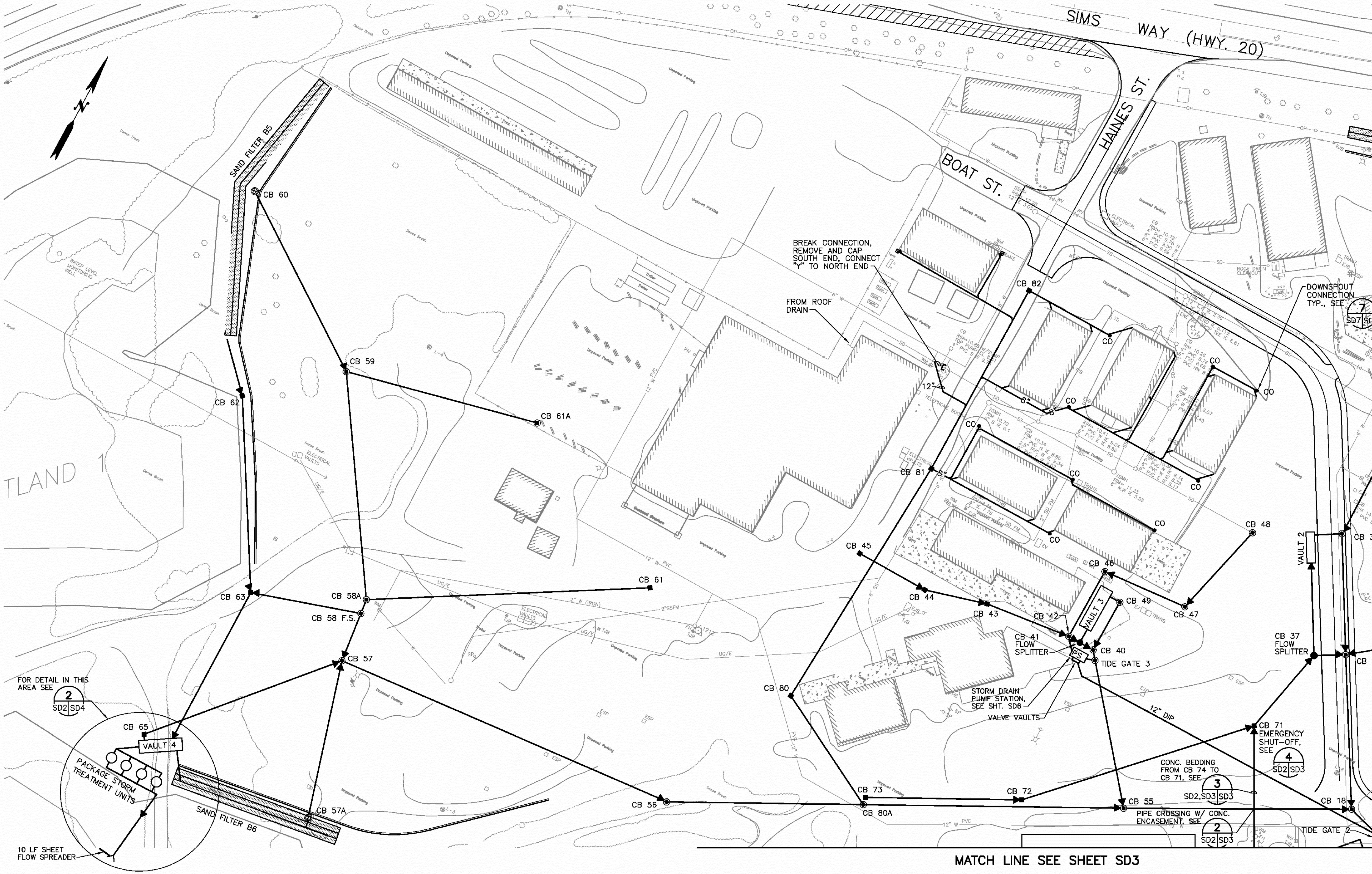
"L"
NOTE:
IF "L" DOES NOT MEASURE 1" ADJUST SCALES ACCORDINGLY.
I:\24\93\022\SD1-2-3.DWG

LANDAU ASSOCIATES, INC. | V:\304\006\030.033\SDTD\Figure 3_4.dwg (A) "Figure 3" 8/28/2013

LANDAU ASSOCIATES

Source: Reid Middleton 1996

Port Townsend Boatyard Port Townsend, Washington	Stormwater System - East	Figure 3



NOTES:

1. FOR PIPE AND STRUCTURE TYPE AND LOCATION SEE SHEETS SD8 AND SD9.
2. FOR LEGEND SEE SHEET T3.
3. ROOF DRAIN COLLECTION PIPE: 6" PVC, UNLESS NOTED OTHERWISE.

SCALE IN FEET
40 0 40 80

CALL 48 HOURS
BEFORE YOU DIG
1-800-424-5555

"L"
NOTE:
IF "L" DOES NOT MEASURE 1" ADJUST SCALES ACCORDINGLY.
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LANDAU ASSOCIATES, INC. | V:\304\006\030.033\SDTD\Figure 3_4.dwg (A) "Figure 4" 8/28/2013

LANDAU ASSOCIATES

Source: Reid Middleton 1996

Port Townsend Boatyard
Port Townsend, Washington

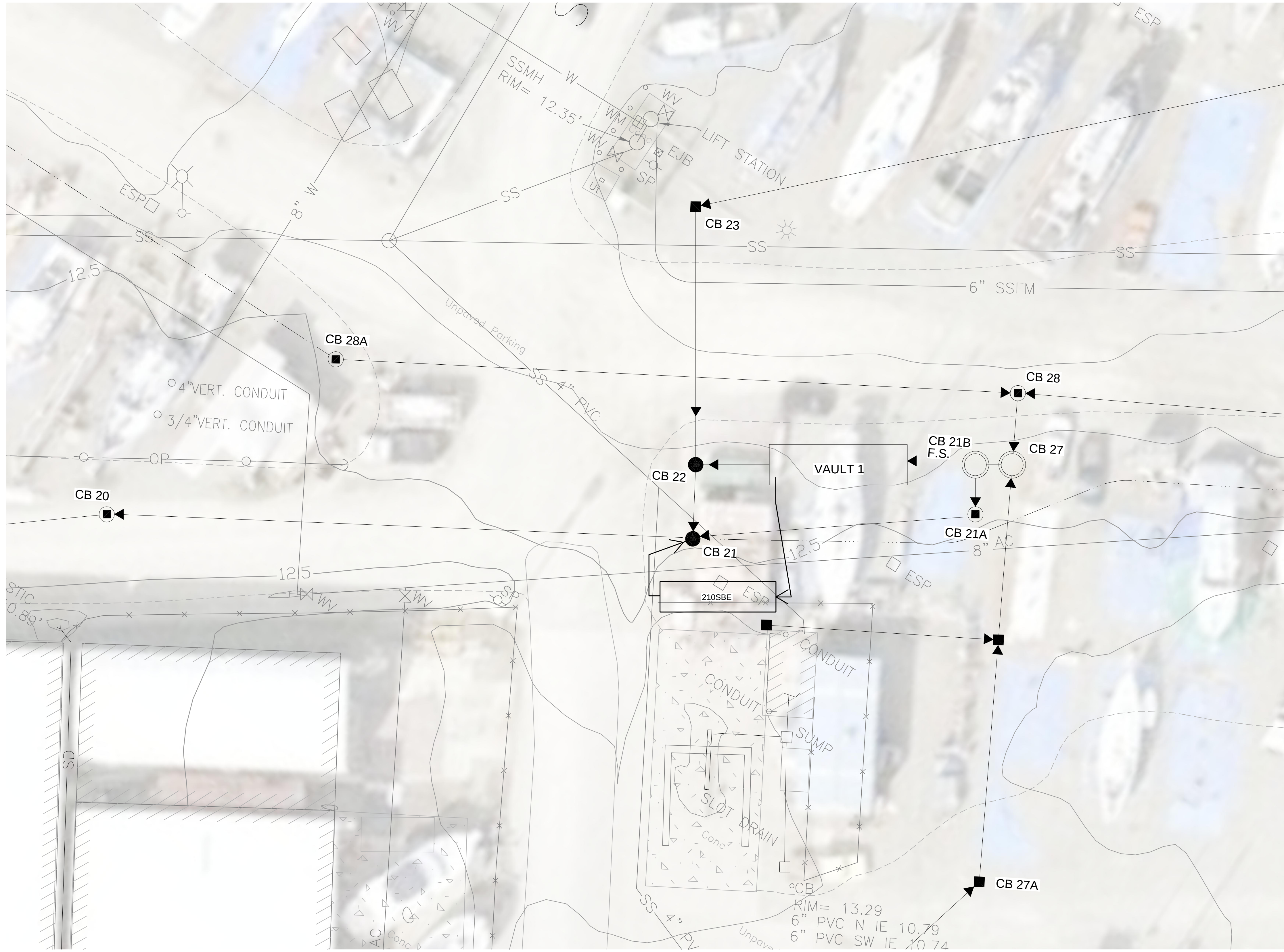
Stormwater System - West

Figure
4

LEGEND

- TREATMENT SYSTEM PIPE
- 210SBE — STORMWATERX AQUIP SYSTEM AND MODEL DESIGNATION
- STORM DRAIN LINE
- PERFORATED DRAIN LINE
- CB 63 — CATCH BASIN LOCATION AND DESIGNATION
- F.S. — FLOW SPLITTER
- FH — FIRE HYDRANT
- WV — WATER VALVE
- VB — VALVE BOX
- HB — HOSE BIB
- SSMH — SANITARY SEWER MANHOLE
- CO — SANITARY SEWER CLEANOUT
- WM — WATER METER
- MON. WELL — MONITOR WELL
- CB — CATCH BASIN
- CBMH — CATCH BASIN MANHOLE
- YD — YARD DRAIN
- ESP — ELECRIC SERVICE PANEL
- EJB — ELECTRICAL JUNCTION BOX
- UTILITY POLE
- SP — SERVICE POLE
- LIGHT POLE
- TJB — TELEPHONE JUNCTION BOX
- GF — GAS FILLER
- GV — GAS VALVE
- GM — GAS METER
- TH — TEST HOLE
- FENCE

N



NOTE

1. LOCATION OF STORM DRAIN UTILITIES AND BASIN BOUNDARIES PROVIDED BY REID MIDDLETON 1996; THE AERIAL PHOTO WAS PROVIDED BY GOOGLE EARTH PROFESSIONAL 2010.

0 30 60
Scale in Feet

Port Townsend Boatyard
Port Townsend, Washington

Vault 1 and Boatyard Treatment System

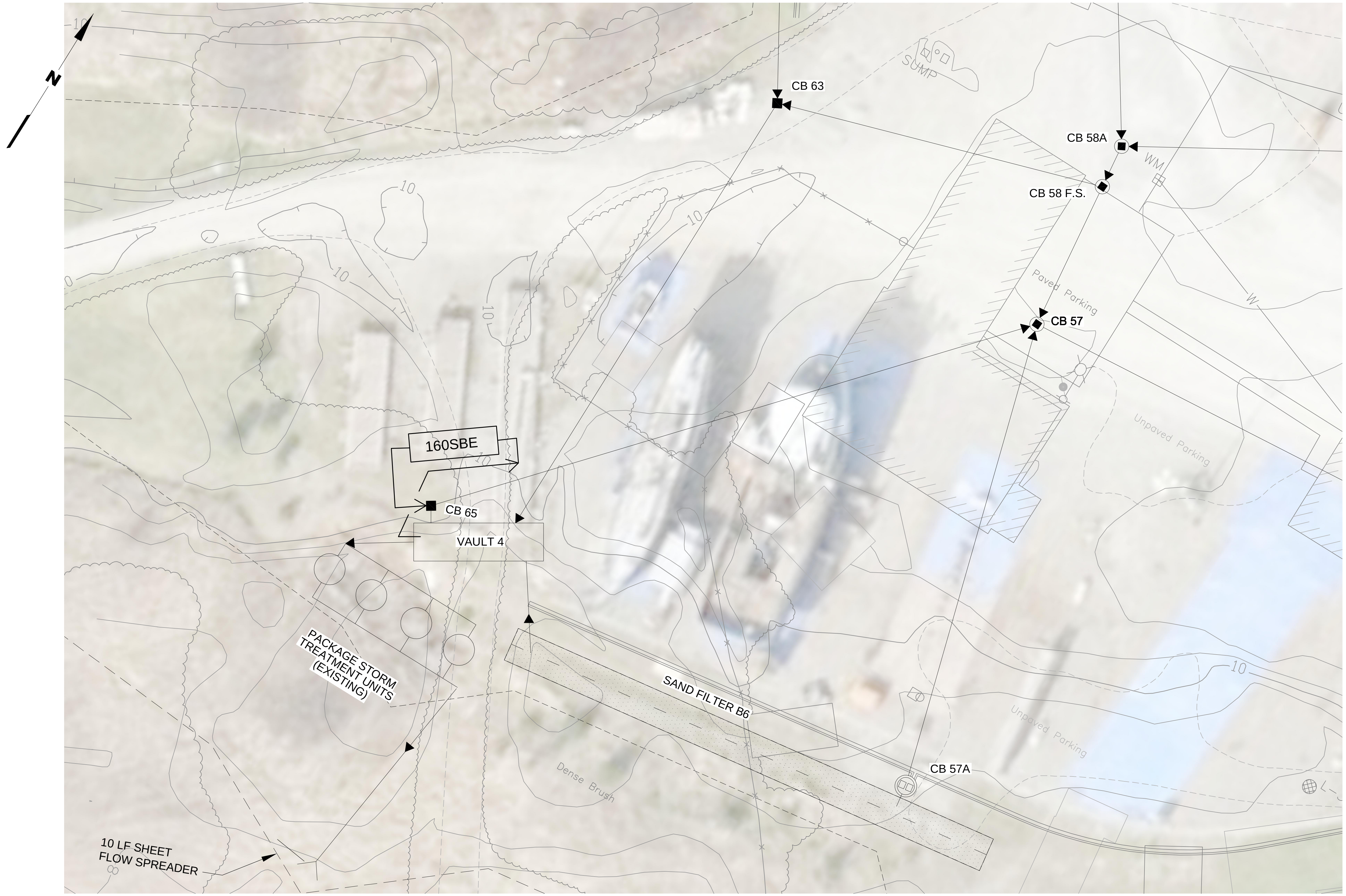
Figure 5

LANDAU ASSOCIATES

LANDAU ASSOCIATES, INC. | V:\304\006\030.033\SDTD\Figure 2_5_6.dwg (A) "Figure 5" 5/31/2011

LEGEND

←	TREATMENT SYSTEM PIPE
160SBE	STORMWATERX AQUIP SYSTEM AND MODEL DESIGNATION
◄──	STORM DRAIN LINE
— · · —	PERFORATED DRAIN LINE
CB 63 ■	CATCH BASIN LOCATION AND DESIGNATION
F.S.	FLOW SPLITTER
FH	FIRE HYDRANT
WV	WATER VALVE
VB	VALVE BOX
HB	HOSE BIB
SSMH	SANITARY SEWER MANHOLE
CO	SANITARY SEWER CLEANOUT
WM	WATER METER
MON. WELL	MONITOR WELL
CB	CATCH BASIN
CBMH	CATCH BASIN MANHOLE
YD	YARD DRAIN
ESP	ELECRIC SERVICE PANEL
EJB	ELECTRICAL JUNCTION BOX
	UTILITY POLE
SP	SERVICE POLE
	LIGHT POLE
TJB	TELEPHONE JUNCTION BOX
GF	GAS FILLER
GV	GAS VALVE
GM	GAS METER
TH	TEST HOLE
—x—	FENCE



NOTE

1. LOCATION OF STORM DRAIN UTILITIES AND BASIN BOUNDARIES PROVIDED BY REID MIDDLETON 1996; THE AERIAL PHOTO WAS PROVIDED BY GOOGLE EARTH PROFESSIONAL 2010.

0 30 60
Scale in Feet

LANDAU ASSOCIATES

Port Townsend Boatyard
Port Townsend, Washington

Vault 4 and West End Treatment System

Figure 6

TABLE 1
SUMMARY OF OUTFALL A AND STORMWATERX AQUIP SAMPLING RESULTS
ZINC AND COPPER
PORT OF PORT TOWNSEND – PORT TOWNSEND, WASHINGTON

	Outfall A		Vault 1 Aquip				Vault 4 Aquip			
	Zinc (µg/L)	Copper (µg/L)	Zinc In (µg/L)	Zinc Out (µg/L)	Copper In (µg/L)	Copper Out (µg/L)	Zinc In (µg/L)	Zinc Out (µg/L)	Copper In (µg/L)	Copper Out (µg/L)
Maximum Daily Benchmark:	90	147	N/A							
Seasonal Average Benchmark:	85	50								
Monitoring Results:										
October 2011	NQSE	NQSE								
November 2011	NQSE	NQSE								
January 2012	NQSE	NQSE								
April 2012 (total metals)	**519**	**1,380**	602	231	1,680	704	U	U	10.7	4.39
April 2012 (dissolved metals)	203	174	312	102	275	83	U	U	4.4	3.7
May 2012	**140**	93.5								
2011-2012 Seasonal Average	**330**	**737**								
October 2012	**133**	129								
November 2012	NQSE	NQSE								
November 2012 (total metals)			483	213	1,590	727	252	137	566	343
November 2012 (dissolved metals)			422	83.5	250	97.3	35.3	8.49	34	14.2
January 2013	**184**	**536**								
February 2013			308	142	647	400				
April 2013	**122**	70.3								
May 2013	67	**300**								
2012-2013 Seasonal Average	**127**	**259**								

Notes:
1. Outfall A stormwater discharge monitoring results collected prior to October 2011 are not included.
2. Monitoring for zinc and copper is not required during the months of February, March, June, July, August, September, and December.

N/A = Not applicable.

NQSE = No qualifying storm event.

Red = Benchmark exceedance.

U = Parameter not detected.

[grey box] = Sampling not completed or not required.

TABLE 2
SOURCE CONTROL SAMPLING RESULTS
AND COMPARISON OF FIELD METER DATA
PORT OF PORT TOWNSEND – PORT TOWNSEND, WASHINGTON

		Zinc (µg/L)			Copper (µg/L)		
	Date	Laboratory	Field Meter	Difference	Laboratory	Field Meter	Difference
CB81 (pipe from north)	2/25/2013	283	360	27%	173	270	56%
CB46	2/25/2013	861	790	-8%	1510	620	-59%
Vault 1 (Influent to Aquip)	2/25/2013	308	590	92%	647	220	-66%
Effluent from Vault 1 Aquip	2/25/2013	142	160	13%	400	200	-50%

TABLE 3
PLANNED AND CONTINGENT STORMWATER TREATMENT IMPROVEMENTS TO ACHIEVE ZINC BENCHMARK AT OUTFALL A
PORT OF PORT TOWNSEND – PORT TOWNSEND, WASHINGTON

Drainage Area	Area (ft^2)	Estimated Existing Average Zinc Concentration (µg/L)	Reduction in Zinc Concentration from BMPs	Estimated Future Zinc Concentration (µg/L)	Estimated Future Weighted Loading as a Portion of Outfall A (µg/L)
Vault 1 Basin	240,000	195	65%	69	20
Vault 2 Basin	105,000	61	18%	50	6
Vault 3 Basin	206,300	98	63%	36	9
Bypass area of Vault 3 Basin	55,300	283	0%	283	19
Vault 4 Basin	223,400	137	56%	60	17
East Sims Basin	34,500	364	90%	36	2
West Sims Basin	43,400	577	90%	58	3
Outfall A	907,900	194	61%	**Estimated Future Zinc Concentration at Outfall A (µg/L)**	**77**

Zinc Benchmarks		
Zinc Benchmarks	Max Daily	90
	Seasonal Avg	85

BMPs to be implemented (a)	Expected zinc reductions to Outfall A	Basin
Oyster shell in Vault 1 or Boatyard Aquip	50% zinc reduction in 90% of basin area	Vault 1
Oyster shell in Vault 3	50% zinc reduction in 90% of basin area	Vault 3
Remove restriction orifices to Vaults 2 and 3	20% zinc reduction in 90% of basin area	Vault 2 and Vault 3
Remove orifice for sand filter B5	40% zinc reduction in 25% of basin area	Vault 4
Remove orifice for sand filter B6	40% zinc reduction in 25% of basin area	Vault 4
Oyster shell in Vault 4 or West End Aquip	50% zinc reduction in 90% of basin area	Vault 4
Rehab East Sims sand filter and remove orifice	90% zinc reduction in 100% of basin area	East Sims
Rehab West Sims sand filter and remove orifice	90% zinc reduction in 100% of basin area	West Sims
Rehabilitate traffic area sand filters	90% zinc reduction in 40% of basin area	Vault 1

Contingent BMPs	Potential future reductions	Basin
Oyster shell in Vault 2	50% metals reduction in 90% of basin area	Vault 2
Downspout filters at Building 13	95% zinc reduction in 2% of basin area	Vault 3
Downspout filters at Building 10	95% zinc reduction in 50% of basin area	Bypass area
Oyster shell in CB 80	25% metals reduction in 70% of basin area	Bypass area
Rehabilitate B5 sand filter	90% metals reduction in 25% of basin area	Vault 4
Rehabilitate B6 sand filter	90% metals reduction in 25% of basin area	Vault 4

(a) In the event that logistical issues arise that prohibit any of these planned BMPs, then Contingent BMPs identified below with an equal zinc load removal will be implemented instead.

APPENDIX A

Port of Seattle Oyster Shell Stormwater Treatment Study

TAYLOR ASSOCIATES, INC.

MEMORANDUM

TO:	Albert Shen, POS Aviation Environmental Programs
FROM:	Suzanne Smith, Taylor Associates, Inc.
CC:	Aaron Moldver, POS Aviation Environmental Programs Curtis Nickerson, Taylor Associates, Inc.
DATE:	December 31, 2008
RE:	Oystershells in StormFilters- Technical Memo

In previous laboratory-based research, Taylor Associates, Inc (TAI) has verified that filtration of stormwater through oystershell media can increase hardness and reduce concentrations of copper and zinc (TAI 2005); however, a field test was necessary to evaluate performance in situ.

TAI conducted this field test using oystershells deployed in a Downspout StormFilter® unit at the Aeroground Building of the South Cargo Centre on Air Cargo Road. The following sections will describe data collection methods, data results, and explain analyses conducted on water quality data to evaluate the performance of oystershells as a potential filtration media for removal of metals in stormwater.

METHODS

Manual grab samples were collected for seven storms at the Downspout StormFilter®. Samples were collected every five minutes, and then combined into two composite samples to represent inlet and outlet concentrations for that storm event. Composite samples were submitted to Aquatic Research, Inc. and analyzed for pH, alkalinity, total calcium, total magnesium, hardness, TSS, turbidity, total recoverable (T_R) and dissolved copper and zinc. Storm characteristics were summarized for each event and are included in the following results and discussion sections.

7104 Greenwood Ave. N.
Seattle, WA 98103
main (206) 267-1400
fax (206) 267-1401

Consulting in the Coastal and Freshwater Sciences

Qualitative analysis of water quality results was conducted to evaluate the overall performance of oystershells as a filtration media, and more explicitly to examine the reduction of metals in stormwater. A Wilcoxon paired sample test was conducted to identify whether the influent concentration is significantly greater than the effluent concentration. Effluent probability was plotted to observe performance trends over a range of concentrations and concentration reduction plots were created to evaluate the capacity of oystershell filtration media to reduce T_R and dissolved copper and zinc.

RESULTS

Table 1 summarizes storm event characteristics for the seven storms sampled from June 28, 2007 through March 13, 2008. All composites included twelve subsamples, except the sample for October 10, 2007, which ended early because it stopped raining (5 subsamples). The duration of dry weather prior to the sampled event (antecedent dry period) ranged from 17 hours and 35 minutes to 81 hours and 35 minutes. The average antecendent dry period was approximately 50 hours and 30 minutes. Rainfall depth during sample collection ranged from 0.02 to 0.15 inches; however average depth was 0.06 inches. The amount of rain that occurred during a sampled storm prior to the start of sampling ranged from 0 inches (sampling during 1st recorded rainfall) to 0.18 inches (average depth was 0.09 inches prior to collection). Maximum rainfall intensities were 0.01 inches per hour for all events, except for the November storm (0.04 inches/hour).

Table 2 summarizes the water quality results for influent and effluent concentrations over the seven storms sampled. In general; pH, alkalinity, Calcium, and Magnesium concentrations were lower in untreated roof runoff than the treated water; and turbidity, TSS, and T_R and dissolved metals (copper and zinc) concentrations were higher in roof runoff than in treated stormwater. Statistical comparison and analysis was only conducted for metals in this study, and results of Wilcoxon (Table 3) analysis indicates that inlet concentrations are greater than the outlet concentrations for T_R and dissolved copper and zinc ($P<0.0005$ for T_R and dissolved copper, $0.0025<P<0.0005$ for T_R and dissolved zinc). This result allowed for use of effluent probability plots as a quantitative tool for examining concentration data. Percent removal for T_R and dissolved copper (Table 3) ranged from 34 to 64 percent and media performance was consistent for the duration of the study. For T_R and dissolved zinc, however, percent removal ranged from -58 to 59 percent and performance decreased over time (Tables 4 and 5). Zinc was exported during the last two storm events. Mean concentration reduction for copper (T_R and dissolved) was 0.48 and 1.01 mg/l and for zinc was 0.37 and 1.37 mg/l, respectively.

Figures 1 and 2 are the effluent probability plots for both T_R and dissolved copper and zinc. For copper, the distance between inlet and outlet concentrations over a range of concentrations does not change much, meaning that performance ability was relatively constant over the range of influent concentrations. For zinc however, influent and effluent values get much closer together at the lower end of the concentrations range observed in this study, meaning that performance was greater when inlet concentrations were high.

Figure 3 shows a comparison between inlet and outlet concentration data for both copper and zinc. Flow reduction lines indicate the percentage of copper or zinc that was removed by filtering through oystershell media in this study. Reduction of copper ranged from 34-64 percent over the entire range of concentrations observed in this study. For zinc however, it was necessary to evaluate the high and low ends of the concentration range separately. At the high end of the range (influent concentration > 1 mg/L), reduction of total and dissolved zinc ranged from approximately 30 to 59 percent. At the low end of the range (inlet concentration < 0.3 mg/L), reduction ranged from -58 to 26 percent. For the last two storm events, zinc was exported (outlet concentration greater than inlet concentration.) Zinc exportation during the last two monitored storm events are likely due to the unusually high loading associated with uncoated galvalume roofing. Tables 4 and 5 represent the metals concentration data and summarize the percent removal data for individual storms.

CONCLUSIONS

Results of this study indicate that there are benefits to utilizing oystershells as a filtration media in StormFilter®cartridges. In general, filtration through oystershells resulted in improved water quality characteristics, including decrease in acidity (increase in pH), a slight decrease in TSS and turbidity concentrations (although influent levels were quite low), and increase in hardness, alkalinity, calcium, and magnesium concentrations. Removal of T_R and dissolved copper was also observed for the entire duration of the study (Table 4 & 5), and both inlet and outlet concentrations were below NPDES effluent limits (0.0636 mg/l) for all storm events. The oystershell media was effective at reducing copper concentrations with no apparent point of irreducible concentration. This attribute is uncommon in most filtration media types.

For zinc the concentration percent reduction results were comparable to copper for a portion of the study (Table 4 & 5), however, for the last two storm events, instead of zinc being removed, it was exported from the StormFilter. Also, both inlet and outlet zinc concentrations were greater than NPDES effluent limits (0.117 mg/l) for all storm events. The extremely high influent zinc concentrations in runoff from the uncoated Aeroground Building galvalume rooftop are not typical of industrial stormwater runoff. Further study is needed in a location that is more representative of roadway or industrial stormwater runoff. Given these considerations, oystershells as a filtration media for stormwater treatment would have to be utilized in conjunction with other methods of treatment to meet NPDES permit requirements when influent zinc concentrations are in the elevated range observed in this study. Further study is needed to determine the effectiveness of oystershell media at reducing zinc concentrations in typical roadway and industrial stormwater runoff with influent concentrations in the range of 50 to 300 μg/L.

The data indicate that the effectiveness of zinc removal decreased over the course of the study. However, coincidentally the influent zinc concentrations also generally decreased during the study, particularly for the last three storm events. The progressively lower influent concentrations can likely be attributed to a reduced accumulation of zinc available for wash-off from the roof as we entered the wet season. Thus it is unclear if the lower zinc removal effectiveness was related to the lower influent zinc concentrations, a loss in the media performance over time, or a combination of the two. To address this question, one would need to deploy fresh oystershells into the StormFilter® cartridges and sample the runoff when influent concentrations are expected to be low. Another consideration is that zinc loading from this cargo-building roof is likely much higher than would occur from a land runoff application, based on zinc concentrations observed in runoff from STIA drainage basins. Thus if oystershells were deployed in a StormFilter® unit to treat land runoff there may be a longer period before a loss in removal effectiveness occurs.

In summary, the oystershells in StormFilter® treatment technology did demonstrate the ability to improve water quality and reduce metals concentrations especially with regard to total and dissolved copper. Further study is required to determine the long-term effectiveness of reducing zinc concentrations in roadway and industrial runoff.

Please contact me with any further questions.

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TABLE 1: Storm Event Characteristics

Storm Number	Storm Date	Sample Time (from COC)	# of subsamples collected per site (Inlet/Outlet)	Antecedent Dry Period (h:mm)	Sampled Rainfall Depth (inches)	Rainfall prior to Sample Start (inches)	Max Rainfall Intensity (5 min interval)
1	6/28/2007	14:51	12	81:35	0.03	0	0.01
2	7/18/2007	9:59	12	21:30	0.03	0.16	0.01
3	7/20/2007	11:30	12	17:35	0.08	0.08	0.01
4	10/10/2007	10:05	5	57:00	0.02	0	0.01
5	11/15/2007	15:52	12	53:05	0.15	0.17	0.04
6	12/13/2007	13:15	12	80:55	0.05	0.08	0.01
7	3/13/2008	10:56	12	43:25	0.05	0.18	0.01

TABLE 2: Raw Water Quality Analytical Results

Sample Name	Sample Collection Date	pH	Alkalinity (mg $CaCO_3$/L)	Turbidity (NTU)	TSS (mg/L)	Ca (mg/L)	Mg (mg/L)	Hardness (mg $CaCO_3$/L)	Total Recoverable Cu (mg/L)	Total Recoverable Zn (mg/L)	Dissolved Cu (mg/L)	Dissolved Zn (mg/L)
INF-062807	6/28/2007	5.26	<1	0.83	1.5	1.07	0.101	3.07	0.0241	1.89	0.0214	1.79
OYSTER-IN-071807	7/18/2007	5.08	<1	4.6	4.3	0.608	<0.1	1.52	0.0214	1.07	0.0195	1.06
OYSTER-IN-072007	7/20/2007	5.60	<1	0.59	0.67	0.355	<0.1	<1.00	0.0116	1.14	0.01	1.09
OYSTERIN101007	10/10/2007	5.78	1	2.1	7	1.08	0.125	3.21	0.0127	1.62	0.0102	1.58
OYSTERIN111507	11/15/2007	5.04	<1	0.3	0.5	<0.1	<0.1	<0.7	0.0048	0.183	0.0045	0.164
OYSTERIN121307	12/13/2007	5.25	<1	0.28	<0.5	0.162	<0.1	<0.7	0.0081	0.236	0.0081	0.229
OYSTERIN031308	3/13/2008	4.94	<1	1.1	0.5	<0.1	<0.1	<0.7	0.0064	0.177	0.0058	0.173
EFF-062807	6/28/2007	6.8	8	1	2	6.25	0.269	16.07	0.0125	0.917	0.0087	0.728
OYSTER-OUT-071807	7/18/2007	6.76	6.9	3.3	<1	3.89	0.119	10.2	0.0111	0.564	0.0087	0.547
OYSTER-OUT-072007	7/20/2007	6.62	4.9	0.61	<1	3.38	<0.1	8.45	0.0077	0.648	0.0054	0.616
OYSTEROUT101007	10/10/2007	6.81	10.7	0.79	<0.5	6.32	0.236	16.7	0.0055	1.14	0.0045	0.97
OYSTEROUT111507	11/15/2007	6.46	3.6	0.24	<0.5	1.89	<0.1	4.72	0.0023	0.147	0.0023	0.122
OYSTEROUT121307	12/13/2007	6.65	5.1	0.23	<0.5	2.73	0.121	7.32	0.0039	0.372	0.0031	0.362
OYSTEROUT031308	3/13/2008	6.45	2.8	0.43	<0.5	1.31	<0.1	3.2	0.0037	0.188	0.0021	0.181

Table 3: Results of Wilcoxon Paired Sample T-test

H_o = influent concentration ≤ effluent concentration
H_a = influent concentration > effluent concentration
$T_{0.05(1),7}$=2

	storm	Influent (m	MS (mg/l)	MS diff	MS rank	MS signed rank
TR Cu	1	0.0241	0.0125	0.0116	7	7
	2	0.0214	0.0111	0.0103	6	6
	3	0.0116	0.0077	0.0039	3	3
	4	0.0127	0.0055	0.0072	5	5
	5	0.0048	0.0023	0.0025	1	1
	6	0.0081	0.0039	0.0042	4	4
	7	0.0064	0.0037	0.0027	2	2
				T+		28
				T-		0
				$T_{0.05(1),7}$=2		
				T- < $T_{0.05(1),7}$ H_o rejected		
				0.0005 > P(T- ≥0)		

	storm	Influent (mg/l)	MS (mg/l)	MS diff	MS rank	MS signed rank
diss Cu	1	0.0214	0.0087	0.0127	7	7
	2	0.0195	0.0087	0.0108	6	6
	3	0.0100	0.0054	0.0046	4	4
	4	0.0102	0.0045	0.0057	5	5
	5	0.0045	0.0023	0.0022	1	1
	6	0.0081	0.0031	0.005	3	3
	7	0.0058	0.0021	0.0037	2	2
				T+		28
				T-		0
				$T_{0.05(1),}$=2		
				T- < $T_{0.05(1),7}$ H_o rejected		
				0.0005 > P(T- ≥0)		

	storm	Influent (m	MS (mg/l)	MS diff	MS rank	MS signed rank
TR Zn	1	1.89	0.917	0.973	7	7
	2	1.07	0.564	0.506	6	6
	3	1.1400	0.6480	0.492	5	5
	4	1.6200	1.1400	0.48	3	4
	5	0.1830	0.1470	0.036	2	2
	6	0.2360	0.3720	-0.136	4	-3
	7	0.1770	0.1880	-0.011	1	-1
				T+		24
				T-		-4
				$T_{0.05(1),7}$=2		
				T- < $T_{0.05(1),7}$ H_o rejected		
				0.0025 > P(T- ≥4) > 0.0005		

	storm	Influent (mg/l)	MS (mg/l)	MS diff	MS rank	MS signed rank
diss Zn	1	1.79	0.728	1.062	7	7
	2	1.06	0.547	0.513	6	6
	3	1.0900	0.6160	0.474	5	5
	4	1.5800	0.9700	0.61	3	4
	5	0.1640	0.1220	0.042	2	2
	6	0.2290	0.3620	-0.133	4	-3
	7	0.1730	0.1810	-0.008	1	-1
				T+		24
				T-		-4
				$T_{0.05(1),7}$=2		
				T- < $T_{0.05(1),7}$ H_o rejected		
				0.0025 > P(T- ≥4) > 0.0005		

Based on these results (T- < T for all cases), we reject the null hypothesis and accept the alternative hypothesis that states the influent concentration is greater than the effluent concentration for both total recoverable and dissolved copper and zinc.

Table 4: Metals Concentration Data

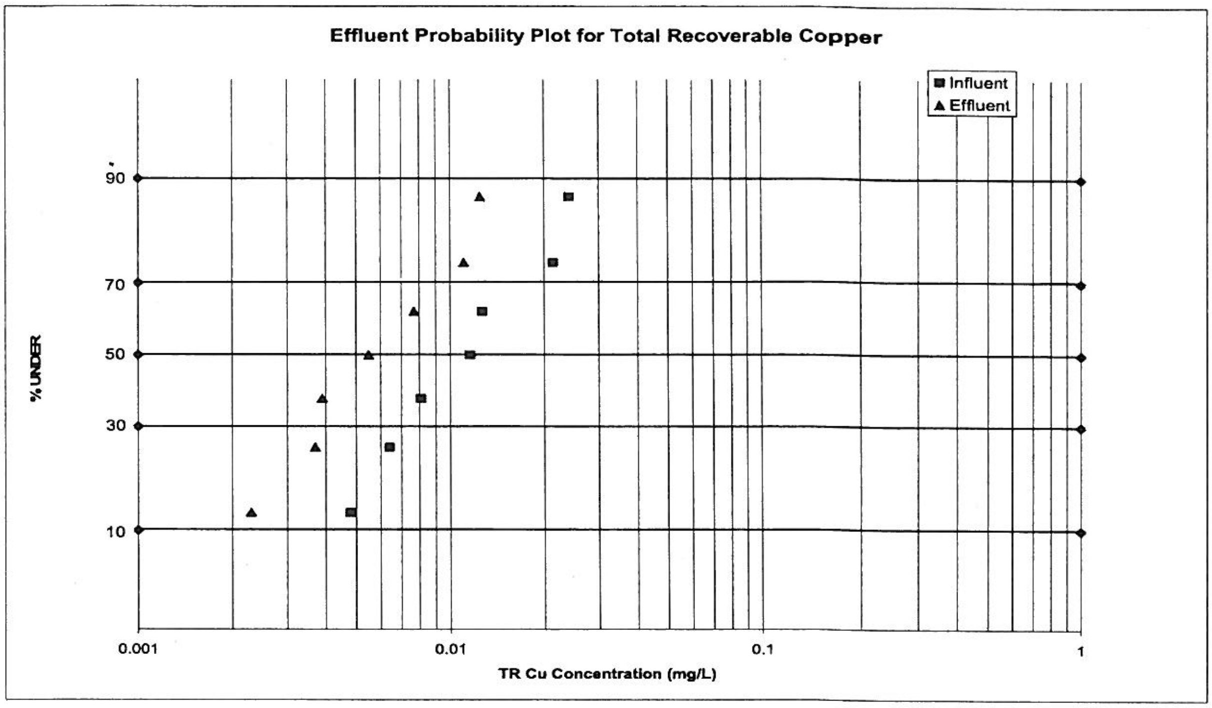
	INLET CONCENTRATION				OUTLET CONCENTRATION			
Sample Date (Storm #)	Total Recoverable Cu (mg/L)	Total Recoverable Zn (mg/L)	Dissolved Cu (mg/L)	Dissolved Zn (mg/L)	Total Recoverable Cu (mg/L)	Total Recoverable Zn (mg/L)	Dissolved Cu (mg/L)	Dissolved Zn (mg/L)
6/28/2007 (1)	0.0241	1.89	0.0214	1.79	0.0125	0.917	0.0087	0.728
7/18/2007 (2)	0.0214	1.07	0.0195	1.06	0.0111	0.564	0.0087	0.547
7/20/2007 (3)	0.0116	1.14	0.01	1.09	0.0077	0.648	0.0054	0.616
10/10/2007 (4)	0.0127	1.62	0.0102	1.58	0.0055	1.14	0.0045	0.97
11/15/2007 (5)	0.0048	0.183	0.0045	0.164	0.0023	0.147	0.0023	0.122
12/13/2007 (6)	0.0081	0.236	0.0081	0.229	0.0039	0.372	0.0031	0.362
3/13/2008 (7)	0.0064	0.177	0.0058	0.173	0.0037	0.188	0.0021	0.181

Table 5: Metals Percent Removal Data

WQ Results	INDIVIDUAL STORM PERCENT REMOVAL							Mean Concentration Reduction(mg/L)[1]
Parameter	1	2	3	4	5	6	7	
TR Cu	48%	48%	34%	57%	52%	52%	42%	0.48
TR Zn	51%	47%	43%	30%	20%	[redacted]		0.37
Diss Cu	59%	55%	46%	56%	49%	62%	64%	1.01
Diss Zn	59%	48%	43%	39%	26%	[redacted]		1.37

[1] Mean Concentration Reduction was the average reduction in specified metal concentration calculated by summing the individual storm concentration reductions and then dividing that value by the number of storms sampled.

Figure 1: Effluent Probability Plots for Total Recoverable and Dissolved Copper



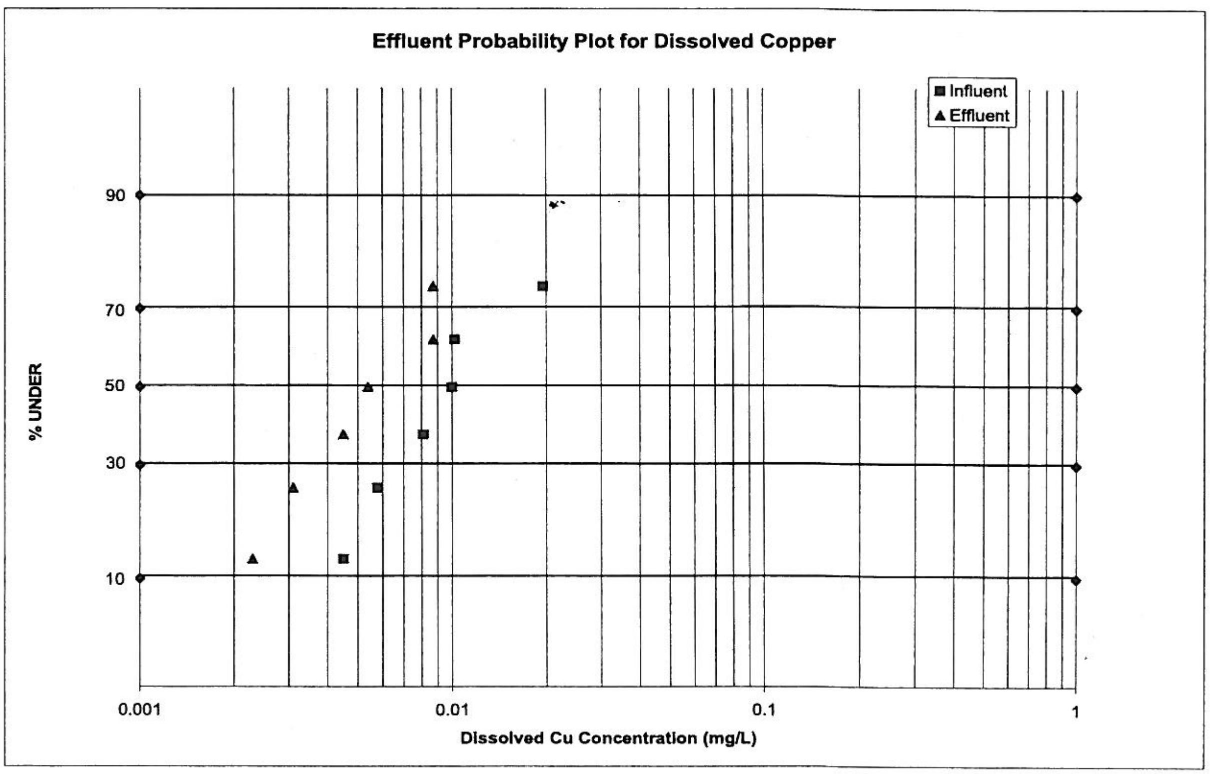
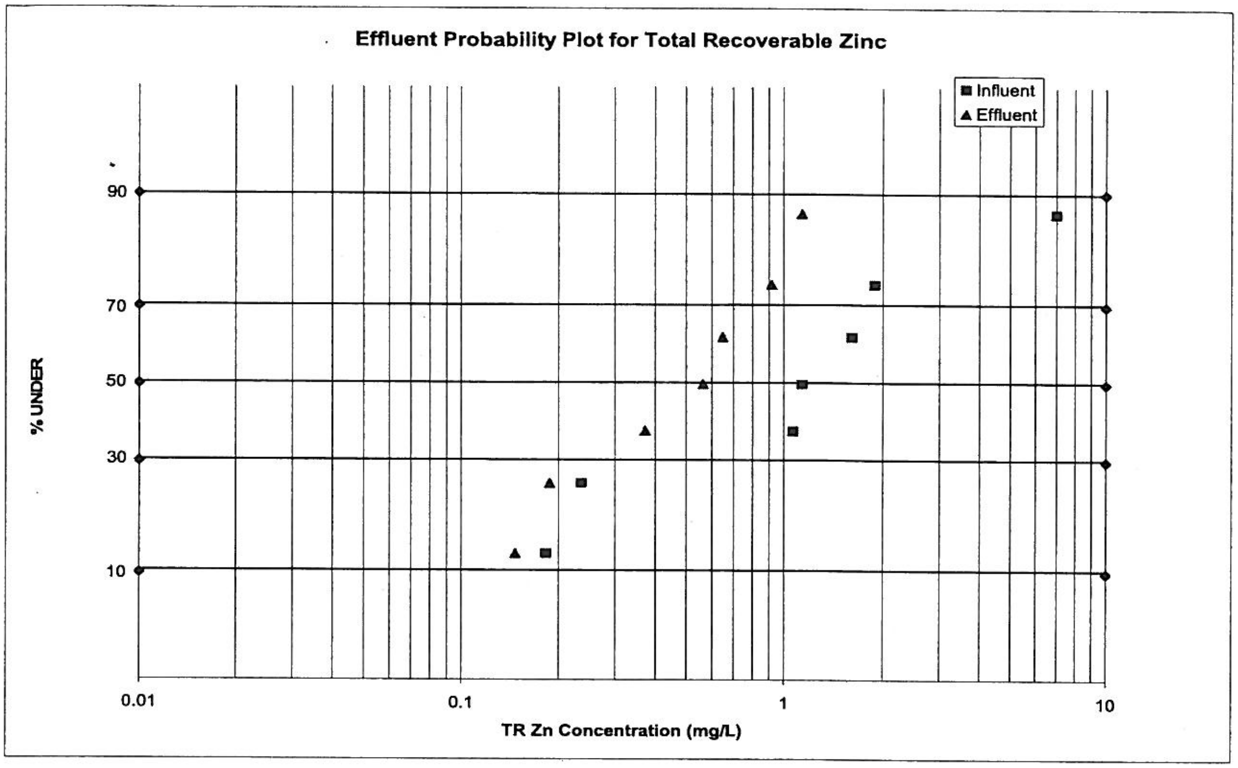


Figure 2: Effluent Probability Plots for Total Recoverable and Dissolved Zinc.



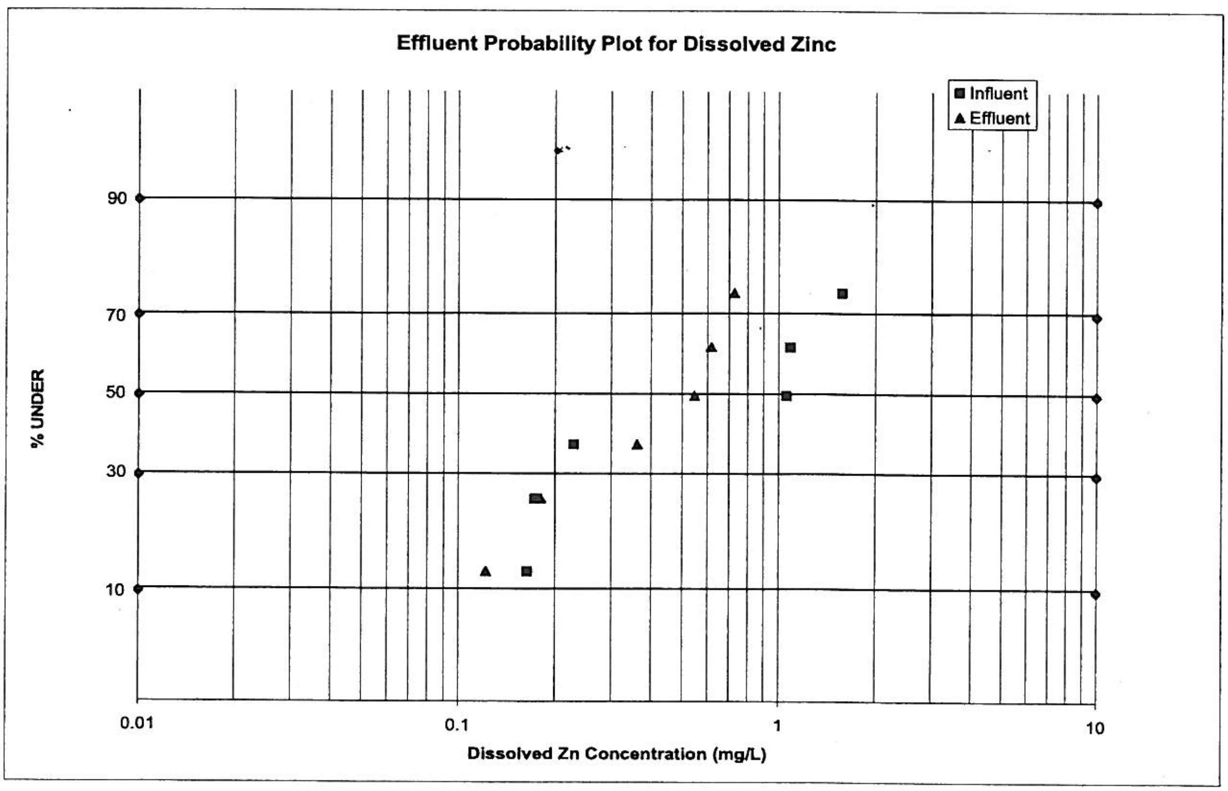


Figure 3: Comparisons of Influent and Effluent Total Recoverable and Dissolved Copper and Zinc Concentrations