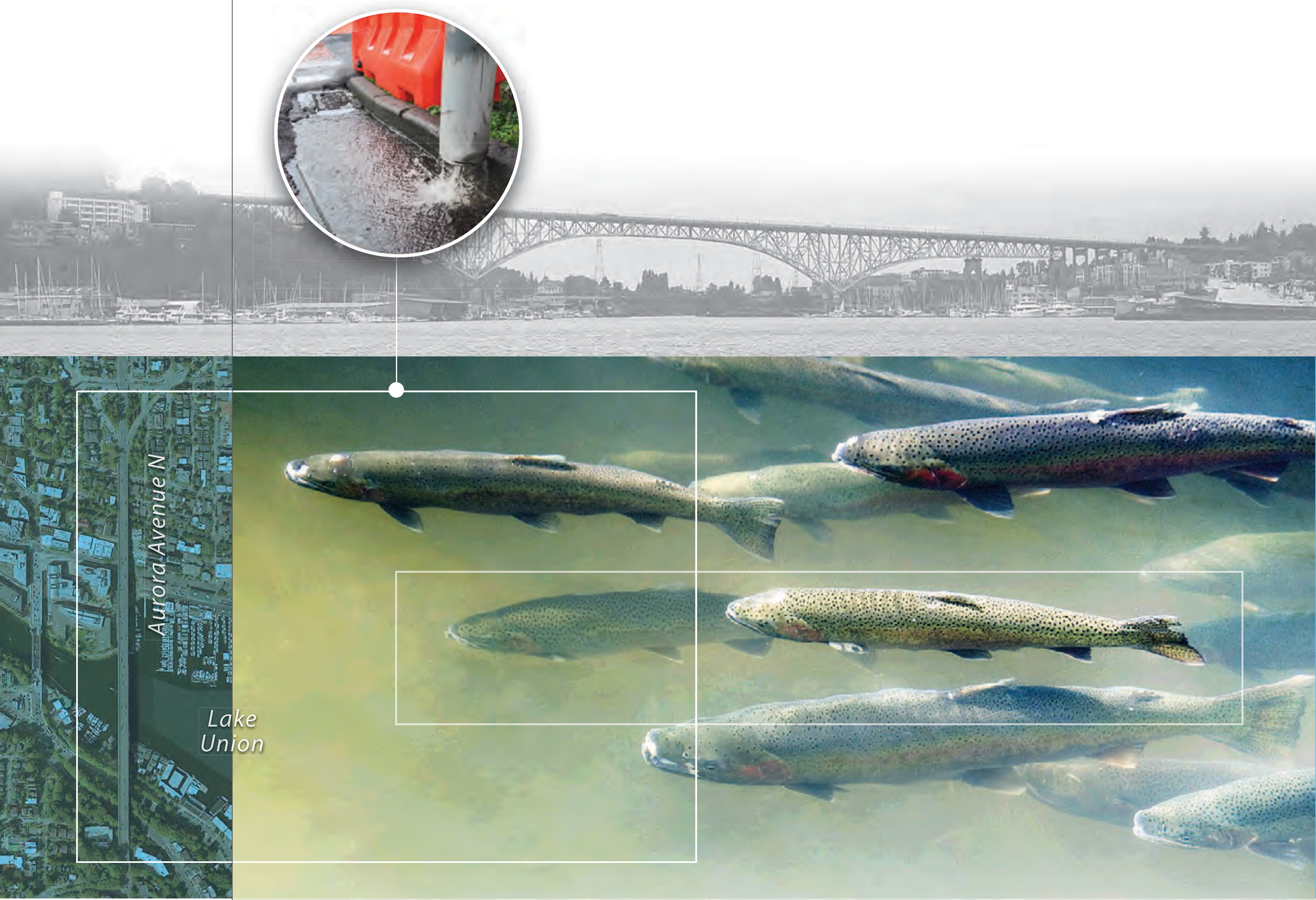
SALMON-SAFE INC.

THE AURORA BRIDGE MITIGATION PROJECT



Salmon-Safe Inc.
1201 Alaskan Way, Suite 200
Seattle,Washington 98119
206.579.8645
info@salmonsafe.org

SALMON SAFE PugetSound

www.salmonsafe.org

TABLE OF CONTENTS

Headline from a Puget Sound Business Journal online news story published January 14, 2016.

Introduction | Baby Salmon Spawn Urban Intervention

The Aurora Bridge Mitigation Project was spawned from the brain trust of the Center of the Universe LLC partnership and their approach to developing two new projects at the corner of 34th and Troll Avenue known as the Data 1 and Watershed Buildings.

Stephen C. Grey & Associates (SGA) is developing the new commercial projects with First Western Development Services. Mark Grey of SGA and Mike Hess of First Western said a video of dying baby salmon inspired them to build a fish-friendly project. “Mike and I saw a video showing baby salmon being put in water runoff from the State Road 520 Bridge and instantly dying,” said Grey. “And then the developers showed them surviving after they were put in water that had been passed through soil a few times.”

With the two new buildings designed to capture water runoff from the Aurora Bridge and pass it through soil cells, cleaning it before it makes its way to Lake Union, they decided to take a proactive approach by building a bioswale under the bridge across North 34th, adjacent to Lake Union and the mouth of the Fremont Canal, which leads to Puget Sound for further intervention. The bridge’s stormwater runoff at this site impacts a critical migration route for salmon. Chinook, Coho, sockeye and steelhead trout all swim from the Pacific Ocean and Puget Sound back through the canal and Lake Union to reach their spawning grounds in the upper watershed. Working with Salmon-Safe, the design team of KPFF Engineers and Weber Thompson Architects and Landscape Architects is trying to establish a ground-breaking effort to treat nearly two million gallons of polluted bridge runoff and create a replicable model of private-public partnerships for the future.

Samples of bridge runoff were taken in the winter and spring of 2017 to determine what pollutants were evident in the water and provide a water quality baseline for testing bridge runoff and treatment over the next five years. The water quality reports and their comparison to the SR-520 Bridge runoff results are featured in the supporting materials that follow.

THE PROJECT AND DESIGN OPPORTUNITIES

The Aurora Bridge Mitigation Project presents a new opportunity for innovative water quality treatment of polluted stormwater runoff. Currently, runoff from the Aurora Bridge is polluted by vehicular traffic. It is then partly discharged as untreated stormwater to a Ship Canal outfall. The rest is discharged to Seattle's capacity-constrained combined sewer system. During periods of wet weather and/or equipment malfunctions, untreated sewage and stormwater from the combined sewer system is released into surrounding Puget Sound water bodies, which are referred to as combined sewer overflows (CSO's). The following table describes the outflow of the catch basins:

Table 1. Catch basin outflows

Project Basins	Description	Bridge Area (sq ft)	Number of Bridge Down-spouts	Average Annual Discharge (Gallons)
A	Untreated stormwater runoff is discharged from a bridge downspout to the curb on Troll Avenue, where it is collected and conveyed through the municipal storm sewer system to a culvert outfall at the Ship Canal.	9,000	1	175,000
B	Untreated stormwater runoff is tight-lined from bridge downspouts directly to the municipal storm sewer system discharging by culvert to the Ship Canal.	25,000	2	450,000
C	Untreated stormwater runoff is tight-lined from bridge downspouts to the municipal combined sewer system with ultimately connects to the King County Metro trunk line in North 34th Street conveying sewage to the West Point treatment plant.	30,000	2	580,000
	Total	64,000	5	1,205,000

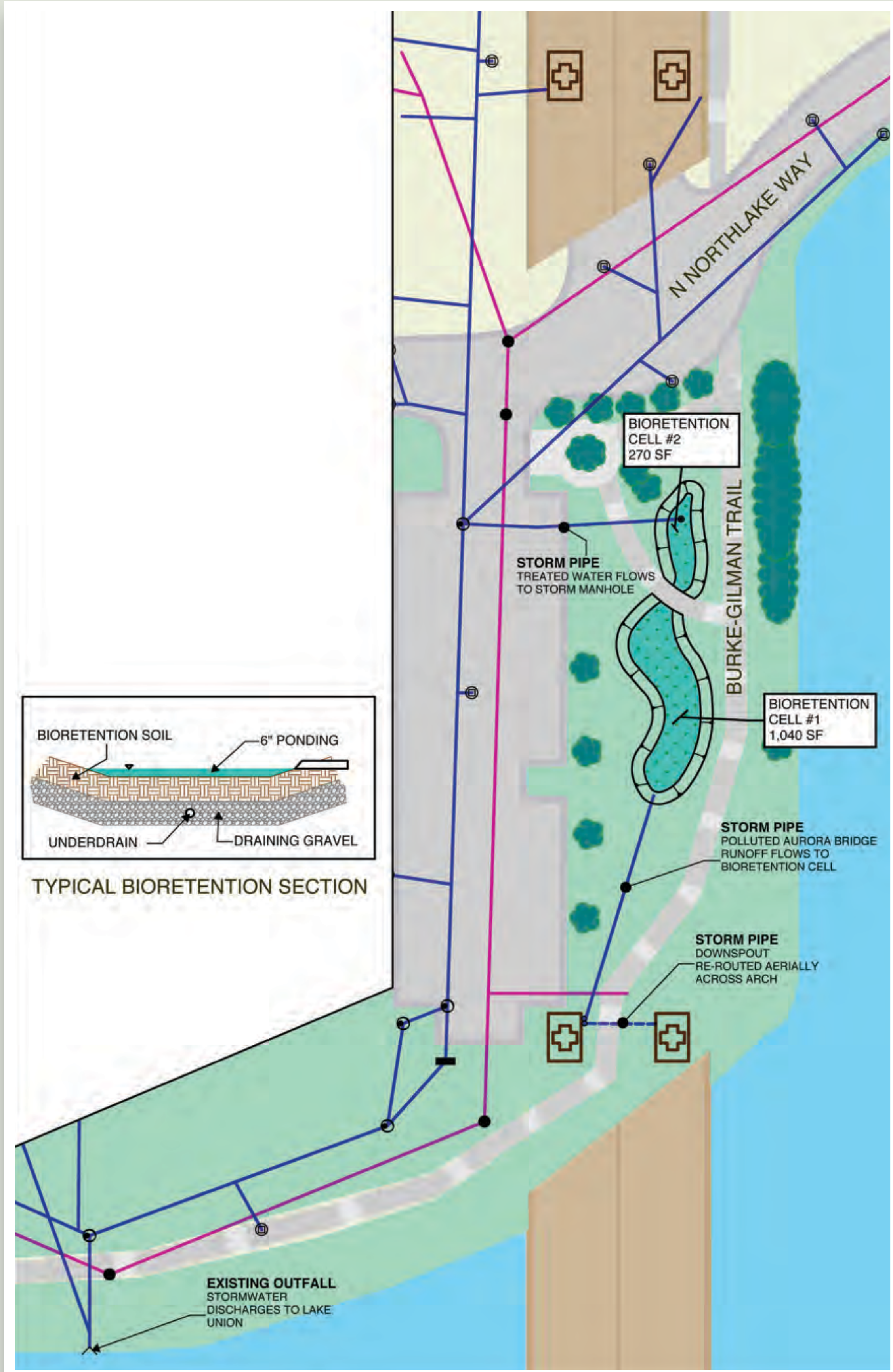


Figure 1. Aurora Bridge bioretention site locations

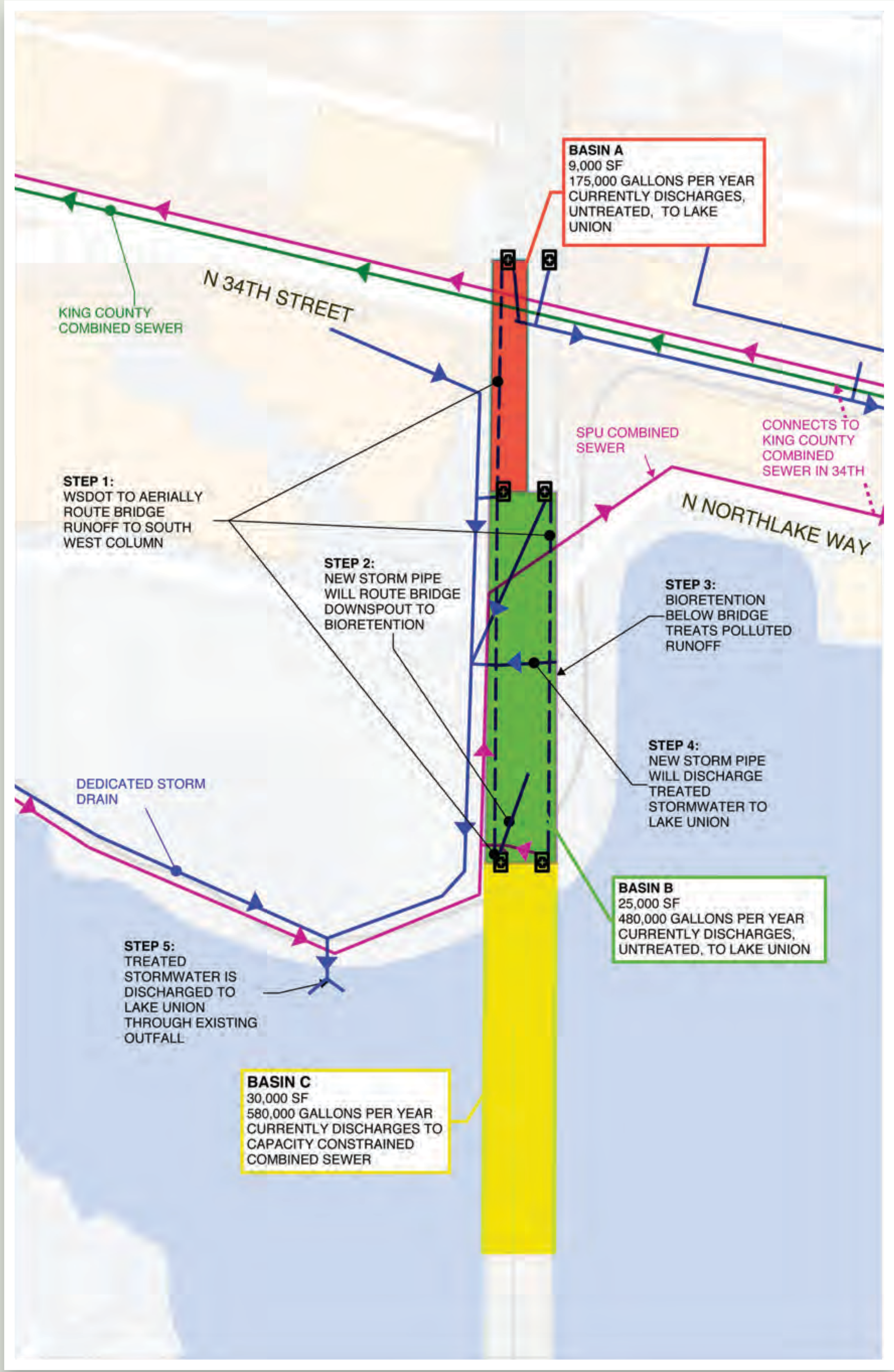


Figure 2. Aurora Bridge mitigation map as prepared by KPFF Engineers

This project proposes to intercept stormwater runoff from all five subject downspouts and route previously untreated stormwater runoff to a bioretention facility constructed in the open green space below the Aurora Bridge, adjacent to the Burke Gilman Trail (see Figure 1 and 2). The facility will be designed to meet or exceed the 2016 City of Seattle and Washington Department of Ecology standards for basic water quality treatment. Preliminary designs for the facility indicate the following geometry:

- infiltration rate through amended soils — 6 inches / hour
- bottom area (infiltrative surface) — 1,310 square feet
- amended soil depth — 2 feet
- ponding depth — 6 inches
- freeboard — 6 inches

The facility was modeled using MGSFlood continuous rainfall-runoff modeling. The results of this model indicate that the bioretention facility will provide enhanced water quality treatment for approximately 98% of all stormwater the facility receives based on the model's 158-year record. This exceeds the City of Seattle standard of treating 91% of the total runoff volume based on the same record. Enhanced treatment is intended to remove 80% of total suspended solids (TSS's), 30% of dissolved copper, and greater than 60% of dissolved zinc.

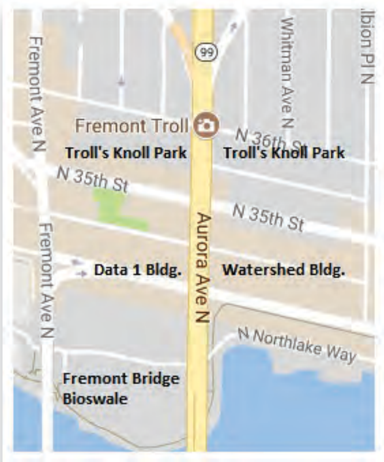
Table 2 below provides an executive summary of the preliminary engineer's estimate for construction. An important percentage of the costs are in the conveyance and rerouting from the bridge downspouts to the bioretention facility. WSDOT (Washington State Department of Transportation) has expressed some openness to aerially reroute stormwater from four of the rain leaders to a designated fifth rain leader for simplified conveyance to the bioretention facility. There has also been some discussion with the City of Seattle (COS) regarding waiving permit fees. The cost estimate below does not assume WSDOT or COS assistance.

Table 2. Preliminary cost estimate

Hard Costs	Cost
Division 1 — General	$ 21,000
Division 2 — Temporary Erosion Control	13,000
Division 3 — Site Preparation & Earthwork	32,000
Division 4 — Aggregate & Surfacing	12,000
Division 5 — Pavement Replacement	22,000
Division 6 — Bioretention Facility	49,000
Division 7 — Drainage & Utilities	37,000
Division 8 — Miscellaneous (includes interpretive signage)	22,000
Sales Tax @ 10%	22,000
Subtotal	$ 238,000
Soft Costs	
Design & Consultant Costs @ $15%	$ 37,000
Public Agency Fees @ 5%	13,000
Construction Management @ 8%	20,000
Salmon-Safe Certification, Assessment & Monitoring	15,000
Water Quality Testing (5 Years)	6,500
Subtotal	$ 85,000
15% Contingency	50,000
Grand Total	$ 380,500

NEIGHBORHOOD CONTEXT & GROWING MOMENTUM

The Aurora Bridge Mitigation Project is located adjacent to Lake Union at the southern point of the Fremont canal leading to the Ballard Locks. It is just below the intersection of 34th and Troll Avenue where cascading bioswales and rain gardens are being built to treat the runoff from the new Data 1 Building and the future Watershed Building across the street. Both projects are owned and being developed by Center of the Universe LLC and managed by Mark Grey, who is proposing the Aurora Bridge Mitigation Project.



The urban intervention sites present learning opportunities for pedestrians to better understand the importance of watershed health in urban environments.

With the installation of the bioswale, our team saw an opportunity to link to the larger context of the neighborhood. Inspired by Salmon-Safe certified parks in the Pearl District of Portland, we have identified a three-site link to habitat and natural areas that are currently not part of the built environment along Troll Avenue. Fremont, like the Pearl District, is going through a resurgence of development and experiencing exponential growth. Although the Pearl sites, including The Fields Park, Tanner Springs Park, and Jamison Square, are larger in scale, they do provide a similar trilogy of an urban walking experience. The Fields Park is programmed as open space and play area for kids. Tanner Springs Park is a site for treating urban runoff. Lastly, Jamison Square provides an open space area with a water feature. Our Fremont trilogy could begin at the popular Troll's Knoll, a site that is being revitalized as an active park space and community garden presenting opportunities for habitat and ecological function adjacent to the Fremont Bridge; walking west to the canal, pedestrians can enjoy the open plaza and bioswales of the Data 1 and Watershed Building on either side of the street, ending at the Aurora Bridge Mitigation Project along the Burke Gilman Trail, where one could venture even further throughout Seattle. These three sites will all feature interpretive signage for interactive engagement of visitors (see Figure 3). They also present teaching moments in terms of better understanding urban watershed health, the impacts of polluted runoff impacting Puget Sound, and the wellbeing of salmon and other aquatic species.

The neighboring urban villages of Ballard and the University District have recently inventoried open space planning and green infrastructure sites. Precedence was set

The new Troll's Knoll Park is located in the right-of-way at the north end of the Aurora Avenue Bridge and could be a future site for stormwater treatment of bridge runoff.

in these communities where key stakeholders and the public identified right-of-ways as a priority opportunity for bringing urban habitat into the neighborhoods, treating stormwater and providing a more livable experience for the people that reside there. Although the Fremont neighborhood has not yet conducted a similar process, the Seattle Department of Neighborhoods is seeing the same interest from a multitude of other urban villages. As density influences Seattle's growing neighborhoods there is an increasing need for these types of urban interventions to fill a gap for green space and habitat.

In addition to the individual neighborhood inventories, public private partnerships are also becoming more common in our region. The Swale on Yale serves as a great example of private investment for the common good. When completed, the project will treat an average of 190 million gallons of stormwater flowing from Capitol Hill into Lake Union annually, greatly reducing the amount of pollution flowing into the lake. The Swale on Yale anchors the runoff at the southern end of the lake while our project in Fremont is treating runoff at the northern end. Together the aggregate outcomes are an important step to further restoring water quality in Lake Union.

The new Data 1 and Watershed Buildings will provide learning experiences for pedestrians with a series of interpretive signs that identify native plants and the importance of treating stormwater runoff in the urban environment. Their plazas also offer new found open space at the intersection of N. 34th and Troll Avenue.

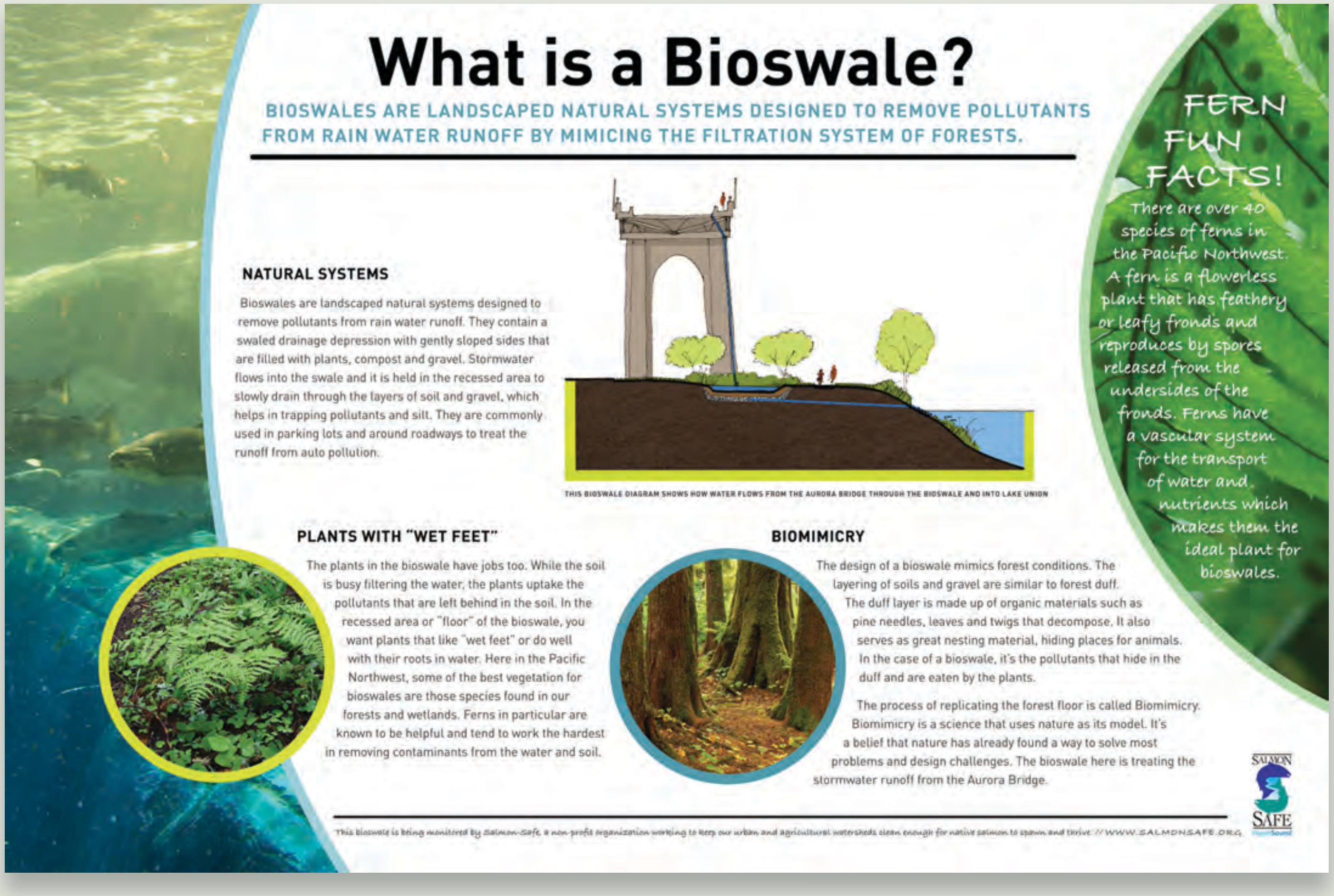


Figure 3. An example of interpretive signage installed at Fremont Bioswale

GOVERNANCE CONUNDRUM

At the beginning of the Data 1 project (Phase 1), KPFF reached out to Seattle Department of Transportation (SDOT) and Seattle Public Utilities (SPU) to share the team's trepidation with entering into the typical permitting regime with the project's innovative stormwater approach. The team earnestly believed in its idea, but feared that the typical review process would put up roadblocks

This bridge aerial illustration shows where the bridge downspouts and mitigation project are located and where runoff will be contained and treated through bioswales.

to anything out of the ordinary. SDOT responded by assigning an SIP reviewer who was willing to put in extra time to understand the proposal and who allowed the project team to step outside of the normal 30%, 60%, 90% review process with additional meetings and coordination. Additionally, SPU assigned a dedicated engineer to help with permit review and expediting. This cooperative effort continued into the Watershed project (Phase 2). We made similar attempts to engage Washington State Department of Transportation (WSDOT) with phases 1, 2, and 3, as their infrastructure is the source of the polluted runoff. WSDOT participation in Phases 1 and 2 was to communicate to SDOT that they had no objections to the proposal. The team is in initial discussions with WSDOT regarding rerouting storm leaders to help accomplish Phase 3 at less cost than the prior phases. It remains to be seen if WSDOT will assist with the endeavor. WSDOT Bridge Repair Engineering Division has indicated willingness to reroute four bridge downspouts to the Fremont Bioswale on the condition that they do the work themselves following approval from SPU and SDOT. WSDOT has said that they intend to charge Stephen Grey and Associates (SGA) for their services and are requiring that SGA assume liability and achieves approval from SPU and SDOT. The design team has requested a cost from WSDOT and they have yet to provide that information. The team has also met with the Department of Ecology (DOE) Water Quality and Non-Point Pollution team. DOE is in favor of the project and at one point had hopes to help fund its construction through two potential grant programs. As of June 2017, those funding streams are on hold until there is further clarity of overall EPA funding distribution for Washington State.

Based on RC 47.24, the Aurora Bridge section of SR-99 is a Managed Access Highway within the City of Seattle city limits. As such, drainage responsibility and right-of-way are vested with the City. WSDOT has a Maintenance Agreement (GM20) with the City of Seattle for this area and has identified the City of Seattle as the lead agency for projects such as this. WSDOT does not intend to maintain the proposed facility.

THE SWALE ON YALE EXAMPLE

Using the Swale on Yale example as a private public partnership example, the Swale on Yale, also known as the Capitol Hill Water Quality Project, is an innovative collaboration between Vulcan Real Estate and Seattle Public Utilities (SPU) to reduce the amount of pollution flowing into Seattle's Lake Union. The project incorporates a natural drainage system of four biofiltration swales set along two Vulcan-owned blocks in South Lake Union at Yale and Pontius Avenues North treating polluted runoff from 630 acres of land on Capitol Hill. The total cost of this project is approximately $11 million.
SPU received a $1 million stormwater grant from the Washington State DOE's FY2011 Stormwater Retrofit and Low Impact Development (LID) Competitive Grant Program and a $1.8 million loan from the Washington State Water Pollution Control Revolving Fund Loan Program. SPU is actively working with Vulcan Real Estate, a local Cascade Neighborhood Partner, in developing and funding the Swale on Yale. Vulcan Real Estate has provided technical and professional services and will be funding $1.2 million of the design and construction costs of the two-phase project.

WHAT'S IN THE WATER?

Introduction

Property redevelopment at the northwest corner of N 34th Street and Troll Avenue N in Seattle is incorporating bioretention-type green stormwater infrastructure (GSI) to treat runoff from approximately 8,000 ft^2 of the Aurora Avenue N Bridge (State Route 99) passing over Troll Avenue N. The project has received Salmon-Safe certification because of its overall practices beneficial to salmon, including reaching beyond its own site boundaries to mitigate a major neighborhood water pollution source. In planning are additional GSI facilities on other properties in the vicinity to treat more of the bridge surface runoff. To form a baseline of the highway runoff water quality prior to the installation of treatment, samples of the flow from the bridge were collected on five occasions during February–April 2017. The intention is to monitor discharges from the eventual treatment facilities for comparison with this baseline.

Sampling and Analysis Methods

Sample containers were obtained from Fremont Analytical, Inc., located less than 1/4 mile from the sampling location. The containers were cleaned as required for the analyses to be performed and preservatives were added as necessary. Samples were collected directly into the containers from a vertical downspout draining the Aurora Bridge near the northwest corner of N 34th Street and Troll Avenue N. Sampling was timed to occur as soon after the onset of runoff as logistically possible to represent the "first flush" of pollutant transport.[1] The samples were transported to the Fremont Analytical laboratory immediately upon completing collection. They were placed under temperature control until the beginning of analytical

[1] Sampling was planned using the website *https://weather.com/weather/hourbyhour/l/USWA0395:1:US* (last accessed on 4/13/17), which gives hour-by-hour forecasts of precipitation probability for Seattle.

procedures, which were completed within five business days. Table 3 lists the analyses performed, the methods used and the quality control checks applied.

Analytical Results

Table 4 presents the pollutant concentrations measured in each sample and the rainfall recorded on the sample collection date and the preceding day. Most of the quantities are consistent in being in the same order of magnitude in the respective samples. Others differ more substantially (TSS, DPb, TPH-Dx and TPH-heavy oil). TPH-Gx was not detected in any sample.

All quality control checks are within acceptable limits with the following exceptions. Dissolved copper and total recoverable zinc appeared in the method blanks run on the 2/15/17 sample, whereas they should have been undetectable. The quantities are just above the reporting limits, however, and are only 2.4 and 1.0 percent of the respective DCu and TZn concentrations measured in the sample.

Table 3. Analytical methods

Water Quality Variable (Abbreviation)	Method	Quality Control[a]
Total suspended solids (TSS)	Standard Methods 2540D[b]	MB, LCS, Dup
Total recoverable copper (TCu)	EPA Method 200.8[c]	MB, LCS, Dup, MS, MSD
Dissolved copper (DCu)		
Total recoverable lead (TPb)		
Dissolved lead (DPb)		
Total recoverable zinc (TZn)		
Dissolved zinc (DZn)		
Total petroleum hydrocarbons-gasoline (TPH-Gx)	NWTPH-Gx[c]	MB, LCS, LCSD, Dup
Total petroleum hydrocarbons-diesel (TPH-Dx)	NWTPH-Dx/Dx Ext.[d]	
Total petroleum hydrocarbons-heavy oil (TPH-heavy oil)		

[a] MB—method blank, LCS—laboratory control sample, Dup—duplicate, MS—matrix spike, MSD—matrix spike duplicate, LCSD—laboratory control sample duplicate

[b] American Public Health Association, American Water Works Association and Water Environment Federation. 2016. *Standard Methods for the Examination of Water and Wastewater.* APHA, AWWA and WEF, Washington, DC.

[c] U.S. Environmental Protection Agency. 1994. *Method 200.8, Revision 5.4: Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma – Mass Spectrometry.* Environmental Monitoring Systems Laboratory, Cincinnati, OH.

[d] Washington Department of Ecology. 1997. *Analytical Methods for Petroleum Hydrocarbons.* Washington Department of Ecology, Olympia, WA.

Table 4. Analytical results and rainfall records

Variable (unit)	Sample Date				
	2/8/17	2/15/17	3/24/17	3/29/17	4/5/17
TSS (mg/L)	1890	370	630	319	567
TCu (µg/L)	471	344	311	200	251
DCu (µg/L)	32.8	21.8[a]	25.8	14.4	25.1
TPb (µg/L)	301	447	319	690[a]	345
DPb (µg/L)	ND	2.41	3.30	6.64	4.28
TZn (µg/L)	2520	1910[a]	1570	1440	1410
DZn (µg/L)	255	271	218	149	270
TPH-Gx (µg/L)	ND[b]	ND[b]	ND[b]	ND[b]	ND[b]
TPH-Dx (µg/L)	ND[b]	339	284	503[a]	436[a]
TPH-heavy oil (µg/L)	11100	13300	3310	7890	5600
Time rainfall began[c]	6:00 AM–12:00 PM	12:00 AM–6:00 AM	6:00 AM–12:00 PM	12:00 AM–6:00 AM	12:00 AM–6:00 AM 4/4/17
Sample Collection Time	11:40AM	9:35AM	9:11AM	9:15AM	9:10AM
Rainfall on Sampling Day (inch)[d]	0.70	1.63	0.52	0.44	0.53
Rainfall on Preceding Day (inch)[d]	0.01	0.23	0.18	0.07	0.07

[a] A quality control check was outside of established limits. See discussion below.

[b] ND—not detected

[c] From *https://www.timeanddate.com/weather/usa/seattle/historic?month=2&year=2017* (last accessed 4/13/17), which reports rainfall occurrence in 6-hour intervals.

[d] From *https://www.wunderground.com/history/* (Historical Weather for Zip Code 98103; last accessed 4/13/17).

Matrix spike (MS) and matrix spike duplicate (MSD) checks on TPb and TPH-Dx in the 3/29/17 sample and TPH-Dx in the 4/5/17 sample are outside of the designated limits in initial and repeated tests, indicating possible matrix interferences. The term matrix refers to the components of a sample other than the analyte of interest. MS involves adding a known concentration of the analyte to the sample and determining the degree of agreement in the analytical result with the expected concentration. MSD is a repetition of that procedure. Matrix interference refers to sample characteristics that interfere with the test method execution. Examples include extreme pH, high alkalinity or acidity, and chemical constituents that react

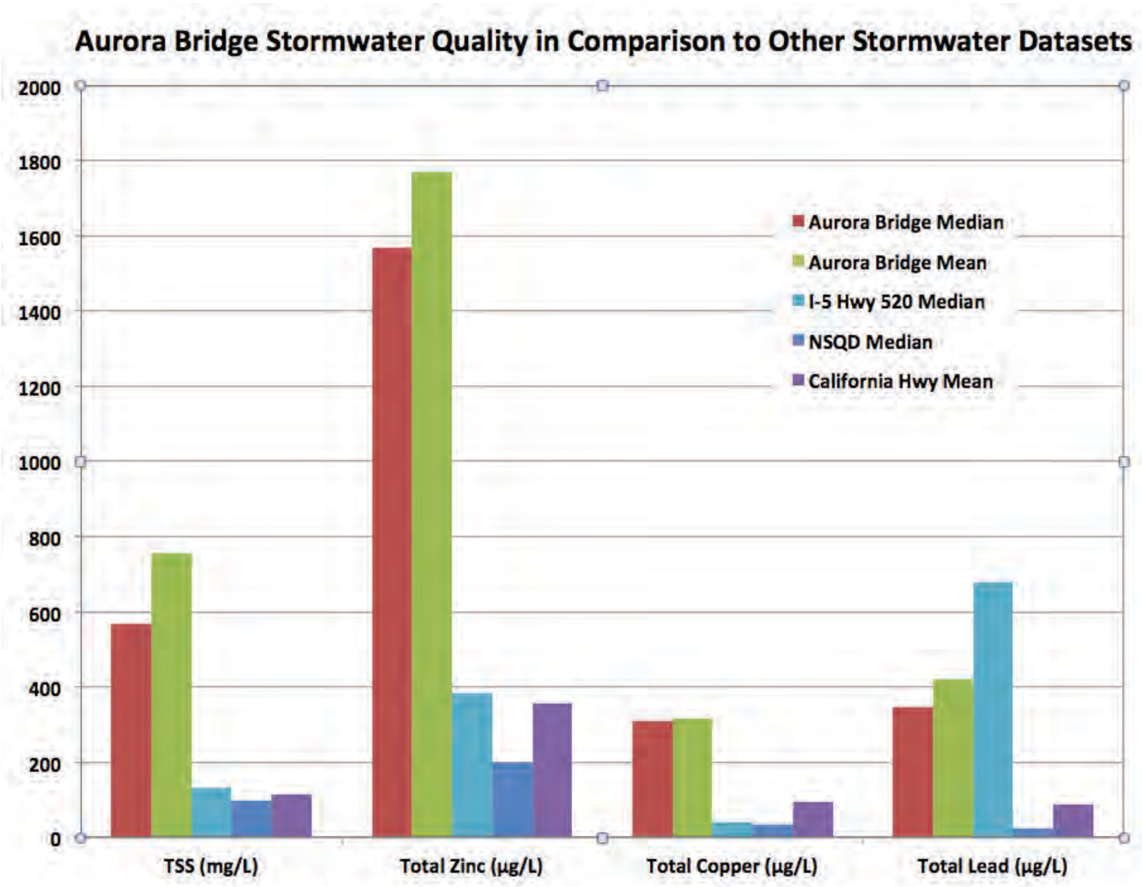


Figure 4. Aurora Bridge stormwater and other stormwater datasets compared

with target analytes. The latter is the most likely cause in this case. Measurements in the affected samples do not differ substantially from those in the samples taken on other dates not having indications of matrix interferences.

Sampling generally occurred relatively soon after the onset of runoff, as planned. Antecedent dry periods were not long, however, generally less than 24 hours. Seattle was experiencing almost daily rainfall, totaling near record amounts for the months of February and March 2017. Thus, the study does not represent the build-up or pollutants that may occur with extended antecedent dry weather. It rained 122 continuous days in the first four months of 2017—the rainiest period on record in the history of Seattle.

The Results in Context

The municipal permits under which the Washington State Department of Transportation (WSDOT)[2] and City of Seattle[3] drainage systems operate state no numeric limits on pollutants in stormwater discharges. To put the Aurora Bridge results in context, the National Stormwater Quality Database (NSQD)[4] provides data from a representative number of municipal stormwater permit holders across the nation. To date it serves as the largest urban stormwater database ever developed and includes data from freeway sampling. Median freeway concentrations as reported in the Fact Sheet for the WSDOT permit for pollutants also measured in the Aurora Bridge runoff appear in Table 5 in comparison to this study's results. The median is the number at which half of the measurements fall above and half below.

Excepting DPb, even the minimum Aurora Bridge concentrations are far above the nationwide medians. The Aurora Bridge TCu, TPb and TZn medians are a full order of magnitude higher than the same statistic in the national data. The TSS and dissolved metal medians are as much as five times as high.

Table 5. Median freeway pollutant concentrations from the National Stormwater Quality Database (NSQD) compared to Aurora Bridge results

Variable (unit)[a]	NSQD Freeway Median	Aurora Bridge Median	Aurora Bridge Minimum	Aurora Bridge Maximum
TSS (mg/L)	99	567	319	1890
TCu (µg/L)	35	311	200	471
DCu (µg/L)	10.9	25.1	14.4	32.8
TPb (µg/L)	25	345	301	690
DPb (µg/L)	1.8	3.30	0.25	6.64
TZn (µg/L)	200	1570	1410	2520
DZn (µg/L)	51	255	149	271

[a] The database does not report TPH fractions.

[2] National Pollutant Discharge Elimination System and State Waste Discharge Municipal Stormwater General Permit No. WAR043000A (2014).

[3] National Pollutant Discharge Elimination System and State Waste Discharge General Permit for Discharges from Large and Medium Municipal Separate Storm Sewer Systems (2012, as modified 2015 and 2016).

[4] NSQD Version 4.02 (last updated January 2015). *http://www.bmpdatabase.org/nsqd.html* (accessed on March 16, 2017).

The Washington State Highway Runoff Water Quality research project performed by the University of Washington from 1977 to 1982 provides another frame of reference. This study collected 653 stormwater samples from nine highways across the state, including 283 from Interstate 5 and SR-520 in Seattle.[5] Table 6 presents median concentrations for some pollutants measured on these two high volume-highways near Aurora Avenue N. The medians are in the same general magnitude as those in the NSQD data set, except for TPb, which is much higher and also generally higher than the Aurora Bridge median. The latter result is understandable, in that lead was not banned from gasoline until the 1990 amendments to the Clean Air Act, which did not take effect until 1995. The large majority of the NSQD data points are from after the phase-out date.

Table 6. Median pollutant concentrations in stormwater runoff from I-5 and SR-520 in Seattle measured in the 1977-1982 Washington State Highway Runoff Water Quality Research Project[6] compared to Aurora Bridge results

Variable (unit)[a]	1977-1982 Median[b]	Aurora Bridge Median	Aurora Bridge Minimum	Aurora Bridge Maximum
TSS (mg/L)	130	567	319	1890
TCu (µg/L)	40	311	200	471
TPb (µg/L)	680	345	301	690
TZn (µg/L)	385	1570	1410	2520

[a] The study did not measure dissolved metals and the TPH fractions.

[b] Based on data from Western Washington monitoring stations on I-5 and SR-520 lanes carrying 42,000-53,000 average vehicles per day. The Seattle Department of Transportation's *2014 Traffic Report* gives the volume as 37,950 vehicles per day on Aurora Avenue N south of N 145th Street.

Excepting TPb, the Aurora Bridge minimums exceed the more than 35-year old median concentrations by percentages of 250-500. The medians range up to more than seven times as high.

Another contextual illustration can be drawn from an extensive study of stormwater best management practices (BMP's) suitable for application on highways performed by the California Department of Transportation from 1999 to 2004.[7]

[5] Mar, B.W., R.R. Horner, J.F. Ferguson, D.E. Spyrikakis and E.B. Welch. 1982. Summary—*Washington State Highway Runoff Water Quality Study, Report No. WA-RD-39.16*. Washington State Department of Transportation, Olympia, WA.

[6] Horner, R.R. and B.W. Mar. 1982. *Guide for Water Quality Impact Assessment of Highway Operations and Maintenance, Report No. WA-RD-39.14*. Washington State Department of Transportation, Olympia, WA.

[7] California Department of Transportation. 2004. *BMP Retrofit Pilot Program Final Report*. California Department of Transportation, Sacramento, CA.

Table 7 presents the arithmetic mean concentrations of pollutants common to both that study and the Aurora Bridge monitoring. These numbers are from sampling of highway drainage (prior to its receiving treatment) at a number of sites in Los Angeles and San Diego Counties, on urban freeways carrying higher traffic loads than Aurora Avenue.

Table 7. Arithmetic-mean pollutant concentrations in California highway runoff compared to Aurora Bridge results

Variable (unit)[a]	California Study Arithmetic Mean	Aurora Bridge Arithmetic Mean	Aurora Bridge Geometric Mean	Aurora Bridge Minimum	Aurora Bridge Maximum
TSS (mg/L)	114	755	603	319	1890
TCu (µg/L)	94	315	302	200	471
DCu (µg/L)	18	24.0	23.2	14.4	32.8
TPb (µg/L)	87	420	400	301	690
DPb (µg/L)	8	3.38	2.24	0.25	6.64
TZn (µg/L)	355	1770	1727	1410	2520
DZn (µg/L)	122	233	227	149	271

[a] The study did not measure the TPH fractions.

While the California means are higher than the freeway values in the NSQD, they are in every case lower than any statistic in the Aurora Bridge data set, except for DPb. Aurora Bridge geometric means are included in the table, because this statistic moderates for the effect of a relatively few values that may be well outside the predominant range. In this case, though, the geometric and arithmetic means do not differ substantially, indicating that concentrations in various Aurora Bridge samples are relatively uniform. The difference in the two means is greatest for TSS, where one sample measured three times as high as any other and, for DPb, for which one sample was below detection.

Although the operative permits do not put numeric limits on highway discharges, the study's results can be placed in further context by comparison with benchmarks issued to industrial stormwater dischargers under Washington's Industrial Stormwater General Permit (ISGP), given in Table 8.

Table 8. Washington Industrial Stormwater General Permit (ISGP) benchmarks compared to Aurora Bridge results

Variable (unit)[a]	ISGP Benchmark[a]	Aurora Bridge Median	Aurora Bridge Minimum	Aurora Bridge Maximum
TCu (µg/L)	14	311	200	471
TPb (µg/L)	81.6	345	301	690
TZn (µg/L)	117	1570	1410	2520
TPH-Dx (µg/L)	10,000	339	24.9	503

[a] Benchmarks are not set for TSS, dissolved metals, TPH-Gx and TPH-heavy oil.

Even the minimum Aurora Bridge metals concentrations are far higher than the amounts set for industrial discharges. According to the ISGP, a benchmark exceedance requires a review of best management practices and specification of additional measures to attempt to meet the benchmark. Only TPH-Dx in the Aurora Bridge runoff would not be subject to that provision if the flow were coming from a permitted industry.

SUMMARY AND CONCLUSIONS

Concentrations of solids, total metals and dissolved metals measured in runoff from Seattle's Aurora Bridge are markedly much higher overall than those found in extensive highway runoff studies performed in the region and nationwide over many years. While only five samples have been collected at the bridge in this study, the results are consistent in this pattern, as demonstrated by the minimum values usually exceeding the medians or means in other studies and the relative congruity of the arithmetic and geometric means. There is definite concern with this finding, since the bridge's runoff flows into the Lake Washington Ship Canal, a key salmon migration corridor and, from there, to Puget Sound. Research studies have extensively established negative impacts of the contaminants measured in this study on aquatic ecosystems in general and salmon in particular, as briefly summarized in the appendix of this report.

The question arises, of course, as to why the Aurora Bridge runoff is so contaminated relative to many other examples of stormwater from high-traffic highways. The reason is probably not found in the quantity or composition of traffic. Aurora Avenue carries less traffic and probably also less heavy truck traffic, than the highways in the 1977-1982 Washington research and the 1999-2004 California study. Other possible reasons are atmospheric deposition and deterioration of the highway and bridge structures. Atmospheric deposition is not likely the explanation, as Aurora Avenue is in the same vicinity as I-5 and SR-520 studied earlier. There are less industrial air pollution sources in the air basin now than there were 35 years ago, when industries operated in the near and far field and have since shut down. The road is 85 years old and it is possible that deteriorating structural integrity is involved in what this study has shown. Whatever the reason, treating the runoff with the planned green stormwater infrastructure can only make a positive contribution to water quality and aquatic biotic health in the Ship Canal and Puget Sound.

Summary of Negative Effects of Measured Pollutants on Salmonid Fish

There is a large amount of literature on the specific lethal and negative sub-lethal effects of metals on fish and other aquatic life. Copper, especially, has received a great deal of attention in the Puget Sound region for its inhibition of various salmon physiological processes, to the detriment of migration, feeding, reproduction and rearing.

Short-Term Impacts of Metals

As just one example, Baldwin et al. (2003)[1] used coho salmon olfactory capacity, a reliable indicator of sublethal toxicity, in a series of studies. Exposure to 10 µg/L of copper for 30 minutes reduced responses to three odorants by 35-67 percent and the reduced olfactory function persisted for hours. Impairment was evident within 10 minutes for exposures ranging from 2 to 20 µg/L. The researchers defined the threshold for sublethal, copper-induced coho neurotoxicity to be 25 percent reduction in olfactory responses. They found the threshold to be 2.3-3.0 µg/L (depending on odorant) above the 3.0 µg/L background in source water; i.e., the presence of approximately 5-6 µg/L of copper reduced olfactory function by 25 percent. For context, the geometric mean total recoverable and dissolved copper concentrations measured in the Aurora Bridge samples are 302 and 23.2 µg/L, respectively.

Zinc concentrations as low as 93 µg/L have been found to be lethal to 50 percent of juvenile rainbow trout in 96 hours of exposure.[2] Sublethal effects at even lower concentrations include avoidance of rearing habitat and inhibited immune response.[3] Such negative effects interfere with growth, ability to avoid predators and resistance to disease. Geometric mean total recoverable and dissolved zinc in the Aurora Bridge samples measure 1727 and 227 µg/L, respectively.

Lead concentrations as low as 8-14 µg/L cause chronic sub-lethal effects on salmonids.[4] This threshold compares to 400 and 2.24 µg/L of total recoverable and dissolved lead, respectively, measured in the Aurora Bridge samples.

---

[1] Baldwin, D.H., J.F. Sandahl, J.S. Labenia and N.L. Scholz. 2003. Sublethal effects of copper on coho salmon: Impacts on nonoverlapping receptor pathways in the peripheral olfactory nervous system. *Environmental Toxicology and Chemistry* 22(10):2266-2274.

[2] Chapman, G.A. 1978. Toxicities of cadmium, copper and zinc to four juvenile stages of Chinook salmon and steelhead. *Transactions of the American Fisheries Society* 107: 841-847.

[3] Price, M.H.H. 2013. "Sub-lethal Metal Toxicity Effects on Salmonids: a review". Report prepared for SkeenaWild Conservation Trust. Smithers, BC, Canada. 64 pages.

[4] Price, *Ibid.*

In this case the dissolved quantity appears to be safely below the toxic level, if no more lead is solubilized in the receiving water. While lead is a relatively insoluble metal, there is still the possibility of release into the dissolved form.

Long-term Impacts of Metals

The negative effects of metal toxins are not necessarily limited to short-term, acute lethal or medium-term sublethal impacts. Over time an organism can accumulate metals in tissue, a process known as bioaccumulation. When predators consume organisms with bioaccumulated metals, they concentrate them in their tissues. The top predator in an aquatic ecosystem tends to have the highest concentrations, through biomagnification up the food chain. The salmonid fish of the Puget Sound tributary ecosystem are subject to these impacts.

Aquatic sediments become repositories for particulate metals through gravity settling and for dissolved metals through various adsorption and ion exchange processes. In addition to their toxicity to bottom-dwelling organisms, these captured metals can become remobilized into the water column by disturbance and dissolution and thus harm pelagic aquatic life long after their initial release.

Impacts of Particulates

Solids transported in flow are an instrumental feature of water quality because of their numerous ecological consequences, including:

- Covering and seeping into coarse bed materials where fish spawn and eggs develop; in filling the pore spaces, sediments restrict the flow of water carrying dissolved oxygen, resulting in asphyxiation of the young;
- Covering the surfaces serving as habitat for fish food sources (e.g., insects, algae);
- Filling deeper areas, tending to produce a more homogeneous bed and less habitat diversity and specifically reducing pools where fish rest and seek refuge from predators;
- Reducing visibility, making it harder for fish to find food and avoid predators;
- Reducing light penetration to underwater plants and algae;
- Abrading the soft tissues of fish, especially gills; and
- Transporting other pollutants present in the soil or picked up in transport.

Regarding the latter impact, sediments are a transport medium for many contaminants in other categories of water pollutants: metals, organic chemicals, nutrients and pathogens.

Impacts of Petroleum-Based Materials

Petroleum-based materials contain many chemicals, certain ones of which are toxic to aquatic life. They produce harmful sublethal, if not immediately lethal, reactions negatively affecting reproduction, development and behavior. These materials decompose relatively slowly and tend to accumulate in the aquatic environment. The gradual decomposition reduces the oxygen supply needed by aerobic water life, from fish to the microorganisms responsible for the breakdown themselves. The total petroleum hydrocarbon-heavy oil fraction that was measured at relatively high concentrations in the Aurora Bridge samples is especially subject to comparatively slow decomposition and extended presence in the environment.

Naphthalene is an important component of the total petroleum hydrocarbons and has been studied more than most of the many constituent chemicals. Laboratory bioassays have shown that naphthalene is moderately toxic to rainbow trout (*Onchorynchus mykiss*), bluegill sunfish (*Lepomis macrochirus*) and fathead minnows (*Pimephales promelas*). In Coho salmon (*Onchoryncus kisutch*) chronic naphthalene exposure resulted in reductions in feeding, growth and survival rates.[5] Naphthalene and methyl naphthalenes are among the most water soluble and toxic components of petroleum and are accumulated by marine organisms.[6]

In the aquatic environment, naphthalenes are especially hazardous compounds due to their particular combination of mobility, toxicity and general environmental hazard. In fact, some studies have concluded that the toxicity of an oil appears to be a function of its di-aromatic hydrocarbon (that is, two-ring hydrocarbons such as naphthalene) content. Environmental effects of such compounds often are the result of exposures to complex mixtures of chronic-risk chemicals.[7]

---

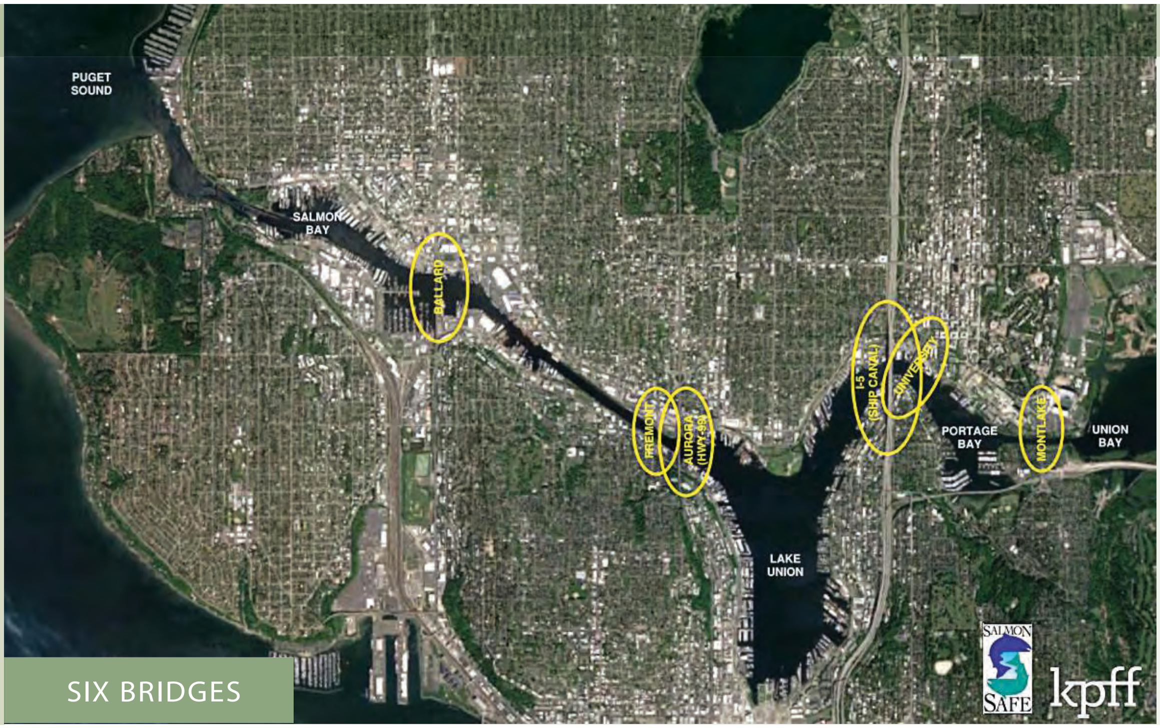
5 From National Pesticide Information Center, *http://npic.orst.edu/factsheets/naphtech.html.*

6 Liu, D. and B.J. Dutka (eds.). 1984. *Toxicity Screening Procedures Using Bacterial Systems,* (p. 392). Marcel Dekker, Inc., New York, NY.

7 Irwin, R.J., M. VanMouwerik, L. Stevens, M.D. Seese, and W. Basham. 1997. Environmental Contaminants Encyclopedia. National Park Service, Water Resources Division, Fort Collins, Colorado. *http://www.nature.nps.gov/ water/ecencyclopedia/assets/contaminant-pdfs/nap2met.pdf* (accessed September 15, 2016).

APPENDIX B | Green Bridges Pilot Study

The Green Bridges Pilot Study is an outcome of the original Aurora Bridge Report. In the Fall of 2017, following a presentation by The Nature Conservancy regarding the research conducted for the Aurora Bridge, a private anonymous donor offered to fund a brief study to determine if the other five bridges that impact the Lake Washington Ship Canal had the potential for green infrastructure to mitigate stormwater runoff from the bridge deck spans. Salmon-Safe retained KPFF Engineers to conduct the feasibility study and calculate the runoff. The runoff calculations are based on Seattle's annual rainfall of 38 inches. In addition, KPFF identified a composite bridge deck material which could be used to replace the grating on four of the draw bridges and collect additional contaminated runoff that may have normally fallen through the grates. The product, Fiber Span, has been used in other parts of the country.

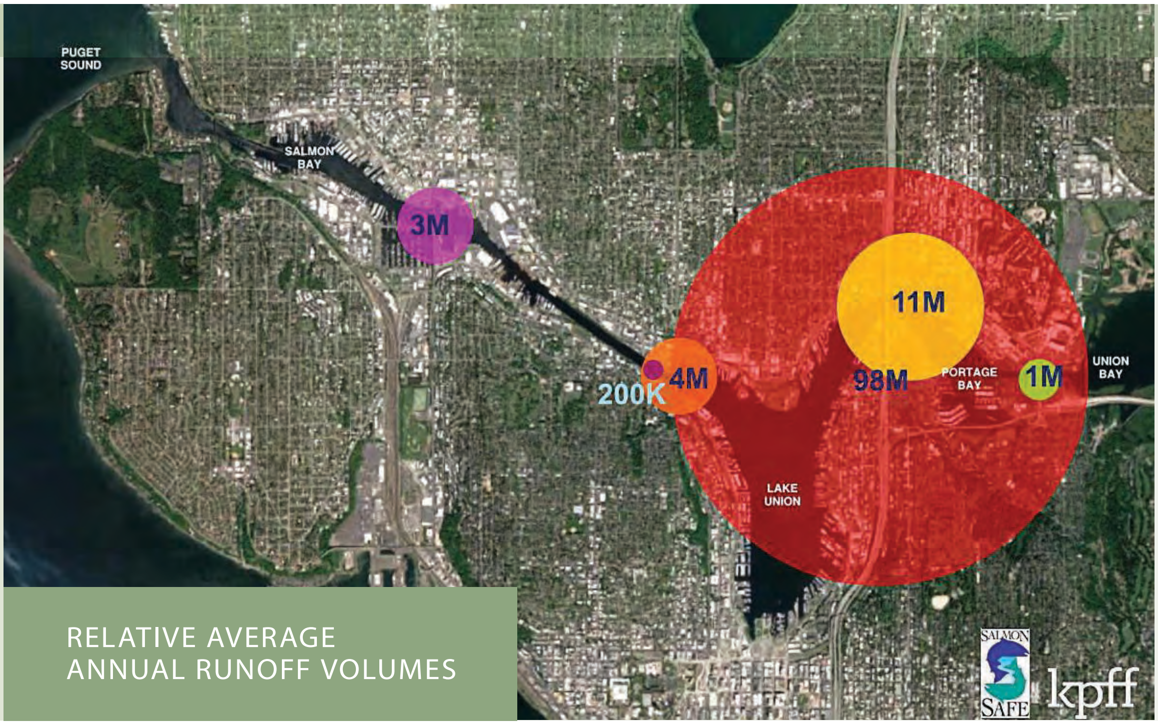


SIX BRIDGES

There are six bridges spanning Lake Washington ship canal, a key salmon migration corridor into the North Lake Washington and Lake Sammamish watersheds.

Pilot Study Findings

This study included the Ballard Bridge, Fremont Bridge, I-5 Bridge, University Bridge and Montlake Bridge. The scope of work was to determine the functionality of the existing runoff collection system, to quantify the extents of the collection basins, to develop new runoff collection and treatment strategies, and to locate adequate treatment sites. City of Seattle utility maps and record drawings were the key sources used to gather information about each bridge and provided the means to create feasible runoff mitigation solutions. Once the initial background information was obtained for each bridge, an approximate ratio of the bioretention area required to treat subsequent basin areas was used to size the treatment facilities. This ratio was approximated during the study of the Aurora Bridge stormwater runoff mitigation.



RELATIVE AVERAGE ANNUAL RUNOFF VOLUMES

If we were able to redirect runoff from all six bridges, we could mitigate 98,000,000 gallons of polluted stormwater from entering Puget Sound.

The investigation into the bridges crossing the ship canal revealed that the I-5 Bridge and its surrounding areas contribute the largest amount of untreated stormwater runoff out of all the bridges. The runoff from the bridge deck and contributing areas of the I-5 Bridge is almost five times that of the other four bridges combined. The cause for this extensive impact is not only the size of the I-5 Bridge but is also due to the layout of the surrounding stormwater infrastructure. The large outfall that carries runoff from the I-5 bridge deck has been utilized to serve the surrounding neighborhoods creating a substantial collection basin that has a singular discharge point. This is also the case for the University Bridge, which is the second largest contributor of runoff. In total, all five bridges contribute approximately 113,000,000 gallons of untreated stormwater runoff per year. However, treatment solutions can be achieved for each of these bridges by investing in rerouting of stormwater to bioretention facilities. These bioretention facilities would not only serve to treat stormwater, but also serve as an improved green park space for public benefit and public awareness of stormwater mitigation.

A brief summary of each bridge condition can be found in Appendix C of this report.

Montlake Bridge

AHJ's: WSDOT[1] — Bridge and ROW[2]
SPU[3] — Combined Sewer|

Drainage Area: 1± Acre

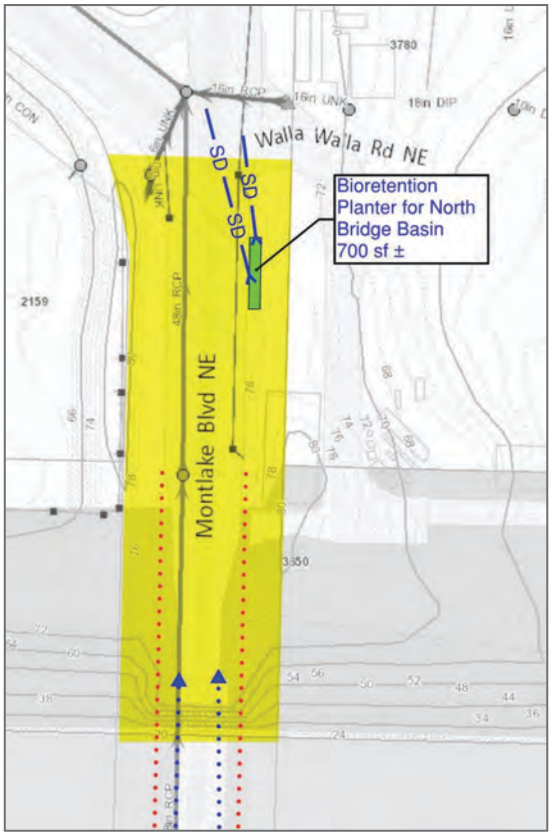
Connects to: SPU Combined Sewer

North Mitigation

Reroute storm pipe conveyance for approximately 0.5 acres of north approach to a 700 square foot ± bioretention area in the right-of-way adjacent to Montlake Blvd NE and connect the existing SPU drainage lateral to the bioretention.

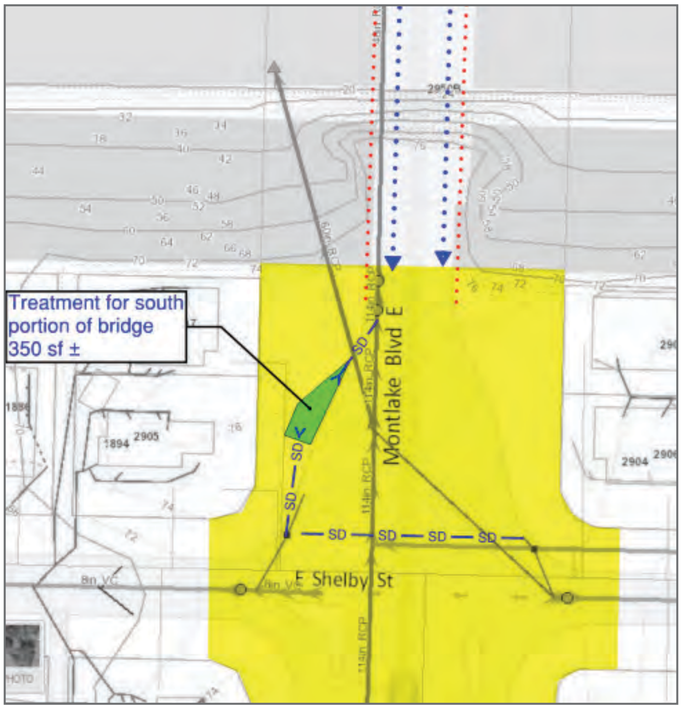
South Mitigation

Replace grated bridge panels with composite panels with runnel and route approximately 0.5 acres of bridge deck and south approach area to a 350 square foot ± bioretention area in the right-of-way adjacent to Montlake Blvd NE and connect the existing SPU drainage lateral to the bioretention.



North

South



[1] Washington State Department of Transportation
[2] Right of Way
[3] Seattle Public Utilties

University Bridge

AHJ's: SDOT[4] — Bridge and ROW
SPU — Storm and Combined Sewer Mains

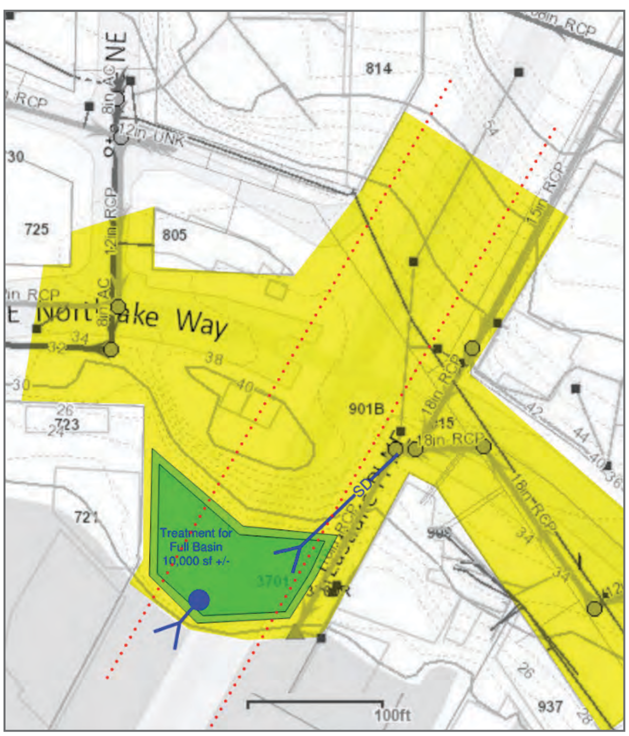
Connects to: SPU Dedicated Storm (North)
SPU Combined Sewer (South)

North Mitigation

Reroute bridge downspouts from approximately 1.7 acres of north bridge deck and approach, and daylight the dedicated storm main collecting runoff from approximately 10 acres of adjacent neighborhood into a 10,000± square feet bioretention area in the SDOT right-of-way beneath the bridge. Connect bioretention outfall to existing 18" RCP[5] culvert. Design challenge will be even distribution of a large volume of water.

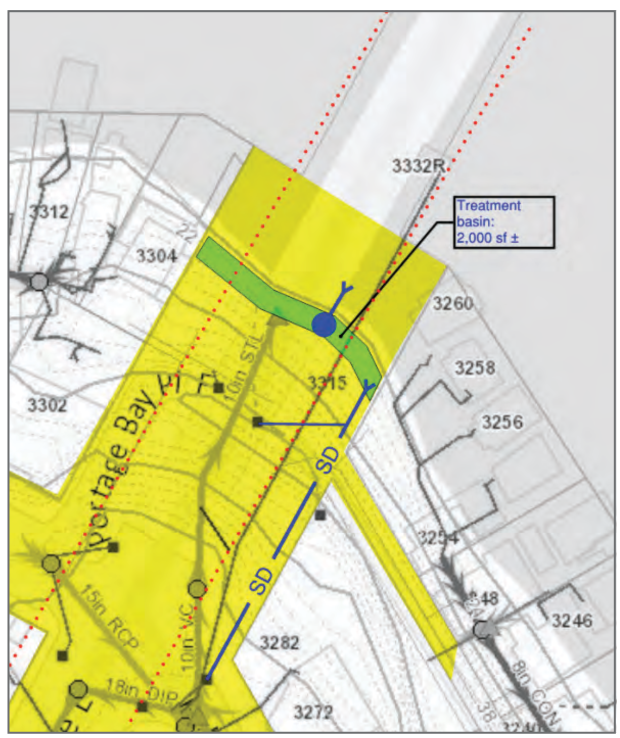
South Mitigation

Replace grated bridge panels with composite panels with runnel and route approximately 1.0 acres of bridge deck and south approach and an additional 1.0 acres of right-of-way road runoff area to a 2,000± square foot structured bioretention planter box in SDOT right-of-way beneath the bridge. Repurpose an existing 10" RCP combined sewer overflow as the outfall.



North

South



[4] Seattle Department of Transportation
[5] Reinforced Concrete Pipe

kpff

I-5 Ship Canal Bridge (North)

AHJ's: WSDOT — Bridge and Storm Main
SPU — Drainage to WSDOT Main
SDOT[6] — ROW at ground plane
Seattle DPR[7] — North Passage Point Park

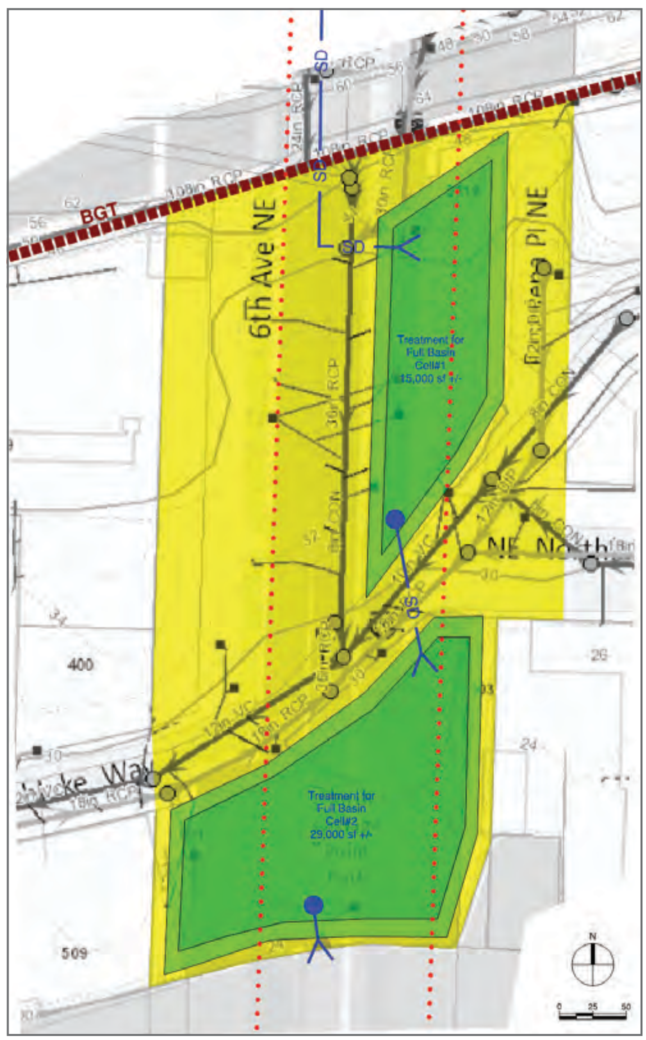
Drainage Area: 21± Acres (5 Ac Bridge and 16 Ac Approach); 65± Acres Neighborhood Adjacent

Connects to: WSDOT 36″ Storm Culvert

North Mitigation

Daylight the existing 36″ RCP outfall to a large multi-tiered bioretention area in the SDOT right-of-way and a Seattle Parks parcel. The approximate bioretention size is 60,000 square feet, and would require multiple level pools, even distribution of large volumes of water, and culverting under Northlake Way.

The bioretention would outfall to the existing culvert. The SDOT right-of-way may have an existing lease with Lincoln Towing. The Seattle Parks portion of the treatment area would require a more intensive design creating public recreation space over and around the stormwater treatment.



[6] Seattle Department of Transportation
[7] Seattle Department of Natural Resources

kpff

I-5 Ship Canal Bridge (South)

AHJ's: WSDOT — Bridge and Storm Main
SPU — Drainage to WSDOT Main
SDOT — ROW at ground plane
Seattle DPR — South Passage Point Park

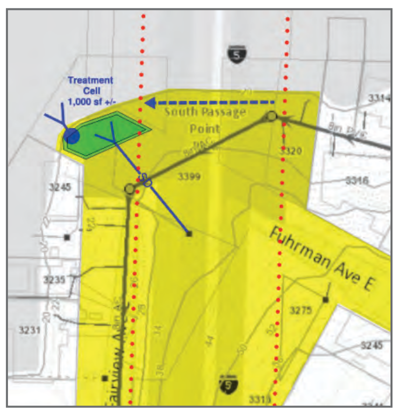
Drainage Area: 31± Acres (7 Ac Bridge and 24 Ac Approach); 1± Acre Neighborhood Adjacent

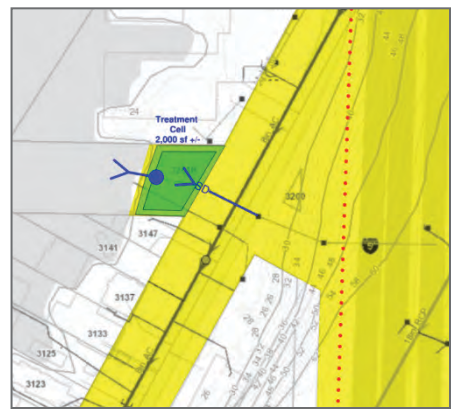
Connects to: 6" PVC at terminus of Fuhrman Ave E
18" pipe within pocket park adjacent to Fairview Ave E
30" RCP at terminus of E Allison St

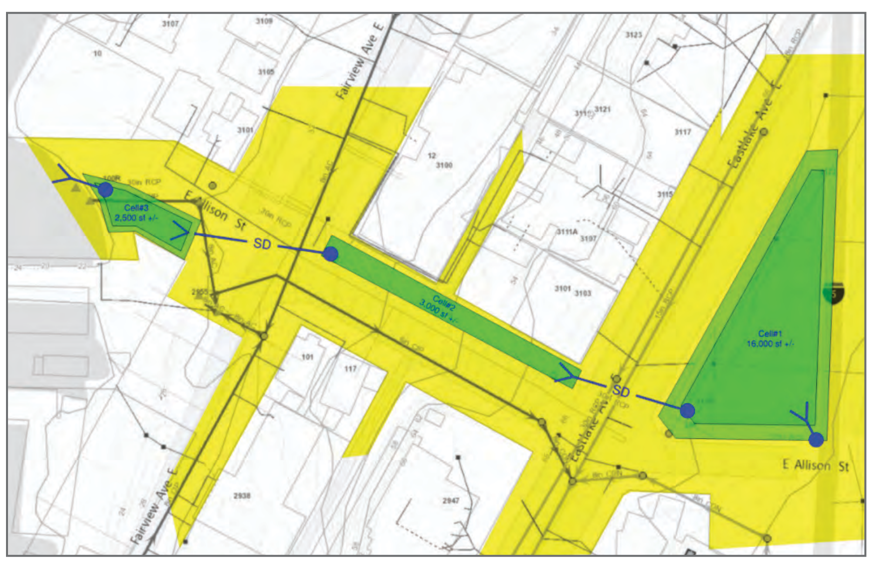
South Mitigation

Daylight the existing outfalls to multiple bioretention areas in the SDOT right-of-way. Mitigation areas appear to all be in the SDOT right-of-way, but portions may be maintained by Seattle Parks and coordination with DPR may be necessary. The 6" and 18" daylighting areas would be single-cells of approximately 1,000 and 2,000 square feet respectively. The 30" daylighting area would have an approximate bioretention size of 21,000 square feet, and would require multiple level pools, even distribution of large volumes of water, coordination with existing driveways and culverting under Eastlake Way and Fairview Avenue.

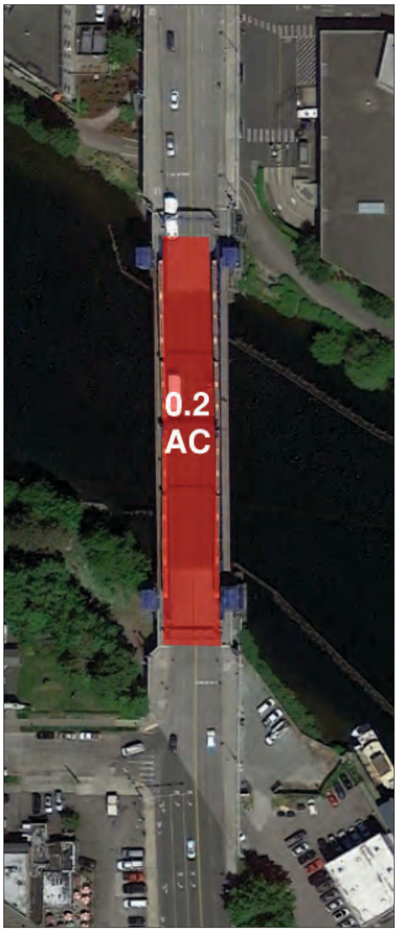
The bioretention areas would utilize the existing outfalls.







Fremont Bridge



AHJ's: WADNR[8] — Shoreline
SDOT — Bridge and ROW
SPU — Storm and Combined Sewer Mains

Connects to: SPU Dedicated Storm (North)
SPU Combined Sewer (South)

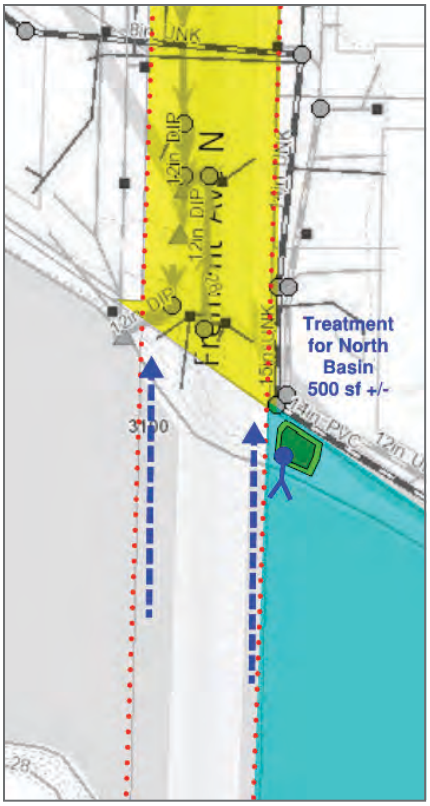
North Mitigation

Replace grated bridge panels with composite panels with runnel and route approximately 0.1 acres of bridge deck and north approach to a 500± square foot bioretention area on DNR land adjacent to the bridge. Outfall from the bioretention area would be routed to an existing SPU 12" DIP outfall on the west side of the bridge.

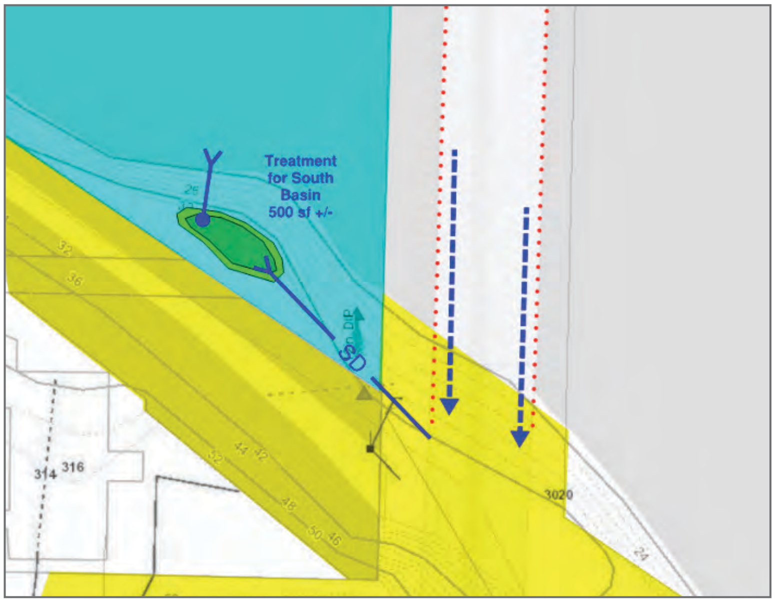
South Mitigation

Replace grated bridge panels with composite panels with runnel and route approximately 0.1 acres of bridge deck and south approach to a 500± square foot bioretention area on DNR land adjacent to the bridge. Outfall from the bioretention area would be routed to an existing SPU 12" DIP outfall on the west side of the bridge.

North



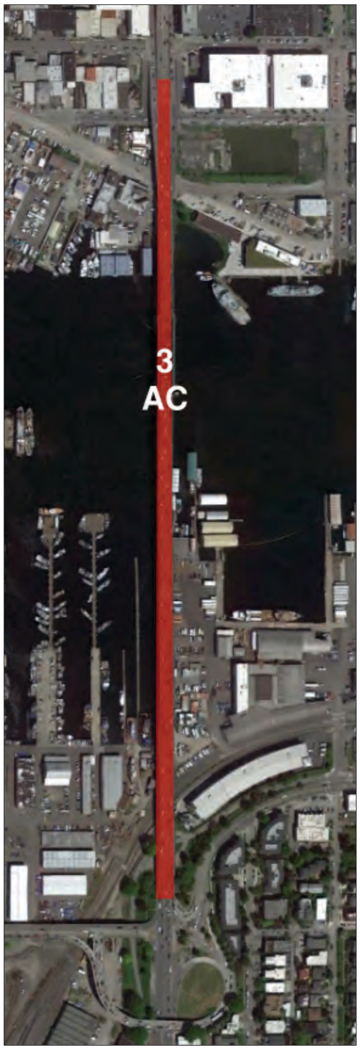
South



[8] Washington Department of Natural Resources

kpff

Ballard Bridge



AHJ's: SPU — Storm and Combined Sewer Mains
SDOT — Bridge and ROW
USACE[9], Ecology, and WDFW[10] if new outfall required

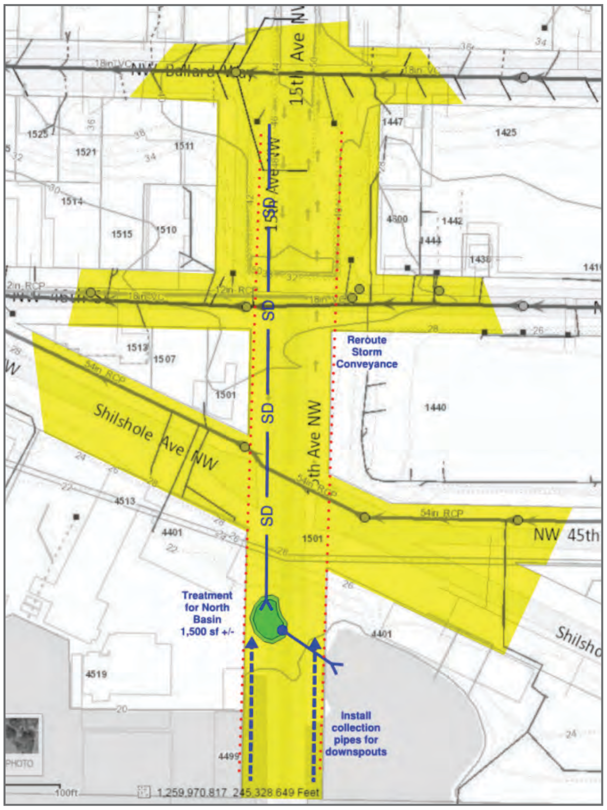
Connects to: SPU Dedicated Storm (North)
SPU Combined Sewer (North & South)

North Mitigation

Intercept the existing open downspouts and construct a suspended storm main on the bridge joining with the rerouted storm main on the north approach collecting an approximately 1.0 acre area going to a 2,500± square foot bioretention area in the SDOT right-of-way beneath the bridge. There is no existing culvert outfall, and so a new culvert or spillway discharge would be required.

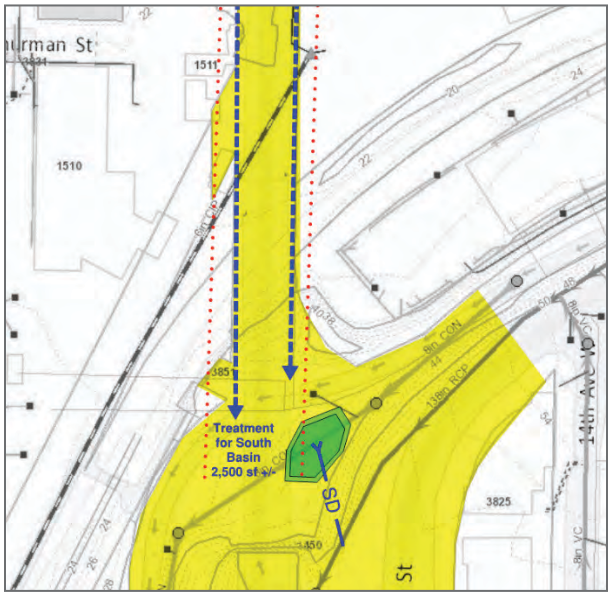
South Mitigation

Replace grated bridge panels with composite panels with runnel and route runoff from approximately 2.0 acres of bridge deck and south approach to a 2,500± square foot bioretention area in SDOT right-of-way. The outfall would connect to existing combined sewer mains.



North

South



[9] US Army Corps of Engineers
[10] Washington Department of Fish and Wildlife

The Project Team

Ellen Southard, Hon. AIA, LFA — *Salmon-Safe*
Richard Horner, PhD, UW Emeritus — *Salmon-Safe Assessor*
Jeremy Febus, P.E., LEED AP, Principal — *KPFF*
Kelly Kobashigawa, Civil Design Engineer — *KPFF*
Lexie England — *KPFF*
Aaron Olson, P.E. — *KPFF*
Rachael Myer, PLA, GRP, LEED AP, Landscape Architecture Principal — *Weber Thompson*
Leslie Riibe, Graphic Designer — *Weber Thompson*
Mark Grey, Owner — *Stephen Grey & Associates / COU LLC*

The Salmon-Safe team would like to thank Boeing for their support of the Aurora Bridge case study and for funding the water quality research and jurisdictional coordination of the project.

SALMON SAFE PugetSound

kpff

WEBER THOMPSON

STEPHEN C. GREY & ASSOCIATES, L.L.C.

Report Design / Cover Montage / Production Assistance : Jay Tracy Studios

www.salmonsafe.org