Duwamish Estuary/Inner Elliott Bay and Lake Union/Ship Canal Loadings Report

Olivia Wright, Bob Bernhard, and Tim Clark
January 27, 2016
King County CSO WQA
Study Questions

Impairments

1. What are the existing and projected water quality impairments in receiving waters (water bodies) where King County CSOs discharge?
2. How do County CSOs contribute to the identified impairments?
3. How do other sources contribute to the identified impairments?

Corrective Actions

4. What activities are planned through 2030 that could affect water quality in the receiving waters?
5. How can CSO control projects and other planned or potential corrective actions be most effective in addressing the impairments?

Effective CSO Project Sequences

6. How do various alternative sequences of CSO control projects integrated with other corrective actions compare in terms of cost, schedule, and effectiveness in addressing impairments?
7. What other possible ways, such as coordinating projects with the City of Seattle and altering the design of planned CSO control projects, could make CSO control projects more effective and/or help reduce the costs to WTD and the region of completing all CSO control projects by 2030?
Goals and Objectives

**Source** is an object or activity from which a contaminant is initially released to the environment.

**Pathway** is the route by which a contaminant is transported from its source to a water body.

- Use existing WQ and flow data to estimate mean annual loadings (mass/year) of contaminants entering the study areas from major **pathways**.

- Planning level analysis to compare relative magnitude of contaminant loading from major pathways.

- Identify data gaps and other missing information.
Study Areas

- Lake Union/Ship Canal
- Duwamish Estuary/Inner Elliot Bay
Contaminants of Interest (COIs)

<table>
<thead>
<tr>
<th>Category</th>
<th>COI</th>
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<tbody>
<tr>
<td>Indicator bacteria</td>
<td>Fecal Coliform</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Total Nitrogen</td>
</tr>
<tr>
<td></td>
<td>Total Phosphorus</td>
</tr>
<tr>
<td>Solids</td>
<td>Total Suspended Solids</td>
</tr>
<tr>
<td>Metals</td>
<td>Total Arsenic</td>
</tr>
<tr>
<td></td>
<td>Total Copper</td>
</tr>
<tr>
<td></td>
<td>Total Lead</td>
</tr>
<tr>
<td></td>
<td>Total Mercury</td>
</tr>
<tr>
<td></td>
<td>Total Zinc</td>
</tr>
<tr>
<td>Organics</td>
<td>Benzylbutyl phthalate (BBP)</td>
</tr>
<tr>
<td></td>
<td>Bis(2-ethylhexyl)phthalate (BEHP)</td>
</tr>
<tr>
<td></td>
<td>Total PAHs</td>
</tr>
<tr>
<td></td>
<td>Total PBDEs</td>
</tr>
<tr>
<td></td>
<td>Total PCBs</td>
</tr>
</tbody>
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Loading Pathways

- Upstream watersheds (Green River and Lake Washington)
- Stormwater drainage basins
- Local tributaries
- Highway bridges
- Uncontrolled combined sewer overflows (CSOs)
- Controlled CSOs
- Wet weather treatment facilities
- Atmospheric deposition
- Vessel discharges
- Antifouling paint
- Creosote-treated wood pilings
- Groundwater
- Shoreline erosion
- Puget Sound
Methods

• Estimated mass of contaminant entering study area per year.

• Unique approach and data for each pathway.

• Used most recent monitored and modeled WQ and flow data representing current conditions.

• Calculated loadings using mean and 95% confidence intervals of WQ and flow data.

• Estimated loading range for vessel discharge, antifouling paint, and creosote-treated pilings.
Upstream Watershed: Green River

- **WQ data:**
  - KC’s routine ambient monitoring (GR: 3106, A310; BR:0317) : **2000-2013**
  - LDW Remedial Investigation (Windward 2010): **2005-2008**
  - Green River Watershed Surface Water Data Report (King County 2014): **2011-2014**

- **Flow data:**
  - Hydrologic Simulation Program-Fortran (HSPF) model of Green River and Black River (**WY 2000-2009**)
Upstream Watershed: Lake Washington

- **WQ data:**
  - KC’s routine ambient monitoring location (Montlake cut: 0540) **2000-2008**
  - Lake Washington PCB/PBDE Study (KC 2013) **2011-2012**

- **Flow data estimated using Lake Water Balance (KC 2013) **2002-2011**
  - Gauged tributary flow
  - Elevation data at locks (USACOE)
  - Evaporation and precipitation data

Loadings (kg/yr) = contaminant concentration (kg/L) X flow (L/yr)
Stormwater Basins

• Includes:
  – Separated and partially separated stormwater sewer basins
  – Direct discharge areas along shoreline

• WQ data:
  – Lake Washington Watershed PCB/PBDE Loadings Study (King County 2013) 2011-2012

• Flow:
  – Seattle Public Utilities Pollutant Loading Model (PLM)
  – Estimates pollutant load during storm events based on rainfall, impervious surface area, and land use.
  – Model used for Seattle’s Integrated Plan
  – Input mean and 95% confidence intervals of water quality and annual rainfall data
Local Tributaries

- 7 tributaries
- Stormflow + baseflow
- Drainage area: fully separated, partially separated, and combined sewer systems
- Extrapolate areal loading rates from Puget Sound tributaries:
  - Toxics in Surface Runoff to Puget Sound: Phase 3 Data and Load Estimates (Herrera 2011) 2009-2010

\[
\text{Loading} \left( \frac{\text{kg}}{\text{yr}} \right) = \text{areal loading rate} \left( \frac{\text{kg}}{\text{km}^2 \cdot \text{yr}^{-1}} \right) \times \text{fully and partially separated areas (km}^2\text{)}
\]
Highway Bridges

• Local and highway bridges cross study area water bodies and directly discharge to study areas.

• Highway bridges crossing study areas
  – Duwamish Estuary: I-5 and SR 99 (untreated and treated)
  – Lake Union/Ship Canal: I-5, SR 99, and SR 520 (untreated only)
  
  Runoff = bridge surface area X rainfall (Sea-Tac rain gage WY 2005-2014)

• Untreated highway runoff WQ:

• Treated highway runoff WQ:
  – WSDOT’s NPDES Municipal Stormwater Permit BMP Effectiveness Monitoring Program (WSDOT 2014)

Loadings (kg/yr) = contaminant concentration (kg/L) X flow (L/yr)
**Uncontrolled CSOs**

- Uncontrolled CSOs
  - 15 King County
  - 11 Seattle

- WQ data:
  - KC CSO Effluent Data *1996-2015*

- CSO discharge volume:
  - KC monitored data (*WY 2005-2014*)
  - Seattle monitored data (*WY 2009-2014*)

**Loadings (kg/yr) = contaminant concentration (kg/L) X flow (L/yr)**
Controlled CSOs

- Controlled CSOs
  - 12 King County
  - 20 Seattle

- WQ data:
  - KC CSO Effluent Data 1996-2015

- CSO discharge volume:
  - KC monitored data (WY 2005-2014)
  - Seattle monitored data (WY 2009-2014)
  - Modeled data (32-yr) for recently controlled CSOs or those under supplemental compliance (i.e. Ballard, Dexter Ave, Harbor Ave, Denny Way)

Loadings (kg/yr) = contaminant concentration (kg/L) X flow (L/yr)
Wet Weather Treatment Facilities

- Two primary treatment facilities: Mercer/Elliott West and Henderson/MLK

- NPDES permit requirement:
  - 50% reduction in TSS
  - Maximum 400 CFU/100mL fecal coliform geometric mean

- WQ data:
  - Used CSO discharge data to identify statistically significant relationships between TSS and other contaminant concentrations.

- Monitored discharge volumes:
  - Mercer/Elliott West (WY 2006-2014)
  - Henderson/MLK (WY 2007-2014)

Loadings (kg/yr) = contaminant concentration (kg/L) X flow (L/yr)
Atmospheric Deposition

- 5 King County monitoring locations: Duwamish, Georgetown, South Park, Beacon Hill, and Sand Point (2011-2013)

- Contaminant flux data: mass deposited per unit area per day

\[
\text{Loading} \left( \frac{\text{kg}}{\text{yr}} \right) = \text{flux} \left( \frac{\text{kg}}{\text{km}^2 \cdot \text{yr}^{-1}} \right) \times \text{water body surface area (km}^2\text{)}
\]
Vessel Discharges

- Loading rates from 2010 EPA study (commercial fishing vessels and non-recreational vessels <79 ft)

- Discharges: bilge, deck washdown/runoff, fish holds, prop and generator engine effluent, firemain, graywater, & shaft packing gland effluent

- Assumed 5 – 8 month boating season

- Does not include: black water or ballast discharges, recreational and non-fishing large commercial vessels (>79 ft)

\[
\text{Loading (kg/yr)} = \text{loading rate (kg/day)} \times \text{# of vessels (n)} \times \text{boating season (days/yr)}
\]
Antifouling Paint

• Estimated total copper loading only.
• Loading from recreational and commercial vessels.
• Cu leaching rate from 3 studies:
  – 4.0 µg/cm²/day (Schiff et al. 2003)
  – 8.2 µg/cm²/day (Navy estimate; Valkirs et al. 2003)
  – 6.5 µg/cm²/day (CRWQCB 2005) – EPA TMDL
• Vessel surface area estimated with desk top analysis and state registered vessel in King County.
• # of days in study area varied based on type of vessel.

\[
\text{Loading} \left( \frac{\text{kg}}{\text{yr}} \right) = \sum \left( \text{vessel surface area} \ (\text{cm}^2) \right) \times \text{leaching rate} \left( \frac{\text{kg}}{\text{cm}^2 \times \text{day}^{-1}} \right) \times \# \text{ days in study area} \left( \frac{\text{days}}{\text{yr}} \right)
\]
Creosote-treated Wood Pilings

• Estimated total PAH loading only.
• Using exponential decay rate.
• Initial contaminant concentration in pilings from industry report (Vlosky 2007).
• Total PAH leaching rate obtained from study in Vancouver (Bramhall and Cooper 1972).
• Volume of pilings estimated using desktop analysis of surface area and near shore depth from bathymetry.
• Assumed pilings were 30 and 75 years old.

\[
M_0 = V_{piling} \times \text{conc}_0 \\
M_\Delta = (M_0 \times e^{rt}) - (M_0 \times e^{r(t+1)})
\]

\[r \equiv \text{contaminant leaching rate} \quad (-0.0072)\]
\[M_0 \equiv \text{initial contaminant mass in piling (kg)}\]
\[V_{pilings} \equiv \text{volume of pilings (m}^3\text{)}\]
\[\text{conc}_0 \equiv \text{initial concentration of contaminant in piling} \quad \left(\frac{kg}{m^3}\right)\]
\[M_\Delta \equiv \text{annual change in mass of contaminant} \quad \left(\frac{kg}{yr}\right)\]
\[t \equiv \text{time} \quad \text{(years)}\]
Pathways Not Quantifiable

• Literature review for:
  – Groundwater
  – Shoreline erosion
  – Puget Sound
Uncertainty

• Estimated upper and lower bounds of loadings with 95% confidence intervals or range of data.

• Limits to the spatial and temporal data available.

• Methods vary for different pathways based on data available.

• Data missing for some pathways or parameters.

• Approach is appropriate for comparing relative magnitudes of loadings from different pathways.
Results
Fecal coliform

Different scales

Duwamish Estuary/Inner Elliott Bay

Lake Union/Ship Canal

King County
Protecting Our Waters
Doing our part on rainy days

Fecal Coliform Contaminant Data Summary

<table>
<thead>
<tr>
<th>Pathway</th>
<th># of Samples</th>
<th>% detected</th>
</tr>
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<tbody>
<tr>
<td>Green River</td>
<td>136</td>
<td>100%</td>
</tr>
<tr>
<td>Black River</td>
<td>174</td>
<td>100%</td>
</tr>
<tr>
<td>Lake Washington</td>
<td>100</td>
<td>84%</td>
</tr>
<tr>
<td>Stormwater</td>
<td>280</td>
<td>95%</td>
</tr>
<tr>
<td>CSO</td>
<td>77</td>
<td>100%</td>
</tr>
</tbody>
</table>

NA= Not applicable
NE= Not estimated

Mean
95% UCL
95% LCL
Fecal coliform

Fecal Coliform Contaminant Data Summary

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<td>174</td>
<td>100%</td>
</tr>
<tr>
<td>Lake Washington</td>
<td>100</td>
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</tr>
<tr>
<td>Stormwater</td>
<td>280</td>
<td>95%</td>
</tr>
<tr>
<td>CSO</td>
<td>77</td>
<td>100%</td>
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NA= Not applicable  
NE= Not estimated
**Total Nitrogen**

**Duwamish Estuary/Inner Elliott Bay**

**Lake Union/Ship Canal**

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<tr>
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<td>100%</td>
</tr>
<tr>
<td>Black River</td>
<td>176</td>
<td>100%</td>
</tr>
<tr>
<td>Lake Washington</td>
<td>101</td>
<td>100%</td>
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<tr>
<td>Stormwater</td>
<td>401</td>
<td>87%</td>
</tr>
<tr>
<td>CSO</td>
<td>39</td>
<td>100%</td>
</tr>
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NA = Not applicable
NE = Not estimated
Total Phosphorus

**Duwamish Estuary/Inner Elliott Bay**

**Lake Union/Ship Canal**

### Total Phosphorus Contaminant Data Summary

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<tr>
<td>Black River</td>
<td>175</td>
<td>100%</td>
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<tr>
<td>Lake Washington</td>
<td>99</td>
<td>98%</td>
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<tr>
<td>Stormwater</td>
<td>351</td>
<td>97%</td>
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<tr>
<td>CSO</td>
<td>44</td>
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NA= Not applicable
NE= Not estimated
# Total Suspended Solids

**TSS Contaminant Data Summary**

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<td>Green River</td>
<td>150</td>
<td>100%</td>
</tr>
<tr>
<td>Black River</td>
<td>176</td>
<td>100%</td>
</tr>
<tr>
<td>Lake Washington</td>
<td>106</td>
<td>94%</td>
</tr>
<tr>
<td>Stormwater</td>
<td>380</td>
<td>100%</td>
</tr>
<tr>
<td>CSO</td>
<td>126</td>
<td>100%</td>
</tr>
</tbody>
</table>

**图表展示**

- **Duwamish Estuary/Inner Elliott Bay**
- **Lake Union/Ship Canal**

NA= Not applicable  
NE= Not estimated

![Bar chart for TSS in Duwamish Estuary/Inner Elliott Bay](chart1)

![Bar chart for TSS in Lake Union/Ship Canal](chart2)
Total Arsenic

**Total Arsenic Contaminant Data Summary**

<table>
<thead>
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<th># of Samples</th>
<th>% detected</th>
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<tr>
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<td>17</td>
<td>100%</td>
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<tr>
<td>Black River</td>
<td>36</td>
<td>100%</td>
</tr>
<tr>
<td>Lake Washington</td>
<td>21</td>
<td>100%</td>
</tr>
<tr>
<td>Stormwater</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>CSO</td>
<td>152</td>
<td>94%</td>
</tr>
<tr>
<td>Air Dep</td>
<td>108</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Duwamish Estuary/Inner Elliott Bay**

**Lake Union/Ship Canal**

NA = Not applicable
NE = Not estimated
### Total Copper

#### Duwamish Estuary/Inner Elliott Bay

- Green River: 58 samples, 98% detected
- Black River: 36 samples, 100% detected
- Lake Washington: 21 samples, 100% detected
- Stormwater: 395 samples, 100% detected
- CSO: 148 samples, 100% detected
- Air Dep: 108 samples, 100% detected

#### Lake Union/Ship Canal

- NA = Not applicable
- NE = Not estimated

---

**Total Copper Contaminant Data Summary**

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<thead>
<tr>
<th>Pathway</th>
<th># of Samples</th>
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<td>Green River</td>
<td>58</td>
<td>98%</td>
</tr>
<tr>
<td>Black River</td>
<td>36</td>
<td>100%</td>
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<tr>
<td>Lake Washington</td>
<td>21</td>
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<tr>
<td>Stormwater</td>
<td>395</td>
<td>100%</td>
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<tr>
<td>CSO</td>
<td>148</td>
<td>100%</td>
</tr>
<tr>
<td>Air Dep</td>
<td>108</td>
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Total Lead

**Total Lead Contaminant Data Summary**

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<td>81%</td>
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<td>Black River</td>
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<td>100%</td>
</tr>
<tr>
<td>Lake Washington</td>
<td>21</td>
<td>100%</td>
</tr>
<tr>
<td>Stormwater</td>
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<td>100%</td>
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<tr>
<td>CSO</td>
<td>148</td>
<td>95%</td>
</tr>
<tr>
<td>Air Dep</td>
<td>108</td>
<td>100%</td>
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</table>

**Duwamish Estuary/Inner Elliott Bay**

**Lake Union/Ship Canal**

NA = Not applicable  
NE = Not estimated
Total Zinc

Duwamish Estuary/Inner Elliott Bay

Lake Union/Ship Canal

NA= Not applicable
NE= Not estimated

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<td>100%</td>
</tr>
<tr>
<td>Black River</td>
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<td>100%</td>
</tr>
<tr>
<td>Lake Washington</td>
<td>20</td>
<td>85%</td>
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<tr>
<td>Stormwater</td>
<td>394</td>
<td>100%</td>
</tr>
<tr>
<td>CSO</td>
<td>148</td>
<td>100%</td>
</tr>
<tr>
<td>Air Dep</td>
<td>108</td>
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Protecting Our Waters
Doing our part on rainy days
Benzyl Butyl Phthalate

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<td>Green River</td>
<td>20</td>
<td>15%</td>
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<td>8</td>
<td>40%</td>
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<tr>
<td>Lake Washington</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>Stormwater</td>
<td>395</td>
<td>22%</td>
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<tr>
<td>CSO</td>
<td>124</td>
<td>70%</td>
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<tr>
<td>Air Dep</td>
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Duwamish Estuary/Inner Elliott Bay

Lake Union/Ship Canal

NA= Not applicable
NE= Not estimated
Bis(2-ethylhexyl) Phthalate

BEHP Contaminant Data Summary

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<td>Black River</td>
<td>8</td>
<td>25%</td>
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<td>12</td>
<td>33%</td>
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<td>Stormwater</td>
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<td>73%</td>
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<td>CSO</td>
<td>122</td>
<td>75%</td>
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<tr>
<td>Air Dep</td>
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Duwamish Estuary/Inner Elliott Bay

Lake Union/Ship Canal

NA = Not applicable
NE = Not estimated
**Total PAHs**

**Duwamish Estuary/Inner Elliott Bay**

**Lake Union/Ship Canal**

<table>
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<td>29</td>
<td>66%</td>
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<tr>
<td>Black River</td>
<td>8</td>
<td>63%</td>
</tr>
<tr>
<td>Lake Washington</td>
<td>13</td>
<td>31%</td>
</tr>
<tr>
<td>Stormwater</td>
<td>386</td>
<td>84%</td>
</tr>
<tr>
<td>CSO</td>
<td>120</td>
<td>81%</td>
</tr>
<tr>
<td>Air Dep</td>
<td>110</td>
<td>100%</td>
</tr>
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NA= Not applicable  
NE = Not estimated
Total PBDEs

<table>
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<th>% detected</th>
</tr>
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<td>--</td>
</tr>
<tr>
<td>Black River</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>Lake Washington</td>
<td>6</td>
<td>100%</td>
</tr>
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<td>Stormwater</td>
<td>25</td>
<td>100%</td>
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<tr>
<td>CSO</td>
<td>8</td>
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</tr>
<tr>
<td>Air Dep</td>
<td>14</td>
<td>100%</td>
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</tbody>
</table>

NA= Not applicable
NE= Not estimated

Duwamish Estuary/Inner Elliott Bay

Lake Union/Ship Canal

King County
Protecting Our Waters
Doing our part on rainy days
Total PCBs

**Total PCB Contaminant Data Summary**

<table>
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</tr>
</thead>
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<tr>
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<td>15</td>
<td>100%</td>
</tr>
<tr>
<td>Black River</td>
<td>10</td>
<td>100%</td>
</tr>
<tr>
<td>Lake Washington</td>
<td>6</td>
<td>100%</td>
</tr>
<tr>
<td>Stormwater</td>
<td>51</td>
<td>76%</td>
</tr>
<tr>
<td>CSO</td>
<td>88</td>
<td>56%</td>
</tr>
<tr>
<td>Air Dep</td>
<td>54</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Duwamish Estuary/Inner Elliott Bay**

- Green River: 15 samples, 100% detected
- Stormwater: 10 samples, 100% detected
- Local Tributaries: 6 samples, 100% detected
- KC Uncontrolled CSOs: 51 samples, 76% detected
- Seattle Uncontrolled CSOs: 88 samples, 56% detected
- Seattle Controlled CSOs: 54 samples, 100% detected
- Wet Weather Treatment Facilities: 200% detected
- Highway Bridges: 200% detected
- Air Deposition: 200% detected
- Vessel Discharges: 200% detected
- Treated Piling: 200% detected

**Lake Union/Ship Canal**

- Lake Washington: 6 samples, 100% detected
- Stormwater: 10 samples, 100% detected
- Local Tributaries: 51 samples, 76% detected
- KC Uncontrolled CSOs: 88 samples, 56% detected
- Seattle Uncontrolled CSOs: 54 samples, 100% detected
- Seattle Controlled CSOs: 200% detected
- Wet Weather Treatment Facilities: 200% detected
- Highway Bridges: 200% detected
- Air Deposition: 200% detected
- Vessel Discharges: 200% detected
- Treated Piling: 200% detected

NA = Not applicable
NE = Not estimated

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Conclusions

• No pathway was the largest contributing pathway for all contaminants.

• Upstream watersheds and stormwater were often the largest contributing pathways amongst the COIs.

• Uncontrolled CSOs were the largest contributing pathway for fecal coliform loading.

• Creosote treated pilings were largest contributing pathways for total PAHs.

• Antifouling paint were one of the largest contributing pathways for total copper.
Limitations

• Low sample numbers, some none at all:
  – Phthalates for upstream watersheds.
  – Small data sets for PCBs and PBDEs.
  – No PBDE data for Green River.
  – No total arsenic data for stormwater.

• Limited studies/info available to estimate loads from treated pilings, antifouling paint, and vessel discharges.

• Lack of data to estimate loadings from groundwater, shoreline erosion, Puget Sound.
Next Steps: Synthesis Report

• Summarize and synthesize previous reports:
  • WQAs (Elliott Bay, Duwamish Estuary, and Lake Union/Ship Canal)
  • Data Gaps (CECs, Bacteria, Sewage Tracer)
  • Loadings Report

• Review future planned activities that will affect water quality.

• Estimate future contaminant load reduction from planned activities.
Questions?
Lake Washington Water Balance

\[ Q_{out} = (Q_{in} + Q_{prec}) - (Q_{\Delta S} + Q_{evap}) \]

- \( Q_{out} \): total outflow to Lake Union \( \left( \frac{ft^3}{yr} \right) \)
- \( Q_{in} \): watershed inflows \( \left( \frac{ft^3}{yr} \right) \)
- \( Q_{\Delta S} \): change in storage \( \left( \frac{ft^3}{yr} \right) \)
- \( Q_{evap} \): evaporation \( \left( \frac{ft^3}{yr} \right) \)
- \( Q_{prec} \): precipitation \( \left( \frac{ft^3}{yr} \right) \)
Estimates pollutant load and runoff volume for stormwater basins and direct discharge areas during storm events with the Simple Method:

\[ AARV = P \times P_j \times R_v \times A \]

\[ \text{Load} = AARV \times RC \]

- \( AARV \) = annual average runoff volume \( (\frac{ft^3}{yr}) \)
- \( P \) = annual rainfall \( (\frac{ft}{yr}) \)
- \( P_j \) = fraction of annual rainfall that produces runoff (0.9)
- \( R_v \) = runoff coefficient (impervious surfaces = 0.95, pervious surfaces = 0.05)
- \( A \) = drainage area \( (ft^2) \)
- \( RC \) = runoff concentration (ex. \( \frac{mg}{L} \))
Modeled vs Observed wet weather treatment facility effluent