THE IMPORTANCE OF NATURAL WATERSHED HYDROLOGY

AND HOW TO ADVANCE IT IN URBAN AREAS
Pacific Northwest Forest Hydrology

Trees
- Intercept rainfall, evaporate much
- Create “duff”, which absorbs and stores water
- Take water from soil and store and transpire it

Soils
- Store considerable water
- Infiltrate and convey to groundwater and water bodies through subsurface paths

- **Surface runoff** rare, slow sheet flow when it occurs
Urban Hydrology

- Trees removed, hydrologic services lost
- Soils removed and compacted in construction, much storage lost
- Most land cover impervious and impervious-like surfaces
- Hydrologic output surface runoff instead of evapotranspiration, and infiltration
- Runoff occurs rapidly in pipes and ditches
- Human activities generate hundreds of water pollutants
**Forested and Urban Hydrology Compared**

<table>
<thead>
<tr>
<th></th>
<th>Impervious</th>
<th>~0%</th>
<th>~20%</th>
<th>~60%</th>
<th>~95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface runoff</td>
<td>&lt; 5%</td>
<td>~20%</td>
<td>~55%</td>
<td>~85%</td>
<td></td>
</tr>
<tr>
<td>Total output</td>
<td>1X</td>
<td>~2X</td>
<td>~4X</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
Impacts of Urban Hydrology on Streams and Aquatic Life

- High velocities sweep away small life, stress fish, cause bed and bank erosion and loss of riparian vegetation
- Increased sediments reduce light, irritate fish tissues, carry other pollutants, clog fish spawning gravels and fill pools
- From land runoff, higher pollutant concentrations and mass loadings
Benthic Index of Biotic Integrity, a Measure of Bottom-Dwelling Invertebrate Community Health

Highest B-IBI only possible with < 5% impervious; lowest inevitable with > 45%
B-IBI declines in a similar pattern with impervious area and peak flow rate rise.

Highest B-IBI only possible with 2-year frequency rise < 10X.
Hydrology Relative to Urbanization

2-year frequency rise ≤ 10X generally only possible with impervious < 7%
Fish Community Relative to Urbanization

Coho salmon lose in competition with cutthroat trout, a species more tolerant of urban hydrology.
HABITAT TYPES RELATIVE TO URBANIZATION

Figure 47a: Sub-basin %TIA < 5%

Figure 47b: Sub-basin %TIA 5-10%

Figure 47c: Sub-basin %TIA 10-20%

Figure 47d: Sub-basin %TIA 20-30%

Figure 47e: Sub-basin %TIA 30-45%

Figure 47f: Sub-basin %TIA > 45%
Water Quality Relative to Urbanization

[Graph showing relationship between total zinc event mean concentration (µg/L) and total impervious area (%).]

- Acute aquatic life criterion
- Chronic aquatic life criterion
INTRAGRAVEL DISSOLVED OXYGEN (IGDO) MONITOR
IGDO RELATIVE TO URBANIZATION

Potential threshold level of adverse effects
IGDO and Salmon Success
What Can Be Done to Alleviate Urban Impacts?

Naturalizing urban drainage systems by utilizing or mimicking hydrologic functioning of natural vegetation and soil to reduce the quantity of stormwater runoff produced and improve the quality of remaining runoff.

SEATTLE’S NATURAL DRAINAGE SYSTEM PROJECTS
Relatively Flat Street Situation

STREET EDGE ALTERNATIVES (SEA STREETS)

• Impervious reduction
• Compost-amended soils
• Several vegetation canopy layers
Sloping Street Situation
SEA Street Performance

- **Baseline**—Old street discharged in all 35 events monitored
- **First 2 years**—Discharged in only 6.8% of events and 1.9% of volume/unit rainfall as old street
- **Since Dec. 14, 2002:**
  - No discharge despite 10/03 largest storm and 11/06 wettest month in history
  - Thought that maturing vegetation—
    - Intercepts rain for evaporation
    - Stores water in tissue for transpiration
    - Pipes water along roots for infiltration
NW 110th Cascade

3” of river rock
12” of swale mix (70% mineral aggregate, 30% decomposed organic soil matter)
System retained at least 48% of all inflows, and probably closer to 75% considering non-monitored intermediate flows.
Outlet Hydrology

- Discharged in only 49 of 235 storms
- Fully retained storms up to 1” in dry conditions
- Fully retained storms up to 0.3” in any condition
Total Suspended Solids Concentrations

110th Cascade Inlet and Outlet -- TSS

- Paired EMCs
  - Inlet = Outlet
  - KTRL, outlet = 0.08*inlet + 20
  - OLS, outlet = 0.06*inlet + 20
Total Copper Concentrations

Total copper --
110th Cascade inlet vs. outlet

- Inlet total copper = outlet total copper
- KTRL, outlet = 0.096*inlet + 0.004
- OLS, outlet = 0.075*inlet + 0.004
Soluble Reactive Phosphorus Concentrations

110th Cascade inlet and outlet -- SRP

Inlet SRP = Outlet SRP
KTRL, outlet = 0.7*inlet + 0.03
OLS, outlet = 1.8*inlet + 0.02
Summary of Effluent Quality

- Established **reliable maximum and irreducible minimum concentrations** for pollutants (e.g., 40 and 9 mg TSS/L, respectively)
- Estimated **pollutant mass loading reductions**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Min. % (90% CI)</th>
<th>% Accounting for Estimated Side Flows</th>
<th>Typ. % with Conventional Practices*</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>84 (72-92)</td>
<td>93</td>
<td>50-80</td>
</tr>
<tr>
<td>TN</td>
<td>63 (53-74)</td>
<td>82</td>
<td>10-45</td>
</tr>
<tr>
<td>TP</td>
<td>63 (49-74)</td>
<td>83</td>
<td>10-60</td>
</tr>
<tr>
<td>SRP</td>
<td>-44</td>
<td>28</td>
<td>Negative-20</td>
</tr>
<tr>
<td>Total Cu</td>
<td>83 (77-88)</td>
<td>90</td>
<td>30-60</td>
</tr>
<tr>
<td>Dissolved Cu</td>
<td>67 (50-78)</td>
<td>79</td>
<td>Negative-60</td>
</tr>
<tr>
<td>Total Zn</td>
<td>76 (46-85)</td>
<td>90</td>
<td>30-60</td>
</tr>
<tr>
<td>Dissolved Zn</td>
<td>55 (21-70)</td>
<td>86</td>
<td>Negative-60</td>
</tr>
<tr>
<td>Total Pb</td>
<td>90 (84-94)</td>
<td>93</td>
<td>75-90</td>
</tr>
<tr>
<td>Motor oil</td>
<td>92 (86-97)</td>
<td>96</td>
<td>50-75</td>
</tr>
</tbody>
</table>

*Highly variable depending on volume reduction*
Summing Up

• Surface runoff rare in a natural Northwest landscape; infiltration supplies water bodies in dry periods

• Runoff dominates urban hydrology and flows quickly into water bodies

• Increased flow and the pollutants it carries create many negative effects in streams and other waters

• Naturalizing drainage systems by exploiting soils and vegetation goes a long way toward alleviating these impacts

• Range of techniques available to apply in new development, redevelopment, and retrofitting
More Advanced Watershed Analysis

• Watershed Condition Index (WCI) development began with the selection of nine possible metrics chosen because of their relatively high correlation with B-IBI.

• 7-variable WCI optimum in fitting B-IBI as a function of WCI (linear, $R^2 = 0.53$) and CS:CT (exponential, $R^2 = 0.75$).

• Variables:
  - TIA and forest cover—watershed-wide and in 50- and 300-m riparian bands
  - Paved + urban grass-shrub cover in 300-m band
Two methods of predicting category membership:

- Discriminant function analysis (DFA)—combines independent variables into a single variable that best discriminates (according to Wilk’s lambda statistic) scoring in selected dependent variable categories.

- Logistic regression (LR)—forecasts probability of falling in selected dependent variable categories based on WCI.

\[ P = \frac{e^L}{1 + e^L} \]

where the logit \( L = b_0 + b_1(WCI) \).
Effectiveness of Discriminant Function and Logistic Regression Analyses

<table>
<thead>
<tr>
<th>Biological Integrity Group</th>
<th>Correctly Predicted in Group By DFA(%)</th>
<th>Using WCI Only</th>
<th>Using WCI Variables</th>
<th>Correctly Predicted Not in Group By LR (%)</th>
<th>Correctly Predicted in Group By LR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-IBI ≥ 85% of best</td>
<td></td>
<td>69</td>
<td>85</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>B-IBI ≤ 25% of best</td>
<td></td>
<td>65</td>
<td>61</td>
<td>96</td>
<td>29</td>
</tr>
<tr>
<td>CS:CT ≥ 2.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>91</td>
<td>63</td>
</tr>
<tr>
<td>CS:CT ≤ 1.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>93</td>
<td>86</td>
</tr>
</tbody>
</table>
## Cost Comparison

<table>
<thead>
<tr>
<th>Street/Drainage System Types</th>
<th>Cost Per Block (330 linear ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local/SEA Street</td>
<td>$325,000</td>
</tr>
<tr>
<td>Local/Traditional</td>
<td>$425,000</td>
</tr>
<tr>
<td>Collector/Cascade</td>
<td>$285,000</td>
</tr>
<tr>
<td>Collector/Traditional</td>
<td>$520,400</td>
</tr>
<tr>
<td>Broadview Green Grid (15 block area)</td>
<td>Average per block: $280,000</td>
</tr>
</tbody>
</table>