



emerging trends in LID flow control and WQ treatment performance

Topics

Residential LID pilot flow control performance

Pervious pavement flow control and WQ performance

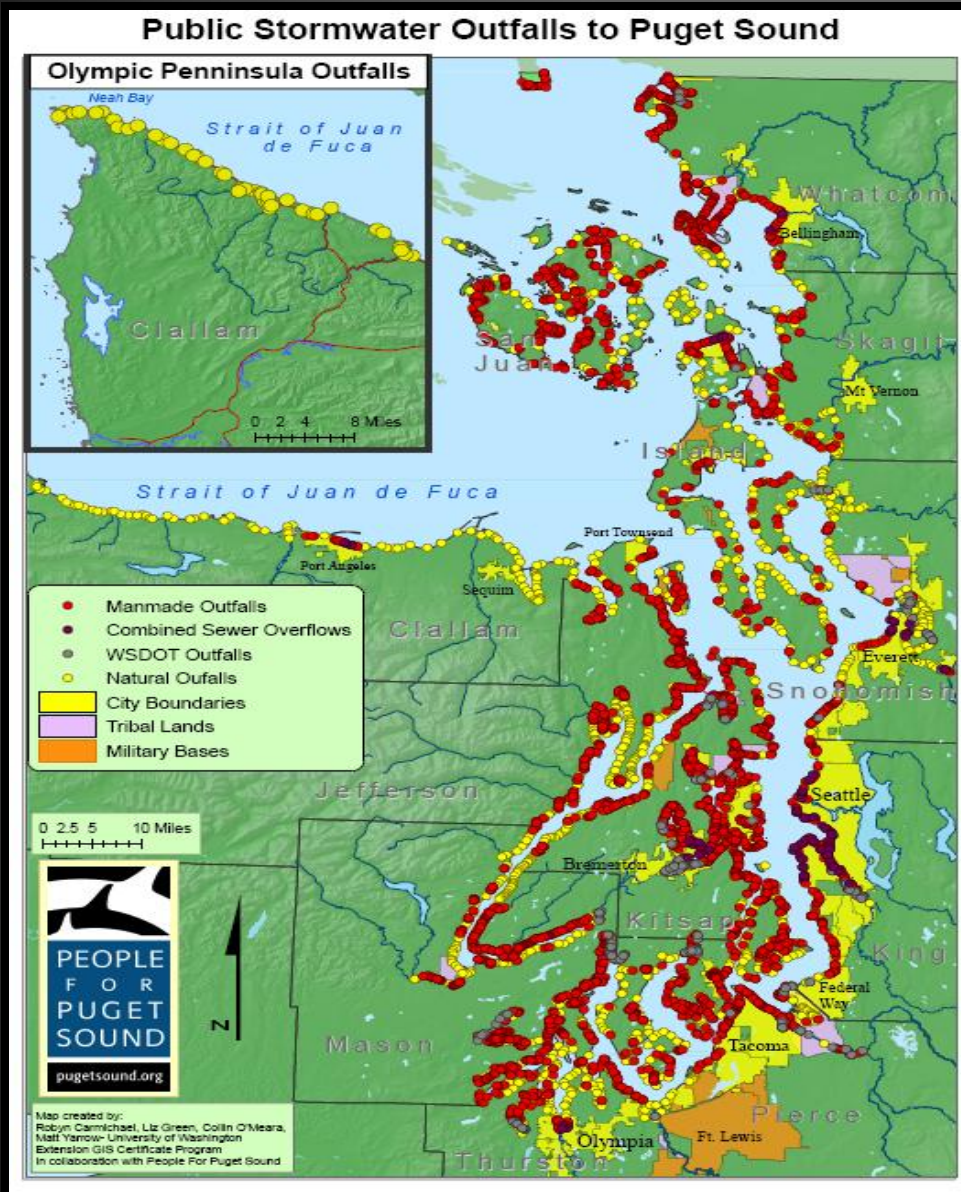
LID data gaps and future research

Some characteristics of urban pollutants



- **PBDE levels in seals up from 50 parts per billion in fatty tissue to more than 1,000 ppb over the past 20 years.**
- **Annual loading of oil to Puget Sound ~22,580 metric tons (Exxon Valdez spilled ~33,500 metric tons).**
- **Many pollutants associated with fines (particularly metals), many <0.45 microns (dissolved).**
- **~344 metric tons/yr of Zn to Puget Sound annually.**
- **Water quantity and quality implicated ...Structural stormwater controls alone have limitations for protecting native characteristics of receiving waters.**

Puget Sound Conditions



Stormwater outfalls:

- 4,529 manmade.
- 2,123 natural drainages.
- 93 CSO.
- 297 WSDOT.

Low Impact Development Principles and Practices



A land use development strategy that emphasizes protection and use of on-site natural features to manage stormwater.



Integrated engineered, small scale stormwater controls. WQ treatment integral in all LID controls.

LID Objectives

- **Protect and restore native soils/vegetation.**
- **Reduce the development envelope.**
- **Reduce impervious surfaces and eliminate effective impervious area.**
- **Manage stormwater as close to its origin as possible.**
- **Integrate stormwater controls into the design—create a multifunctional landscape.**
- **Reduce concentrated surface flow, minimize stormwater contact with impervious surfaces, and increase stormwater contact with soils and vegetation.**





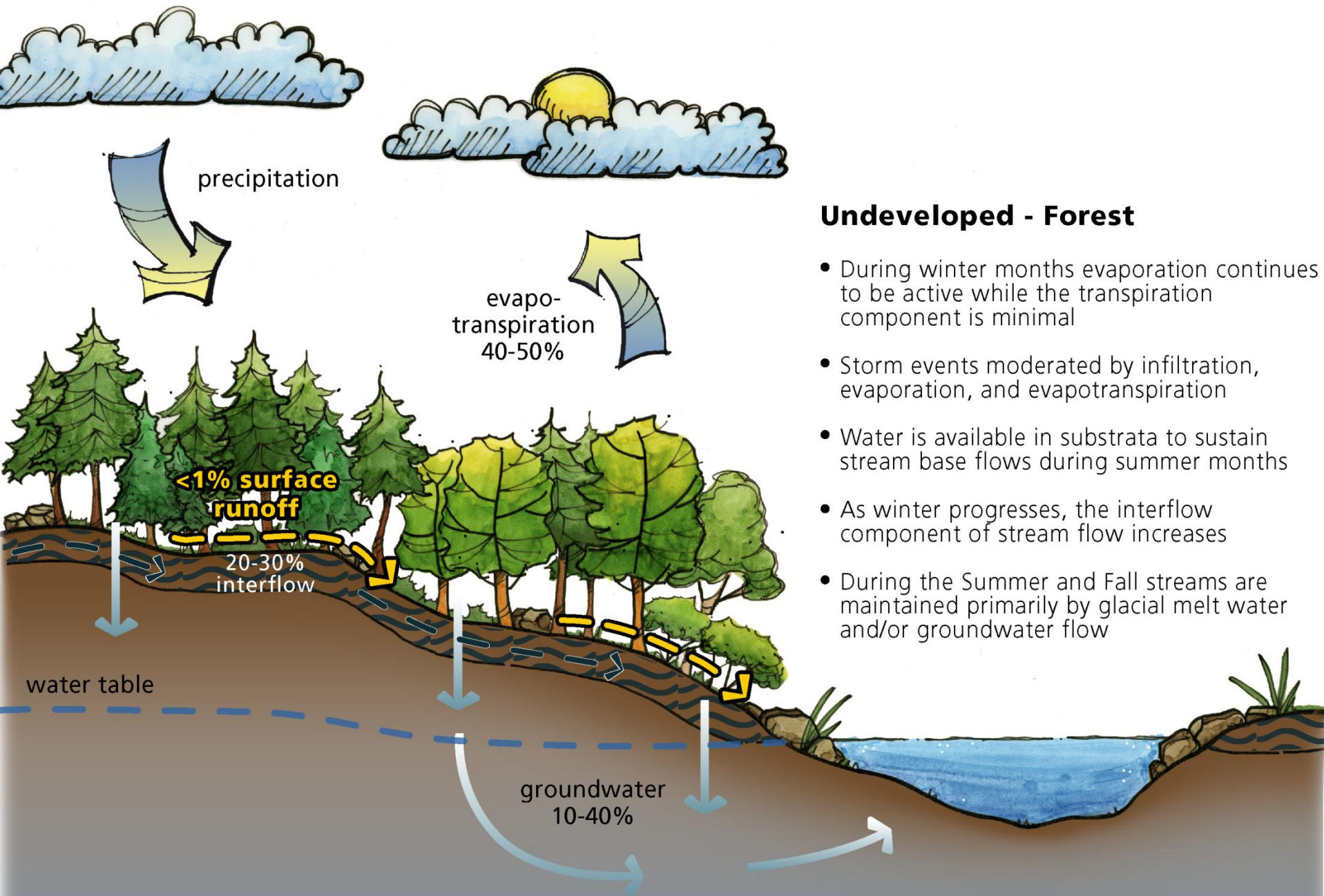
- **Approximately 98% stormwater volume reduction compared to pre-existing street design**
- **Last recorded discharges on 12/14/02 and 12/07!**

SEA Street project, 2nd Ave NW, from NW 117th to NW 120th

Comprehensive Stormwater Management Program

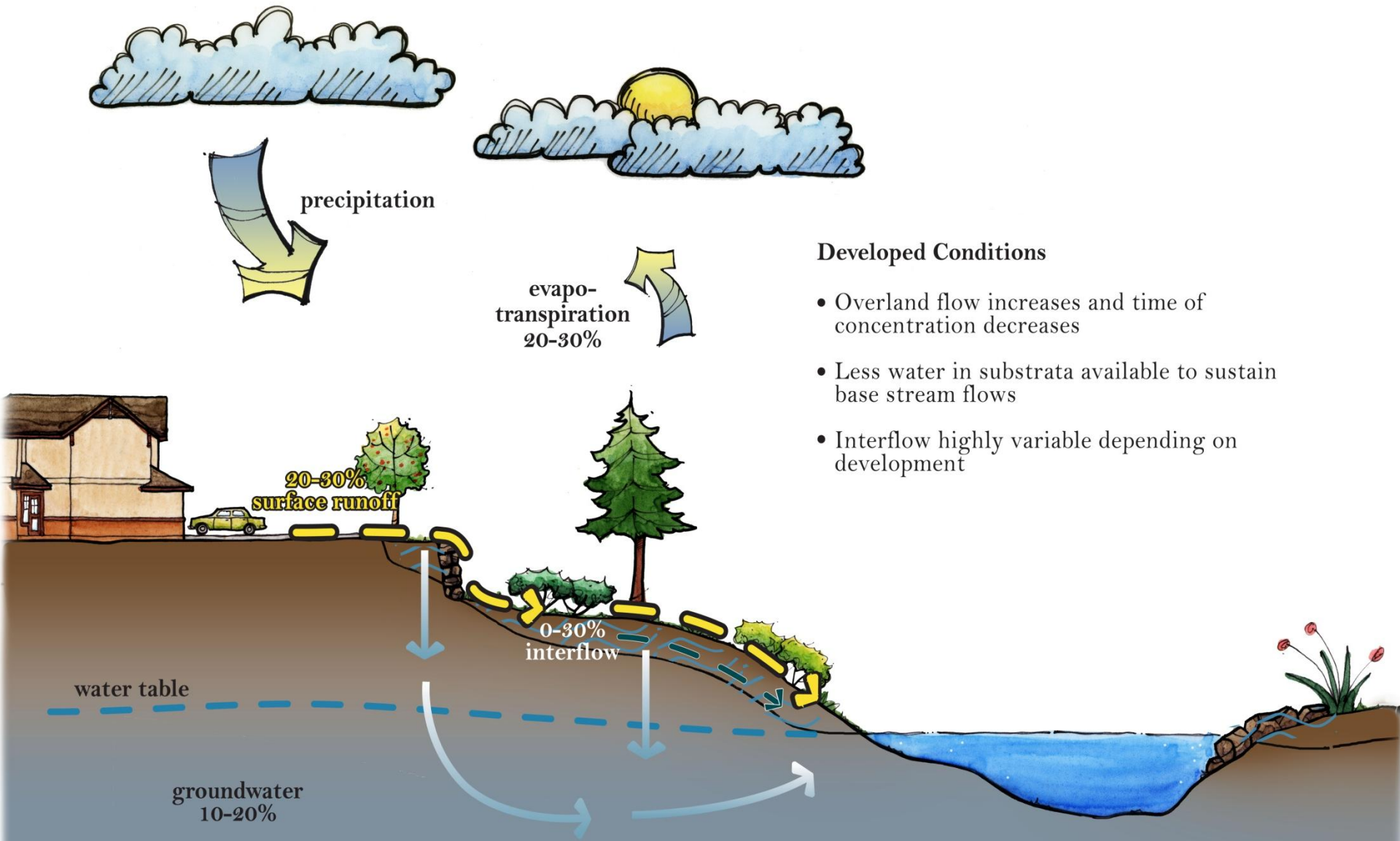
- Land use planning
- Standards equal to Ecology's
- Site plan review
- Construction site inspections
- Maintenance
- Source control
- Illicit discharges & problem response
- Existing problems
- Public education & involvement
- Watershed or basin planning
- Monitoring
- Stable funding
- Low impact development

From Puget Sound Water Quality Management Plan



Undeveloped - Forest

- During winter months evaporation continues to be active while the transpiration component is minimal
- Storm events moderated by infiltration, evaporation, and evapotranspiration
- Water is available in substrata to sustain stream base flows during summer months
- As winter progresses, the interflow component of stream flow increases
- During the Summer and Fall streams are maintained primarily by glacial melt water and/or groundwater flow



Developed Conditions

- Overland flow increases and time of concentration decreases
- Less water in substrata available to sustain base stream flows
- Interflow highly variable depending on development

Meadow on the Hylebos: project background

- **Project initiated in 2002.**
- **Partnership among Pierce County, AHBL, owner and developer for planning and construction.**
- **WSU lead and developed funds for monitoring.**
- **Approximately 5 years to complete planning, construction and monitoring.**



Monitoring program was generously supported by:

- **The Russell Family Foundation**
- **Washington State Department of Ecology**
- **Pierce County Advanced Planning**
- **Water Environment Research Foundation**

Project Goals

Design an integrated low impact development system that more closely mimics native hydrologic function to protect adjacent stream values, enhance groundwater recharge, as well as construct an affordable and livable neighborhood.

Monitoring Objectives

- **Determine if project meets flow control standards.**
 - **Flow control standard: match peak flow and flow durations for pre-development pasture condition from 50% of the 2-year peak flow up to the full 50-year peak flow.**
- **Determine flow performance for individual basins and water budgets for individual LID techniques.**
- **Assess general stormwater runoff quality for project as a whole at point-of-compliance.**
- **Develop highly accurate instrumentation and sound data.**

Monitoring Products

- Verify flow control objectives.
- General water balance.
- Detailed bioretention flow control performance.
- Peak flow reduction.
- Sloped bioretention flow control performance and water balance.
- Permeable concrete infiltration over time.
- Partition bioretention surface and under-drain flow).
- Soil water content related to flow control performance.
- General water quality assessment at POC.



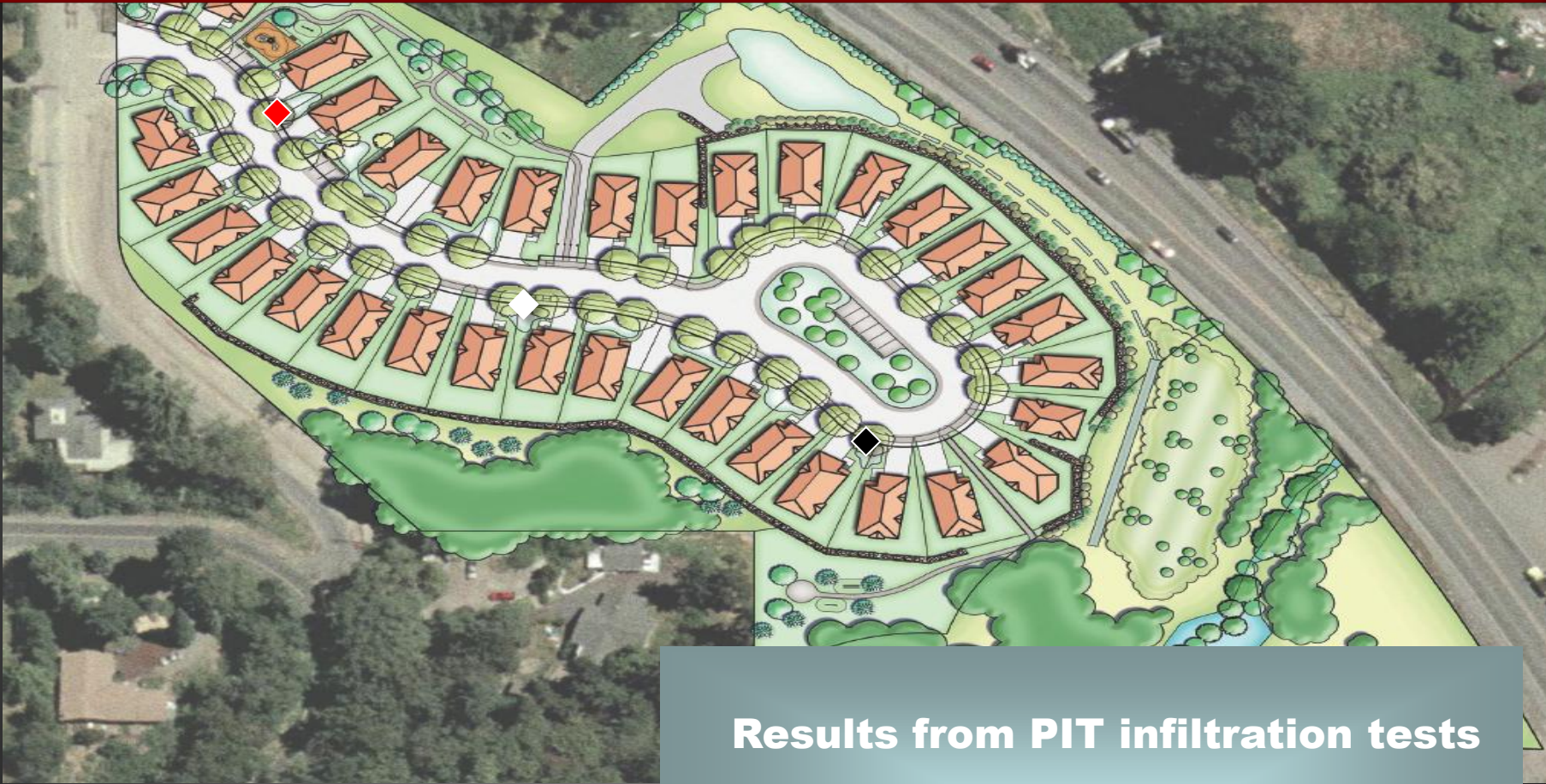




70TH STREET

PACIFIC HWY

Soil Types and Infiltration Rates



Soils: fine silt loams overlaying till, with occasional gravelly, sandy loam post glacial meltwater layers. Total relief ~90ft, slopes 5-20%.

Results from PIT infiltration tests

- ◆ Pit 1: 0.3 in/hr
- ◆ Pit 2: 0.0 in/hr
- ◆ Pit 3: 2.5 in/hr



LID features include

- **Bioretention swales along road ROW.**
- **Permeable concrete road shoulders and parking.**
- **Compost amended soils and sloped bioretention.**
- **“LID light”.**





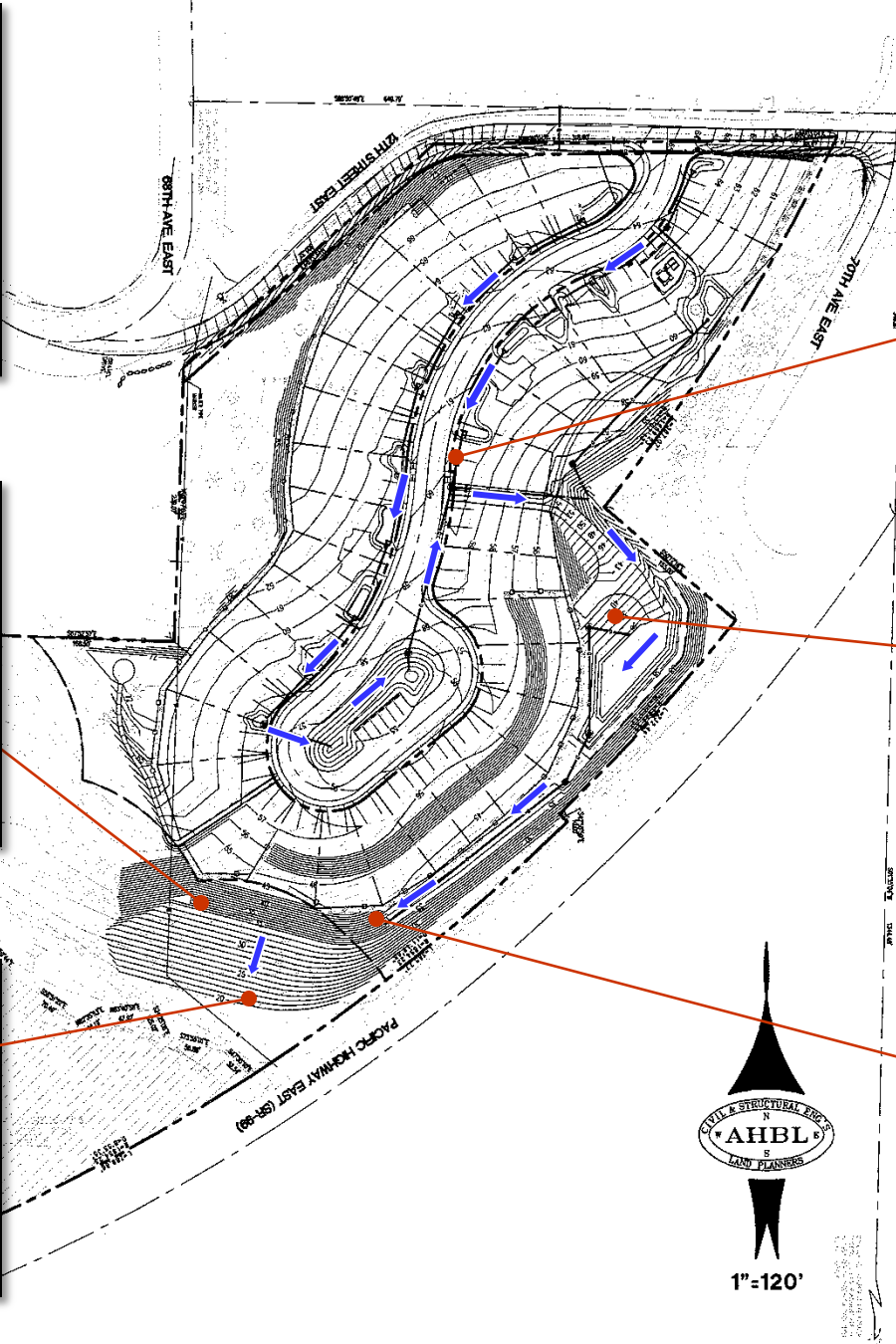








11 Monitoring wells



(5-6) Catch-basin



(1) Weather station



(2) Point of compliance



(4) Under-drain flow



(7) Final dispersion area

Precipitation Summary (mm)

	Oct	Nov	Dec	Jan	Feb	March	April	May
On site (07-08 avg.)	68.84	67.05	175.77	100.08	56.13	82.55	38.10	22.60
WRCC (07-08 avg.)	92.46	67.31	212.34	117.60	72.14	105.66	44.70	25.65
WRCC (1971-2000 Avg.)	86.11	154.94	149.61	136.65	112.78	106.17	72.90	51.05

- **Total precipitation on site (avg.): 651.25**
- **Average annual (WRCC): 989.33**

Overall Precipitation and Flow Volumes





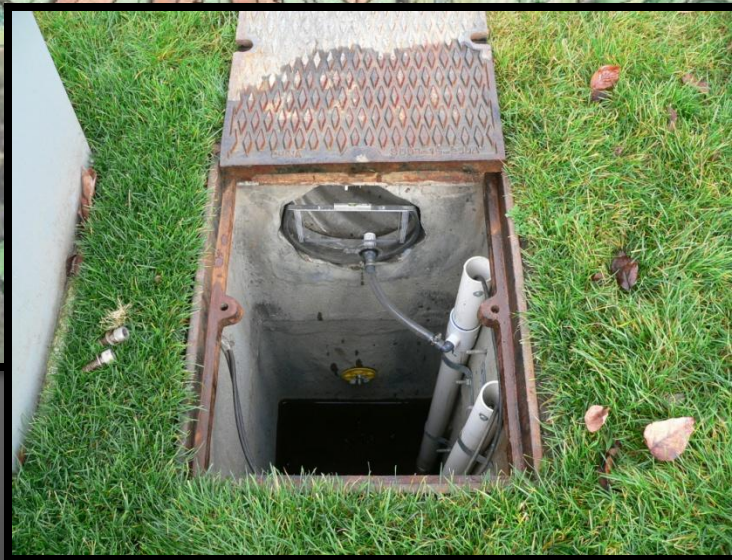
CAMPBELL SCIENTIFIC, INC.

Precipitation and Flow Response Volume Summary

	Total Precipitation Volume (m³)	Evapotranspiration (mm)	Total Flow Volume (m³)	Total Precipitation Volume Retained (m³)
2006-07 POC	19,527.07	249.75 (23%)	7,384.75	12,142.32 (62%)
2007-08 POC	10,563.62	149.79 (23%)	3,252.92	7,310.70 (69%)
2007-08 Slope	11,376.20	149.79 (23%)	431.08	10,945.12 (96%)

- **Total precipitation volume is the product of contributing area and total precipitation depth minus ET.**
- **POC contributing area = 5.2 acres, dispersion slope contributing area = 5.6 acres.**
- **Total precipitation on site (Avg.): 651.25.**

Bioretention Swales Precipitation and Flow Volumes





Precipitation and Flow Response Volume Summary

	Total Precipitation Volume (m³)	Evapotranspiration (mm)	Total Flow Volume (m³)	Total Precipitation Volume Retained (m³)
2007-08	1,625.17	149.79 (23%)	15.71	1,609.46 (99.99%)

- **Total precipitation volume is the product of contributing area and total precipitation depth minus ET.**
- **Bioretention swale contributing area = 0.8 acres.**
- **Total precipitation on site (Avg.): 651.25.**
- **Ratio of bioretention area to contributing area: ~15%**

Modeling Overview

• Objectives














- Modeling of post-construction performance.
- Evaluate forested and pasture pre-developed conditions.
- Design feedback.

• Methods

- WWHM3 Professional Version.
- Rainfall
 - Onsite data.
 - McMillan, scaling factor 1.0.
- Dispersion of roof runoff on lawns → lateral flow to grass.
- Permeable pavement → gravel infiltration trench.
- Engineered bioretention slope → lateral flow to pasture.

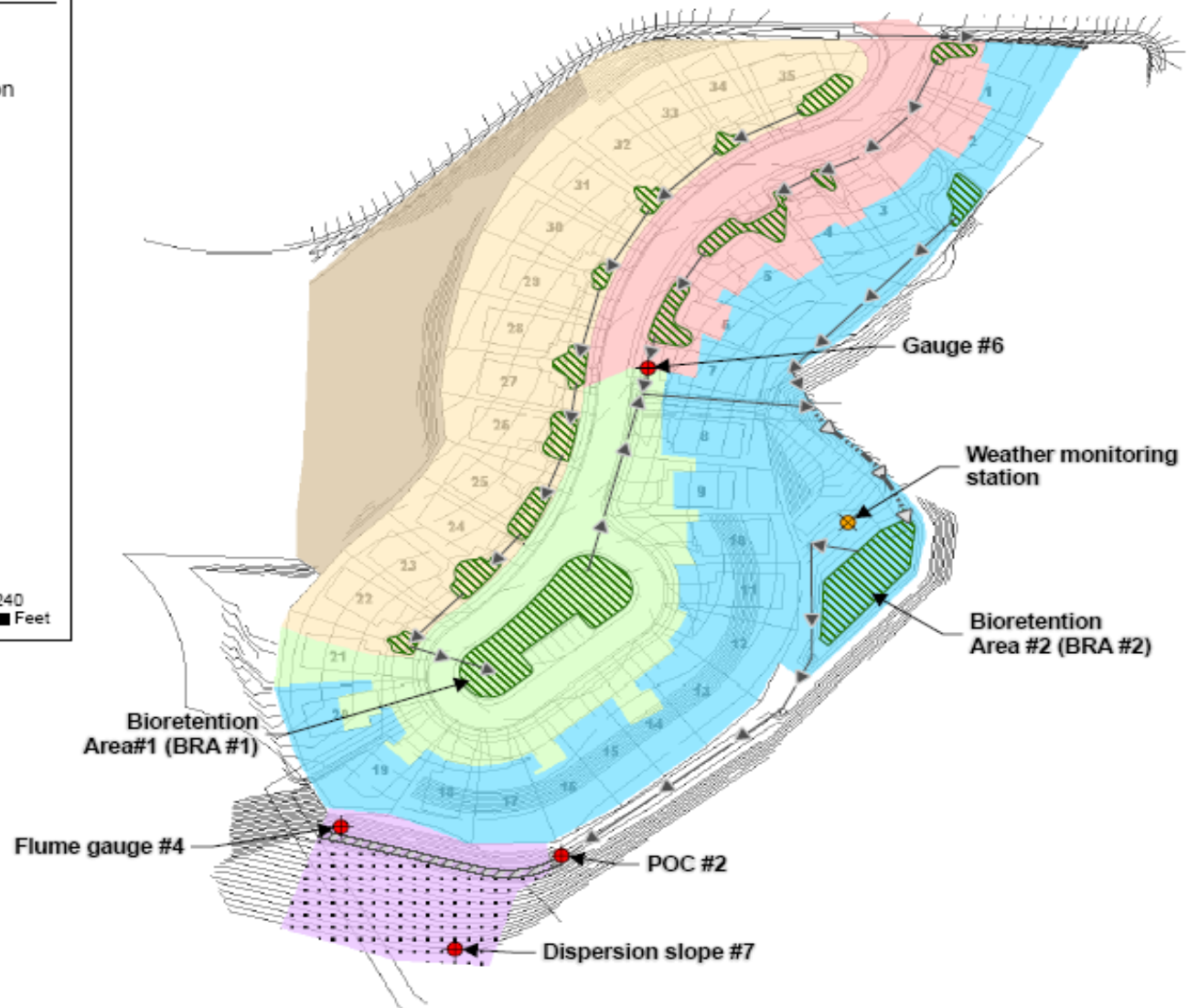
Model Layout

Legend

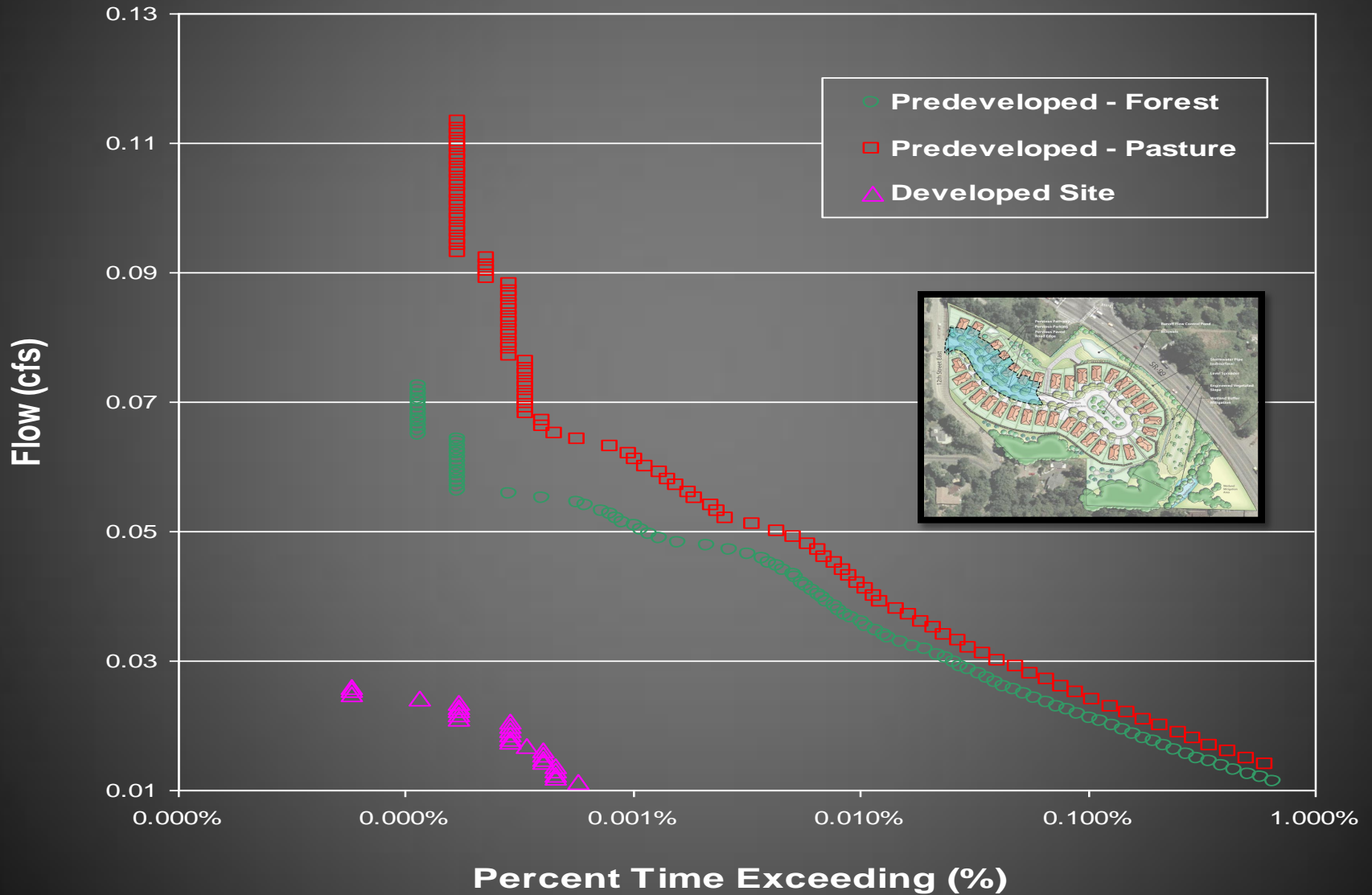
-  Flow monitoring gauge location
-  Weather monitoring station
-  Pipe
-  Open ditch
-  Bioretention
-  Gravel level spreader
-  Bioengineered slope
-  Subbasin 1 (0.77 acres)
-  Subbasin 2 (1.85 acres)
-  Subbasin 3 (0.99 acres)
-  Subbasin 4 (1.46 acres)
-  Subbasin 5 (0.71 acres)
-  Subbasin 6 (0.40 acres)



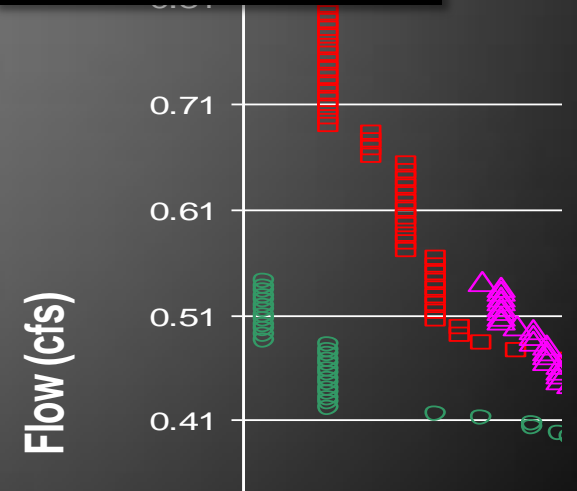
0 60 120 240
Feet



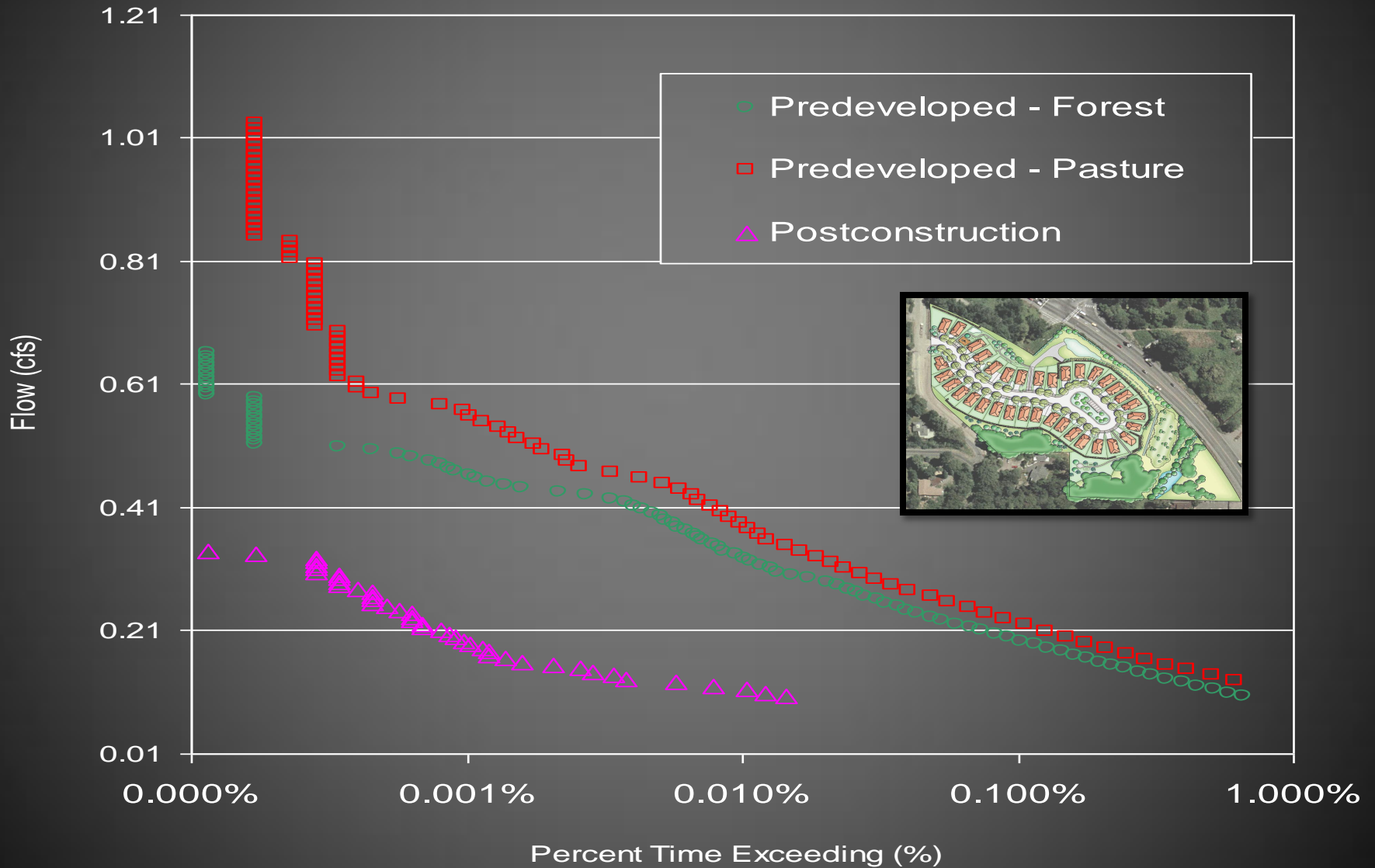
Swales Station 6: Flow Duration Results



POC Station 2: Flow Duration Results



Dispersion Slope Station 7: Flow Duration Results



Water Quality Treatment

Meadow on the Hylebos Sample Results for Metals with Comparative Studies.

	Pb total (µg/L)	Cu total (µg/L)	Zn total (µg/L)	Pb dissolved (µg/L)	Cu dissolved (µg/L)	Zn dissolved (µg/L)
Project Sample	0.002/ 0.003	0.02/ <0.02	<0.05	<0.002	<0.02	<0.05
NURP* (median)	144	33	135	not reported	not reported	not reported
NSQD** (median)	12	12	73	3.0	7.0	31.5

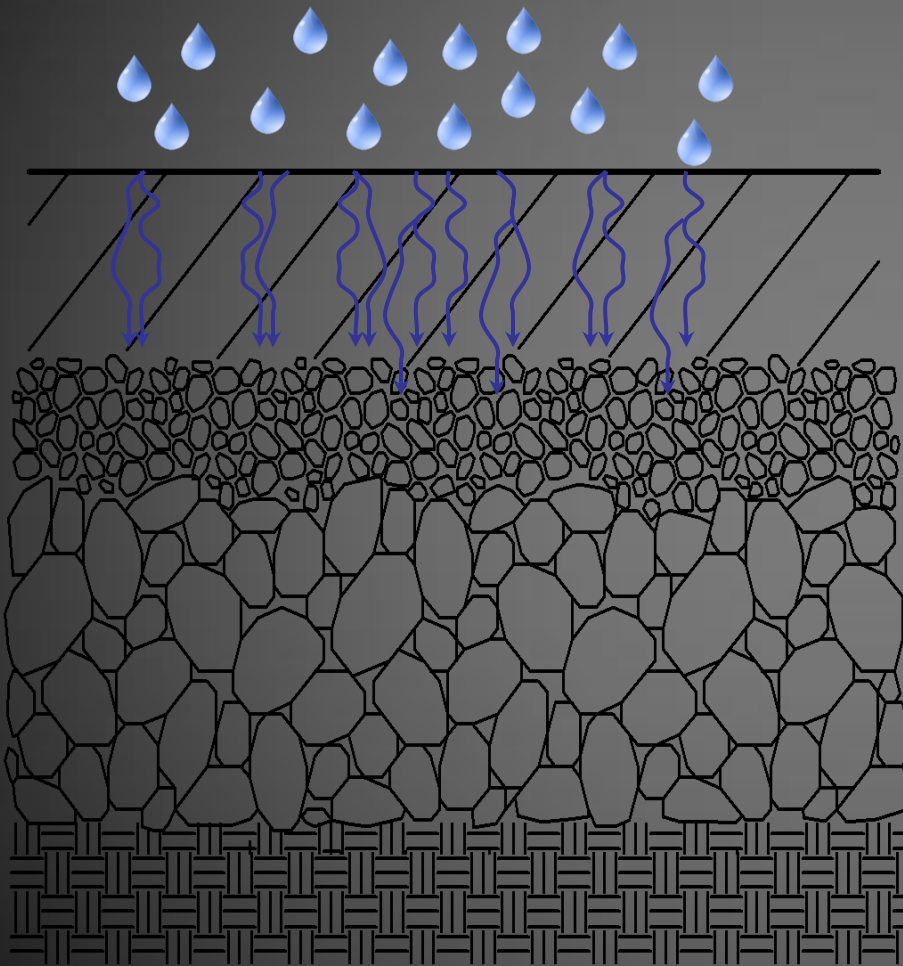
*National Urban Runoff Program (residential land use)

**National Stormwater Quality Database (residential land use)

Hardness: 110/74 (mg/L as calcium carbonate) for project samples

Project sample: one number reported if both sampling events the same, 12/02/07 sample/2/6/08 sample reported if different.

Pervious pavements: water quality treatment summary



Treatment mechanisms

- Stormwater volume reduction.
- Reduced spray and vehicle wash off.
- Biological degradation.
- Filtration.
- Adsorption.
- Volatilization.

Median of average effluent concentrations (EMC's) of various BMP's

	SS (mg/L)	TCu ($\mu\text{g/L}$)	TPb ($\mu\text{g/L}$)	TZn ($\mu\text{g/L}$)	TP (mg/L)
PP (n=6)	16.96	2.78	7.88	16.60	0.09
DP (n=25)	26.74	15.91	14.57	58.66	0.19
WP (n=46)	9.74	5.82	3.40	21.58	0.10
WB (n=19)	13.38	3.35	2.51	29.21	0.11
BF (n=57)	17.84	9.63	5.42	27.93	0.27
MF (n=38)	10.85	7.63	2.62	32.23	0.11
HD (n=32)	23.48	11.82	5.05	75.12	0.20

International BMP Database.

- PP = permeable paving, DP = detention pond, WP = wet pond, WB = wetland basin, BF = biofilter, MF = media filter, HD = hydrodynamic.

Mean concentrations for nine test parking stalls in Renton WA (2001-2002, 9 storm samples)

	Cu ($\mu\text{g/L}$)	Pb ($\mu\text{g/L}$)	Zn ($\mu\text{g/L}$)	Motor Oil (mg/L)
Gravelpave	0.89 (66%<MDL)	ND	8.23 (66%<MDL)	<MDL
Grasspave	<MDL	ND	13.2	<MDL
Turfstone	1.33 (44%<MDL)	ND	7.7 (33%<MDL)	<MDL
EcoStone	0.86 (77%<MDL)	ND	6.8 (33%<MDL)	<MDL
Conventional Asphalt	7.98	--	21.6	0.164

- MDL: motor oil 0.10 mg/l, Cu 1.0 ($\mu\text{g/L}$), Zn 5 ($\mu\text{g/L}$)
- Permeable paving sections ~10 cm deep. 90-100% occupancy during business hours. Test plots 6 years old. Dissolved metals.
- Conventional asphalt section exceeded WA surface flow WQ standards for Zn in all but one sample (acute and chronic).

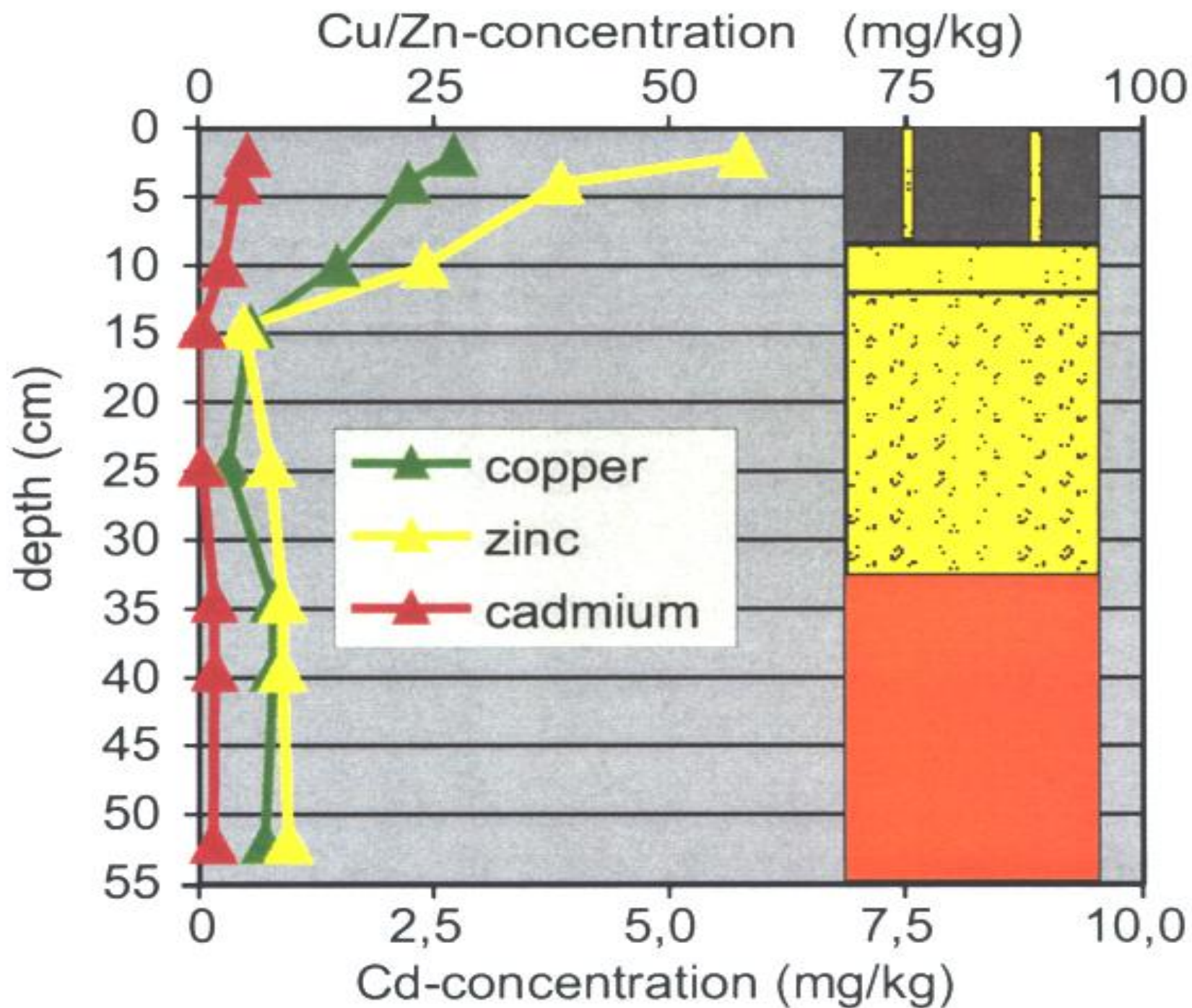
Comparison of water quality parameters for permeable and conventional asphalt

Study		TSS (mg/L)	TH/PAH's (mg/L)	Pb (µg/L)	Zn (µg/L)	Cu (µg/L)	Cd (µg/L)
Legret et al (1996)	Perm	12	TH <0.02	5.4	46	15	0.49
	Conv	33	TH <0.02	26.0	165	11	1.48
Barrett et al (2006) PFC	Perm	7.6	(PAH's <detect)	0.9	40.4	26.8	--
	Conv	117.8	(PAH's <detect)	12.6	167.4	6.8	--
Berbee et al (1999) PFC	Perm	17	PAH's 5.2-5.8	7	47	40	0.2
	Conv	194	PAH's <0.3	93	452	121	0.8

- Legret: permeable asphalt road France, ~2000 vehicle trip/day. Study estimates that ~97% of stormwater infiltrates in reservoir structure and soil.
- Barrett: 4 lane divide highway Austin TX, 20m² retrofitted with 50mm PFC, ADT 43,000.
- Berbee: 2 highways near Amsterdam, 1 conventional (53,000veh/day) and 1 PFC (83,000 veh/day).

Concentrations of dissolved metals in 60 cm laboratory rigs with permeable pavers and four different base aggregate materials (simulates 50 yrs of loading)

	Lead ($\mu\text{g/L}$)	Cadmium ($\mu\text{g/L}$)	Copper ($\mu\text{g/L}$)	Zinc ($\mu\text{g/L}$)
Synthetic Stormwater	180	30	470	660
Effluent				
Gravel	<4	0.7	18	19
Basalt	<4	0.7	16	18
Limestone	<4	3.2	29	85
Sandstone	<4	10.5	51	178
Percent Retention				
Gravel	98%	98%	96%	97%
Basalt	98%	98%	96%	98%
Limestone	98%	88%	94%	88%
Sandstone	98%	74%	89%	72%

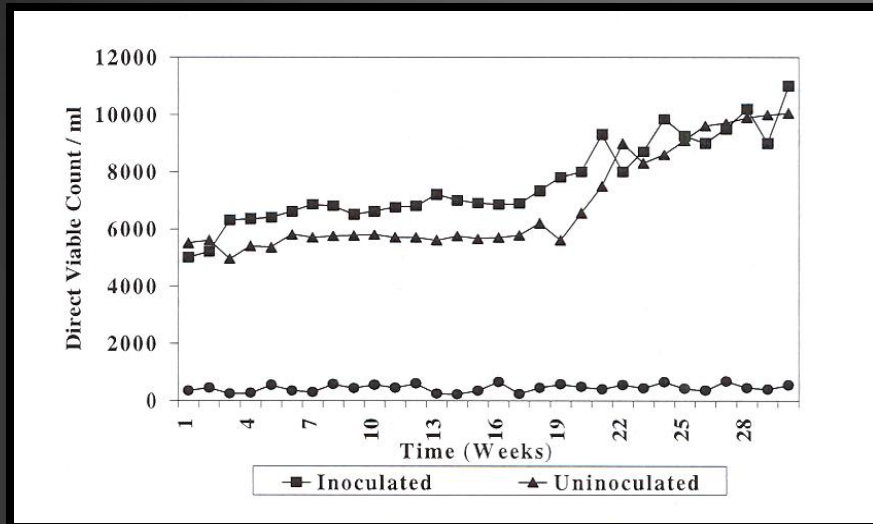


Soil pollutant concentrations in soil beneath permeable paving installations

Study	Depth	MOH (mg/kg)	PAH's (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Cd (mg/kg)
Legret etal (1996)*	surface	--	--	190	383	46	0.30
	60-75 cm	--	--	50	97	15	0.11
	110-150 cm	--	--	29	111	15	0.05
Dierkes etal (2002)	surface	133	ND(<1.5)	--	~60	~26	~5
	0-5 cm	26	ND(<1.5)	--	backgrnd	backgrnd	backgrnd<1
	5-10 cm	20	ND(<1.5)	--	backgrnd	backgrnd	backgrnd<1
MTCA		30/4,000**	0.1	250			2

- Legret: 6-yr old asphalt road, ~2,000 vehicle trips/day.
- Dierkes: 15 year-old permeable paver supermarket parking lot.
- *Study estimates that ~97% of stormwater infiltrates in reservoir structure and soil.
- **Gas with benzene/mineral oil.

Permeable pavements appear to be highly effective for hydrocarbon biodegradation

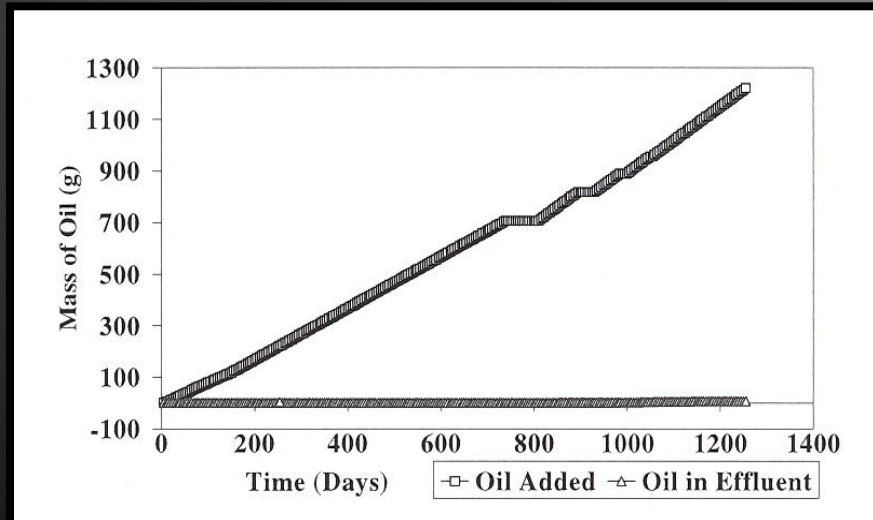


A diversity of microbes (flagellates, amoeba, rotifers) colonize permeable paving immediately.

97-99% removal capability.

Geotextile primary substrate for microbes... Non-woven perform better than woven.

Nutrient need for microbial population unclear.



UNH Stormwater Center finding significant reduction of deicing salts for permeable paving compared to conventional paving



May reduce salt use by 70% by allowing snowmelt and rain to infiltrate.



Permeable pavements are as, or more, effective for managing typical road and parking pollutants than conventional practices



Hydrocarbons, metals and nutrients.

Much of the pollutant capture and transformation happens in the upper few inches of the paving structure...geotextiles.



No significant contamination of soil has been observed in the research.

We currently do not give any water quality treatment credit for permeable pavements.

High initial infiltration rates in permeable paving will diminish over time...important to consider context and maintenance

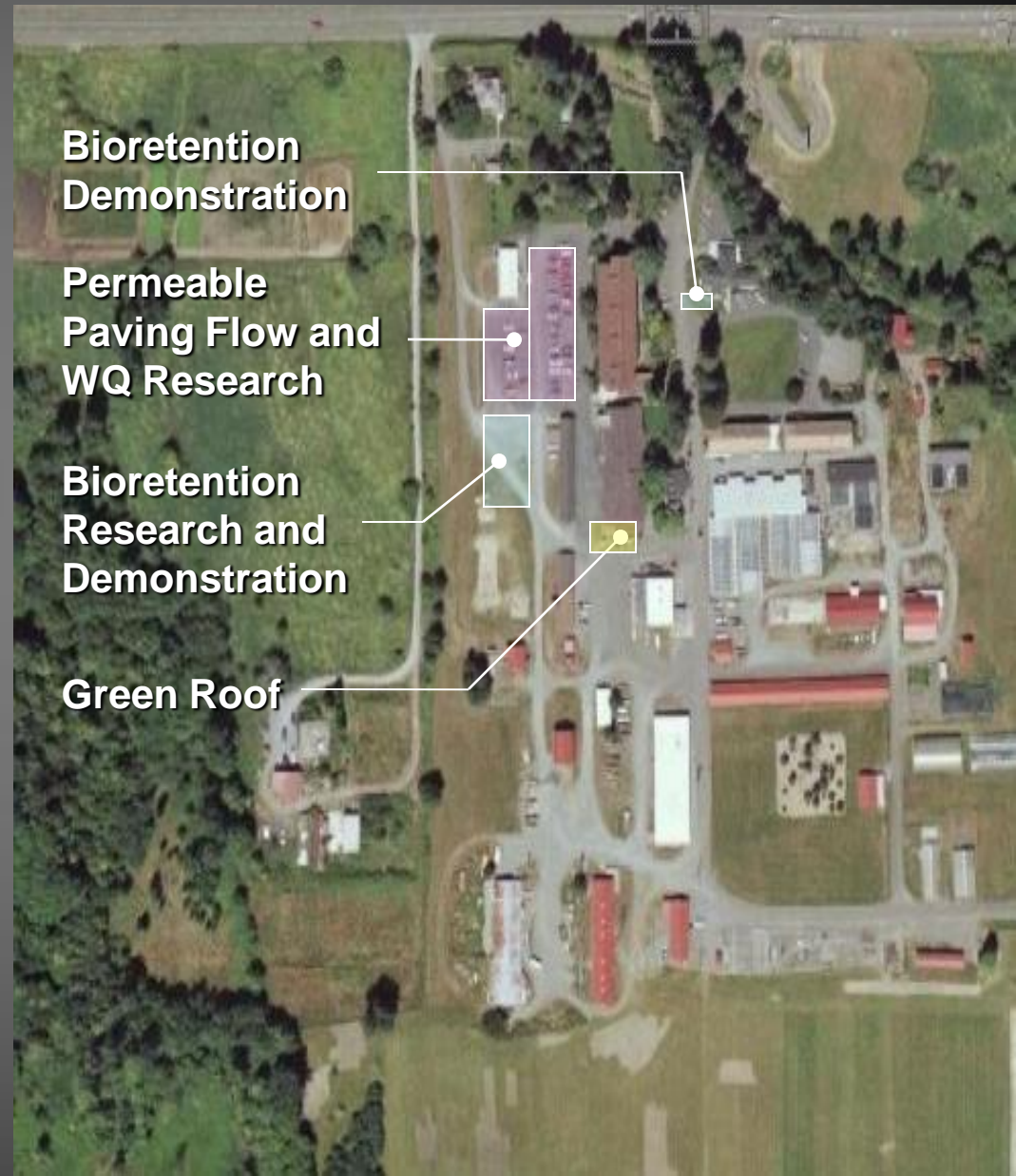


Infiltration Rates Over Time

- Most conservative 3.0 in/hr (ICPI).
- 50% of initial infiltration rate typical recommendation.
- Permeable asphalt hwy: 1986 100 in/hr, 1990 28 in/hr.
- Florida permeable concrete field evaluation: 6.5 yrs old: 240 in/hr, 8 yrs old: 42 in/hr.
- Borgwardt: reports a long-term infiltration rate for permeable pavers of 4.25 in/hr.
- Worst case: 1096 cm/hr reduced to 3.32 cm/hr observed...105 cm/hr after cleaning (Hinman, 2007).

WSU Puyallup LID Research Program

- **A center for LID research and education in Puget Sound and the west.**
- **Pilot scale and replicated research.**
- **Research will integrate civil engineering, soil science, plant science, aquatic toxicology, etc.**
- **Excellent graduate research and publishing opportunities.**



WSU Puyallup LID Research Program

pervious concrete



research

- hydraulic focus (unlined).
- volume, peak flow attenuation, saturated zone, infiltration on soils with low-permeability.
- long-term pollutant concentrations in soils beneath pavement.
- infiltration with and without maintenance.

Thanks...questions



High initial infiltration rates and surface flow reduction well established

Average permeable pavement surface infiltration rates (cm/hr)

DATE	PC	PICP1	CGP	PICP2
06/2006	3087	771	91	457
09/2006	6152	1027	89	171
03/2007	4466	1299	87	376
07/2007	4941	1536	101	267

(Hunt 2007)

Percent surface runoff reductions from rainfall depth

	Asphalt (n=44)	PC (n=40)	PICP1 (n=41)	CGP (n=40)	PICP2 (n=40)
MEAN	34.65	99.86	99.33	98.17	99.51
MEDIAN	29.43	99.94	99.37	98.67	99.68
MIN	-2.73	99.03	97.76	91.11	96.94
MAX	84.80	100.00	100.00	100.00	100.00

(Hunt 2007)

Conclusions and Next Steps

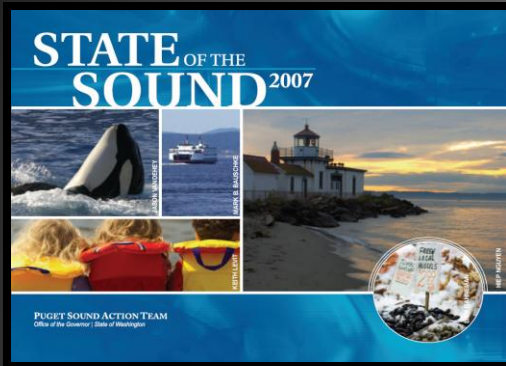
- **To meet flow duration goal at POC Station 2, need infiltration in BA 1.**
- **Flow duration goals exceeded at Station 6 and DS Station 7.**
- **Modeled runoff volume reductions**
 - **100% at Station 6.**
 - **49% at POC Station 2.**
 - **84% at DS Station 7.**
- **Possible next steps**
 - **Calibrate with onsite rainfall, evaporation, soil moisture, and flow monitoring data.**
 - **Bioretention with under-drain.**

Overall Precipitation and Flow Volumes

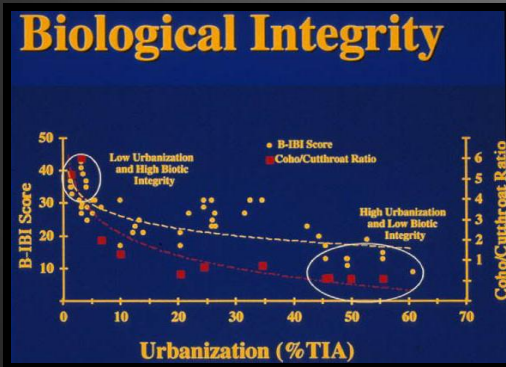


Area outside drainage plan = 2.67 acres.

Environmental conditions in Puget Sound and surrounding watersheds are in decline



The State of the Sound 2007 documents the precarious health of orcas, salmon and marine and birds. New pollutants and synergistic effects of pollutants emerging.



Stormwater a primary driver for decline...stream and wetland degradation can occur at low levels of development ...water quantity and WQ implicated.



Structural stormwater controls alone have limitations for protecting native characteristics of streams, lakes wetlands, and Puget Sound.