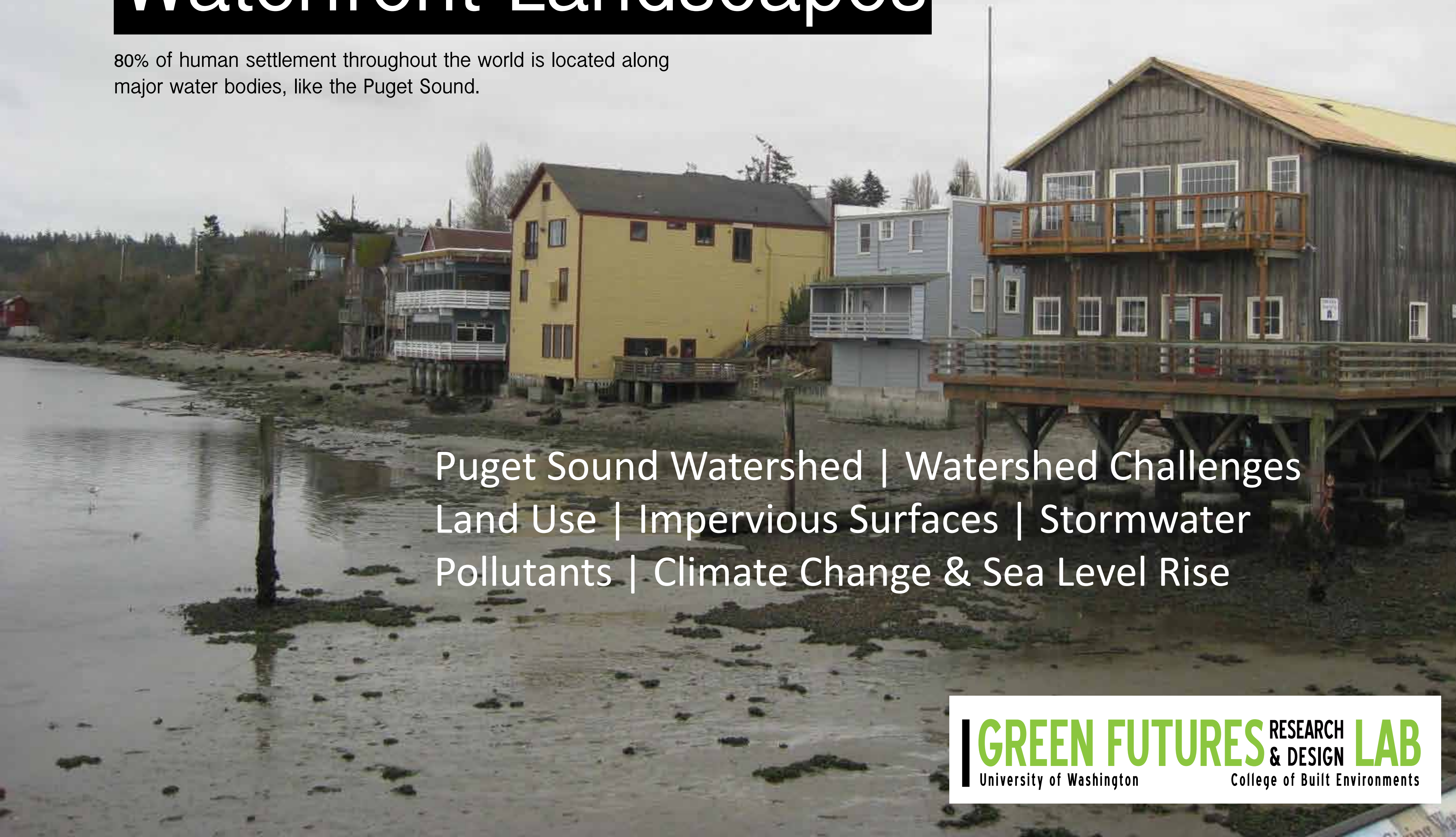
Context: Puget Sound Waterfront Landscapes

80% of human settlement throughout the world is located along major water bodies, like the Puget Sound.



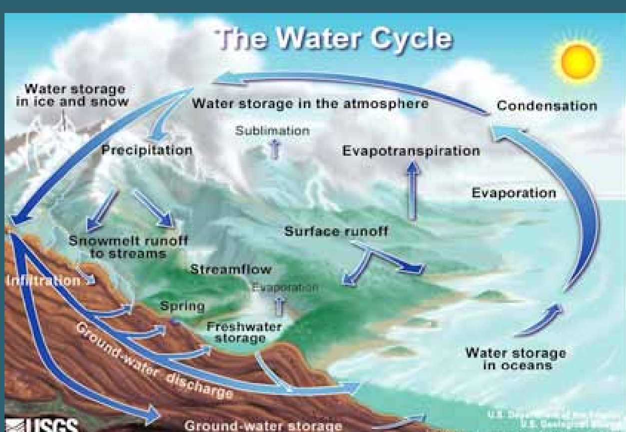
Puget Sound Watershed | Watershed Challenges
Land Use | Impervious Surfaces | Stormwater
Pollutants | Climate Change & Sea Level Rise

GREEN FUTURES RESEARCH & DESIGN LAB
University of Washington College of Built Environments

WATER CYCLE

Every drop of water travels through a complex and important natural cycle. Water evaporates from oceans, rivers or lakes, forms clouds and falls on the landscape as rain, sleet, hail or snow. Vegetation and soils absorb some of the water acting like sponges that recharge groundwater an important reservoir for drinking water. Groundwater is slowly released, year-round, into streams and wetlands further down the watershed. Surface flows run across the landscape and the various land uses becoming rivers that flow back to the ocean, or Puget Sound where the cycle begins all over again. In urban areas most of the surface flows are conveyed as stormwater runoff into a stormwater or combined sewer system that discharge to Puget Sound.

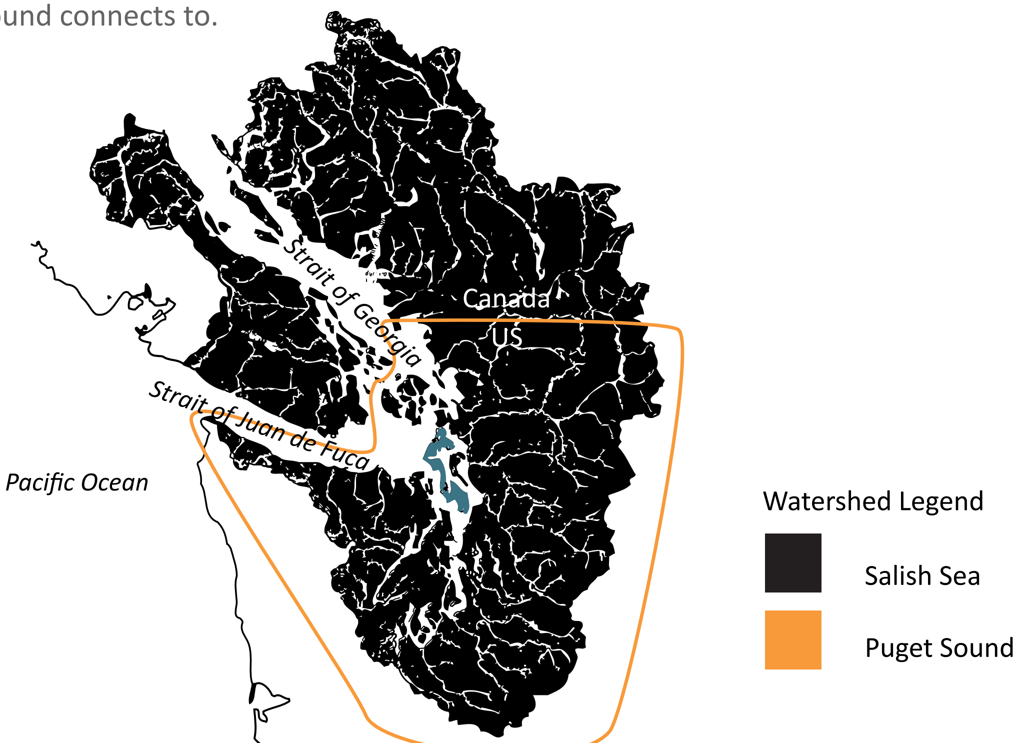
The area that drains rain to a common location is called a watershed. The Puget Sound Watershed itself is composed of 14 smalller watersheds.



The water cycle transfers and transforms water and is a critical natural process. Credit: USGS

THE PUGET SOUND WATERSHED

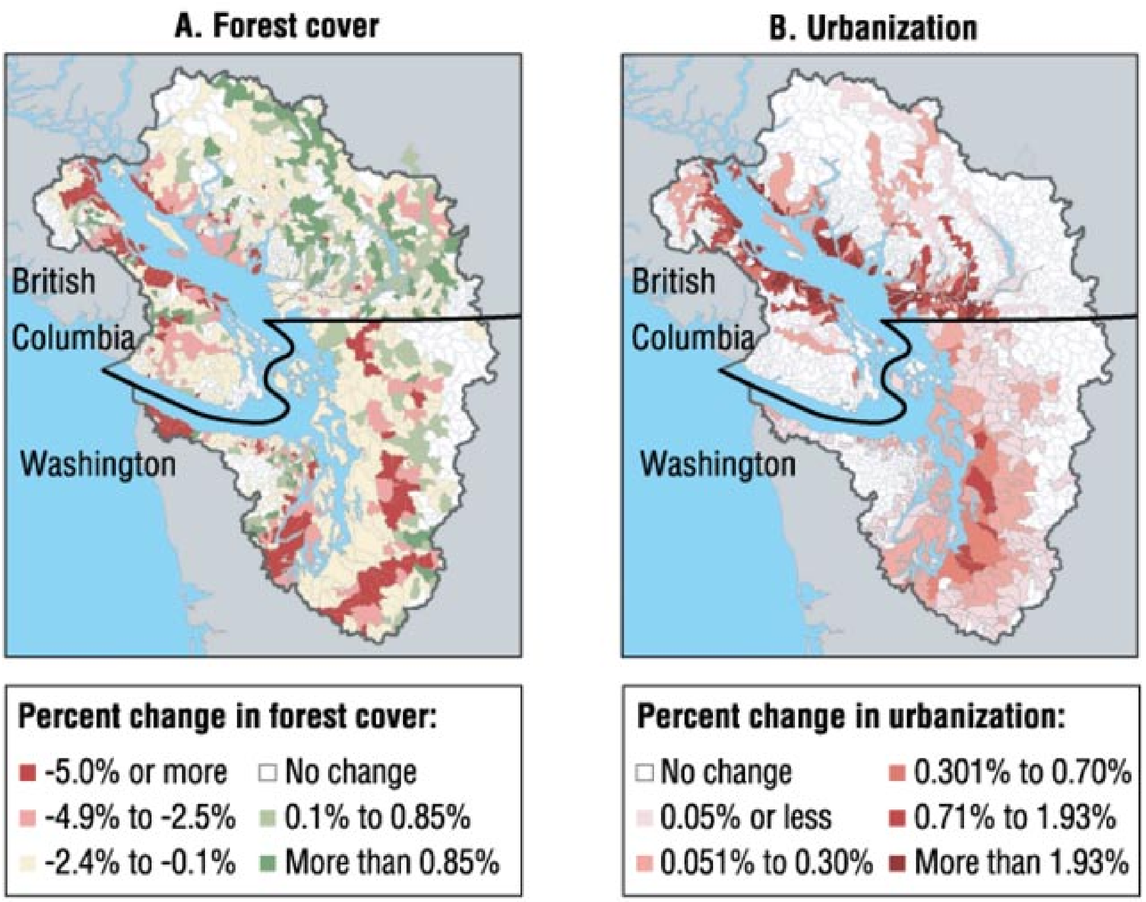
Puget Sound is a Pacific Northwest regional icon. Known as our Inland Sea, its vast beauty supports an abundance of fish and wildlife, recreational activities and stunning vistas. This fjord shaped estuary is an extensive water body that stretches beyond the Canadian-United States border to form the Salish Sea with the Strait of Georgia as the northern limit and the Strait of Juan de Fuca as the western limit. This saltwater portion covers a surface area of 7,000 square miles and connects the Seattle-Tacoma-Olympia, and the Vancouver, British Columbia urban cores to the Pacific Ocean and global communities beyond. Terrestrial freshwater inputs from rivers, lakes and wetlands are a significant factor on coastal waters. In the Salish Sea this area constitutes an additional 42,000 square miles to form a total watershed area of 49,000 square miles (Frelan 2009). The Puget Sound watershed constitutes a small portion of the Salish Sea watershed, only 2,458 square miles (Puget Sound Partnership 2011). However, the scale of the Salish Sea is a reminder of the larger system that the Puget Sound connects to.



Coastal waters, including estuaries like the Puget Sound, are highly productive ecosystems that support the vast majority of the world's species diversity. These critical ecosystems provide food, nursery grounds for juvenile fish and invertebrates, refuge from predators, and improve water quality. As a result, in Puget Sound, native marine species such as Orca whales, five species of salmon, Dahl porpoises, seals, sea otters, grey whales, seaweeds, marine birds and invertebrates flourish. These species account for 4,051 known species that take advantage of the Puget Sound's abundant resources (People for Puget Sound 2011). On a global scale, such abundance in coastal areas supports the majority of the world's catches of fish and shellfish (Mann 2000). Puget Sound is no exception, where $3.2 billion is derived from fishing and shellfish harvest annually (Puget Sound Partnership 2011). Additional economic activities are also reason to celebrate the Sound. Easy access to the Pacific Ocean has led to the establishment of major ports along its shorelines (Seattle/Tacoma is the second largest port in the US for container traffic), boat companies build pleasure and commercial boats that are sold throughout the world (Department of Ecology 2008, Puget Sound Partnership 2011) and large economic engines like Boeing, Microsoft, Adobe, Google, and Starbucks have made the Puget Sound region their home; in large part due to the high quality of life afforded through the stunning landscape. Puget Sound is a treasure cherished by those who live and work here, and admired by those who visit.

PUGET SOUND WATERFRONTS:

The Puget Sound is framed by 2,500 miles of shoreline that consist of rocky coasts, beaches, embayments and large river deltas, each having distinct ecological functions (Shipman 2008). These glacially formed land and water thresholds have been polished, rounded, flattened and broken by currents, wind and waves. Shoreline typology continues to change as wind, wave and current action continue to erode, accumulate and modify these coastal edges. Puget Sound's tidal regime consists of a mixed, semi-diurnal pattern that includes two high tides and two low tides all of unequal height that affect species distribution based on capacity to withstand certain levels of inundation (Downing 1983). Winds influence wave height and energy that is dispersed along the shoreline. This relationship drives currents and mixes nearshore waters to make temperature, salinity and dissolved pollutants more uniform in the water column, washes logs and debris ashore to form seasonal berms, and erodes and transports sediments through net shore drift (Downing 1983). The Puget Sound is fairly protected from the strong winds of the Pacific Ocean, so waves are not as high as on the outer coast, making Puget Sound a safe refuge. Fourteen major rivers convey freshwater into Puget Sound through river deltas, linking the upper watersheds to the ocean and driving surface currents. Species that live along the waterfront take advantage of the transition between the uplands and the water to access resources that both landscapes offer.



Change in land use in the Puget Sound and Georgia Basin 1992-2000. Credit: EPA

WATERSHED CHALLENGES

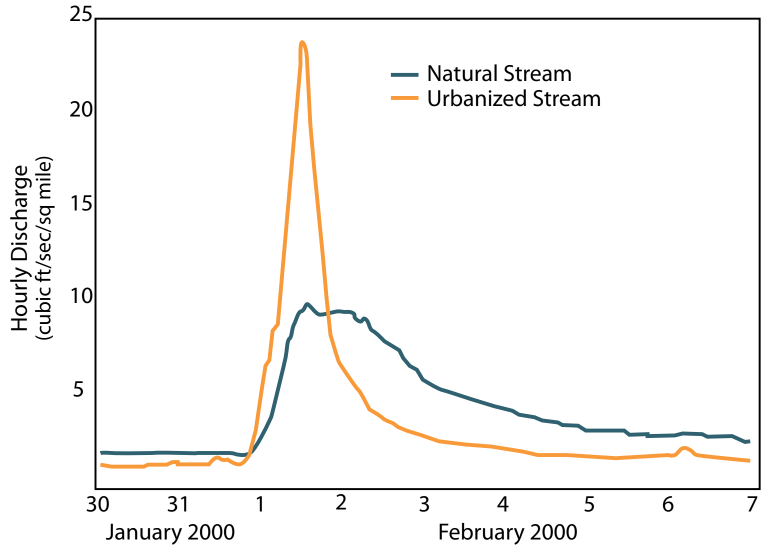
The following briefly describes the challenges Puget Sound faces with emphasis on the issue of stormwater and its source/ issues.

LAND USE

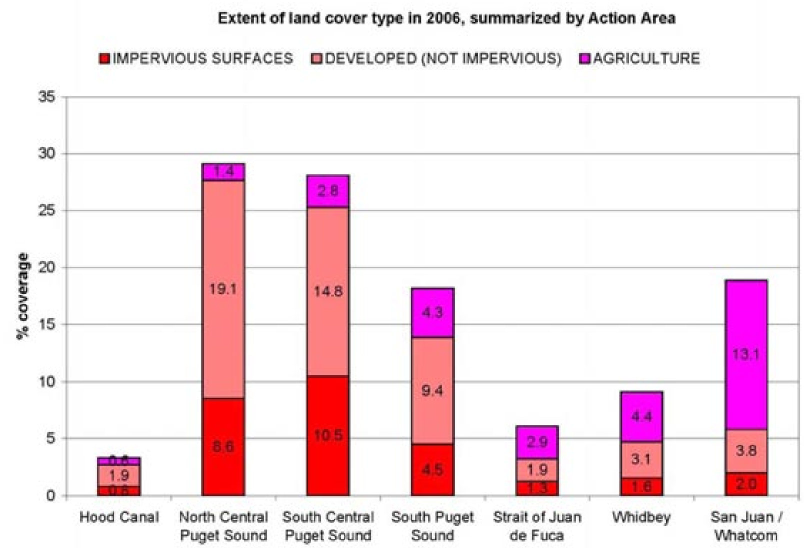
As development has increased in the Puget Sound basin, the natural rain pattern has shifted dramatically. Capped by impervious surfaces the land can no longer absorb, filter and store rainwater. Rather, these important ecological processes, and others, are replaced with buildings, lawns, parking lots and roadways that redirect stormwater into streams or storm drains and combined sewer systems that lack treatment. At a watershed scale cumulative impacts of land use change can significantly alter Puget Sound and has been listed as a factor to closely monitor (PSAT 2002, 2004).

Development has been a major factor for the conversion of Puget Sound's intertidal wetlands and for shoreline simplification. In the last 150 years there "have been dramatic losses of intertidal wetland types across much of the Basin…"(Puget Sound Partnership 2010). This has impacted habitat and the species that occupy these habitats, especially salmonids, and has disrupted the natural processes that attenuate flooding, recharge aquifers for drinking water and irrigation, filter and remove pollutants, recycle nutrients, nourish beach formation, store carbon and provide food and recreation (Puget Sound Partnership 2010). These beneficial services are greatly at risk due to the expansion of urban areas that overlook these services.

Puget Sound's shoreline length has also been reduced by 15% with many ecosystems, including fresh and intertidal wetlands and river deltas, replaced with fill for development. Bulkheads are a favored structure for waterfront development as an erosion control device that take up little space and are relatively long-lasting (Downing 1983). Unfortunately, bulkheads, riprap and other shoreline armoring devices also cut off natural shoreline processes and disrupt habitat. For instance, bulkheads



Hydroperiod heightens and increases with urbanization and impervious surface cover. Credit: Horner 2010



Impervious surface cover in the Puget Sound Basin. Credit: Puget Sound Partnership 2010

prevent natural shoreline erosion that replenishes sediments to beaches through long-shore drift. Vertical walls and large rocks used for riprap sharply grade the shoreline and are not productive habitat spaces for plants or wildlife. Furthermore, bulkheads along Lake Washington reflect wave energy back that causes erosion of nearshore sediments that lead to deeper water over time and threaten species that require shallow nearshore habitat for life stages (City of Seattle 2011).

IMPERVIOUS SURFACES

One of the reasons land use is such an issue is that changes in land use are often paired with an increase in impervious surfaces. Impervious surfaces are solid surfaces that prevent the passage of water into subsurface soils. Impervious surface cover is typically used to describe the conversion of natural landscapes into built surfaces. These hard surfaces replace native vegetation and soils that naturally intercept, absorb, filter and store rainwater with impenetrable asphalt or concrete. Instead, rain runs off these surfaces, often at high velocities and is directed away from urban areas into streams or storm drains and combined sewer systems. The rapidity of runoff is reflected by a heightened and accelerated hydroperiod– a stream's pattern of discharge over time that portrays flow timing and volume.

Research shows that as little as 8-10% impervious surface cover causes ecological degradation of streams, increase water temperatures, decrease aquatic biota diversity, and reduce overall water quality (Booth and Reinelt 1993, May et al 1997). Greater than 50% impervious surfaces requires conveyance mechanisms like underground pipes, channels, or other hard infrastructure (Center for Watershed Protection 2000). Between 2001 and 2006, impervious surfaces increased throughout the Puger Sound watershed by 3% bringing Central Puget Sound within the 8-10% range (Puget Sound Partnership 2010).

STORMWATER POLLUTANTS

When stormwater washes off impervious surfaces pollutants are washed along with the rain and ultimately into regional water bodies without treatment. Stormwater pollutants

URBAN

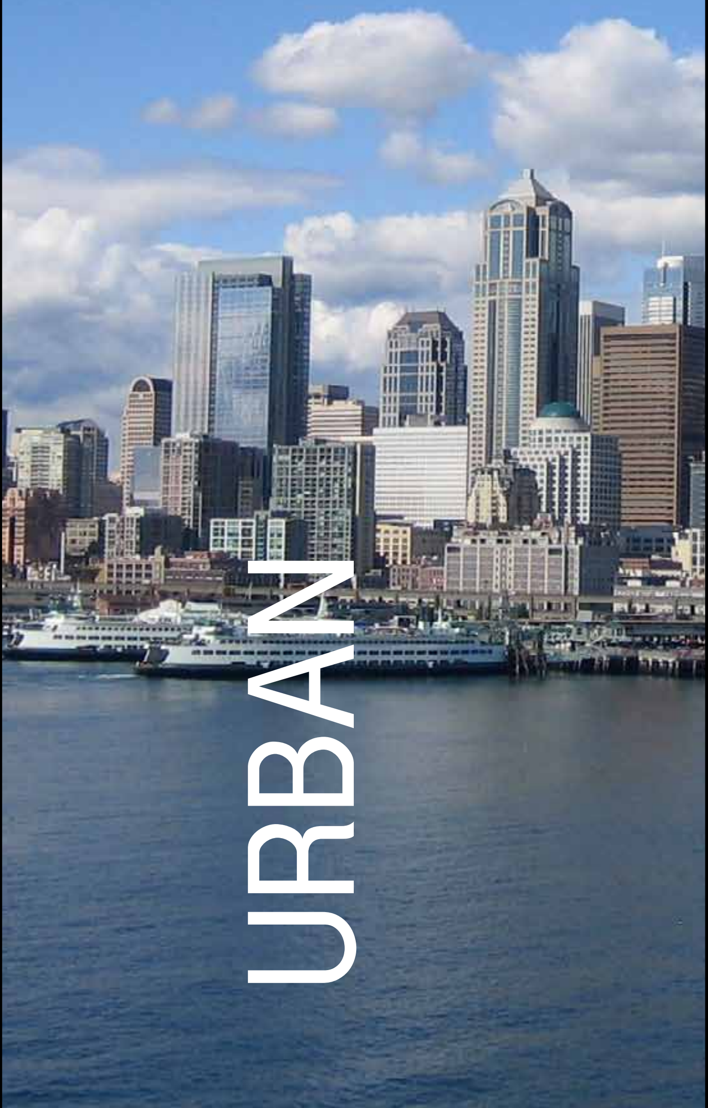
FACTS:

Average Impervious Surface: 90%

Pollutants: oil and grease, nutrients, pathogens, heavy metals, hydrocarbons, toxins

Public Access: Low

Habitat: Low



ROADS

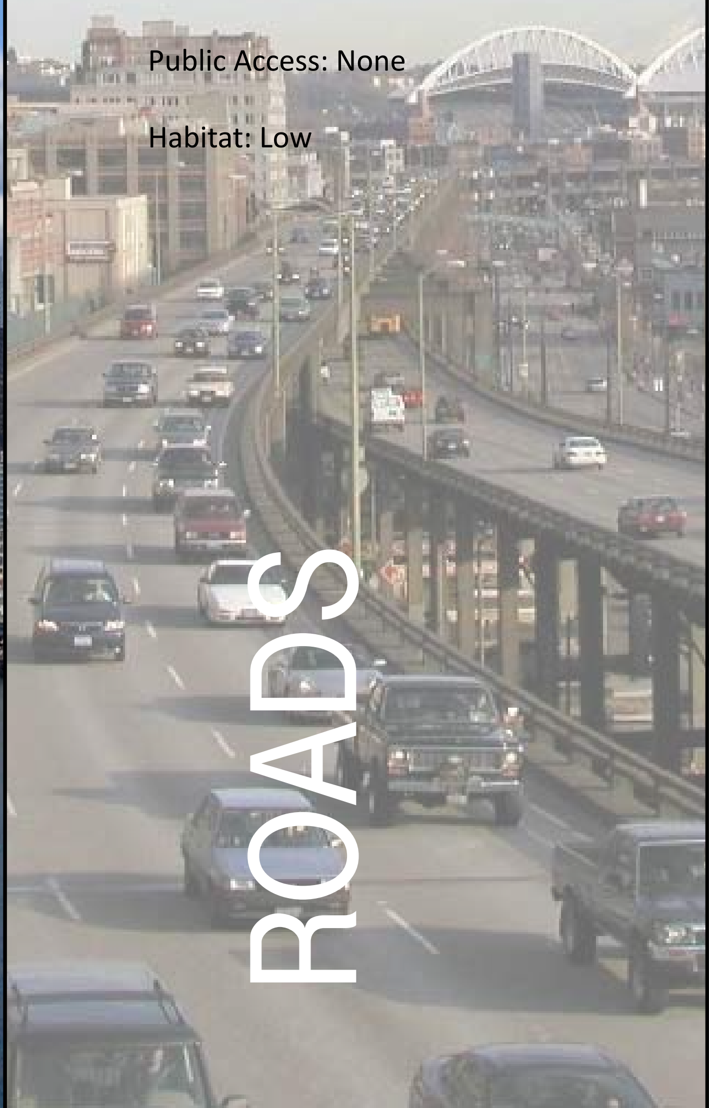
FACTS:

Average Impervious Surface:
Urban: 92%
Suburban: 96%
Rural: 47%
Highway: 50%
Puget Sound Cover:

Pollutants: heavy metals, oil and grease, hydrocarbons

Public Access: None

Habitat: Low



INDUSTRIAL

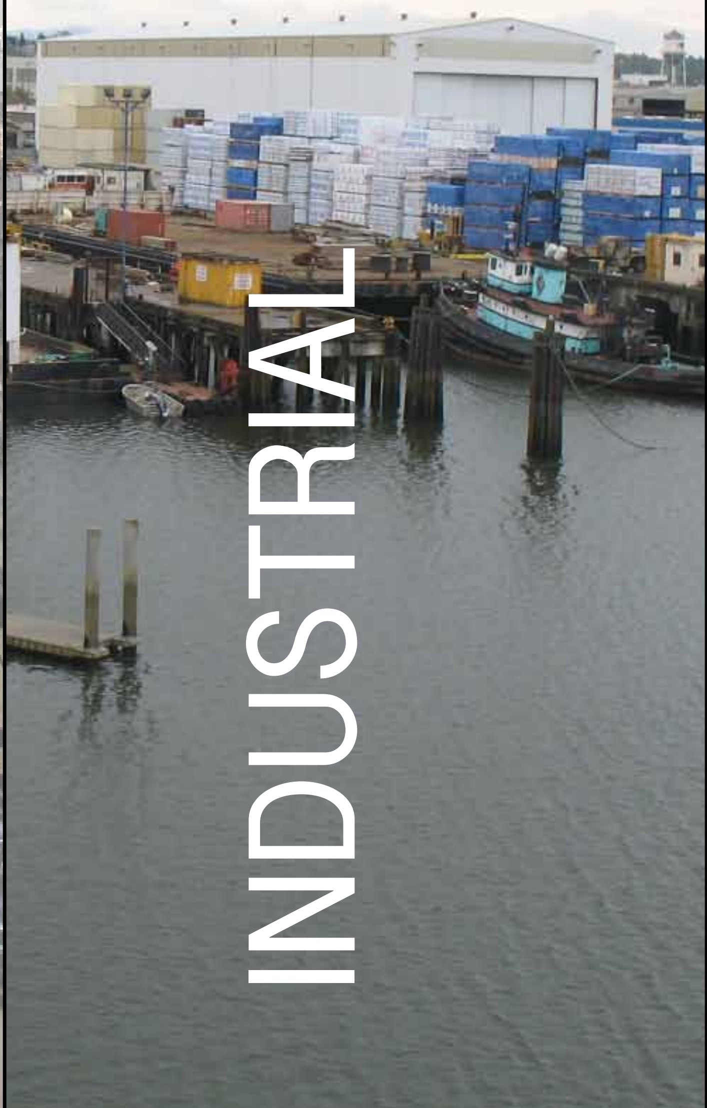
FACTS:

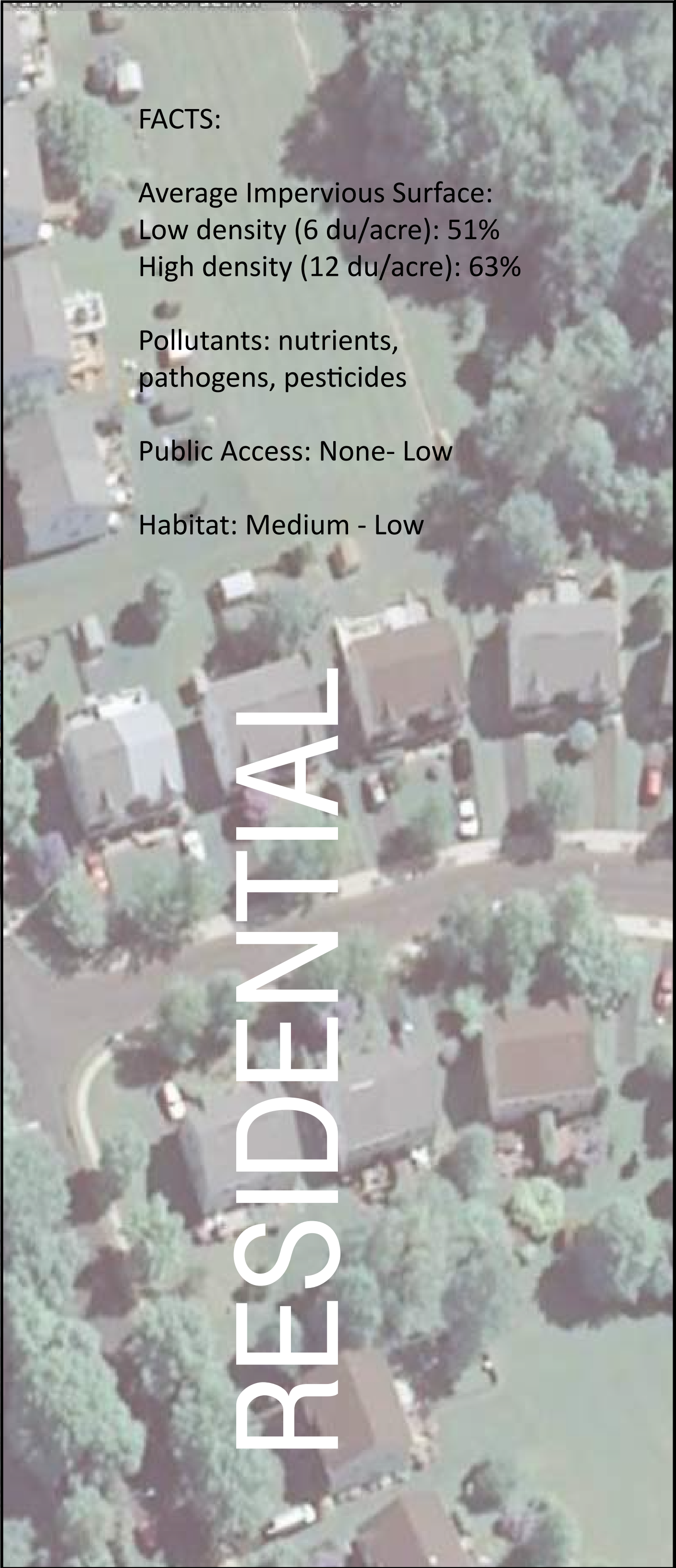
Average Impervious Surface: 80-90%

Pollutants: heavy metals, oil and grease, toxins, hydrocarbons, nutrients

Public Access: None - Low

Habitat: Low





RESIDENTIAL

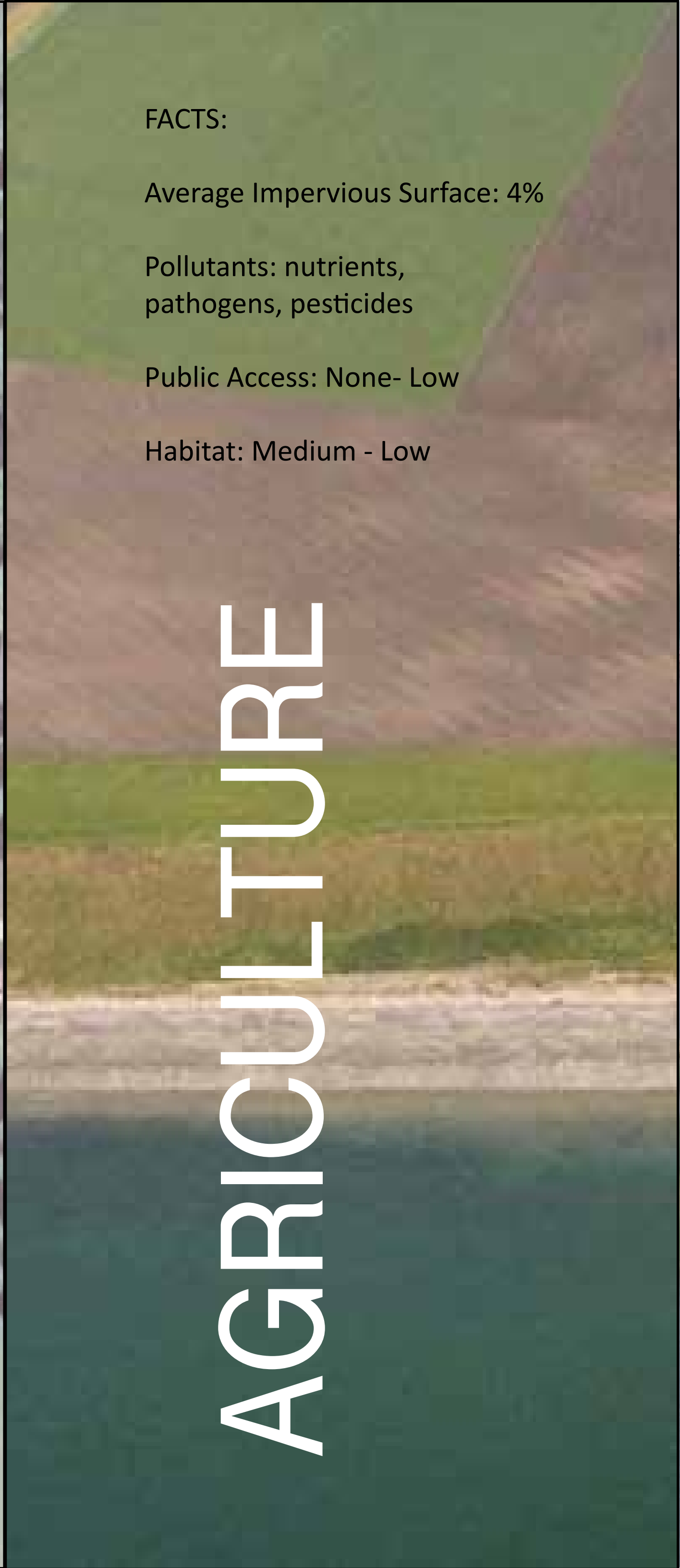
FACTS:

Average Impervious Surface:
Low density (6 du/acre): 51%
High density (12 du/acre): 63%

Pollutants: nutrients, pathogens, pesticides

Public Access: None- Low

Habitat: Medium - Low



AGRICULTURE

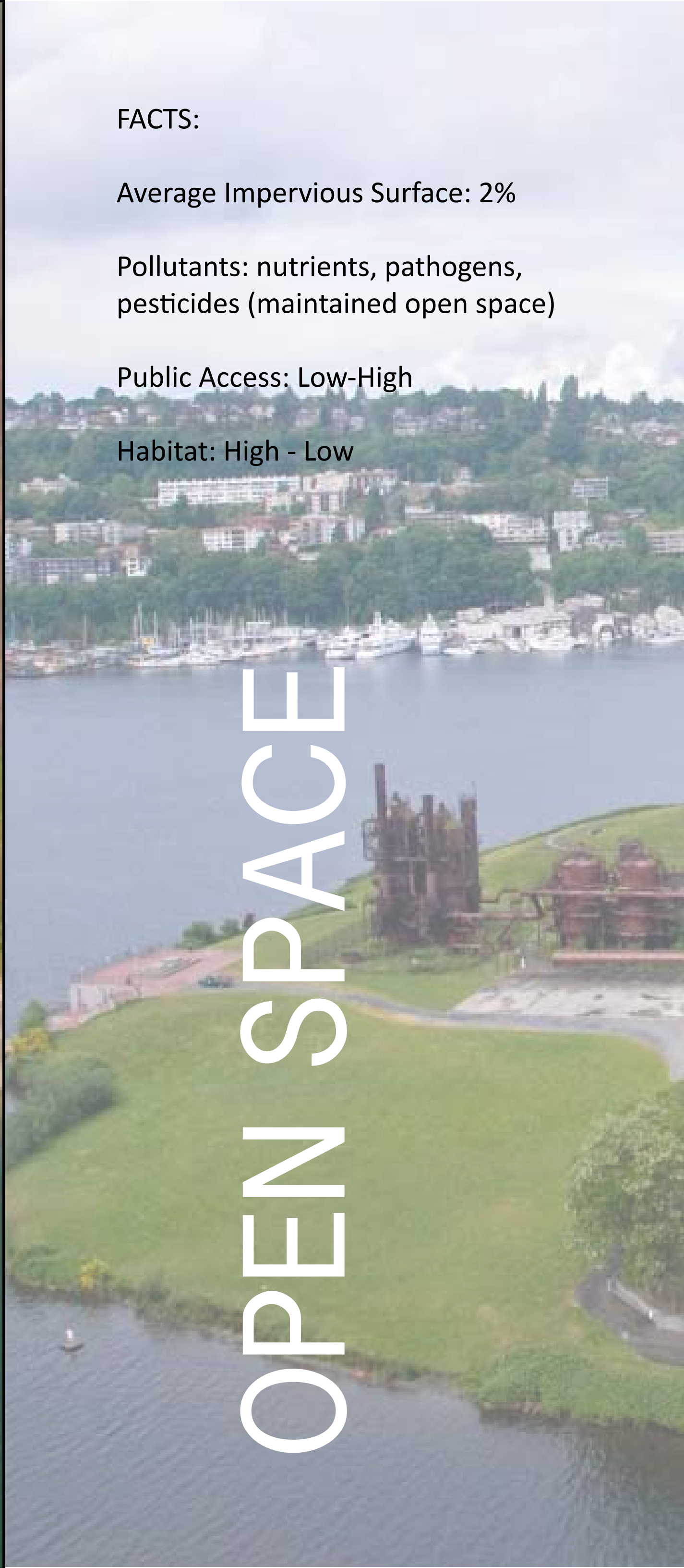
FACTS:

Average Impervious Surface: 4%

Pollutants: nutrients, pathogens, pesticides

Public Access: None- Low

Habitat: Medium - Low



OPEN SPACE

FACTS:

Average Impervious Surface: 2%

Pollutants: nutrients, pathogens, pesticides (maintained open space)

Public Access: Low-High

Habitat: High - Low

Puget Sound chemicals of concern. Credit: Puget Sound Partnership 2007

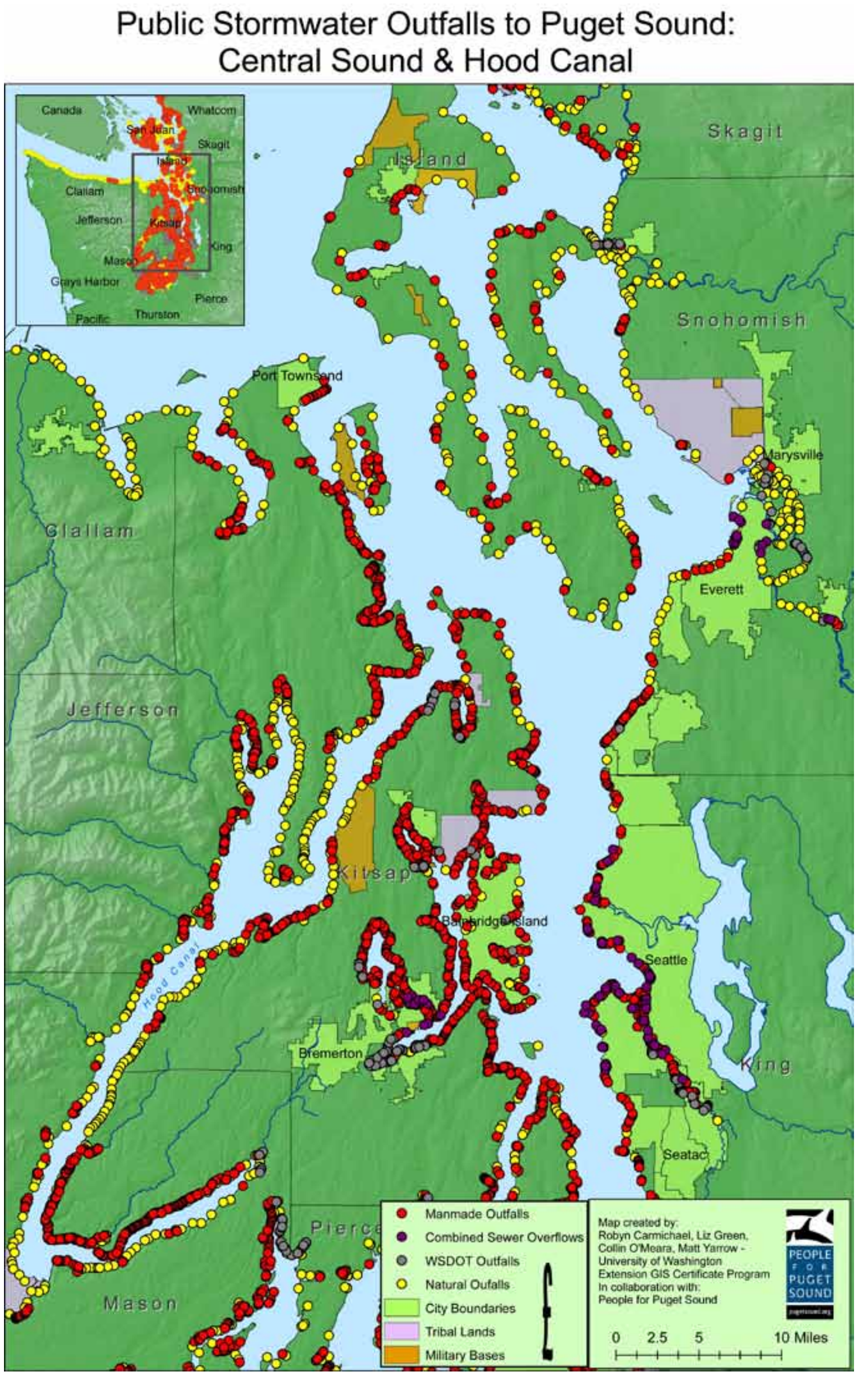
Metals (and organometals)	Organic compounds
Arsenic	Polychlorinated biphenyls (PCBs)
Cadmium	Polycyclic aromatic hydrocarbons (PAHs)
Copper	Pesticides
Lead	Dioxins and furans
Mercury	Phthalate esters
Tributyl tin	Polybrominated diphenyl ethers (PBDEs)
	Hormone-disrupting chemicals – including bisphenol A, nonylphenol, 17b-estradiol, and ethynylestradiol

can generally be divided into six categories: sediments, heavy metals, nutrients, organics, pathogens, and endocrine disruptors. The above table lists the stormwater pollutants that the Puget Sound Partnership has identified as concerns for Puget Sound. Most of the identified pollutants of concern are carcinogenic, persistent and derived through everyday, human actions. For instance, PCBs were banned in 1970, but are still prevalent in marine sediments and are even still found in stormwater discharges into the Duwamish River. The Environmental Protection Agency (EPA) has made significant efforts to reduce human exposure to these toxins by banning their use or manufacture. However, their persistence and ability to amplify up the food chain prohibits immediate eradication from the environment. In addition, some of the pollutants are byproducts of other activities that are difficult to identify. For instance, pharmaceuticals of unknown origin are appearing in stormwater. Eradicating certain pollutants from the environment is also an issue of scale. Zinc is derived from galvanized steel that is used for roof downspouts, highway signs, car and bus bodies and electrical towers. When the number of roof downspouts is calculated in one town, city, state, country, and beyond, the significance of the source problem is revealed. Until we develop new materials, efforts will have to focus on treatment. Lastly, an emerging field of research is working to better understand how different stormwater pollutants react with each other and with climate change to determine their impact on aquatic life and humans.

The most common and problematic pollutants arise from everyday activities such as cars, lawn fertilizers and pesticides, pets, and industry. Research demonstrates that once these pollutants reach Puget Sound, substantial impacts on aquatic wildlife occur at all levels of the food chain. Endangered species such as salmon are particularly affected by dissolved metals at concentrations as low as 1%, which can cause tumors, alter spawning and migration patterns, and be lethal (PSAT 2005). Stormwater runoff also contaminates shellfish beds, causing harvest restrictions on beaches throughout the Puget Sound and impacting Washington's commercial shellfish industry, which is the largest on the west coast (PSAT 2003). Resident Orca whales were recently placed on the Endangered Species list due to decreases in population resulting from high infant mortality that is correlated to exposure to high levels of toxins, like legacy pollutant polychlorinated byphenyl (PCBs).

The extent of water pollution in Puget Sound is significant. 150,000 pounds of toxins per day are conveyed into Puget Sound without treatment (Gregoire 2009). Stormwater is the linking transport mechanism that washes these contaminants from impervious surfaces into drainage systems where they accumulate to toxic levels. People for Puget Sound recently documented 6,700 separated stormwater outfalls lining Puget Sound that lack treatment prior to discharge, thus creating "the most important water quality problem in the Puget Sound Basin" (People for Puget Sound 2009). There is an urgent need to find ways to efficiently and effectively treat the most polluted water that is entering Puget Sound.

Waterfronts are particularly affected by stormwater pollution largely due to the location of stormwater outfalls along



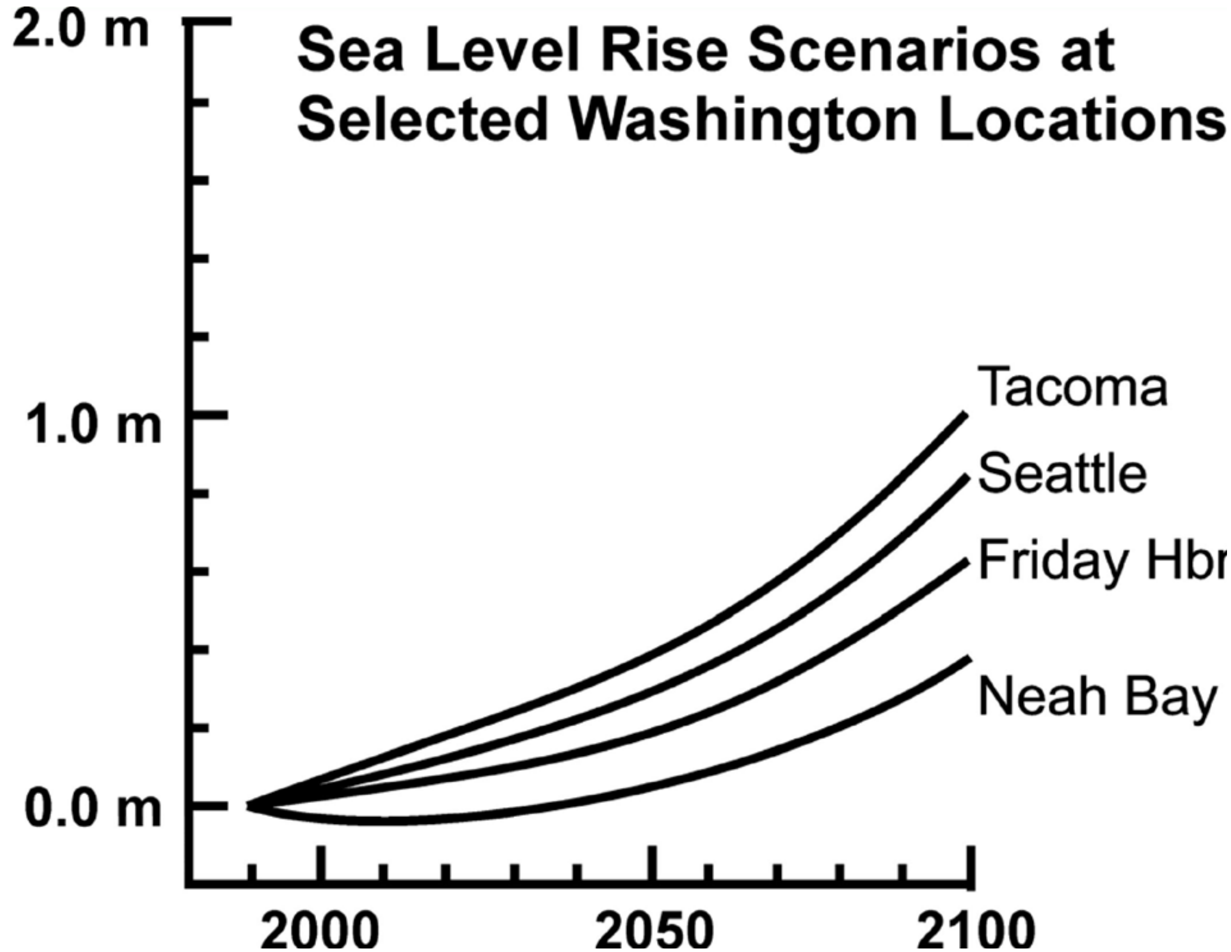
Documented stormwater outfalls on Puget Sound. Credit: People for Puget Sound

the water's edge. Pollutants collect and contaminate the surrounding sediments and water column. Many pollutants adhere to particles and sink to the bottom where they contaminate the sediments while others remain suspended in the water column. Consumption of these particles by bottom feeders, microorganisms, or plankton allows the toxins to move up the food chain and spread to the larger basin (Puget Sound Partnership 2010). An increase in temperature, induced by climate change, may make stormwater pollutants more volatile, which will allow them to spread more easily, and become more toxic. Heavy metals are especially of concern since they become more toxic as temperature increases (Lovett 2010).

CLIMATE CHANGE & SEA LEVEL RISE

For the Puget Sound region, climate change models predict an overall temperature increase that will cause warmer, wetter winters and warmer, drier summers. The hydrologic impacts of this temperature rise include: increased winter precipitation in the form of rain, not snow, thus a reduction in winter snowpack that is a critical reservoir for the region's drinking water; increased winter streamflow and flood risks; earlier snowmelt with earlier peak runoff; and low stream flows during the summer that may cause conflict between municipal water demands and aquatic species (Climate Impacts Group 2004). Ocean warming is also a predicted outcome that will reduce mixing, increase temperatures that are harmful to aquatic species and contribute to sea level rise. Furthermore, absorption of carbon dioxide into Puget Sound is causing acidification that affects the base of the aquatic food chain (phytoplankton), in addition to shellfish (oyster, crabs, mussels, etc) (NOAA 2010). This is of great concern for all species since the base of the food chain is at risk, not to mention the potential collapse of Puget Sound's shellfish industry.

Sea level rise is also a significant impact of climate change. Over the next century, the Intergovernmental Panel on Climate Change (IPCC) projects that global sea levels will rise between 7-15" in a low emissions scenario, or between 10-23" for a high-emission scenario (IPCC 2007). The University of Washington's Climate Impacts Group (CIG) estimate that local factors within Puget Sound will produce sea level rise that closely matches global patterns and will fall within the range of 6-13" (Mote et al 2008). However, the CIG recommends that any long-term, low risk project such as development or public infrastructure should consider higher sea levels of 22" by 2050 and 50" by 2100 due to the melting of global ice (Greenland and Antarctic ice masses), seasonal variability in winds that may drive water towards shore, and vertical land movement (land is subsiding in south Puget sound and rising on the Olympic Peninsula) (Mote et al 2008).



Sea level rise scenarios for Puget Sound and Coastal locations. Source: Wa Dept of Ecology

As these pages have described, the impact of land use, impervious surfaces, stormwater pollutants and climate change are critical threats on a multitude of levels, but especially to the livability of our urban areas. Considering that a majority of the population is concentrated along waterfronts, developing solutions to these issues becomes all the more pressing. The intent of this project, Waterfront Stormwater Solutions, is to develop and inspire new design approaches to waterfronts that address stormwater issues while also incorporating a variety of unique amenities that support wildlife and serve the public, ultimately creating spaces and cities that are lively, functional and delightful.

New Forms of Treatment Mimicking Natural Systems

Green Shorelines | LID

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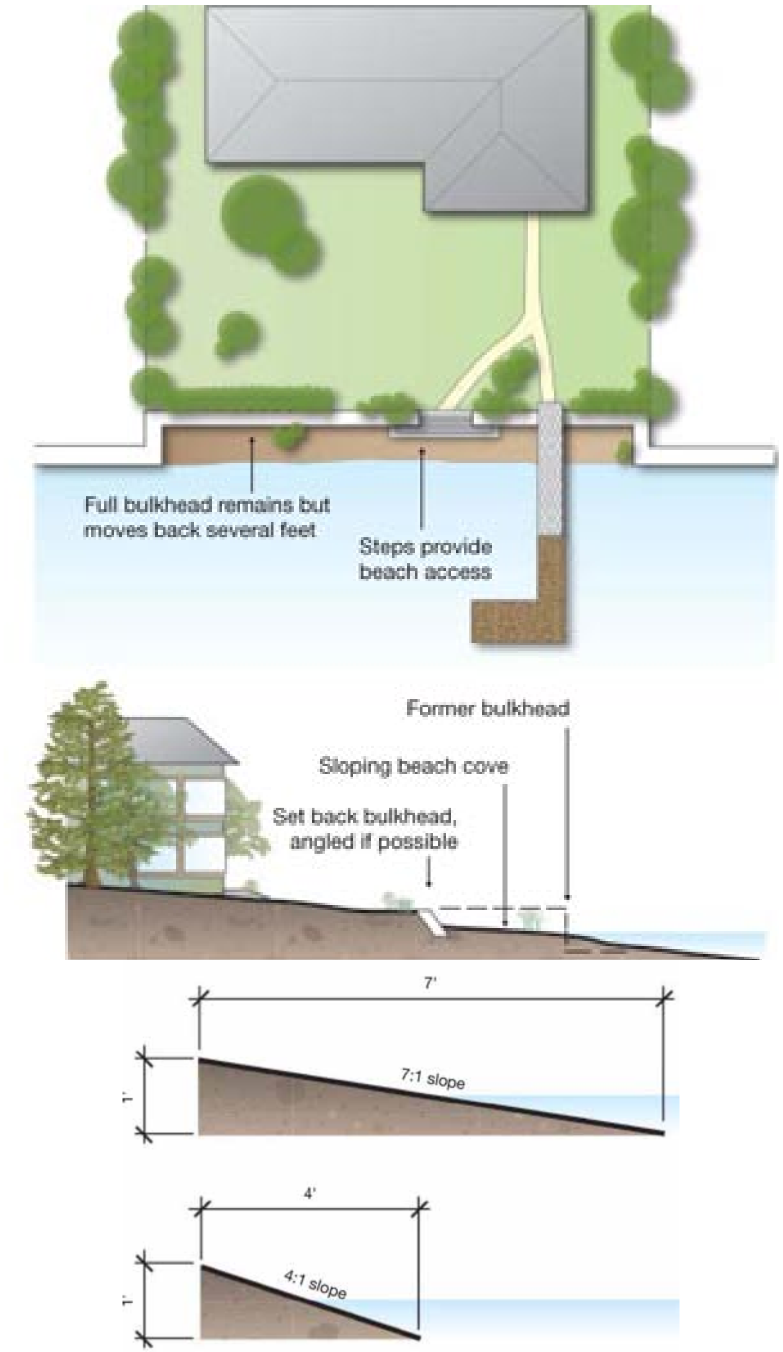
GREEN SHORELINES

A partnership between the City of Seattle, King County and Washington State Department of Ecology developed a guidebook for waterfront homeowners that encourages homeowners to reduce shoreline armoring and establish natural waterfront features that better support ecological systems and creates attractive spaces. The Green Shorelines Guide provides information about how bulkheads can be removed or pulled back to allow the creation of beaches and coves. The guide also recommends ways to prevent erosion using logs and vegetation to stabilize slopes and deflect wave energy. Plants are also strongly suggested to filter rainwater runoff from residential surfaces that are often high in fertilizers, pesticides, oil, gasoline, and pet wastes. Plants along the shore's edge provide shade and food over shallow water that is necessary for fish and birds. Each of the recommendations suggests that through ecologically sensitive shoreline design more attractive settings can be established for the social and personal enjoyment of the homeowner while also allowing the waterfront ecosystem to flourish. This is particularly valuable since 90% or 2,250 miles of Puget Sound's shoreline is in private ownership. Through cumulative efforts and participation of private landowners, the waterfront ecosystem can become a productive and attractive landscape.



Green Shorelines recommendations for bulkhead removal and shoreline design for ecological processes and aesthetics. Credit: City of Seattle

LOW IMPACT DEVELOPMENT

In the 1980s, Prince George's County, Maryland, recognized that conventional stormwater systems failed to treat stormwater quality. They developed an alternative method that mimics natural processes of pre-development sites. Known as Low Impact Development (LID), these techniques utilize the biologic, chemical and physical properties of soils and plants to filter, infiltrate, and store stormwater runoff. In this sense the natural hydrologic regime is restored and water is treated at the source, as opposed to being quickly conveyed off site. LID also incorporates habitat and aesthetics; both are important additions to stormwater treatment.

LID Goals:

- Incorporate hydrologic planning at the beginning of site design

- Protect and retain native soil and vegetation

- Reduce coverage of impervious surfaces

- Maintain hydrologic regime: Promote evapotranspiration and infiltration on-site

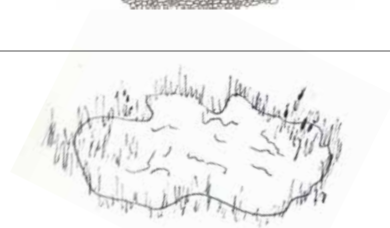
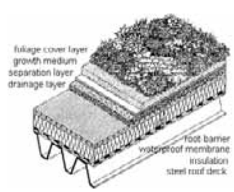
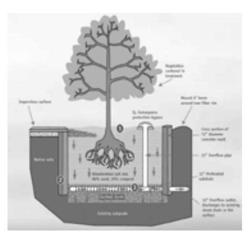
- Prevent damage to streams, lakes, wetlands and other natural aquatic systems

In 2005, the Washington State University, in partnership with the Puget Sound Action Team (PSAT) (now Puget Sound Partnership), published a technical guidebook to help landowners, developers, planners, designers and students design and implement LID projects in the Pacific Northwest. This important document is currently being updated with new findings from pilot LID projects that have been built in the years following the first volume. Today, LID has been implemented in numerous projects in the Puget Sound area, demonstrating the functional and aesthetic benefits of this more distributed and naturalistic approach. This number is slated to grow in the near future as the Washington State Department of Ecology is in the process of updating its Stormwater Manual, which mandates new development to reduce stormwater runoff to match predevelopment conditions by applying LID Best Management Practices (BMPs).

Summary of LID Treatment Mechanisms

BMPs include structural and non-structural systems to manage stormwater. Structural BMPs are built systems that control stormwater quantity or quality whereas non-structural BMPs are preventative systems such as education or pollutant source control. Landscape design typically focuses on structural BMPs to capture any pollutants that end up in stormwater despite source control efforts, with the goal of educating the public about stormwater pollution through design. Structural BMPs are the focus of the following discussion.

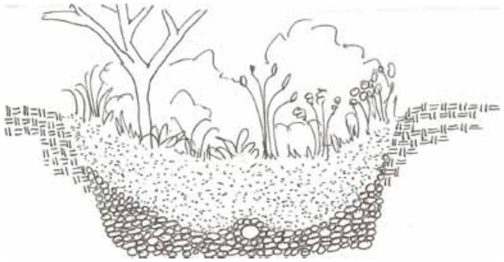
There are several proven LID BMPs that have been designed and tested in a number of locations with variable site and climate conditions. This document focuses on the treatment systems that specifically improve water quality.

Treatment Type	Image	Purpose	Performance
Bioretention		Increase vegetation, add multiple canopies, filter and settle pollutants and sediments, utilize infiltration and evapotranspiration processes. Visually appealing.	Total suspended solids, heavy metals, petroleum hydrocarbons, nitrogen
Constructed Wetland		Sediments drop out, pollutant breakdown by microorganisms and biochemical processes, supports habitat	Total suspended solids, heavy metals, may contribute nutrients through plant material
Subsurface Wetland		Built in areas with limited spaces. Filters water through dense roots, and aggregate underground. Are constantly saturated and do not infiltrate. Typically used for wastewater treatment	Total suspended solids, heavy metals, petroleum hydrocarbons, nutrients- plant material may contribute nutrients
Porous Asphalt/ Permeable Pavement		Replaces impervious surfaces, allows for direct infiltration	Total suspended solids, heavy metals, petroleum hydrocarbons
Green Roof		Reduce roof runoff, work where other BMPs cannot fit, contibute to other sustainability goals	Atmospheric compounds, reduces pH, removes nitrates; media may be source of heavy metals and phosphorus
Tree Well		Work in constrained spaces, combine street trees and bioretention system	Total suspended solids, heavy metals, petroleum hydrocarbons, nutrients

BIORETENTION AREAS|RAIN GARDENS

These vegetated depressions or raingardens were the original LID treatment mechanism (PSAT 2005). They expand upon vegetated (grass) swale systems often used along roadsides in earlier stormwater management practices. Bioretention processes promote the chemical, physical and biological properties that more effectively treat stormwater, and that underlie more recent forms of LID BMPs. Bioretention areas are typically shallow depressions that contain a soil mix designed to infiltrate stormwater at a certain rate in order to filter out pollutants, and plants that are adapted to the local climate and fluctuating water levels. Plants are an important component as they play multiple roles. Plants intercept rainwater on their leaves and branches that reduce overall stormwater volume, filter pollutants structurally and through absorption, provide visual interest through flowers, color and growth patterns, and create habitat. Together, the soils and plants mimic predevelopment conditions that support a more natural hydrologic regime.

Performance: Pollutant removal by bioretention systems include total suspended solids, petroleum hydrocarbons, nitrogen and heavy metals (University of New Hampshire 2009).

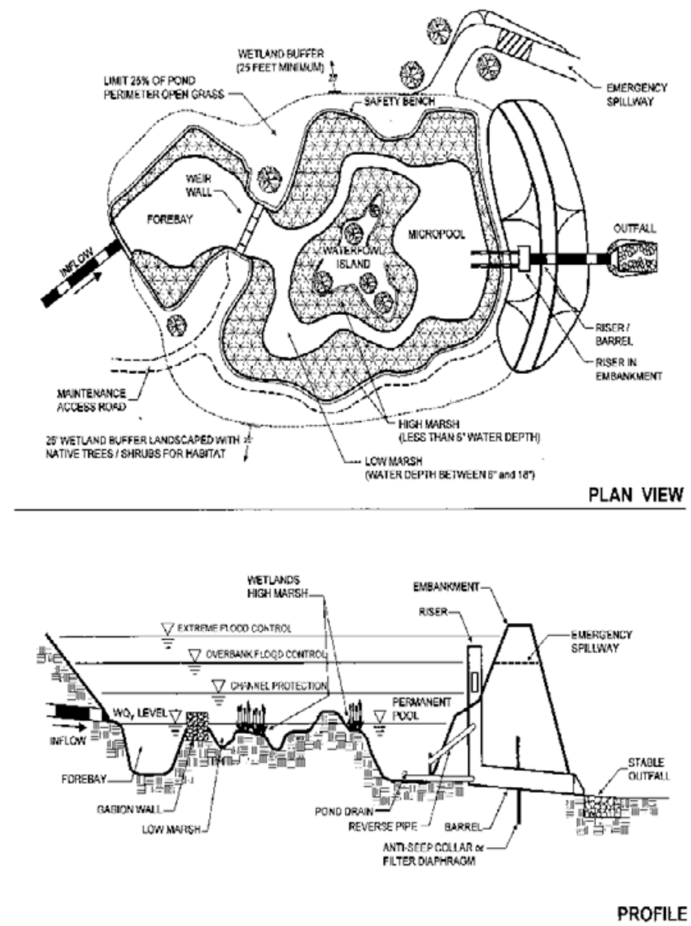


Clockwise: Functioning bioretention swale at High Point, Street side raingardens in Portland, Oregon, Cross-section of bioretention area, Weirs control runoff in Seattle's SEA streets bioretention swales. Credits: SvR Design, www.oregonlive.com, Brad Lancaster

CONSTRUCTED WETLANDS

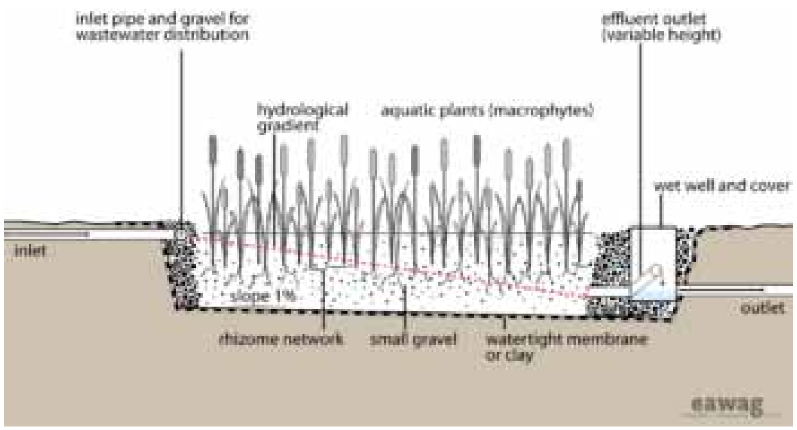
Mimicking the natural processes associated with natural wetlands, constructed wetlands are used to slow, store and filter stormwater. They also provide visual interest, educational opportunities, and support habitat for waterfowl and amphibians. When used singularly, they require large spaces to manage stormwater volumes (Figure 8). A sediment forebay is necessary to settle out sediments and prevent clogging or sedimentation that would require dredging of the wetland- a maintenance task that might cause the pollutants to be re-suspended, or could disrupt habitat.

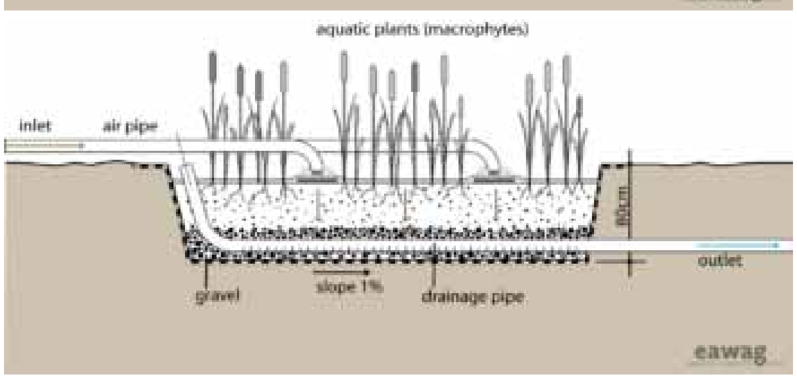
Performance: Pollutants that are removed from constructed wetlands include: sediments, heavy metals, and nutrients. Challenges associated with constructed wetlands include undesirable smells associated with anaerobic decomposition of organic matter; open water bodies are ideal habitat for mosquitoes and are potential drowning risks; and establishing a hydraulic regime may be problematic.



Top: Constructed wetlands require a forebay to settle sediments, plants that can tolerate certain levels of inundation and shallow slopes. Other features such as overflow and liners will depend on site conditions. Credit: Stormwater Center

Left: Constructed stormwater wetland slows and filters stormwater runoff and provides habitat and walking trails. Credit: Leslie Batten





SUBSURFACE WETLANDS (SSW)

Originating from tertiary wastewater treatment mechanisms, subsurface wetlands treat water below ground through a layer of gravel planted with facultative plant species that can also withstand episodes of drought during the summer. SSW require less space than constructed wetlands and can be used in heavily urbanized areas (Alberson 2011). Much like wetland systems, this treatment mechanism relies on the biological, chemical and physical properties of the soil media, plant roots and microorganisms to filter and remove pollutants. They are favored in areas where open water might not be desirable, since water is treated below ground which reduces safety concerns, the potential for smells, and insect vectors like mosquitoes (Figure 9). The treatment process is as follows. Stormwater first enters a forebay where sediments and particulates are settled. Forebays prevent clogging that prolongs the lifespan of the system and are a required component of SSW. Next, water moves either vertically, or horizontally into and through the subsurface wetland. Horizontal flow is typically preferred to reduce clogging and channelization that reduces filtration capacity that can be caused in down-flow or up-flow vertical systems (Alberson 2011). Plants physically filter out sediments and fine particulates and absorb macro- and micronutrients. Soil microbes transform nutrients like phosphorus under aerobic conditions, and nitrogen under anaerobic conditions into usable form for plant uptake. The soil media adsorb pollutants and control the flow rate. Studies indicate that when the SSW soil media contains materials that are highly porous and have large sorption capacity, such as expanded shale, the SSW functions are enhanced and can help decrease the size of the SSW (Alberson 2011).

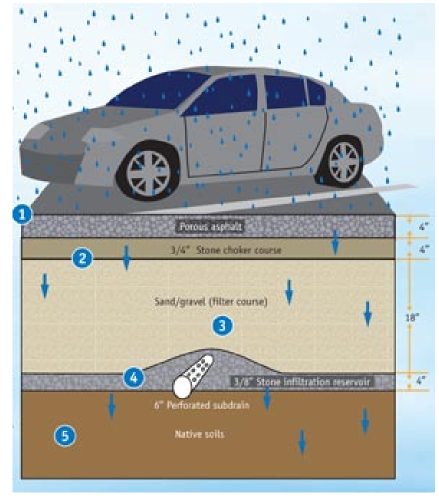
Performance: Sub-surface wetlands have been proven to remove total suspended solids, heavy metals, nutrients, and petroleum hydrocarbons (University of New Hampshire 2008).

Subsurface wetlands treat stormwater underground through the soil media and plant roots. Credit: University of New Hampshire Stormwater Center; Sandec/eawag http://www.akvo.org/wiki/index.php/Vertical_Flow_Constructed_Wetland

PERMEABLE PAVEMENTS & POROUS ASPHALT

Instead of capping soils with impenetrable materials, a permeable surface of concrete or asphalt is utilized for areas where hard surfaces are necessary (roads, highways, parking lots, sidewalks, etc). These surfaces are built with larger void spaces that allow rainwater to infiltrate into special substrates or native soils and recharge groundwater instead of pooling and quickly discharging from paved surfaces. Particulates are filtered out of the stormwater and are trapped in the voids, adhere to soil particles or are degraded by microbial organisms. This feature must be actively maintained through vacuuming to prevent clogging of the voids that would prohibit infiltration and particulate trapping.

Performance: Permeable surfaces have demonstrated strong capacity to remove pollutants including total suspended solids, petroleum hydrocarbons, copper, lead, and zinc (University of New Hampshire 2009).



Porous asphalt filters out pollutants through infiltration and sorbtion. Credit: UNHSC

TREE WELLS

Tree wells are closely related to bioretention areas. They are typically specialized street tree inserts that include specific soil mixes that promote infiltration and pollutant adsorption, and a curb cut that serves as the inlet for roadway stormwater runoff. An underdrain and outlet might also be included to allow appropriate drainage. Since roads carry the highest pollutant concentration, intercepting runoff is highly beneficial for receiving water bodies.

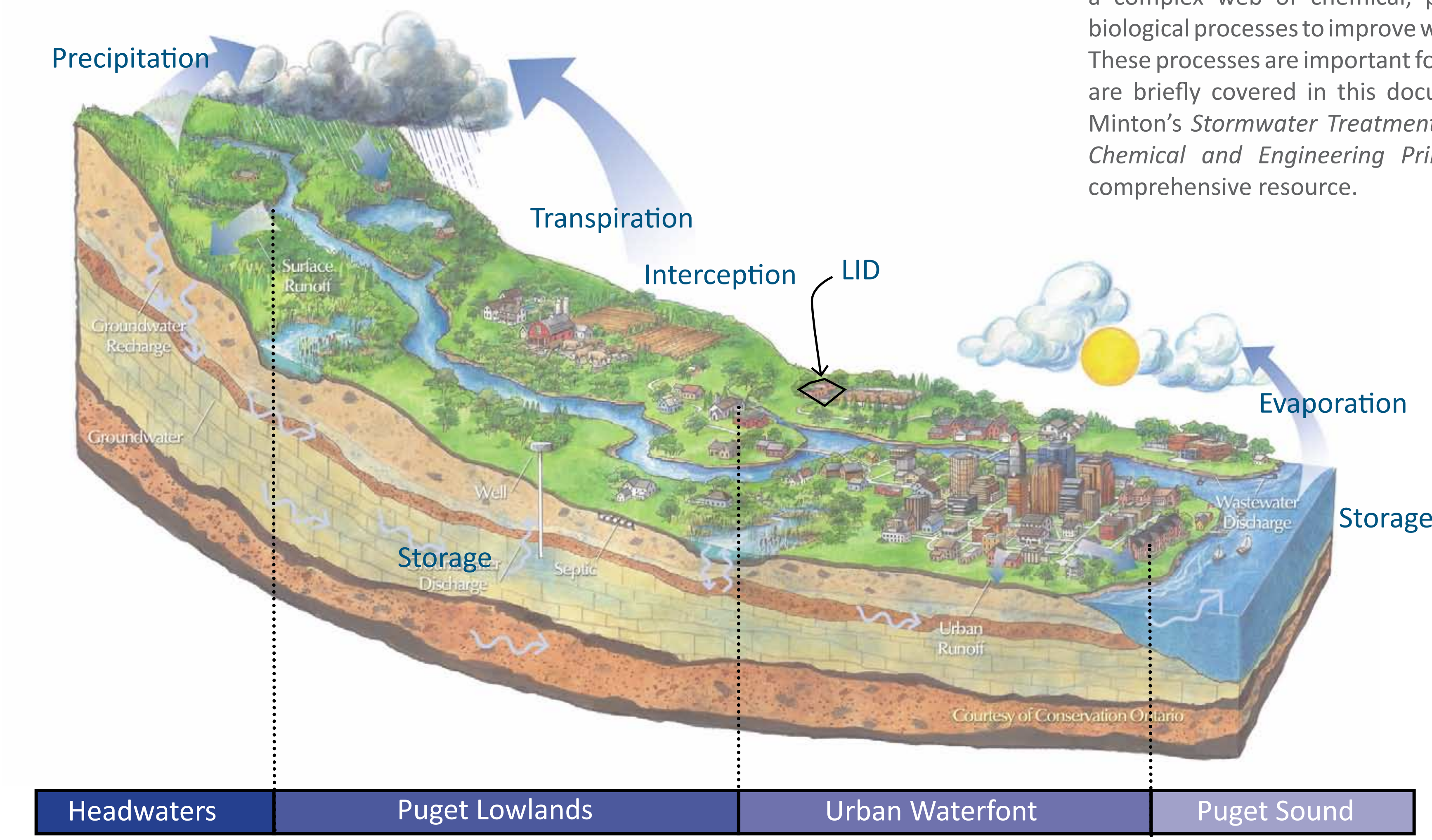
Performance: Tree wells utilize bioretention principles and have proven effective at reducing total suspended solids, petroleum products, total phosphorus, total nitrogen and zinc (University of New Hampshire 2009)

Tree wells function like smaller scale bioretention swales to treat stormwater. Credit: City of Wellington

LID PROCESSES

Within the watershed LID strives to replicate natural watershed processes on a site-scale basis- addressing water on-site to reduce runoff.

The greatest benefit of LID systems is the promotion of natural processes to achieve the desired water quality outcomes. When carefully designed these systems combine a complex web of chemical, physical and biological processes to improve water quality. These processes are important for design and are briefly covered in this document. Gary Minton's *Stormwater Treatment, Biological, Chemical and Engineering Principles* is a comprehensive resource.



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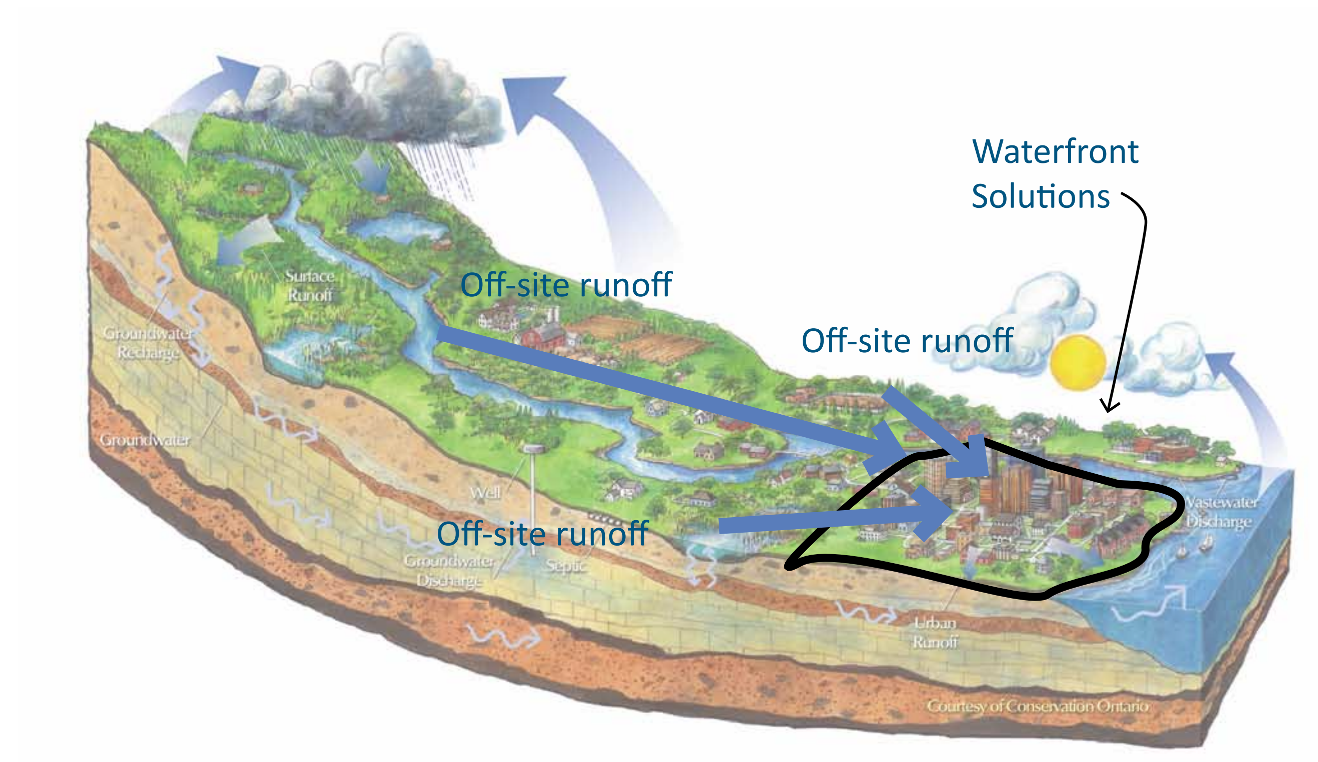
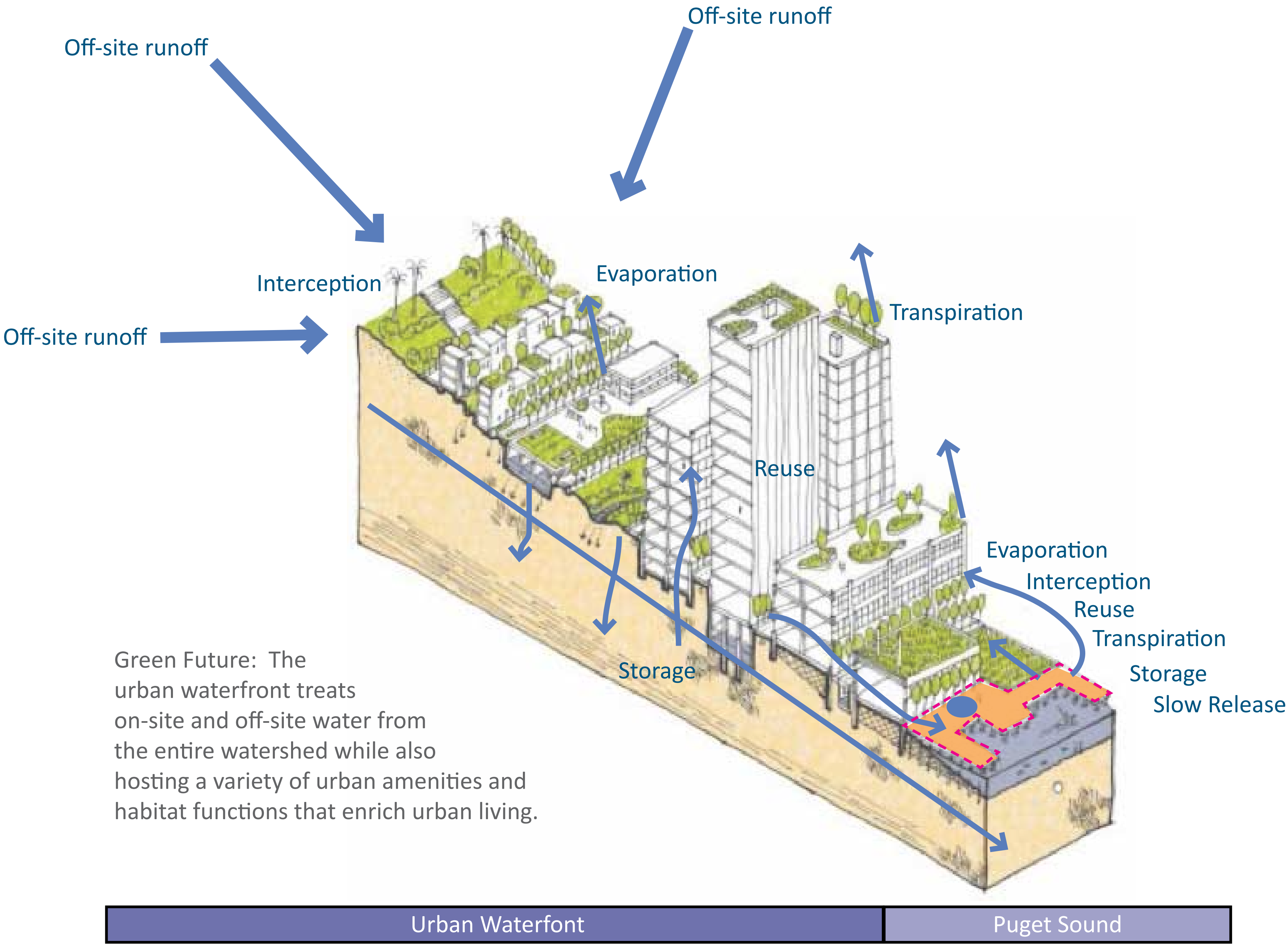
BEYOND SITE RUN-OFF

Stormwater BMPs are typically implemented to only treat and attenuate on-site runoff. As individual stand-alone interventions they are often combined to form a treatment train that achieves the desired water quality before leaving the site. However, there is rich opportunity to expand these BMPs beyond the site to create dynamic, integrated whole systems that maximize pollutant removal on a watershed scale. More importantly, there is ample opportunity to incorporate additional goals that will encourage BMPs to become an integrated component of urban settings. For instance, combining forces with trail systems, habitat restoration, public spaces, and art will help cities achieve water quality goals and equally foster biodiversity and high quality of life goals.





Green Future: The
urban waterfront treats
on-site and off-site water from
the entire watershed while also
hosting a variety of urban amenities and
habitat functions that enrich urban living.

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