ABSTRACT

Homeowner's Handbook
to
Protecting Puget Sound Streams

Jan G. Tangen

Streams and groundwater of the greater Puget Sound Lowlands directly feed the larger water bodies of the region, including Lake Washington, Hood Canal, and Puget Sound itself. Therefore, stemming the flow of pollutants into streams and groundwater, and ensuring adequate recharge of groundwater, is vital to protecting the productivity of these ecologically and economically important Puget Sound water bodies. Most pollutants of Puget Sound streams are non point-sourced - meaning they cannot be definitively tracked back to a single, or several, polluters. Instead, the pollution comes as a result of a more difficult-to-control, amalgamation of human-induced factors. Research shows the main antagonists for non-point source pollution of water bodies in the Puget Sound region are chemical fertilizers, storm water runoff, dysfunctional (and even functional) septic systems, and urbanization of once rural areas. Indeed, the Governor's 2005 Puget Sound Partnership found that reducing and controlling non-point source pollution from these same antagonists to be one of the most pressing issues regarding the clean-up and revitalization of ailing Puget Sound. First understanding how these factors combine to pollute the streams that feed Hood Canal and Puget Sound, and then making some small investments and simple changes in the way we manage the water that flows from our property into these streams and groundwater, are significant steps toward alleviating the pressure of urbanization and pollution on the health of Puget Sound and the greater Puget Sound watershed. This paper surveys the ecological problems created by urbanization and conventional stormwater management in the Puget Sound region, and explores the feasibility of implementing raingardens, pervious pavement, and native plantings to facilitate stormwater runoff reduction and bioremediation.

Homeowner's Handbook

to

Protecting Puget Sound Streams

by

Jan G. Tangen

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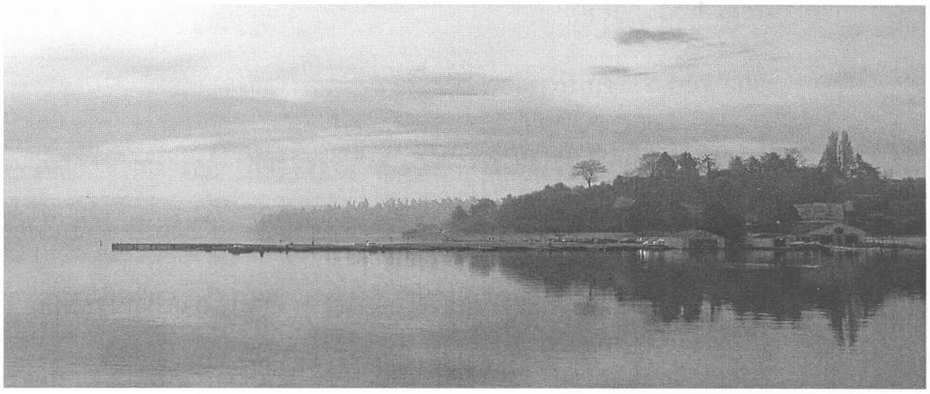


Lake Sammamish

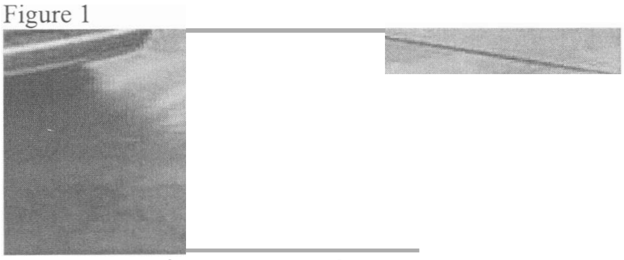
Washington State has become increasingly concerned about the water quality and overall health of our economically and ecologically important fish-bearing streams and the Puget Sound. In 2005, Gov. Gregoire created the 22-member Puget Sound Partnership -a group of agency scientists and state leaders-to investigate the reasons behind the pollution-caused problems throughout Puget Sound (shellfish-harvesting closures, struggling wild salmon populations, and Hood Canal eutrophication, for example) and then develop recommendations for restoring it. A year later, the Partnership reported that human waste from on-site septic systems is a main source of shellfish-harvesting bans, that highly polluted creeks were contributing to the mortality of returning Coho salmon (Oncorhynchus kisutch) before it manages to spawn, and that surface runoff has in fact polluted nearly every water body in the Puget Sound Basin (PSP, 2007).

Recent research from the United States Environmental Protection Agency has shown that once a drainage basin has had about 10% of its area converted to impervious surface, the occurrences of habit-damaging flooding, chemical and nutrient pollution, and the scouring of salmon eggs increase sharply (EPA, 2008). Furthermore, one five-year survey of the greater Puget Sound basin revealed that low and mid-lying drainage-areas below 2000 feet in altitude showed a significant increase in impervious surface over this short time span-some as much as 19% (EPA, 2008).

With over 7 million inhabitants, and 2 million more projected by 2020, the Puget Sound region is suffering from intense urbanization. This means more roads, homes and concrete structures are being built in lowland areas that were recently forest-covered or countryside, all without an addition ofland or resources.

Roofs & Runoff

Figure 1



Impervious surface in Renton, during a rain event. Motor oil from surface runoff is a major non point-source pollutant of Puget Sound streams.

Modem storm-water increases are a direct result of the roofs, gutters, downspouts, curbs and roads of conventional storm-water management infrastructure, which is designed to concentrate and move water away from where it fell as quickly as possible. These systems compact the soil and result in decreased porosity, further increasing the speed and volume of runoff (Landers, 2004).

Figure 2

Downtown Woodinville, after 2007 storm. Runoff is unable to infiltrate soil due to impervious asphalt, and picks up hydrocarbon pollutants to deliver into nearby stream. Impervious surface also heats runoff that enters streams, harming egg and salmon fry survival rates (EPA, *20081* Frazer, 2005)

Surface runoff carries sediment, oil, chemicals, bacteria and other nutrients across impervious surfaces such as rooftops and pavement, and delivers them into streams and wetlands, rather than allowing for slow percolation and filtration through the soil into the groundwater.

Roofs account for a very large portion of impervious surface area in housing developments. They are designed to accumulate large volumes of water in their gutters and whisk it rapidly away into the sewer system. This rapid runoff can increase flooding and result in sewer overflows, and doesn't allow for any groundwater replenishment (VanWoert, et. aI, 2005). Also, excessive surface runoff has increased peak flow in streams, causing erosion and stream bank instability (Bean, Hunt, Biddelspach, 2007)

Figure 3

An example of lost vegetation and increased impervious surface at a golf course near Snoqualmie Ridge, an area that was recently forest and wetland. Lawn is highly compacted, and grass roots provide little nutrient and stormwater uptake.

Roots & Rain

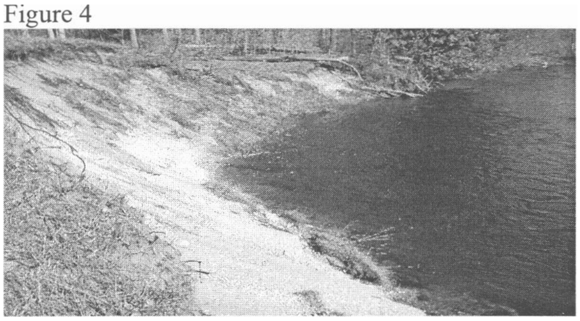
A 1998 study comparing two neighboring catchments near Lake Sammamish suggested the buffering effectiveness of deep roots in slowing runoff velocity: it found that the forested (at the time) Novelty Hill Basin allowed only 12-30% of its annual rainfall to leave the basin as runoff, while the denuded Klahanie Basin lost 44-48% of its rainfall to surface runoff. Even at a pervious location in the Klahanie Basin, a simulated 50-year storm caused a peak runoff flow 10 times higher than at the Novelty Hill site (Burges, 1998).

Another study conducted of a 10-county region near Atlanta, Georgia (which has experienced severe water-shortages in reservoirs in recent years), found that the area had undergone a 20% loss in vegetation between 1986 and 1993, which resulted in an increase of 1 billion cubic feet of storm-water runoff (American Forests, 1997).

The Sub-surface & Salmon

Pollution isn't the only danger to stream ecosystems brought by surface runoff. Benthic invertebrates - relied upon by salmon :fry after emerging from their gravel redds - have adapted to the subsurface flows of groundwater and nutrients entering their streams, but the relatively sudden hydrological shift from subsurface to surface flow has severely decreased B-IBI (benthic index of biological integrity - based on benthic macroinvertebrates) as urbanization increases here (Morley, 2002). A survey demonstrated that only 10% of 45 stream-sites tested had healthy B-IBI. Along sockeye-bearing (O. nerka) Little Bear Creek - in the quickly urbanizing Sammamish basin - high B-IBI occurred in zones where native vegetation was prevalent, but was dramatically reduced further downstream in more developed settings. Clearly, native riparian roots and stormwater percolating deep into soil are vital to the biological health of a stream.

Figure 4



Little Bear Creek, Sammamish Valley. According to Washington State Department of Ecology, decreased groundwater levels have been found throughout Puget Sound, as well as increased groundwater contamination. Groundwater flow into streams is decreased as surface runoff replaces it, and increased volume and velocity of surface runoff inundating creeks results in creek bed erosion and sediment deposition. This change in hydrology and velocity effects levels of sensitive benthic invertebrates critical to salmon (Morley, 2002). Groundwater is also vital to sustaining streams in dry periods.

Septic Systems & Sea-life

Of course, with an estimated half million residential septic tanks in the Puget Sound region, much of the non point-source pollution making its way into water bodies is in the form of human waste. According to Puget Sound Partnership, nitrogen and phosphorus from septic and sewage-effluent is the primary reason for shellfish-harvesting closures (PSP, 2007). This has not only health impacts, but economic - as Washington is the country's number one producer of shellfish. A study in Liberty Bay, on Hood Canal, found elevated levels of coliform bacteria, a direct result of wastewater from leaking or otherwise faulty septic systems. It also found high levels of phosphorus and nitrogen nutrients (Takesue, et. al, 2006), which can cause the algal population explosions that lead to the recurring problem of eutrophication in Hood Canal. As the algae eventually die and decay, bacteria suck up the available oxygen and choke out marine species, creating "dead zones."

Picking Priorities

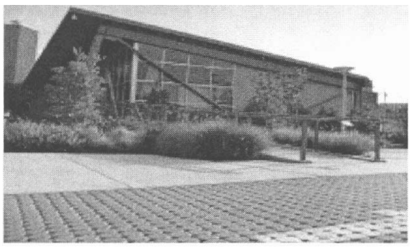
So with salmon populations, shellfish harvests, fresh water supplies, and overall ecological health severely damaged by the conventional stormwater management, impervious surfaces and septic systems of urbanization, it is not surprising Puget Sound Partnership has allocated 24% of it's total budget ($76,831,744) to "prevent nutrient and pathogen pollution" from septic and sewage systems, and 9% ($29,759,300) to "prevent harm from stormwater runoff' (PSP, 2007).

But once individual homeowners understand these non point-source pollution problems inherent to urbanization, they can apply cost-effective, easy-to-implement strategies that help restore the ecological vitality and natural hydrological system ofPuget Sound streams. This paper will explore the effectiveness and practicality in the Puget Sound lowlands ofbio-retention cells (or raingardens), native plantings, and porous pavement applied at a residential scale.

2

Bioswales, Buffers, Porousness and Plants:

Figure 5



Discovery Center, Seattle. A system of raingardens and porous pavers minimizes impervious surface areas and limits the links between them, allowing stormwater to infiltrate the surface and percolate within the sub-soil.

Increasing attention has been paid to Low Impact Development (LID) techniques, as many regions attempt to undo the problems they've encountered due to conventional storm-water management (Landers, 2004). LID techniques attempt to restore natural hydrological functions, where rainfall and snowmelt is absorbed and percolated back into the groundwater system or absorbed by roots, and very little leaves the site as runoff.

The most familiar housing development type in the United States in *conventional curvilinear*, with cul-de-sacs, large lots, and minimal open space (Brander, et. aI, 2004). The most low-impact of development types is called *urban cluster.* It is designed to maximize open space and use smaller lots. It produces less runoff than any other type of development, as it retains more of the natural features of the area.

A subdivision in Maryland was originally conceived as a traditional housing development in 2002, but it instead incorporated LID standards without increasing expenses: "fingerprinting" situated sites in such a way as to retain 50% of the natural area, reducing the cost of clearing by $160,000, as well as the cost of grading; 2 storm-water retention ponds were eliminated in favor of natural drainage systems (saving $200,000 for the developer); replacing gutters and curbs with swales reduced construction costs by $60,000; and narrower roads reduced the price of paving by 175 (Landers, 2004).

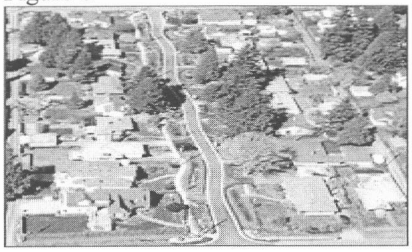
Where soil conditions are favorable to percolation, on-site filtration practices are quite effective and relatively inexpensive to implement (Brander, et. aI, 2004). For example, improving water-infiltration on residential property is far simpler than improving that of a parking lot. A good strategy is to redirect runoff from impervious surfaces to more pervious ones. Runoff from streets, driveways and sidewalks can be redirected into raingardens. These are sloped basins of highly-permeable soil atop natural subsoil. Preferably, the vegetation should be native so as to be well-suited to the area's climate and hydrology. Roof downspouts can also be modified to spread runoff into vegetated swales rather than into street-side drains (Brander, et. aI, 2004).

Case Study:
Street Edge Alternatives

In fact, natural drainage systems can cost 15-25% less than conventional infrastructure redevelopment (Edwards, 2005). A pilot project along one street in Seattle, Washington - dubbed "Street Edge Alternatives" (SEA) - showed the total volume of water leaving the street was reduced by 98%! This was accomplished with a redesigned street that reduced imperviousness by 11%, along with the addition of 100 trees and 1100 shrubs (Edwards, 2005).

Though no pervious pavement was used, a main goal was minimization of impervious surface area. SEA redesigned the street into a narrower, curvilinear path that allows for more porous surface area and keeps runoff from increasing in volume and speed along the street. It added soil and native plants along the edges of the road to help slow runoff and filter pollutants, and vegetated swales (broad, shallow channels, densely planted with native vegetation adapted to the precipitation and soil of the area) and stormwater cascades were constructed. This allowed the ground to accept high volumes of runoff through staged absorption.

Figure 6

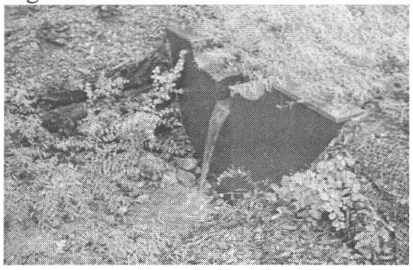


2nd Av NW, Seattle. The re-designed, curvilinear street minimizes impervious surface, re-directs street runoff into vegetated swales, and doesn't allow it to increase in volume and velocity. A drawback of this type of decrease in impervious pavement may be the drastic reduction in available parking along the street.

These cascades are a system of stepped pools alongside the street, connected to one another by catch-basins. These pools collect and slow runoff on its way down-gradient (Edwards, 2005; Landers, 2004). The system costs $50,000 to $200,000 less per block to install than a conventional system with large underground detention tanks (Landers, 2004).

The new trees and shrubs also provided evapotranspiration - not just filtration and aeration, and excavated soils were mixed with organic compost to reduce plant maintenance.

Figure 7



Retention swales collect and reduce runoff. When the weir is topped, runoff proceeds to the next retention swale down, where it is collected and reduced until it tops the weir again, and so on until very little remains at the bottom of the system.

This sort of "green infrastructure" doesn't deteriorate over time like the conventional system of pipes, gutters, grates and curbs. In fact, it becomes more effective as trees and plants grow (Edwards, 2005). Further, it increases aesthetics, reduces property flooding, and improves ground- and stream-water quality by filtering out pollutants from runoff - although the presence of remaining street pollutants (like motor oil and trace elements) after percolation through the soil remains to be studied (Lubick, 2001).

660 feet of 2nd Av, NW were retrofitted in this LID project that successfully eliminated the flooding and erosion in Piper's Creek by mimicking pre-development hydrological patterns - at the bargain-basement price of $300,000 per block (Lubick, 2001).

Figure 8

Vegetated bio-swales retain runoff and filter pollutants through bioremediation as stormwater percolates through the well-aerated soil.

Figure 9

Vine maple (Acer circinatum). The roots of native plants aerate the soil, allowing for recharge of groundwater, and the bioremediation of pollutants. They are adapted to Pacific Northwest climatic and precipitation patterns, and therefore require little maintenance and watering. They also provide local streams with the appropriate allochthonous inputs important to salmon fry growth.

The design achieved 100% retention by the final swale in 14 of 36 precipitation events, according to a study from July 2000 to January 2001 (Homer, et. aI, 2002). During dry periods, a full 78% of the runoff entering the system was retained or otherwise infiltrated into the soil within the swales, and 38% over all periods. 38% retention/infiltration is good, but in comparison to the previous drainage ditch it is outstanding: under the same condition, the old ditch would have retained/infiltrated 67% less than the new system managed. It is estimated the new curvilinear street design achieved a 42% reduction in runoff from the previous street design. It is also estimated that pollutant loadings are reduced by at least that same amount, if not more due to bioremediation provided by the native plants within the swales (Homer, et. aI, 2002).

Apparently, the design achieved the best results in rains of moderate intensity. Since this is the prevailing pattern in Seattle, the system is well-suited.

The previous conduit that was replaced by the cascade design would have released approximately 191000 cubic ft more runoff into Piper's Creek than the new system during the 2001-2002 wet season. Furthermore, SEA prevented discharge of runoff into Piper's Creek 100% during the dry season, 98% during the wet season, and reduced velocity by 20% (Homer, et. aI, 2002).

Case Study:
Maplewood, Minnesota

Figure 10

Runoff has easy access to this bioretention cell, a gently sloped basin capable of retaining and draining most of the runoff from the lawn and nearby road.

Maplewood, MN, a suburb of the Twin Cities with a population of approximately 30,000, was forced to implement raingardens due to a lack of adequate space to treat stormwater, and to inadequate sewage in the older neighborhoods. With its enormous supply of freshwater lakes, and increasing impervious development, Minnesota faces similar pollution threats to Puget

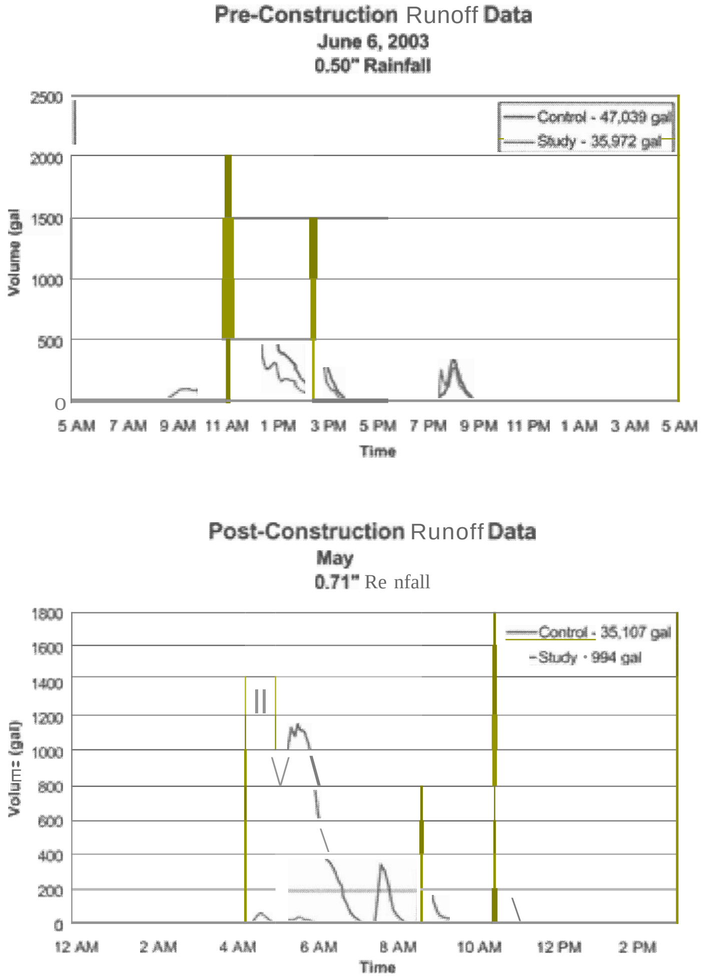
Sound, with our plethora of salmon-bearing freshwater streams in urbanized settings.

Begun in 1996 as the Birmingham Pilot Project, the project now encompasses at least 376 homes, 2 schools, and includes a nature center and a 5000 sq. ft "raingarden park". At least 231 raingardens have been created. Its intent was to improve street drainage without harming the neighborhoods' character, to bioremediate pollutants before they reach nearby lakes, and to minimize the price of retrofitting. It was designed to keep rainfall on-site and withstand a ten-year precipitation event (Larabee, 2004)

The raingardens are vegetated bioretention cells that not only capture and reduce street runoff by infiltration and root uptake, but also break down stormwater pollutants through aerobic remediation - although little work has been done to quantify actual pollutant load (Larabee, 2004).

The original gardens were simply six inches of native topsoil and 3/4 to 4 inches of wood mulch, built a top a French drain, which was basically a vertical perforated pipe covered in 12 inches of aggregate intended to contain and slowly disperse stormwater beneath the soil. The early versions were deemed by the Minnesota Pollution Control Agency to be an illegal type 5 well, while the USEPA granted the city 2nd place nationally for Outstanding Municipal Storm Water Program. Gardens were located at the lowest point of the boulevards to capture runoff, as the streets were curbless and runoff sheeted from streets onto boulevards, and swales were constructed to direct runoff into the gardens. Driveways were graded so that runoff could flow from one raingarden down to the next - similar to the SEA's cascade design. For driveways with negative grades, a hump was constructed street side to prevent runoff from flowing down the driveway and encroaching on private property: the new system was integrated into the old system, as in SEA, especially for emergency overflows.

Figure 11:

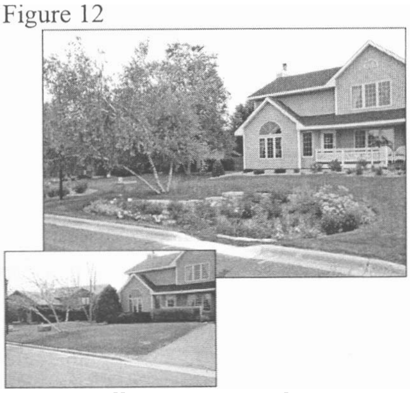


The blue line records runoff in a nearby "control" neighborhood, and the red line records runoff on two single days for the town of Bumsville: one before raingarden construction and one after. Despite a larger amount of rain on May 29,2004, compared to June 6, 2003 - before construction began - runoff was reduced from 35,972 gallons to a mere 994 gallons. Most of the rain that fell on the pilot area remained there, filtered by the roots of the raingarden plants, and percolating into the groundwater system - a reduction in stormwater runoff of97.3%! The control site, as expected, shows an increase in stormwater runoff on the day that received more rainfall.

The second Project - Harvester - was built in 1999, and did make use of French drains in the design (which are generally intended to disperse water, not retain it and allow it to infiltrate). Another advancement was the use of input and output pipes: this allowed runoff easy access into the raingarden near the bottom of the trench, but in cases of over-inundation, the runoff could forgo the raingarden and exit through the higher output pipe (Larabee, 2004). Some raingardens were also constructed with emergency output directly into a swale or sewer.

Through six projects in all, the garden and curb designs improved and adapted to account for the characteristics of streets, gradients and residential lot situations of the varying neighborhoods, and maintenance has been minimal for homeowners: weeding and watering in year 1, and replenishing mulch every 3-5 years. Woodchips used as mulch in the original projects have clogged outlets, and some erosion has occurred where curbs open to allow street runoff to access raingardens.

Figure 12



A Burnsville, MN raingarden strategically placed to collect down-slope runoff. Notice the curb has been amended to allow the conventional system and the raingarden system to function together.

Step by Step Raingarden:

1) Locate low points in the garden, the outer edge of a sloping property, or areas where puddling occurs. This is where runoff tends to be carried, or where compaction has made infiltration difficult. Low spots near downspouts are most conducive to collecting roof runoff. A collection of smaller rain gardens strategically located to handle specific runofflocales can keep a single, larger raingarden from being overwhelmed by an inundation of stormwater.

-avoid locating the rain garden near the leachfield of a septic system, within 10 feet of a home's foundation, near underground utility lines or pipes, on or near slopes steeper than a 15% grade, or within the root-systems of large trees.

-avoid locating in clay-like soil, or soil with a high water-table: dig a 1 to 2 foot deep hole in the location under consideration, and observe if water begins filling the hole. If so, the groundwater table is too high, and the location is non-conducive to retention cells. Or if the soil can be easily formed into a ball when wetted, it is clay-like and not conducive to retention cells.

2) Choose areas with most penneable soil. Clays are compacted and do not infiltrate well: excavating and in-filling with native, loamy soil and compost is necessary to improve clay's percolation-potential. Loamy and sandy soils infiltrate well.

Test for proper soil infiltration rate (Hinman, et. aI, 2007):

a) Fill 1 to 2 foot hole with water.

b) Measure amount of water filled in hole, in inches.

c) Time how long it takes for that amount to completely drain.

d) The amount of water filled in hole divided by the amount of time it took to completely drain is the soil's infiltration rate (measured in inches per hour).

e) If the infiltration rate is 0.1 inch per hour, the location is poorly suited to a rain garden.

f) If the infiltration rate is 0.5 in/hr or better, this is well-draining soil and ideal for a rain garden.

g) Between 0.25 and 0.5 in/hr is not ideal, but still conducive to a raingarden. Infiltration may be slow during wet season, and result in standing water for brief periods. Any properly located and maintained raingarden will never have standing water for more than 48 hours.

3) Detennine size of rain garden. Table 1 is for a rain garden 18 inches deep total. By increasing the depth in poor-draining soils, annual volume can be increased.

Table 1

Rain garden size as percentage of Impervious surface drainage area	Annual volume of water held in rain garden with poor-draining soil	Annual volume of water held in rain garden with well-draining soil
10%	70%	99%
20%	90%	100%
50%	99%	100%
80%	100%	100%

(Hinman, et. al, 2007) The first row explams that if the newly mstalled ramgarden is to be about 10% the size of the impervious surface area it will be draining (such as a house root), it will manage to hold 70% of the runoff generated by that inipervious surface over the course of a year in poorly-draining soil. That is a major reduction in stormwater runoff. While in well-draining soils, that same-sized raingarden will achieve almost 100% runoff retention over the course of the year!

4) Sloping properties can benefit from a rain garden built into or supported by a porous retaining wall, such as one constructed of stone or concrete blocks, that allows water to collect and infiltrate the soil within the cell, and the excess to weep through the wall and join the conventional runoff. This is complementary to conventional systems. Runoff into the rain garden can be slowed on the way through a system of small gravel pools or dams.

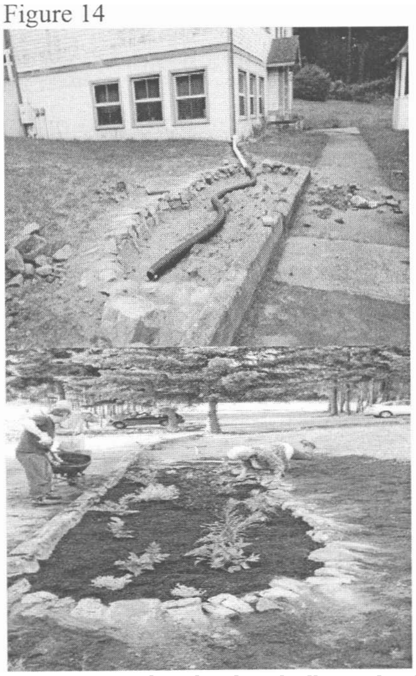
5) After designing the size and shape of the rain garden, excavate between 18 and 30 inches. Side-walls should be sloped, not vertical. Level the trench and then churn the bottom 8 inches of the soil, being careful to avoid compaction.

Figure 13

During trench excavation in Maplewood, MN, the backhoe stayed on the road in order to avoid compaction of the soil.

6) If intending to collect roofrunoff, divert downspout and direct it into rain garden using buried PVC piping or a shallow, gravelly trench lined with native plants. Connect perforated piping and lay it across bottom of excavated rain garden, within a bed of clean gravel. If not diverting a roof downspout, but simply allowing runoff to flow down gradient into raingarden, a short, graded trench backfilled with clean gravel around a perforated pipe allows runoff easy entrance and dispersal inside the rain garden.

Figure 14



Bayview High School, Whidbey Island. A building's downspout has been diverted into an excavated basin, and a perforated pipe laid within to aid stormwater dispersal. Overflow access to the street is provided. This basin is not as deep as generally recommended, nor was it backfilled with course gravel.

7) Backfill with native soil/compost mix (about 65/35) no less than 6 inches from top of trench, and level it. Collected runoff should be allowed to pond in the rain garden.

8) Ensure that excess storm water has drainage access to the street. Again, the rain garden is intended as a complementary system to the conventional system already in place. Outlets constructed near the top of the trench allow as much storm water as possible to infiltrate before any excess is drained out to the conventional system.

9) To prevent erosion during overflow of rain garden, line upper edges and outlets with layer of clean gravel.

10) Plant native species within and around the perimeter of the rain garden. Group the plants in to "wetland" and "upland" categories: wet soil/moisture loving plants should be located in the low area of the rain garden - the "wetland" area; plants preferring well-drained soil should be located on the upper slope and perimeter of the rain garden. Avoid species with deep, spreading roots (such as large trees) that may hann piping and make maintenance difficult. Refer to the Native Plants chart in Appendix 1 to select appropriate plants.

11) Spread 2 to 3 inches of mulch a top surface, and water well.

12) Most maintenance is needed in first 3 years, as raingarden establishes itself. This includes:

-weeding, mulching, and cutting back dead material to promote growth.

-watering adequately in summer

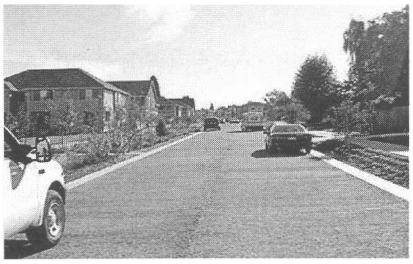
-clearing excessive debris and sediment to avoid clogging.

13) Allow raingarden to grow and establish. It will become more effective every year at taking up storm water and nutrients, aerating the soil, filtering pollutants, and allowing groundwater recharge as roots and leaves spread.

Pervious Pavers & Percolation

Clearly, replacing actual impervious surface with something more porous promotes groundwaterlsurfacewater interface. Concrete walkways and asphalt driveways allow no infiltration. Replaced with pervious pavers and asphalt, rain and snowmelt can pass through and be filtered of contaminants. Pervious pavement is relatively new, and is at this point effective in limited uses (EPA, 1999). Constructed of coarse aggregate with interconnected voids intended to create permeability, both porous pavement and porous concrete are installed a top a layer of gravel and crushed stone which is intended to work as a storage reservoir. This layer can be modified to accommodate the amount of rainfall encountered on any particular parcel, and perforated pipes within the layer can drain away excess water. Unfortunately, where porous pavement has replaced conventional concrete and asphalt, it has had a 75% failure rate. Generally, this is due to poor installation and upkeep, a lack of engineers experienced with the technology, and use atop soils non-conducive to high infiltration. (EPA, 1999)

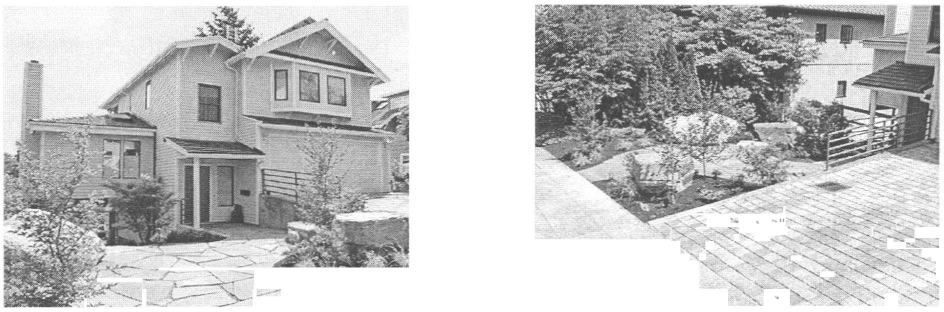
Figure 15



Highpoint Neighborhood, Seattle. Open-graded aggregate porous asphalt allows hydrocarbons like motor oil to be filtered aerobically below the surface through bioremediation, instead of entering streams through surface runoff.

Porous pavement and asphalt has been shown to be an effective substitute for conventional pavement and asphalt in limited uses, such as sidewalks, driveways, and parking areas: a residential driveway seems to be quite well suited.

Figure 16



A porous walkway and driveway at a residence on Queen Anne Hill, Seattle. Implementing open-jointed paving blocks to alleviate excessive runoff that was de-stabilizing a backyard slope.

A study on the east coast tested infiltration rates at 40 various pervious pavement sites, and found infiltration nearly doubled when simulated maintenance of sediment removal from surface was performed - from 4.9 cmlh to 8.6 cm/h - in one test group. But in another group situated in proximity to unstable or disturbed soil, the infiltration rates were significantly lower. The study concluded that maintenance and location are vital to high stormwater infiltration through pervious pavement, and recommends: 1) maintenance by removing top 13-18mm of sediment and within voids using a vacuum to keep infiltration at top capacity; then backfilling the voids with sand to avoid compaction. 2) locating a pervious pavement system within a stable watershed, because fine sediment accumulation dramatically reduces surface infiltration capacity (Bean, et. al, 2007).

Non-Polluted Parking Lot

Brattebo, et. al, 2003, King County, Washington, evaluated 4 different penneable pavement systems (and one non-penneable, conventional asphalt as a control) in a well-used parking lot in Renton after 6 years of usage, to see if the pervious pavement was still effective and functional. The study tested for structural stability, infiltration capacity, and water quality. It found virtually no signs of wear, almost no runoffleaving sites, and pollution in infiltrated water was greatly reduced: significantly lower levels of copper and zinc than the asphalted areas; no motor oil in infiltrated water from any of the penneable sites, while it was found in 89% of samples from the asphalted sites. All the penneable pavement systems resulted in virtually no runoff during 15 distinct precipitation events throughout November 2001, and throughout January, 2002, while runoff from the asphalt control site closely followed precipitation rates during all 15 precipitation events.

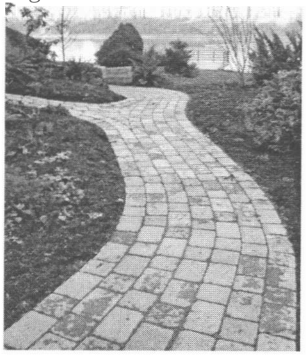
The study's authors point out that the success of the systems in this locale can be greatly attributed to the high-infiltration rate of the soil, and the typically low-intensity rainfalls of the Pacific Northwest. While not mentioned in this study, it can be assumed that the region's lack of a freeze-thaw cycle or excessive snow-clearing may well suit the long term stability of the pavement system.

Various Pervious Pavements

Figure 17

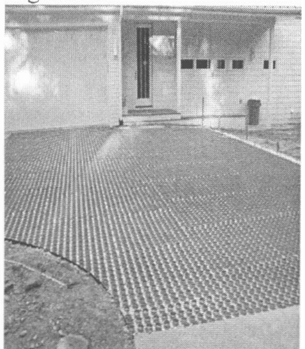
Open-celled paving grids

Figure 18



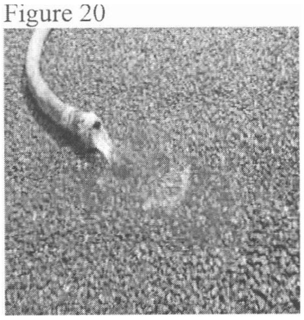
Open-jointed paving blocks: ideal for heavy foot traffic

Figure 19



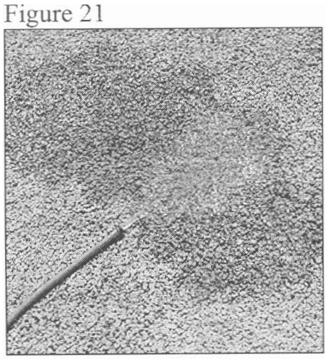
Plastic geocells: a non-compacting base that can be covered with sad or gravel.

Figure 20



Porous asphalt

Figure 21



Pervious concrete

Installing Permeable Pavement:

1) Ensure soil of area to be paved has high infiltration, similar to steps taken in choosing appropriate locale for raingarden. Allow 3 foot buffer between bed-bottom and top of water-table. Avoid slopes of greater than 5 degrees.

2) Excavate area to be paved 12-36 inches deep, with vertical walls.

2) Level soil, being careful not to compact bed.

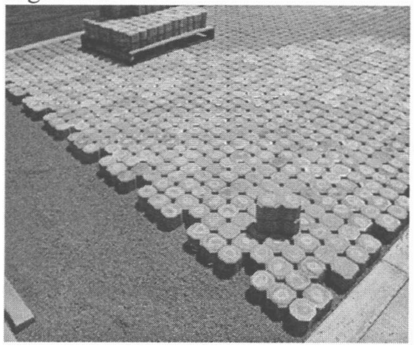
3) Cover soil-bed with non-woven geo-textile to avoid soil clogging the course aggregate overlay.

4) Place perforated piping atop soil bed for dispersal.

5) rnfill with 12-36 inches of 1.5 to 2 inch clean, course aggregate.

6) Apply choice of pervious pavement surface. Grids, blocks and geo-cells are most recommended for residential installations.

Figure 22



A bed of clean aggregate provides structure and stability, and promotes aeration, stormwater dispersal, and non-compaction for pervious surfaces.

3

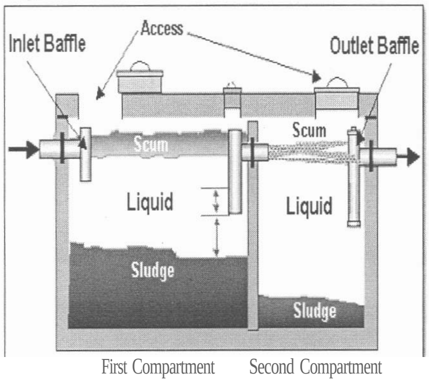
Septic Systems

Due to increasing land use in once rural areas, and to the realizations that traditional methods are contributing to eutrophication in Hood Canal and other water bodies, once acceptable septic practices that focused on dispersal for treatment are no longer adequate.

But with 500,000 Puget Sound homes attached to septic tanks, and because septics are economical, last up to 30 years, and require no outside energy to function, it is unlikely they will be phased out and replaced by expensive sewer systems (Hallahan, 2002).

In the meantime, conscientious septic owners will have to rely on proper maintenance and improved filtering technology. For many, though, improper sight-location and too little space has made their septic systems the number one emitter of pathogens into water bodies in the state.

Figure: 23



Newer septic systems in Puget Sound have 2 compartments. When wastewater enters, heavier solids drop to the bottom of the compartment and become sludge, while lighter solids rise to the top as scum. The liquid effluent undergoes anaerobic treatment by bacteria, and eventually overflows into the second compartment when more wastewater is added to the tanle In compartment 2, the same process occurs, until the liquid effluent is released through the outlet into the gravelleachfield. In the leachfield it disperses and is further broken down through aerobic processes and evapotranspiration.

The septic system's efficient design is over 100 years old. Unfortunately, today's home uses more water, sits on comparatively tiny parcels ofland, and may not be situated upon soil with adequate infiltration. For example, clay or bedrock requires much larger leaching beds than those that are fit into the limited space provided by the smaller lots of housing developments.

Septic systems installed in soil with a water-table close to the surface do not function properly. One reason for this is wastewater from the septic tank is supposed to be dispersed into the surrounding soil through perforated pipes, where aerobic organisms continue to break down pathogens, viruses and parasites. If the soil is saturated it can't filter the wastewater. The tank may also back up and get clogged (Steinfield, 2002). This typically results from a failure to pump the tank remove when the sludge has come within 12 inches of the output, or the scum within 3 inches. Inundations of wastewater into the tank can cause leaks as well. Unfortunately, a study in Ohio showed that residential septic education programs are largely ineffective at developing good septic-management practices (Silverman, et. aI, 2005).

Of course, even a well-maintained tank releases effluent that can make it's way into Puget Sound or its streams. As chemical additives have been proven ineffective at increasing the microbial populations inside the tank that break down the effluent (Pradhan, et. aI, 2008), responsible septic owners are left to invest in expensive effluent-filters.

A simple effluent filter can be attached to the outlet of a conventional tank, to catch effluent before it enters the leaching bed. It is relatively easy to install and maintain, and costs around $300. Effluent filters reportedly reduce Total Suspended Solids (TSS) 50-60%, and 5-day biochemical oxygen demand (BOD) by 30-60%. Other systems have more integrated filtration, like manufactured foam balls that ensure aerobic conditions during effluent filtration before dispersal into the leaching bed (this is the Waterloo Biofilter). This achieves a 90-95% reduction in TSS and BOD, as well as 95-99% reduction in total coliforrns and 20-50% in total nitrogen! Unfortunately, installing this system costs well over $10,000! Another uses a peat filtering system and achieves similar results for a cost of $9000, plus total peat replacement every 8 years.

Cost-effective Riparian Buffers

It turns out, riparian buffers are more cost-effective than septic-upgrades in reducing phosphorus pollution in NW lakes and streams in most every case (Kramer, et. al, 2006). Moreover, vegetated buffers can reduce phosphorus input without actually pinpointing the source. A statistically analysis tested the cost-effectiveness of two different strategies for reducing phosphorus pollution in 25 Minnesotan lakes spanning a broad range of characteristics and development - septic system upgrades, versus riparian buffers - and found riparian buffers to be the best option for reducing sedimentary phosphorus input to acceptable standards. The study assumed at $400/acre establishment cost for vegetated buffers, and $20 annually for maintenance in 1996. Of the 25 lakes, 16 met the phosphorus-loading reduction criteria using 15-61m wide vegetated buffers encircling the lake, at a cost as low as $8476. 7 met the criteria using septic upgrades alone, at a minimum cost (depending on lake size and amount of septic systems) of$62,500. For 6 lakes that did not meet the criteria for phosphorus reductions, the authors believe a combination of the septic upgrades and riparian buffers would have been necessary. When the study ran another simulation that assumed the main culprits of the phosphorus inputs were septic systems - rather than a range that included rain falling directly on the lakes, lawn runoff, pasturelands and agriculture - 15 met the criteria using riparian buffers alone, and 10 using septic upgrades alone. In each simulation, the authors found it was possible to reduce phosphorus loading below the threshold in a greater number of lakes using only buffer zones than using only septic upgrades.

Table: 2

Upgrade type	Installation cost	Annual maintenance cost	25-year cost
Conventional tank w/mound	$4000-12000	$80-$500	$12900
Sand/peat filter	$5000-$15000	$500-$1000	$22000
Aerobic tank	$4000-$7500	$600-$1700	$28,750
Holding tank	$2000-$3000	$2000-$3000	$70,000
Municipal sewer	$4000-$10000	$200-$400	$13000

(Gustafson, 2002) Column 1 lIsts vanous expensIve upgrades to the conventIOnal septIc tank wIth a trench which are intended to reduce phosphorus pollution. Research shows that investing in native plants to filter phosphorus from septic effluent is far more affordable than these costly upgrades that may not be more effective than roots and aeration.

4

Conclusion:

All the LID techniques and technologies discussed herein are growing in popularity and implementation. It is my hope that after completing this Thesis, the reader has a strong understanding of how the greater Puget Sound watershed is degraded by surface runoff and non point-source pollution from stormwater infrastructure, urbanization, and septic systems, and of how it can be revitalized through the proper application of permeable surfaces, native plants, and bioretention swales.

Though the 2 case studies evaluated community-wide, government-sanctioned solutions, they serve as excellent examples of these LID techniques from which individual homeowners can draw inspiration and understanding.

The Homeowner's Handbook to Protecting Puget Sound Streams is intended to show the potential these fun, relatively inexpensive, and easy-to-implement strategies has for improving the health of Puget Sound and our community.

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Figure 7: http://www2.seattle.gov/util/tours/ll0thCascade/slide3.htm. retr. May 15,2008

Figure 8: http://www2.cityofseattle.net/utilltours/seastreet/slidel.htm. retr. May 15, 2008

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Figure 10: http://www.metrocounci1.orgienvironment/WaterSupply/images/raingardensmjpg, retr. May 15, 2008

Figure 11: http://www.1andandwater.comlfeatures/voI48n05/voI48n05_2.php, retr. May 15, 2008

Figure 12: http://www.1andandwater.comlfeatures/voI48n05/voI48n05_2.php, retr. May 15, 2008

Figure 13: http://www.1andandwater.comlfeatures/voI48n05/voI48n05_2.php, retr. May 15, 2008

Figure 14: http://www.whidbeycd.org/What.s%20New!.htm. retr. May 15, 2008

Figure 15: http://www.djc.comlnews/en/ll177213.html. retr. May 15, 2008

Figure 16: http://www.inharmony.comlsherhart.html , retr. May 15, 2008

Figure 17: http://www.metaefficient.comlimages/ex3car.jpg. retr. May 15,2008

Figure 18: http://www.ecofriend.orglimages/one_day_pavers_may_be_able_to_collect_and_purify_rainwater.jpg&imgrefurl=http://www.ecofriend.orglentry/pavers-to-collect-purify-run-off-channeling-it-to-underground-tanks-for-reuse/&h=419&w=360&sz=47&hl=en&start=3&um=l&tbnid=qin4A8KOkIsBLM:&tbnh=125&tbnw=107&prev=/images%3Fq%3Dporous%2Bpavers%26um%3D1%26hl%3Den%26rls%3DHPIA,HPIA:2006-36,HPIA:en%26sa%3DN, retr. May 15, 2008

Figure 19: http://www.millennialliving.comlfiles/resizedphotos/porous-paver-system-driveway_Ojpg, retr. May 15, 2008

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Figure 21: Yoders, Jeff. Retrieved June 7, 2008 from http://www.bdcnetwork.comJarticle/CA6297622.html

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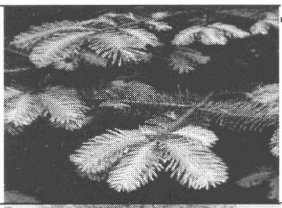
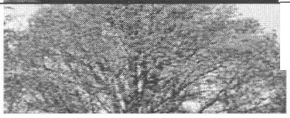
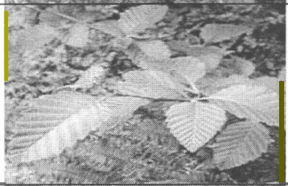
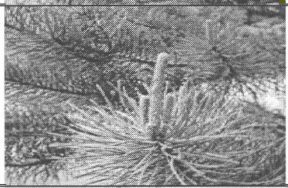
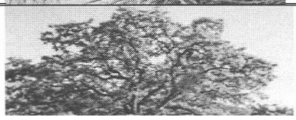
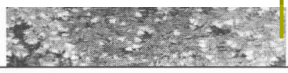
Table 2: Gustafson, D.M., lL. Anderson, S.F. Heger, and B.W. Liukkonen. Choosing an alternative septic system for a homesite with a high water table. University of Minnesota Extension Service, St. Paul, Minnesota, 2002

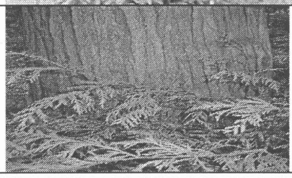
Appendix 1: http://dm.metrokc.gov/wlr/pi/go-native/, retr. May 15, 2008

Appendix 1

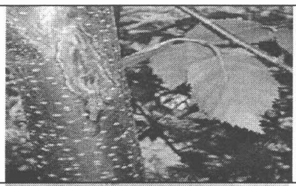
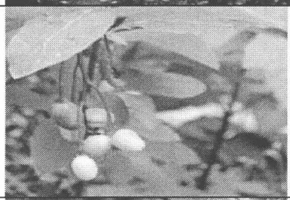
All species listed are drought-tolerant, well-adapted to typical Puget Sound climatic pattern of wet winters and dry summers. This list is only partial.

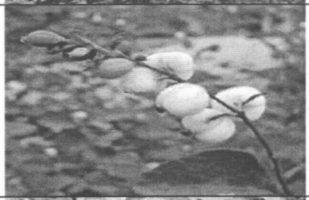
Native Species: **Large Trees**

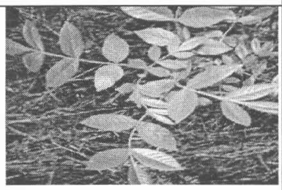
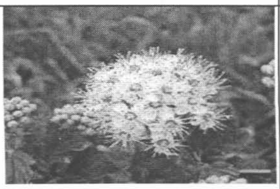
Species		Soil Moisture	Light Requirements	Notes
Grand fir Abies grandies		moist to dry	sun to shade	stabilize slopes
Big leaf maple Acer macrophyllum		moist to dry	sun	erOSIOn control
Douglas fir Pseudotsuga menzlelsll		any soil besides very moist	sun to shade	ubiquitous
Red alder Alnus rubra		moist to dry	sun to part shade	fix nitrogen; provide filtered light
Shore pine Pinus contorta		dry to very moist soil	sun to part shade	groups, rows, hedges
Garry Oak Quercus garryana		dry	sun to partial shade	provide filtered light
Western hemlock Tsuga heterophylla		moist to wet soil preferred	part shade to deep shade	tolerates even full sun well

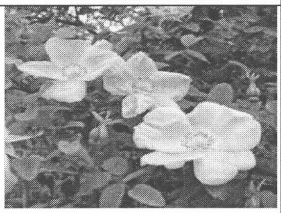
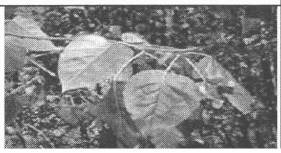
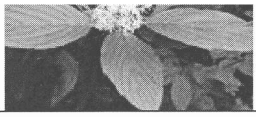
Sitka spruce Picea sitchensis		moist to very moist	sun to part shade.	damp areas
Western red cedar Thuja plicata		moist to very moist	partial to **full** shade	damp areas; keep off slopes

Native Species: Smaller Trees and Shrubs

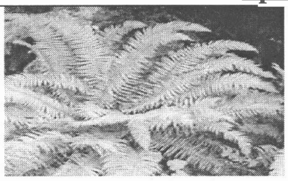
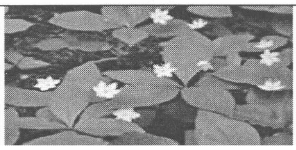
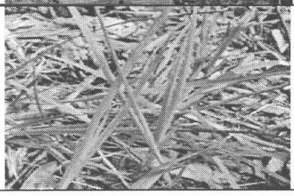
Paper birch Betula papyrifera		moist	sun to partial shade	growth up to 90'
Indian plum Oemleria cerasiformis		dry to moist	shade only	
Bald-hip rose Rosa gymnocarpa		dry to very moist	sun to shade	
Kinnikinnick Arctostaphylos uva-urSI		dry	sun to partial shade	stabilize slopes
Red-flowering currant Ribes sangumeum		dry to moist	sun to partial shade	well-drained, rocky, sunny sites
Mock orange (Philadelphus lewisii		dry to moist	sun to partial shade	hedge

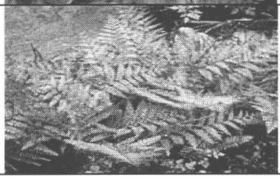
Serviceberry (Amelanchier alnifolia		dry to moist soil	sun to full shade	erosIOn control
Snowberry (Symphoricarpos albus		dry to moist soil	sun to full shade	extremely tolerant; fast growth
Tall Oregon grape (Mahonia aquifolium		dry to very moist	sun to full shade	

Red elderberry Sambucus racemosa		dry to moist	sun to shade	
Goldenrod Solidago Canadensis		dry to moist	sun to partial shade	grouped
Oregon ash Fraximus latifolia		moist to very moist	sun to part shade	
Pacific ninebark Physocarpus capitatus		moist to very moist	sun to shade	
Vine maple Acer circinatum		dry to moist	partial to full shade	stabilize soil

Cascara Rhammis purshiana		moderately moist	sun or shade	30' growth
Nootka rose Rosa nootkana		moist to very moist	sun to partial shade	rapid spread
Black cottonwood Populus balsamifera		very moist	sun to partial sun	stabilize soil
Red osier dogwood Comus sericea		moist to very moist	sun to partial shade	very low maintenance

Native Species: Ground Cover

Sword fern Polystichum munitum		dry to moist soil	partial to full shade only	erosIOn control
Western starflower Trientalis latifolia		dry to moist	partial to full shade	
Woodland strawberry Fragaria vesca		dry to moist	partial shade to shade	rapid spread
Dagger-leaf rush Juncus ensifolius		wet	sun to shade	

Reed mannagrass (Glyceria grandis		moist to very moist	sun	meadows
Wild strawberry Fragaria vlrgmlana		dry to moist	partial to **full** shade	rapid spread
Lady fern Athyrium felix-femina		moist	sun to shade	stabilize soil

All pictures (http://dnr.metrokc.gov/wlr/pi/go-native/)