Seattle's Natural Drainage Systems

A low-impact development approach to stormwater management

City of Seattle

Introduction

An entirely different kind of street

In the swales, healthy plants and soils break down pollutants through natural processes while reducing runoff to almost nothing.

For years, planners at Seattle's drainage utility faced a dilemma. Nearly a third of the city has no storm drains. In those areas, stormwater flows along street edges, to the end of the block where it gathers in street-side ditches, plunges through culverts and, laden with roadway pollutants and pesticides and fertilizers from lawns, pours into small lakes or a number of natural creeks leading to Puget Sound or Lake Washington. Residents of these neighborhoods have long clamored for the kinds of amenities that exist in the rest of the city - sidewalks, curbs, gutters and, of course, storm drains. And, as environmental awareness has grown, community activists and creek-side residents have pressured the city to control flooding which regularly scours creek beds destroying salmon spawning areas and creek-side vegetation. A typical piped storm drainage system could solve local flooding problems, of course, but it would still deliver high stormwater volumes and the associated pollutants directly to the surrounding waters. It would also require a huge investment - money Seattle hasn't found in 50 years.

The answer, it turns out, was to create an entirely different kind of neighborhood street, a street where planted swales along the pavement do the work of gutters and drains, capturing stormwater and letting it soak into the ground. In the swales, healthy plants and soils break down pollutants through natural processes while reducing runoff, except during the very largest storms, to almost nothing. This was the first SEA-Street, incorporating a variety of low-impact development techniques to store and infiltrate stormwater, and to capture and begin the biological breakdown of water-borne pollutants. Together, the techniques tested at SEA-Street No. 1 have become the major part of Seattle Public Utilities' **Natural Drainage Systems** (NDS) strategy.

The first SEA Street just after completion in 2001

SEA Street in 2002

Today, in several neighborhoods throughout Seattle - with more to come as funding becomes available - SEA-Streets and their variations have become a much-admired community amenity. Their NDS technologies are being used to provide a variety of community and environmental benefits, including:

- Drainage control thanks to narrower roadways which reduce impervious surface, creating more space for vegetated street-side swales which temporarily hold and often absorb rainwater;
- Improved water quality through "biofiltration" - pollutant removal provided by healthy plants and soils in swales where they capture and break down pollutants washing off roadways and parking areas;
- Increased street-side landscaping, beautifying and adding value to neighborhoods;
- Traffic calming due to narrower pavement, the narrower visual corridor created by street-side vegetation and at some locations by gradually curving roadways that still allow for emergency vehicle access;
- Increased community interaction thanks to residents' collaborative involvement in landscape maintenance, watershed stewardship and the pedestrian friendliness of new sidewalks and streets;
- Public education through neighborhood-scale examples of what communities in Seattle and other cities can do to reduce stormwater runoff and improve water quality with "outside the box" Natural Drainage Systems strategies.

This manual was produced to tell the story of these successes and provide information that other neighborhoods, cities and towns can use to apply NDS strategies to storm drainage problems. The benefits for community residents, neighborhood traffic management, water quality, the environment and drainage utilities like Seattle Public Utilities can be significant.

Facing the problem

Seattle, like other U.S. cities, struggles with a host of infrastructure challenges, many involving storm drainage volumes and storm water runoff which can pollute surrounding streams, lakes and salt water with nutrients and toxic chemi-

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cals picked up from streets and parking lots, roofs and lawns. Increasing populations and motor vehicle use exacerbate the pollution problem. Nevertheless, storm runoff pollution must be controlled within specific limits set by the National Pollutant Discharge Elimination System (NPDES). In Washington, NPDES enforcement and permits for limited discharges are the responsibility of the state Department of Ecology (DOE).

Adding urgency to this, two runs of Puget Sound Chinook salmon that pass through Seattle waters were declared threatened in 1999 under the Endangered Species Act (ESA). The four major streams that years ago Seattle hijacked into its storm drainage system are all capable of supporting salmon runs. Chinook have been found in Thornton Creek in northeast Seattle. The other urban creeks host other varieties, most often coho, sockeye and chum salmon and migratory or resident cutthroat and rainbow trout. In recent years, SPU research has found high coho pre-spawn mortality in the city's streams and NOAA Fisheries research points to contaminants in stormwater runoff as the cause.

For more than two decades many of Seattle's school children have raised salmon fry in tanks in their classrooms and each spring released them into the streams, with high hopes for their return. They've had some success. On Piper's Creek in northwest Seattle, the fall count of returning chum salmon is a community event.

Even before the ESA put official urgency to the need for salmon habitat restoration, Seattle and its citizens had begun that work. With state support from initiatives for the cleanup of Puget Sound, the city and community organizations together developed Watershed Action Plans. Since the early 1990's, these plans have guided efforts to improve riparian habitat on several streams. Building on that work, creek restoration became one of the city's Millennium Projects and more than $14 million was spent on Urban Creeks Legacy improvements in 1999 and 2000. Logs have been placed to create pools where fish can rest and culverts have been redesigned or removed to restore the natural complexities of stream beds. Along the banks thousands of native shrubs and trees have been planted to replace invaders like Himalayan blackberry. Today at one location on Longfellow Creek, beavers returning to the improved habitat have pitched in with a dam of their own.

Seattle Public Utilities, which was consolidated from other city departments as a combined solid waste, water, wastewater and drainage utility in 1996, quickly embraced environmental stewardship as its unifying corporate mission. Given this focus and the other environmental forces at work, it wasn't long before SPU planners realized that NPDES regulatory goals, ESA requirements for habitat protection and community demands for creek restoration could not be satisfied with work along the creeks alone. The real solutions - stormwater control and pollutant reduction - had to take place upstream. Traditionally, that meant curbs and gutters, storm drains and pipes and at the bottom of the hill, large detention pipes or ponds, all in the end discharging into Lake Washington or Puget Sound - and likely into the creeks. Even then, without a stormwater treatment plant at the discharge point, the traditional infrastructure would not reduce the amount of this "non-point" pollution dumped into the receiving waters.

Therein lay the germ of the NDS idea. What if, instead of grabbing it in pipes, rain water was slowed and stopped at the source, in private yards and parking lots and along the city's streets, and allowed to soak into the earth? What if you could recreate or mimic the natural systems that existed before development, before roofs and driveways and streets took over the land? What would that look like?

Seattle's drainage system, or "Drainage 101"

In Seattle, what happens to stormwater depends on where it falls. The city has three different types of storm drainage systems - each serving about one-third of the city's area - created at different times in Seattle's development.

The oldest area, downtown and the neighborhoods immediately surrounding it, are served by combined sewers, pipes that collect sanitary sewage from offices and homes and, when it rains, also fill with water from roofs and streets. All this water - sewage and storm water combined - goes to sewage treatment plants before its release offshore, deep in Puget Sound. Unfortunately, in heavy rains, some of the combined sewer pipes reach and exceed capacity. At that point, to prevent sewage backups, as an emergency measure the system is designed to overflow directly into Puget Sound or Lake Washington. The city is required by NPDES regulations over time to steadily reduce these combined sewer overflows (CSOs). Generally, this has been done by increasing storage capacity with larger pipes or large underground vaults.

The second area includes those neighborhoods outside of downtown that were part of the city before 1950. In those areas, thanks to 1958 voter funding of Metro, a new county-wide agency to clean up Lake Washington, sanitary sewer mains - large trunk sewers - were constructed to intercept existing pipes and carry sanitary sewage direct to a new sewage treatment plant at West Point. Also in this area, new, separate piping was built to collect stormwater flowing into street drains, separating it from the sanitary system and sending the runoff untreated to Lake Washington and Puget Sound. This area is called "partially separated" because roof drains from most houses and commercial buildings still contribute stormwater to the sanitary sewers.

From both the combined and partially separated areas, storms add significant amounts of rainwater to the flow through sewage treatment plants, contributing to the burden on those facilities and limiting their capacities. That's why, in these areas

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The first SEA Street before and after

as well as in the creek-drained area described below, SPU planners are examining possible applications of NDS and other low-impact development techniques to mitigate stormwater peak flows and total volumes. Because these areas, particularly around downtown, are intensely developed, finding space for NDS applications in street rights-of-way is more difficult. Most of this area has curbs, gutters and sidewalks, suggesting smaller scale NDS applications and the use of NDS and other low-impact development (LID) techniques on private property.

Seattle's third drainage system type is primarily in the north end, an area annexed in 1954. There are similar, smaller areas near the southern city limits, also annexed after 1950. Here, as in the other parts of the city, the Forward Thrust interceptors ended the dumping of raw sewage into Lake Washington and Puget Sound. But most of these areas, particularly the residential neighborhoods, never received formal storm drainage systems. For the most part, except where Natural Drainage Systems have been constructed, rainwater flows off roofs and yards and streets, travels along street edges into drainage ditches, then through culverts under driveways and street intersections. The runoff eventually makes its way directly to the lakes and Puget Sound or flows into the remaining urban creeks in each of the four corners of the city. Carrying pollutants dangerous to fish and all the smaller creatures in their food chain, when it reaches the creeks this stormwater scours out the gravel where salmon spawn and washes away riparian vegetation. It's in this part of Seattle's north end where SPU planners and engineers first applied the SEA Streets NDS strategy.

A pilot project: The first SEA Street

Seattle Public Utilities drainage planners and engineers set a high standard. They wanted their new system (it didn't have a name yet!) to recreate the natural drainage performance of a pre-development pasture, mixed grassland and trees, not the roofs and streets of a city. Rain falling on pasture lands would naturally soak in, with very little surface flow, recharging groundwater and only gradually reaching nearby creeks. Under those conditions creek flow remained relatively constant year-round, perfect for fish. In contrast, runoff from developed neighborhoods is fast and strong and laden with pollutants during winter rains but relatively little rain soaks in to recharge groundwater. Summer creek flows dwindle below their natural levels, harming fish - if any remain. The new system, SPU staff decided, would mimic pre-development pasture conditions. This goal was more stringent than the City's drainage code, which at the time required developers to reduce but not eliminate peak runoff from a two-year, 24-hour storm (equal to 1.68 inches of rain in 24 hours) and a 25-year, 24-hour storm (equal to 3.13 inches of rain in 24 hours).

In the late 1990s, as part of the city's Urban Creeks Legacy Millennium Project, creek restoration work was underway in all four corners of the city where creeks form part of the drainage system. Of the four - Piper's Creek, Thornton Creek, Taylor Creek and Longfellow Creek - Piper's Creek was the best location for the pilot drainage project. The Piper's Creek watershed drains large areas of the Broadview and Greenwood neighborhoods through Carkeek Park into Puget Sound. A crude ditch and culvert systems in the north part of the watershed and underground storm drains in the south prevent localized on-street flooding and speed water into the creek. Community activism played a role, too. A neighborhood group, the Carkeek Watershed Community Action Project, had been the most active in the city in promoting creek and salmon habitat restoration, and had developed a Watershed Action Plan.

SPU staff went to the public with their drawings of streets with drainage swales and shrubbery on either side, areas where water would form temporary ponds in heavy rains and then slowly drain or disappear into specially engineered absorbent soils. On one long block in the Broadview area, this new design would replace the gravel shoulder and surface drainage in front of everyone's home. A sidewalk would be added on one side of the street and parking areas matching residents' use would be provided.

Based on preliminary criteria (not a steep grade, houses set above street level), SPU identified more than two dozen blocks that would work. At a public meeting for those whose streets qualified, the staff asked neighbors to get together and send in a simple petition if they, as a group, wanted to go ahead. Along with the specific characteristics of the petitioners' block, the highest level of interest would determine the choice of the project street. There would be no cost to homeowners.

SPU chose the block between NW 117th and NW120th streets on Second Ave. NW as the best candidate from among several groups that applied, and began a series of meetings with the homeowners to talk through design issues (assuring that sufficient parking would remain was key). They explained how the new drainage system would work and that homeowners would in the end be responsible for maintaining the landscape elements, including more than 100 new evergreen trees and 1,100 shrubs along the swales. SPU staff believe this complete involvement of residents from beginning to end was essential to SEA Street's success.

Looking north along Second Avenue NW from NW 117th Street, before and after

Key requirements for project success

- Involve neighborhood residents in all phases of the project, from earliest concepts through all phases of design and construction. In the end, it's their street and they'll be responsible for maintenance in the years to come.
- Provide the residents with easy to understand graphics to show the proposed final design, so they understand the design before construction begins.
- Approach each project with a comprehensive, interdepartmental project team. The team should be staffed with problem-solvers representing every concern.

Obstacles in the early going

Now, just six years after completion of the first SEA Street in 2001, public acceptance of Natural Drainage Systems makes it easy to forget what a radical departure the design was. There was a lot of skepticism among residents and from professionals in other city departments with time-honored ways of doing things.

Even community members had in mind something different before seeing the SEA Street designs. They wanted - and had wanted since their neighborhoods were annexed to Seattle in the early 1950s - the same curbs, gutters, sidewalks and concrete paving with piped storm drainage (underneath, out of sight) that they saw in neighborhoods closer to the city center. Furthermore, many residents treated significant

How do we know it works?

For the winter prior to construction of the first SEA Street, SPU consultants from the University of Washington (see References) monitored runoff from the block. The monitoring was continued after construction and showed that in the first year the SEA Street NDS reduced flow from the block to only 2% of pre-project runoff. The subsequent years of monitoring showed even better performance, with only 1% of pre-project runoff leaving the street. This high level of stormwater control continues today.

sections of the right-of-way in front of their homes as private property, considering the parking there to be their own, and often landscaping the public areas as continuations of their front yards. More than 15 feet on either side of the existing pavement was "reclaimed" by the SEA Street design which used the full 60-foot right-of-way. Through a series of public meetings, residents of the project street came to understand and accept this and work with the designers on the finished product. It's a testament to the power of NDS designs that most residents on SEA Streets now believe their streets are more interesting and look better than traditional neighborhood streets. SPU and residents also believe SEA Streets have enhanced property values. However, research to validate this is a future project that will require a larger sample of property sales on SEA Streets and, for comparison, on nearby unimproved streets.

Other obstacles came from within the city family. SPU's own staff was trained and proficient in designing and building stormwater conveyance and detention systems. Those things work. Would planted swales perform as hoped? Could the runoff from acres of development really be controlled and infiltrated by streetside "swales?" Skepticism prevailed.

Other departments also had their doubts and brought those to the table. Before agreeing to design the street, the Seattle Department of Transportation (SDOT) took a long, hard look at SPU's proposals to narrow the pavement and introduce graceful curves on the first SEA Street. Curving the street allowed different widths and depths for the drainage swales on either side of the roadway. (Altogether, departures from typical roadway and sidewalk design cut by 11 percent the amount of hard surface on the project block.) The roadway width - a narrow 14 feet with 18-foot flares at intersections - and locating a sidewalk on only one side of the street were among the most debated issues. Importantly, the Seattle Fire Department had to be satisfied that emergency vehicles could get through without problems.

The solution was collaboration. SPU assembled a broad-based interdepartmental project team that worked closely together and with SEA Street residents throughout the design and construction process. SPU believes that a collaborative approach remains essential to the use of NDS and other low-impact development technologies in the solution of urban drainage problems.

Infiltration swales along the first SEA Street

The NW 110th Street Cascade, first year

Cloning success: SEA Streets & Cascades in other neighborhoods

Carkeek Cascade at NW 110th Street

Not far from the original SEA Street, large volumes of storm runoff pour down from Greenwood Avenue North, an arterial lined with apartment buildings and condominiums. The runoff courses through the ditches along neighborhood streets and into Piper's Creek. The ditch and culverts along N/NW 110th Street, overloaded with the runoff generated by 21 acres along Greenwood Ave and the adjacent residential neighborhood, were the next challenge for SPU drainage planners.

Controlling the heavy flows that came down the slope (varying from 1% to a reasonably steep 8%) called for a more robust system. The ditch that the new system would replace had been asphalt-lined to prevent erosion, and heavy storms filled the culvert at the bottom and sent sheets of water across Third Ave. NW, a north-south arterial. To deal with this powerful flow, the natural model would turn out to be a mountain stream.

To slow water from a two-year, 24-hour storm and lesser rainfall, the 110th Street Cascade uses a series of shallow, rock-bottomed pools which step gradually down the slope behind a series of check dams designed as weirs to temporarily detain flow within each swale. In addition, the Cascade provides water quality treatment per City code for the 6-month, 24-hour storm. First, the slowing of the stormwater allows solids and the pollutants that bind to them to settle out. Infiltration of the 3 inches of water held in each pool then causes pollutants to be trapped in the soil. The Cascade extends from Greenwood Ave. N west for four blocks (about 1,300 feet) to Third Ave. NW, just two blocks outside Carkeek Park. Extensive plantings have grown to almost obscure the flow control features of the Cascade since its completion in late 2002.

A series of shallow, rock-bottomed pools which step gradually down the slope behind a series of check dams designed as weirs temporarily detain flow within each swale.

110th Cascade - How do we know it works?

SPU again contracted the University of Washington to conduct project monitoring, comparing flow volumes and water quality from an upstream station to a downstream station. Monitoring shows that the system infiltrates at least 48% of all inflows from the upstream station and likely up to 74% of all inflows when modeling is used to predict inflow from streets downstream of the inflow monitoring location. The system released water in only 49 of 235 storms between October 2003 and March 2006. Water quality monitoring of total suspended solids, total nitrogen, total phosphorus, copper, zinc, lead and motor oil found the following removal rates based on mass loading: total suspended solids (TSS), 84%; total nitrogen, 63%; total phosphorus, 63%; total copper, 83%; dissolved copper, 67%; total zinc, 76%; dissolved zinc, 55%; total lead, 90%; and motor oil, 92%. (See References.)

Broadview Green Grid

The Broadview Green Grid, also in the Piper's Creek watershed, was built to demonstrate the NDS techniques of SEA Streets and the 110th Street Cascade on a relatively large scale, and to provide scientific monitoring on a project-basin scale. The 15-block* Green Grid includes four parallel SEA Streets between the Cascade on N/NW 110th Street and a new, six-block Cascade on N/NW 107th Street. The 107th Cascade collects runoff from the Green Grid's SEA Streets, a 10-acre area. In addition, like the first Cascade on 110th, it slows and infiltrates stormwater from an additional 22 acres along heavily developed Greenwood Avenue North.

The Green Grid SEA Streets swales and Cascade pools were designed to provide decentralized stormwater flow attenuation and water quality treatment through the swales using surface storage in combination with healthy soils and plants. The water quality treatment standard is the same as required for any development with new impervious surfaces by the city of Seattle's drainage code - complete treatment of the runoff from a six-month, 24-hour storm- but here it is done by natural means. The swales and Cascade pools also reduce the peak and duration of flows from two-year flood events as well as all storms of lesser intensity. Built with soils specified to have varying degrees of organic matter to control infiltration depending on location and purpose, the Green Grid swales absorb water at rates between 0.5 and 1.5 inches per hour. All ponded water in the swales must - and does - disappear through infiltration within 72 hours of the end of a rainstorm to prevent mosquito breeding.

Just west of Fourth Ave. NW, flow from the 107th Cascade enters a pipe which carries it down the hillside and discharges into Piper's Creek. Construction was completed in 2004 and landscaping in 2005.

* The street grid in the Broadview area of Seattle has long blocks of approximately 630 linear feet oriented north-south, the direction of flow of the SEA Streets, and shorter blocks of approximately 315 linear feet running east-west, the direction of flow of the Cascades. In the Green Grid, a "block" is considered approximately 315 linear feet on one side of a project street so that a SEA Street is two blocks long.

Broadview SEA Streets just after planting

High Point photos by Anthony Harris

High Point: An immense opportunity

Built as temporary workforce housing during World War II, the 750 single- and two-story duplexes of West Seattle's High Point housing project were more than ready for replacement when the federal government created the HOPE VI program to raze out-moded low-income housing. As it had with two similar HOPE VI projects completed earlier, the Seattle Housing Authority (SHA) planned a mixed-income development that included rent-subsidized townhouses and multiplexes, a low-income apartment building for seniors, and market-rate townhouses and single-family homes. The first half of the project, 419 rental units and 411 market rate homes, was opened in phases during 2005 - 2007. By 2010, the completed project will consist of 1,600 units.

Streets throughout the 129-acre project, many originally ending in suburban-style

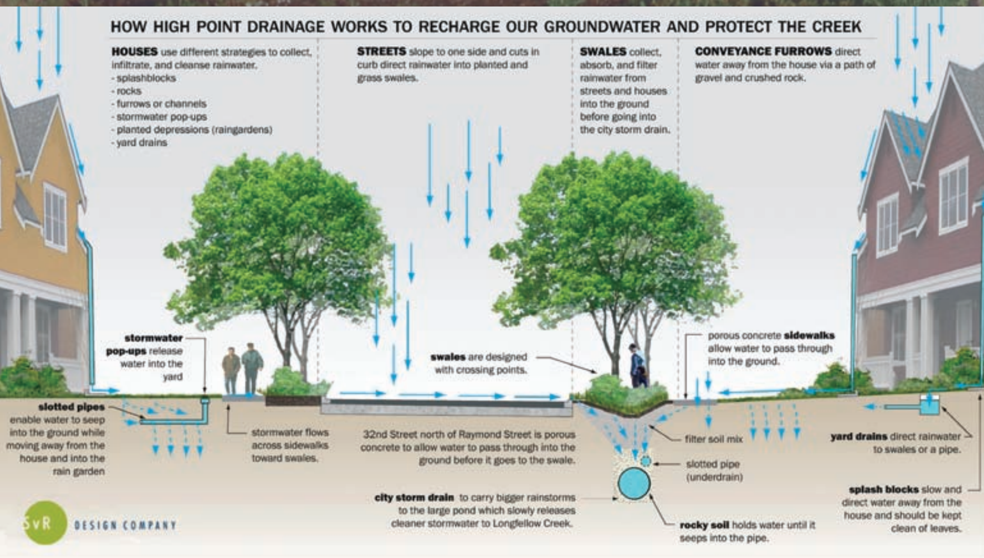
Grassy and vegetated swales at High Point

cul-de-sacs, were relocated, reconnecting them to the city's street grid and ending the physical isolation of the community. Most important from Seattle Public Utilities' point of view, High Point and its bordering green belt make up 8 percent of the Longfellow Creek watershed. The redevelopment provided a chance to apply Natural Drainage Systems on a large scale - properties of High Point's size are rarely available in urban areas - and to significantly effect flow volumes and water quality in the largest creek remaining in southwest Seattle. To this end, in 2004 SPU and SHA entered into a Memorandum of Agreement that NDS strategies would be incorporated into the project. To meet SHA's need to minimize expense, SPU agreed to pay costs above the estimate for a traditional drainage system, about $2.7 million. The funding included a low-interest loan from Department of Ecology's Centennial Clean Water Fund which sought to promote the NDS approach. Requirements were also placed on the drainage covenant and plat agreement establishing impervious surface coverage limitations, designated discharge points and roof area drainage discharge limits. Low-impact development (LID) technologies, the building blocks of Natural Drainage Systems, were required as mitigation for deviation from these standards or increases in impervious surface.

The High Point NDS was designed to a standard higher than the Seattle drainage code, requirements expected to reduce runoff to pre-development levels. With drainage code revisions planned for the near future, SPU saw that High Point provided the opportunity to see if these higher standards could be met using a combination of NDS technologies and a traditional detention pond. This was a significant challenge. At High Point, 65 to 70 percent of the project acreage - roofs, streets and sidewalks - would be impervious surface, compared to 45 percent or less in the Broadview and first SEA Street NDS areas.

Remarkably, but not really surprising to the SPU planners and engineers who were becoming steadily more confident in their new technologies, the High Point NDS design reached the targeted runoff-reduction levels and reduced the size of the detention pond. To achieve the same stormwater benefit with a traditional piped street drainage system would have required a detention pond with five times the volume.

After six years of planning and construction, the Natural Drainage System at High Point is meeting its goals of stormwater flow attenuation, filtration, and bioremediation of pollutants by healthy soils and plants. The design also reduced impervious surface and



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increased vegetation along streets and in public areas. The project preserved 107 decades-old "legacy trees" for their drainage and aesthetic benefits and, at completion of Phase II, more than 3,000 new trees will have been planted at High Point. In the end, Longfellow Creek will receive no more flow from High Point during and after a two-year, 24-hour storm than it would if the 129-acre site were still a grassy pasture.

Among the NDS techniques that work together at High Point:

- Vegetated bioretention swales with under-drains on one side of most streets provide filtration and bioremediation of pollutants. They also delay the time it takes water to reach the detention pond and hence Longfellow Creek. From the streets, water enters the swales through curb cuts. From adjacent properties, water not absorbed by rain gardens or compost-amended lawns also flows into the swales.
- The system meets water quality standards by treating runoff from a six-month, 24-hour storm.
- The majority of downspouts are disconnected. Artist-designed splash blocks disperse roof water for infiltration through rain gardens, infiltration zones or composted amended gardens and lawns. Excess water flows into the streetside swales.
- Among the denser housing, grassy play areas store stormwater underneath as needed.
- To minimize impervious area, one-half of sidewalks and one block of a residential street were made with porous concrete pavement, providing SDOT and SPU a chance to test the technology. Most off-street parking areas use other pervious materials such as pavers or crushed stone.
- Most of the streets are narrower than standard for similar Seattle residential areas, 25 feet, compared to 28 or 32, reducing impervious surface and calming traffic. Traditional curb and gutter construction with curb cuts to channel street drainage to 12-foot wide swales between street and sidewalk also demonstrates that this design can be applied as a retrofit to existing city streets.
- A piped conveyance system picks up overflows from 25-year and larger storms.
- The majority of drainage from the project area enters the detention pond. Peak and duration of stormwater discharge matches predevelopment pasture conditions for the two-year storm frequency. The pond also provides peak-flow control for 25-year and 100-year storms.

To achieve the same stormwater benefit with a traditional piped street drainage system would have required a detention pond with five times the volume.

Anthony Harris

The Pinehurst NDS locates large, deep swales on one side of the roadway

Pinehurst before

Photos except "Before" by Anthony Harris

Pinehurst Green Grid

The several branches of Seattle's Thornton Creek drain almost 12 square miles in northeast Seattle and the city of Shoreline north of Seattle. The area includes major commercial developments, among them Northgate Mall, where in 2007 NDS features to control parking lot drainage were just being constructed. As in the Piper's Creek watershed where the first SEA Street was built, the extensive residential areas in the Thornton Creek drainage send significant storm flows rushing into the creek. Local flooding due to the limits of the ditch and culvert system is a common problem.

In 2004, SPU began design of Pinehurst Green Grid. Building on the experience from Broadview Green Grid, designers could more confidently model flows and system performance. As a result, they were ready to try new designs for the street-side swales, merging elements from the SEA Streets model and the high volume Cascades. Here, the newly paved street was placed on one side of the right-of-way, allowing for larger swales to provide natural drainage on the other. The new, larger swales provided another benefit, too. SPU drainage designers found that the new swales could handle runoff not only from the adjacent street and houses but from an area three to five times that size. The additional capacity allowed for a system that would accept runoff from cross streets and other nearby streets that therefore did not need reconstruction for swales.

Because of these design changes, the six 660-foot long SEA Streets blocks in the Pinehurst neighborhood also control runoff from six additional blocks which received drainage improvements such as conveyance ditches and culverts but not swales and landscaping. These blocks direct flow from a total of 49-acres into the blocks with Natural Drainage Systems for treatment of pollutants and infiltration of the runoff. This again lowered costs for Green Grids.

In Pinehurst, permeable pavement was used for the first time for some of the rebuilt street-to-driveway connections. Otherwise, the NDS streets provided the same amenities developed on the first SEA Street: A new sidewalk on one side of the street (previously, there were no sidewalks at all), a new roadway which

Comparison between Pinehurst Natural Drainage System and traditional street and drainage design
Using Seattle Public Utilities' asset management life-cycle cost analysis

Project Basin Options	Number of Project Streets	Pros	Cons	Annualized Drainage Volume Reduction (gal.)	Achievement of Conveyance Goal	Percentage of Volume Reduction Goal [1]	Percentage of Drainage Peak Reduction Goal [1]	Achievement of Water Quality Goal	Achievement of Neighborhood Goal	Average Annual Maintenance Costs	Estimated Project Cost
Option 1 Do Nothing	0	• No capital cost expenditure	• Does not meet any project goals	0	No	0%	0%	No	No	$11,000	$0
Option 2 NDS	11.5	• Achieves all project goals except peak flow reduction • Achieves the highest level of peak flow reduction • Option is the most cost-effective	• Capital expenditure • Higher maintenance costs than Do Nothing	9,700,000	Yes	100%	51%	Yes	Yes	$18,800	$4,600,000
Traditional	11.5	• Achieves same number and level of project goals as Option 2	• Highest cost option • Mid range of maintenance costs • Must acquire 6 properties	9,700,000	Yes	100%	51%	Yes	Yes	$14,000	$8,854,000

Notes
1) Volume and peak goal levels are reported at project basin outfall.
2) Goals for project set at a minimum target of replicating the pre-developed condition for the 6-month storm, but targeting the 2-year storm.
3) Goal achievement in this table reported for the 2-year storm.

was narrower to reduce impervious surface, extensive landscaping in and around the drainage and bioretention swales and new trees along the streets.

The Pinehurst Green Grid includes 12 city blocks between NE 113th St. to NE 117th St. and 16th Ave. NE and 23rd Ave NE with additional work at the intersection of NE 113th St. and 25th Ave. NE. It was constructed and landscaped between July 2005 and April 2007.

A Pinehurst swale shortly after project completion

Photos by Anthony Harris

The next challenge: Adapting NDS to densely developed areas

SPU's Natural Drainage Systems have been hugely successful in neighborhoods where the streets have lacked curbs, gutters and sidewalks and the piped drainage systems which accompany them. But those areas are not the only ones that present the city with drainage problems. In the areas with combined sanitary and storm sewers, combined sewer overflows (CSOs) that may occur during heavy rains send raw sewage into Lake Washington and Puget Sound. SPU is under federal and state regulatory order to reduce its CSOs. That means reducing the peak flows from rain storms. This can be accomplished, as traditionally, in large part with end of pipe detention tanks, or part of the job can be done upstream with NDS technologies.

Beginning in 2008, the city's revised drainage code plus "Rainwise" drainage rate credits will focus on reducing the impact of stormwater from private property. The Natural Drainage System program will continue to focus efforts on flows from public

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Vine Street Cascade in downtown Seattle

Anthony Harris

Below: 30th Avenue NE in Seattle's Lake City neighborhood

rights-of-way (more than 25 percent of the urban area) as well as the private property that directs runoff to the right-of-way. Currently, SPU planners are looking at NDS strategies to control, clean and infiltrate storm runoff from more densely developed neighborhoods. In order of increasing effectiveness, here are a number of proposed techniques:

A. Retain existing large street trees to maintain the canopy which intercepts rainwater and facilitates evapotranspiration.

B. Construct infiltration and conveyance trenches in planting strips to provide detention and infiltration depending on design.

C. Reduce surface flow by direct infiltration through porous pavement on sidewalks or streets.

D. Build linear bioretention systems in planting strips or by interconnecting tree pits along a street. These systems use special soil mixes, sometimes in subsurface soil vaults that promote tree root growth, runoff treatment and infiltration depending on design. These systems can be built with or without curb and gutter.

E. Construct interconnected vegetated swales similar to SEA Streets using the planting strips and part of the roadway through elimination of parking on one side in residential neighborhoods. Stormwater enters the swales from the sidewalk and from the street through curb cuts. Where driveways cross planting strips, pipes connect the swales.

F. Where feasible, flows can be separated from the combined system, treated using bioretention or biofiltration as described above and discharged to large receiving water bodies.

Case study: A Natural Drainage System in a developing commercial neighborhood - the Capitol Hill Water Quality Channel or "the Swale on Yale."

Seattle Public Utilities' "Swale on Yale" applies NDS techniques to a redeveloping, high-density commercial area north of downtown. To be located on Yale Ave. N in the South Lake Union neighborhood, four blocks of interconnected swales in an extra-wide planting strip between street and sidewalk will provide treatment for one-third of the stormwater runoff from a 600 acre drainage on Capitol Hill, one of the most densely developed multi-family and commercially-zoned neighborhoods in the city.

Because of its dense development, stormwater runoff from the streets of Capitol Hill carries a heavy pollutant load directly to Lake Union. When the Swale on Yale is complete, runoff from moderate rainfall and the first 10 cubic feet per second (cfs) of flow from larger storms will be diverted from an existing storm drain into a pretreatment vault where trash and large particulates are screened or settle out. From the vault, runoff will flow into one of four swales.

Each of the four swales will be about 270 feet - one block - long and 10-ft wide at the bottom. The width and length of the large swales and short, dense vegetation to be planted throughout will act together to slow runoff and provide water quality treatment by allowing sediments and pollutants to settle out. It will take about 10 minutes for water to flow through each swale, sufficient time for pollutants to settle, meeting Washington State water quality treatment standards.

The Swale on Yale has been designed to treat a maximum amount of stormwater in the area available. Each separate block will be able to treat runoff from more than 50 acres of the Capitol Hill drainage. To achieve high-volume treatment, infiltration into the soil is not part of the design or function of the swales. Storm water flowing into Lake Union will be cleaner, but not noticeably reduced. The Swale on Yale NDS project will remove an estimated 40 tons

It will take about ten minutes for water to flow through each swale, sufficient time for pollutants to settle, meeting Washington State water quality treatment standards.

The "Swale on Yale" between street and sidewalk in a commercial area

Anthony Harris

of total suspended solids (TSS) annually. (TSS is a surrogate for pollutant loading.) The design meets the Washington Department of Ecology performance goal of 80% reduction in TSS for runoff passing through the swales.

Swales such as the connected system being build on Yale Ave. N., can fit into a typical existing 60-ft street right-of-way in place of a parking lane and with the sidewalk narrowed from eight or ten feet to six. In the South Lake Union area, one story warehouses and offices are giving way to multi-story mixed-use retail, office and residential buildings. Because Swale on Yale construction can be coordinated with new development along the four blocks, the swales will be integrated with adjacent buildings to create an exciting urban streetscape.

As of mid-2007, the Swale on Yale was in the preliminary design phase. Construction could begin as early as 2008. Completion of all four blocks is dependent on the rate of adjacent redevelopment and may take several years. The total cost of the Swale on Yale is $5 million to $6 million.

Awards for Seattle's Natural Drainage Systems projects

Kennedy School of Government, Harvard University, Innovations in American Government Award, 2004. The award included a $100,000 prize supporting expansion of SPU's NDS program.

Puget Sound Regional Council, 2020 Vision Award, 2003 and 2007.

Glossary

Biofiltration is a water pollution treatment technique using plants and living soils to filter out or enhance the chemical breakdown of pollutants. In Natural Drainage Systems this often takes place in engineered bioswales where stormwater flow is slowed to allow solids and pollutants attached to them to settle out or be captured by plants growing in the bottom and on the sides of the swales.

Design storm. A design storm is a statistical construct that is based on historical records of storm frequency and intensity of rainfall that drainage engineers use as a benchmark for designing traditional or natural-drainage stormwater control facilities. Seattle regulations require on-site water quality treatment for stormwater runoff from a six-month, 24-hour design storm, which is defined as having 1.08 inches of total rainfall in 24 hours and is statistically likely to occur once every six months. In addition to water quality treatment, Seattles regulations require on-site control of the peak discharge rate and runoff volume from storms with recurrence intervals of two years or greater. The two-year, 24-hour storm is defined as 1.68 inches of rainfall in 24 hours and is statistically likely to occur every 2 years.

Low-Impact Development (LID) is the use of building and infrastructure construction technologies that minimize the life-cycle environmental impact of constructing storm drainage and other public and private facilities. Often, as with Natural Drainage Systems which make use of healthy plants and soils for stormwater treatment, these techniques mimic or take advantage of natural processes rather than complex or mechanical systems. In buildings, examples would be increased use of natural light and opening windows to reduce lighting and ventilating equipment use and power demand.

Natural Drainage Systems - The use of low-impact development technologies to mimic the earth's natural hydraulic processes to control stormwater and remove pollution from runoff. NDS systems may include use of trees and plants and special soils in vegetated swales, cascades (a series of small dams or weirs), rain gardens (ponds that dry after a rainfall), porous pavement, disconnection of downspouts from storm drains and rainwater harvesting.

Non-point pollution is water pollution caused by stormwater runoff from streets, parking lots, roofs and other widely distributed sources carrying pollutants such as oils and metals into streams, rivers, lakes and salt water bodies in contrast to pollution arising from a specific source such as an industrial waste discharge.

Swale, bioswale - A swale is a low spot or channel, often with plantings along the sides and bottom, where storm runoff may pond temporarily for infiltration or through which runoff may slowly flow so that pollutants will settle out or be captured by the vegetation.

References, additional information and technical documents

All of the references and documents used to develop this manual and extensive additional references and technical details including plans and specifications for Natural Drainage Systems projects are available on the Seattle Public Utilities web site, www.seattle.gov/util/services. Enter Natural Drainage Systems in the search box. For telephone inquiries call the SPU media relations office at (206) 684-7688.

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City of Seattle

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Seattle Public Utilities, Chuck Clarke, Director

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