Watershed Review
information on water and watersheds

Center for Water & Watershed Studies

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Message from the directors

Welcome to the first issue of the *Watershed Review*, the quarterly newsletter of the Center for Water and Watershed Studies. This center was formed through the merger of two water-related centers at the University of Washington, the Center for Streamside Studies and the Center for Urban Water Resources Management. This newsletter is the latest expression of that merger. The new center maintains the overall goals of its predecessors, namely scientific ***research*** on topics of water resources and watersheds, ***education*** of the students who will become the region's and the nation's practicing professionals in only a few years, and ***outreach and technology transfer*** of the results and implications of the work at the University to the wider professional community.

We have combined the formats of the previous Centers' newsletters. *Streamside Runoff*, the publication of the Center for Streamside Studies, was a 4-page semiannual publication sent free of charge to a mailing list of about 4000. *The Washington Water Resource,* the publication of the Center for Urban Water Resources Management, was an 8- to 14-page publication sent quarterly to about 100 paid and complementary subscribers. In an effort to increase our outreach, we are now offering three different, and complementary, formats:

1. A 4-page newsletter, which will be published quarterly and sent free of charge to the entire combined mailing list of the two centers.

2. This 8- to 12-page newsletter, which is being sent to all current subscribers to the *Washington Water Resource* to complete their 2002 subscription. This format will continue to be published quarterly and mailed as paper copies to all who wish to continue to receive it. It will contain more complete versions of the articles included in the shorter newsletter, but we will charge you for this alternative—both to defray our printing and mailing costs, and to provide an opportunity for agencies and companies to help support the Center financially. Instructions for making an on-line subscription for 2003 are printed on page 12 of this newsletter.

3. Web-based postings of both the short and long versions of the newsletters, available free of charge at http://depts.washington.edu/cwws.

We hope the expanded scope of the new Center will meet your needs and interests more fully than either of our individual efforts was able to in the past. Please let us know if you have any questions. ■

Sincerely,
Derek Booth (co-director)
Clare Ryan (co-director 2002-2003)
Susan Bolton (co-director; on leave 2002-2003)

In this issue

Salmon or power?

Study shows Northwest will be faced with tough choice

By Rob Harrill, UW News and Information
Originally published in University Week, *November 21, 2002*
(http://www.uweek.org/)

People living in the Pacific Northwest will likely face a difficult choice in coming decades as global warming alters the region's climate — they can have water for hydroelectric power or water for salmon runs, but not both. That's one conclusion of a new study, the most rigorous to date of potential impacts on water issues in the Western United States during the next 50 years as greenhouse warming begins to heat up the planet.

"We asked the question, 'Could you mitigate the effects by operating the reservoir system differently?' And the answer, at least in terms of the fish, is probably not."

"The choices are rather stark," said Dennis Lettenmaier, professor of civil and environmental engineering at the UW and one of the researchers contributing to the study. "We asked the question, 'Could you mitigate the effects by operating the reservoir system differently?' And the answer, at least in terms of the fish, is probably not."

The study looks at the implications of climate impact as it relates to water resources in three major hydrologic basins in the Western United States: the Columbia River; California's Central Valley, which includes the Sacramento and San Joaquin rivers; and the Colorado River. The work was conducted by the Accelerated Climate Prediction Initiative, a consortium of a number of agencies, including the UW, Pacific Northwest National Laboratory and Scripps Institution of Oceanography. Along the Columbia River basin, the major issue isn't changes in the amount of precipitation. It has more to do with a receding snowpack, which will reduce natural water storage and affect when water is available. The model predicts that, by mid-century, the yearly average snowpack in the Washington and Oregon Cascades could be reduced by as much as 50 percent.

That would result in big changes in water flows and temperatures in Cascade rivers and streams. "If you warm things up, the snow melt peak occurs earlier and the summer flows are lower so the reservoir is working harder to move that water from when it wants to occur naturally to later in the year when you want it for fish," Lettenmaier said. "That is a hurdle you basically just can't get over." In fact, the window for successful salmon reproduction in the Pacific Northwest may become so shortened by climate change that some species could cease to exist, regardless of what water policies are adopted.

The water resources outlook for the next half-century appears troubled for not just the Pacific Northwest. Climate changes could have a devastating impact in California and along the Colorado, too. The Colorado River reservoir system, according to the study, will not be able to meet all of the demands placed on it—including supplying sufficient water for Southern California and the inland Southwest. Reservoir levels are projected to be reduced by as much as one third and releases by as much as 17 percent. The reason is that the Colorado system is currently in a sort of fragile equilibrium - currently the annual average flow is only slightly larger than the amount of water taken out. "So you're fairly close to a balance point," Lettenmaier said. "But the problem is that you have slight projected decreases in precipitation. And if you reduce the flow by just a bit, that makes a big difference in the average storage in the system."

The upshot is that all users of Colorado River hydroelectric power will be affected by lower reservoir levels and flows, which will result in reductions in hydropower by as much as 40 percent. In addition, the ability to deliver water to lower basin users will be impacted, as will the ability to provide water to Mexico in amounts required by international treaty.

In California, the study indicates that it will be impossible to meet current water system performance levels. As a result, water supplies will be less reliable, as will hydropower and instream flows. With less fresh water available, the Sacramento Delta's ecosystem could be disrupted by a dramatic increase in salinity.

Bill Pennell, director of the Atmospheric Science and Global Change Division at Pacific Northwest National Laboratory, said the study underlines the need for planners and policy makers to pay attention to climate change. "Population and economic growth already are placing severe strains on water resources in the West," Pennell said. "Climate change is one

Continued on page 10

Non-point source nutrient impacts:

Stream nutrient concentrations along a forest to urban gradient

Michael T. Brett, Sara E. Stanley, George B. Arhonditsis, (Dept of Civil & Environmental Engineering, University of Washington), David M. Hartley, Jonathan D. Frodge, and David E. Funke (King County Water and Land Resources Division)

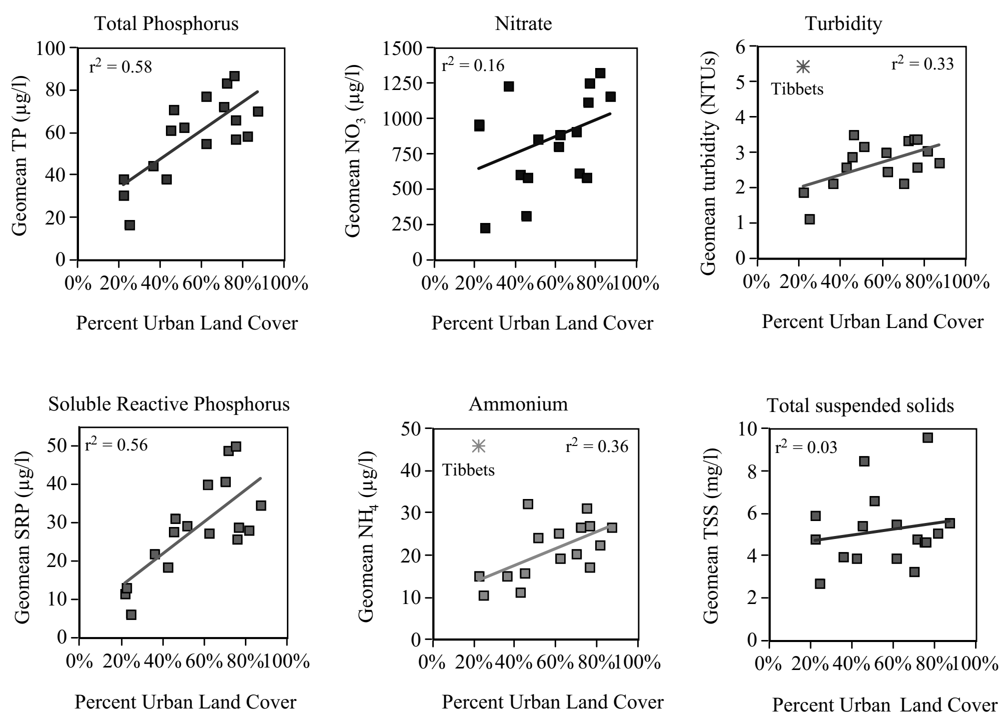
This joint University of Washington-King County study was based on a statistical analysis of long-term records of stream nutrient and sediment concentrations for 17 streams in the greater Seattle region (Big Bear, Cedar, Coal, Evans, Forbes, Issaquah, Juanita, Kelsey, Little Bear, Lyon, May, McAleer, Mercer, North, Swamp, Thornton, and Tibbets). These watersheds are strongly dominated by either urban or forest land cover, with little agricultural area; all data had been previously collected by King County as part of their ambient stream-monitoring program.

Highly urban streams had on average 109% higher total phosphorus (TP) concentrations, 159% higher soluble reactive phosphorus (SRP) concentrations, 29% higher nitrate concentrations, and 71% higher ammonium concentrations during baseline (low-flow) conditions. Turbidity was 72% higher in urban streams but total sus-pended solids (TSS) concentrations did not vary with land cover. Geometric mean nutrient and sediment concentrations were for the most part weakly correlated during baseline conditions, except ammonium and turbidity which were strongly correlated ($r^2 = 0.81$).

During storm events, TP concentrations increased relative to baseline conditions by 41 ± 26% (mean ± 1 SD), ammonium increased by 68 ± 36%, turbidity increased by 168 ± 74%, and total suspended solids (TSS) increased by 220 ± 113%. TP, ammonium and turbidity were also higher in urban streams during storms. However, the concentration change during rainstorms for these constituents was not related to land cover. The responses of TP, turbidity, and TSS to rainstorms were strongly cor-related ($r^2 = 0.79$-0.98). SRP and ni-trate concentrations decreased in urban streams during rainstorms by 11 to 25% respectively, and they increased in forest streams by 23 to 39%, respectively. These trends were moderately related to land cover ($r^2 = 0.55$ and 0.67, respectively). These results suggest that rainstorms wash inorganic nutrients out of forested catchments.

On a seasonal basis, peak concentrations varied by parameter. Specifically, turbidity and TSS concentrations peaked during winter high flows, SRP concentrations peaked during summer low flows, nitrate concentrations peaked during the winter, and ammonium concentrations peaked during the fall.

Overall, these results suggest urbanization will increase stream dissolved inorganic nutrient concentrations by about 60 to 200% and will change the way stream inorganic nutrient concentrations respond to rainstorms. Nutrient enrichment observed in Seattle-area urban streams was substantially less than the nutrient enrichment in agricultural streams noted by prior investigations. Previously studied agricultural streams had about twice the phosphorus and three times the nitrogen as observed in Seattle-area urban streams. These results should be useful to predict how changing land use might impact stream nutrient transport and the potential for stream and lake eutrophication. ■



Bivariate plots of percent urban land cover versus geometric mean constituent concentration for the 17 streams. Asterisked data were excluded in calculations of regression coefficients.

Hydrologic monitoring of the Seattle Ultra-Urban stormwater management projects

By Richard R. Horner, Heungkook Lim, and Stephen J. Burges (Dept. of Civil and Environmental Engineering)

Abstract

Seattle Public Utilities constructed two drainage projects in the northwestern part of the city to decrease stormwater quantities discharged to Pipers Creek, with the goal of reducing channel erosion there and water pollutant loadings to the stream. One project, the Viewlands Cascade Drainage System, replaced a narrow, partially concreted ditch with a wide series of stepped pools. The second installation, at 2nd Avenue NW and known as a Street Edge Alternatives ("SEA Streets") project, involved the complete reconstruction of the street and its drainage system to reduce impervious area and install stormwater detention ponds. These projects have been monitored for flow in relation to precipitation to determine their actual benefits. Flow was sensed with shaft encoder floats and pressure transducers that recorded water depths behind V-notch weirs. Precipitation was recorded using tipping bucket gauges.

Monitoring has demonstrated that the Viewlands Cascade is capable of reducing the influent runoff volume by slightly more than one-third during the wetter months and overall for the year. Based on estimates for the ditch that preceded the Viewlands Cascade project, the new channel reduces runoff discharged to Pipers Creek in the wet months by a factor of three relative to the old ditch.

The 2nd Avenue SEA Streets project has prevented the discharge of all dry season flow and 98 percent of the wet season runoff. It can fully attenuate the runoff volume produced by approximately 0.75 inch (19 mm) of rain on its catchment. Based on estimates for a street drainage system design according to City of Seattle conventions, the SEA Streets alternative reduces runoff discharged to Pipers Creek in the wet months by a factor of 4.7 relative to the conventional street.

Despite serving a catchment less than 10 percent as large as the Viewlands Cascade, the 2nd Avenue NW project retains over one-third as much runoff volume in the wet season as Viewlands, and thus it has higher efficiency on a unit-area basis. However, when normalized in terms of the cost per unit catchment area served, the SEA Streets project is considerably less cost-effective than the Cascade channel.

Background and objectives

The City of Seattle has launched a program to protect and improve the health of the City's freshwater ecosystems. Creative approaches are necessary to manage stormwater in urban areas, since impacts from the developed watershed significantly influence the health of the stream. As such, the National Marine Fisheries Service (NMFS) requires quantitative relationships between stormwater management activities implemented in the watershed and benefits to the associated stream ecosystem. The Washington Department of Ecology (WDOE) is moving in the same direction under the City's stormwater National Pollutant Discharge Elimination System (NPDES) permit.

In the summer of 1999, Seattle Public Utilities (SPU) established a memorandum of understanding with the University of Washington's Center for Urban Water Resources Management to assist in the evaluation of various stormwater management Capital Improvement Projects. The work under the agreement involves testing a variety of innovative "ultra-urban" stormwater management techniques and documenting their benefits with quantitative data. In this context "ultra-urban" is defined as any built environment within the City of Seattle, including a variety of industrial, commercial, residential, and mixed land use types. The first stormwater management projects proposed for testing apply mainly to single-family residential and neighborhood commercial areas.

The broad objectives of the series of ultra-urban studies are to:

1. Determine how effective the selected projects are in reducing peak rates and volumes of runoff;
2. Evaluate receiving water ecosystem benefits that could be achieved with widespread application of these project types; and
3. Develop a long-term, systematic approach to ultra-urban stormwater management in Seattle.

The first two ultra-urban stormwater management projects to be evaluated were the Viewlands Cascades Drainage System and the 2nd Avenue NW Street Edge Alternative (SEA) Streets Millennium Project. The projects were designed to reduce stormwater quantities discharged to Pipers Creek. A related goal in the case of Viewlands was to decrease the high velocities often occurring in the previous drainage ditch to prevent bypass of the drain inlet at its end, and the consequent erosion of the adjacent slope. Both projects were also expected to provide water quality benefits through enhanced pollutant capture by vegetation and soils and reduced pollutant mass loadings associated with lower flow volumes.

The Viewlands Cascade receives drainage from a catchment originally thought to be approximately 26 acres (10.5 ha) in area. Collected runoff is piped to the Cascade, where it flows through 16 stepped cells formed by log weirs to the downstream drain inlet and onward to Pipers Creek via another pipe. Construction cost was approximately $225,000.

The 2nd Avenue NW SEA Streets project represents a full street right-of-way redesign. The width of the 660-ft (201-m) long roadway between NW 117th and NW 120th Streets was reduced from 25 ft (7.6 m) to 14 ft (4.3 m), parking slots were provided at angles to the street, and sidewalks were added. The remainder of the 60-ft (18-m) right of way was devoted to runoff detention ponds planted with native vegetation. The original right of way covered approximately 0.91 acre (0.37 ha), about 0.38 acre (0.15 ha) of asphalt and the remainder in vegetation on the edges. Hard surface was reduced slightly to 0.31 has (0.13 ha) in the redesign, with the remainder given to ponds. The construction cost was initially bid at $244,000. There were substantial additional costs for this first-of-its-type project in reaching community consensus, change orders to satisfy community concerns, etc. The catchment area draining to the 2nd Avenue NW pond system includes properties on the east side of 2nd Avenue NW, as well as the streetscape, and totals approximately 2.3 acres (0.93 ha).

A graduate thesis (Miller 2001) and a technical report in this series drawn from the thesis (Miller, Burges, and Horner 2001) document all events in the ultra-urban stormwater management studies through January 2001. These references provide more extensive background to the projects, a review of relevant literature, descriptions of the monitoring equipment and methods at both sites, data management and analysis procedures, results for the period of coverage, discussion of findings, and what conclusions could be drawn at that time.

Brief description of instrumentation

This subsection provides a basic description of the monitoring systems established at both projects. Refer to Miller (2001) and Miller, Burges, and Horner (2001) for full details.

The log weirs at the ends of cells 1 and 15 of the Viewlands Cascades Drainage System were outfitted with V-notch weirs to serve as controls for comparative flow monitoring near the entrance and exit of the channel. Weir water levels, from which flow rates were computed, were sensed at each point with both float/shaft encoders and submersible pressure transducers.

The Viewlands site has a full meteorology station on the adjacent elementary school property. The station has three precipitation gauges, two tipping-bucket recording gauges and a non-recording collector. Mounted on a tripod are temperature and relative humidity probes, a wind anemometer, a net radiometer, a short-wave pyranometer, and a solar panel for power supply. The station also includes an evaporation pan with an anemometer and a radiometer mounted just above the water surface. Data from all flow and meteorological instruments are logged at one of three data loggers at the station for computer downloading.

With no runoff entering from outside its catchment, the 2nd Avenue NW SEA Streets site was equipped only with a flow monitoring station at the point where runoff exits the project. This station has a float/shaft encoder with a stilling basin and V-notch weir flow control. In an adjacent yard are a tipping-bucket recording precipitation gauge and a non-recording collector. This site has one data logger. Monitoring at both sites will continue to operate for an undetermined period of time to collect more post-construction data.

Summary of results—January 2000 to 2001

For the period July 2000 to January 2001, the Viewlands flow monitoring equipment registered a peak upstream flow rate of 3.9 cfs (110 L/s), approximately one-sixth of the anticipated peak flow rate for the 25-year, 24-hour design rainfall event of 25 cfs (708 L/s). Two storms approximated the 6-month, 24-hour storm. The remaining 34 storms fell beneath this level. Due to the relatively low precipitation, assessment of the performance of the swale design based on calendar year 2000 was limited.

Of the 36 individual storms that produced measurable runoff in the Viewlands channel, in 14 cases no inflow reached the downstream monitoring station, almost all presumably having infiltrated the soil. Regardless of soil moisture conditions, the channel retained up to approximately 1,000 ft^3 (28.3 m^3) of runoff, while high retention (75 to 99.9 percent) was achieved for inflow volumes in the range of 1,000 to 3000 ft^3 (28.3 to 85.0 m^3). The cascade system could fully attenuate runoff from an average precipitation depth of 0.22 inch (5.6 mm) during dry soil moisture conditions and 0.13 inch (3.3 mm) during wet conditions. During the dry soil period, 78 percent of the measured inflow infiltrated or was otherwise retained by the channel. Retention dropped to 34 percent during the wet soil period. Over the course of the July 2000 to January 2001 study interval, the system retained 38 percent of the total inflow. In addition to the hydrologic benefit to Pipers Creek, pollutant mass loading would decrease by at least as much, and most likely more due to contaminant capture in the channel's vegetation and soil. Under the same meteorological conditions, the previous ditch would have infiltrated, at most, an estimated 24,650 ft^3 (700 m^3), or 67 percent less.

For the March to July 2000 pre-construction period, the 2nd Avenue NW flow monitoring equipment registered a peak flow rate of 0.083 cfs (2.4 L/s), less than one-tenth of the anticipated peak flow rate of 1.5 cfs (43 L/s) for a 25-year, 24-hour rainfall event. Analysis of the storm hyetographs and hydrographs for the 35 storms during the predominantly wet soil moisture conditions indicated a rapid, precipitation-driven runoff response. As a result, the runoff hydrograph closely followed the start, rise, and fall of the precipitation hyetograph.

To put the hydrologic analysis of the baseline 2nd Avenue NW conditions into perspective, runoff volumes were estimated for both a conventional street design and the SEA Streets design. The cumulative measured runoff volume from the existing street was 8601 ft^3 (244 m^3) during the study period of March 11 to July 11, 2000. The conventionally designed road with a curb/gutter/sidewalk system would have generated an estimated 14,806 ft^3 (420 m^3) of runoff under the same rainfall conditions, or 72 percent more. It was estimated that, with a SEA Streets design and the same precipitation, the street right of way would have produced 4989 ft^3 (141 m^3) of runoff. This quantity is 42 percent less than the runoff from the pre-existing street and 66 percent less than from a conventionally designed road.

Precipitation and flow analysis

Precipitation analysis

At Sea-Tac Airport, calendar year 2001 precipitation was close to the long-term mean, while 1999 was above the average and 2000 was 25 percent below. Wet season (October-March) totals based on the airport station can be found below:

Initial monitoring occurred during relatively dry winters. The most recent winter approximates typical conditions in the region, and thus it provides a better opportunity to assess performance capabilities of the drainage projects.

52-yr mean—28.7 inches (729 mm)	
1999-2000—17.4 inches (442 mm)	61 percent of 52-yr mean
2000-2001—16.3 inches (414 mm)	57 percent of 52-yr mean
2001-2002—31.3 inches (794)	109 percent of 52-yr mean

The October 2000 to March 2001 wet season had two storms approximating the 6-month, 24-hour rainfall event for the region and one that exceeded 24 hours duration and the precipitation total associated with the 1-year, 24-hour event. In contrast, the following winter period had three storms exceeding 24 hours with rainfall between the 6-month, 24-hour and 1-year, 24-hour totals, plus three additional events lasting over 24 hours and exceeding the 1-year, 24-hour total. Since the outset of monitoring, however, there have been no very large storms with infrequent return periods.

Flow analysis

Data on the Viewlands drainage system rainfall and runoff were collected for 122 events over the period beginning at the onset of the 2001 water year (1 October 2000) and concluding on 30 April 2002. Seven precipitation events during April, June, and July 2001 are missing from the Viewlands flow record because of flow instrumentation malfunction.

The rainfall statistics demonstrate the distinctions between the wet and dry seasons (e.g., a mean antecedent dry period more than three times as long in the dry compared to the wet season). They also indicate the different characteristics of the two wet seasons represented. The 2001-2002 winter was much wetter overall, with 79 percent more precipitation. Its mean precipitation intensity was 27 percent less, however, because rain was spread over an average storm duration 30 percent longer.

With no infrequent, large rainfalls in the data record, peak upstream flow rate has not yet approached the maximum 25 cfs (708 L/s) estimated for the 25-year, 24-hour event during project design. The peak seen thus far was during a December 2001 storm (4.06 cfs, 115 L/s), also approached during the large summer 2001 event (3.97 cfs, 113 L/s).

Notwithstanding seasonal and annual distinctions in rainfall and rainfall-runoff relations, channel hydrology and hydraulics did not differ as much from wet to dry seasons and between divergent winters. Maximum discharge rate and flow volume reductions from upstream to downstream were similar in the two winters, about 53 percent for rate and 70 percent for volume. These decreases rose to 65 percent for flow rate and 80 percent for volume in the dry season (excluding the large August storm). Average velocity was only slightly higher and minimum hydraulic residence time just marginally shorter in the wetter 2001-2002 winter compared to the preceding year. Dry and wet season average minimum residence time and average velocity differed little.

During the initial study period 14 of 36 events (39 percent) produced no downstream discharge (Miller 2001; Miller, Burges, and Horner 2001). The initial analysis found that an average precipitation depth of 0.13 inch (3.3 mm) could be fully attenuated during wet conditions (Miller 2001; Miller, Burges, and Horner 2001). This conclusion was also confirmed with more data.

The new Viewlands drainage system prevented direct release to Pipers Creek of 294,176 ft^3 (8337 m^3) of runoff in the 2001-2002 wet season and 485,379 ft^3 (13,755 m^3) through the current study period. While the proportion of inflow attenuated fell from the preceding, drier winter, the volume retained was 2.3 times as large.

The Viewlands catchment exhibited runoff coefficients differing greatly between seasons and years. Based on a catchment area of 26 acres (10.5 ha), 17.7 inches (450 mm) of precipitation during the 2000-2001 wet season, and 31.1 inches (790 mm) in the following winter, the runoff coefficient (inflow/rainfall volume) was 16 percent in the first case and 30 percent in the second. Cumulative dry period runoff coefficient was only 8 percent. These results demonstrate the large effect of specific conditions on runoff coefficients and the unreliability of characterizing hydrology with their use.

Comparisons of the upstream and downstream hydrographs illustrate the roles of antecedent moisture conditions and, especially, precipitation intensity in determining flow attenuation by the Viewlands channel. Events from winter, spring, and fall exhibit substantial peak rate reductions.

In contrast, the other three hydrographs, again representing three different seasons, show little attenuation. These cases had intense bursts of precipitation, and the April 2001 event had the highest average intensity in the current study period (Figure 1). It is clear that good performance in flow attenuation strongly depends on having moderate intensities, both during intra-storm intervals and over the full storm. Of course, this pattern generally prevails in Seattle, to the benefit of performance in drainage courses like the Viewlands Cascade.

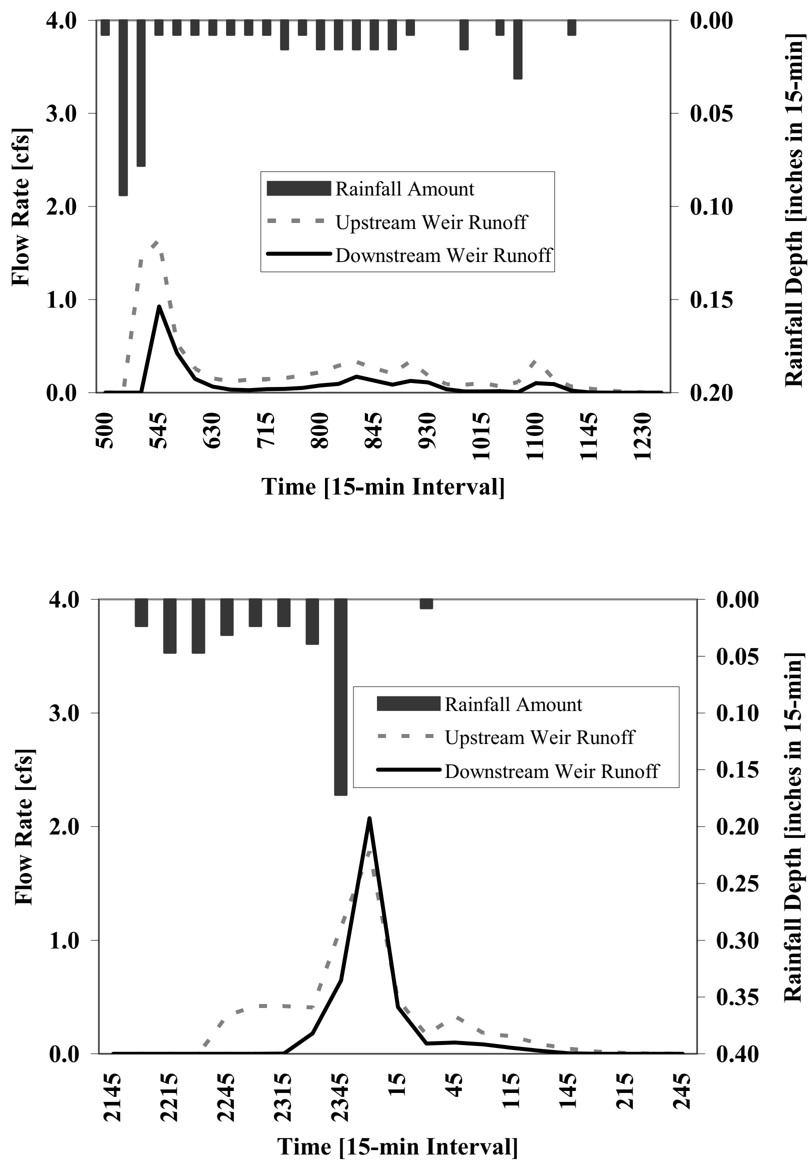


Figure 1. Viewlands Rainfall Hyetograph and Runoff Hydrograph. Top: April 30 (5:00 AM) – April 30 (12:45 PM), 2001. Bottom: April 16 (9:45 PM) – April 17 (2:45 AM), 2001.

The Viewlands Cascade Drainage System compares quite favorably with the ditch that preceded it. With equivalent meteorology, the ditch is estimated to attenuate through infiltration only about one-third as much flow volume, during both dry and wet seasons, under average and maximum conditions, and in total. This uniformity in prediction is an artifact of the simple model used to estimate infiltration from the old ditch but is generally indicative of the different potential recharge in the two cases. The preceding drain-age conduit would have released to Pipers Creek approximately 191,000 ft^3 (5413 m^3) of runoff that was retained by its successor during the 2001-2002 wet season and 319,000 ft^3 (9040 m^3) over the course of the current study period.

Rainfall and 2nd Avenue NW runoff were monitored during 96 events over the period beginning just after completion of construction (20 January 2001) and concluding on 30 April 2002. As to be expected because of the proximity of the two sites, the rainfall statistics demonstrate the same tendencies as described for Viewlands.

There was never any measured discharge when the estimated precipitation volume was less than 2300 ft^3 (65.2 m^3), representing substantial ranges of the meteorological variables. Thus, it was safe to assume that there was no discharge associated with any unmeasured events below that rainfall volume total. This volume is associated with a rainfall total of about 0.75 inch (19 mm), the runoff from which can apparently be completely attenuated by the storage ponds.

After the SEA Streets project was in place, discharge was measured or estimated for only 10 of the 96 events (10.4 percent). In strong contrast, flow over the weir occurred during all 35 events measured before project construction, even though most were in the drier months. With the new street design there was no dry-season release, even during the large August storm, an event when the shaft encoder was functioning well, allowing direct discharge measurement.

Even with so few events yielding any discharge, attenuation was so close to complete that the mean flow volume decreases by storm are quite indicative of recharge over the full seasonal and annual periods (see Table 1).

Table 1. Flow volume decreases by storm events

Date	Season	Percent
1/20/01-3/31/01	partial wet season	99.1%
4/1/01-9/30/01	dry season	100%
4/1/01-9/30/01	dry season excluding August storm	100%
1/20/01-9/30/01	partial water year	99.6%
10/1/01-3/31/02	wet season	97.6%
1/20/01-3/31/01 and 10/1/01-3/31/02	1 + partial wet season	97.8%
1/20/01-4/30/02	current study period	98.2%

Figure 2 shows hyetographs and hydrographs for two somewhat contrasting events at 2nd Avenue NW. The early January 2002 storm (top graph in Figure 2) followed an antecedent dry period of only 10.3 hours, had average intensity of 0.048 inch/hour (1.2 mm/h), and produced an estimated total precipitation volume of 6635 ft^3 (188 m^3). The later January event (bottom graph in Figure 2) had a much longer antecedent dry period of 94.5 hours and about half the average intensity (0.026 inch/hour, 0.7 mm/h), although it had a brief burst of relatively intense rainfall late in the storm. The total volume estimate was 3418 ft^3 (97 m^3). Dur-ations of the two storms were similar (47.8 and 44.8 hours, respectively).

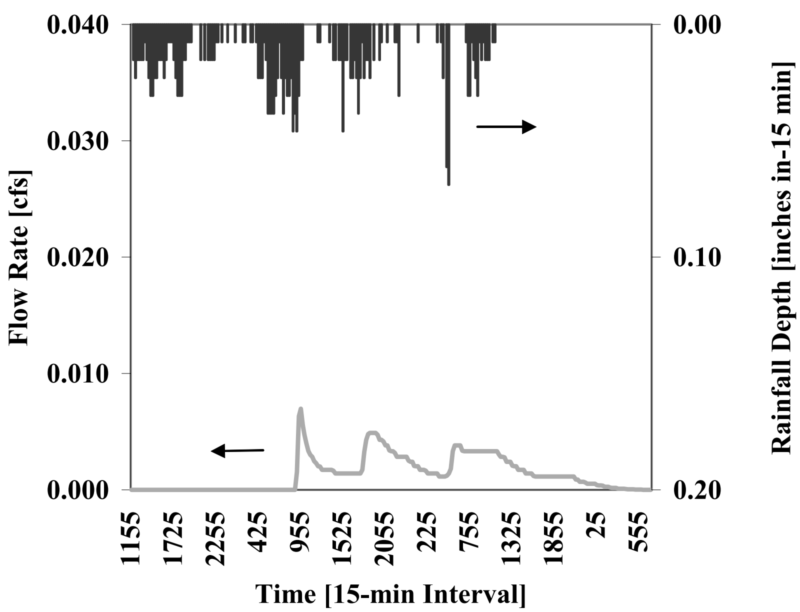
Even with the differences in meteorological and soil moisture conditions in the two cases, the SEA Streets runoff mitigation features performed similarly. Runoff quantities were only 4.9 and 3.2 percent of the precipitation volumes falling on the catchment in the respective events. The project has the ability to attenuate all or almost all runoff over a fairly wide range of conditions.

Design comparison

This section compares the relative amounts of flow volume reduction achieved with the various drainage system designs covered in this report, including: (1) the Viewlands Cascade Drainage System versus the ditch that preceded it, (2) the 2nd Avenue NW SEA 1Streets project versus the original street drainage system, (3) the 2nd Avenue NW SEA Streets project versus a conventional street drainage system design, and (4) the 2nd Avenue NW SEA Streets project versus the Viewlands Cascade Drainage System. The designs are compared as ratios for dry and wet seasons and overall by normalizing in terms of the runoff volume retained per month. In addition, the Viewlands Cascade and SEA Streets projects are compared in relation to: (1) the runoff volume retained per unit area of contributing catchment, and (2) the runoff volume retained per month and per dollar of unit area construction cost.

The benefit ratios for Viewlands Cascade/preceding ditch, SEA Streets/original street, and SEA Streets/conventional street reiterate the points made previously: the improved drainage systems retain several times as much runoff volume as their respective predecessors or, in the case of SEA Streets, the alternative of designing according to the City of Seattle's current convention.

The SEA Streets project attenuates over one-third as much runoff as the new Viewlands channel, even though the SEA Streets project serves less than one-tenth as much contributing catchment area. When placed on an areal basis, that advantage multiplies greatly. The 2nd Avenue NW project has a fractional cost-benefit compared to Viewlands, however, because it costs roughly the same as Viewlands but serves a much smaller catchment. These financial comparisons take no account of potential savings that might be realized with experience and economies of scale in future construction of both project types.



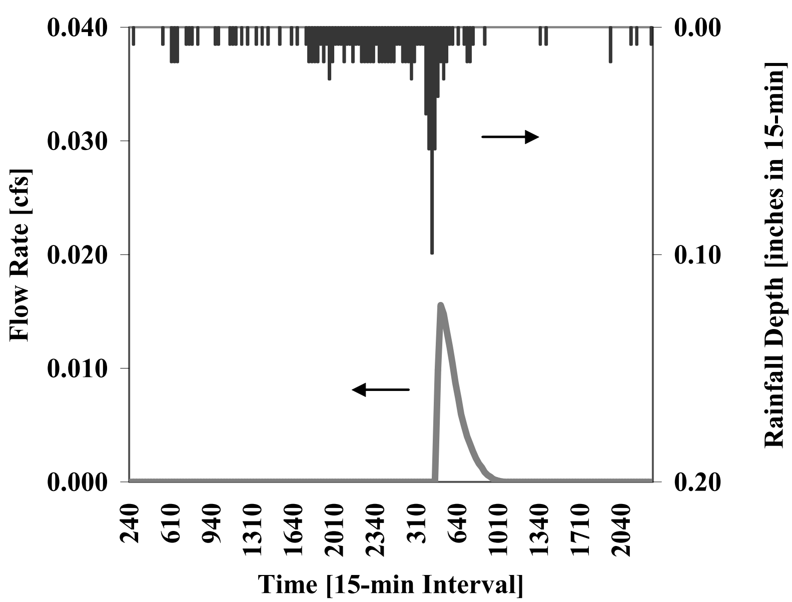


Figure 2. Second Avenue NW Rainfall Hyetograph and Runoff Hydrograph. Top: January 6 (11:55 AM) – January 9, (7:25 AM), 2002. Bottom: January 24 (2:40 AM) – January 25 (10:10 PM), 2002

With its position at the discharge of its subbasin, the Viewlands Cascade might be termed a "downstream" solution. Managing runoff at or near its source, the 2nd Avenue NW project site is an "upstream" solution. Its relatively greater unit-area effectiveness is a demonstration of the common observation in stormwater management that acting closer to the source on smaller quantities of water yields better results than downstream intervention. In this case, the unit cost of the upstream project was much higher because of its nature, not its catchment position. Thus, lower cost-effectiveness is not a general drawback of upstream projects.

Conclusions

1. Flow has been monitored at the Viewlands Cascade Drainage System over two full wet seasons, one complete dry season, a portion of a second one. The 2nd Avenue NW SEA Streets project has received flow monitoring for one full wet season and part of a second one, plus a complete dry season. The wet seasons have differed in meteorological characteristics. The 2000-2001 winter had only 57 percent of the long-term average rainfall. The 2001-2002 winter was slightly above average in total precipitation but had generally low-intensity storms. Neither winter had any very large storms.

2. At both Viewlands and 2nd Avenue NW, flow attenuation by the drainage projects is strongly influenced by rainfall intensity and

antecedent dry-period length. Flow reduction, primarily by infiltration, is markedly greater in low-intensity storms compared to high-intensity events, a pattern that is accentuated with relatively low soil moisture attending a preceding dry period of at least a number of days.

3. Over all of the monitoring performed, the Viewlands Cascade has quite consistently reduced the influent runoff volume by slightly more than one-third during the wetter months and overall for the year (the majority of relatively small dry-season flows are attenuated). Also, about one-third of events exhibit no discharge from the end of the channel. It can completely infiltrate about 0.13 inch (3.3 mm) of precipitation and 1000 ft^3 ($28m^3$) of influent regardless of the season or conditions. During the 2001-2002 wet season the new Viewlands channel retained almost 300,000 ft^3 (8500 m^3) of runoff that entered it, preventing its direct release to Pipers Creek and the elevation of erosive flows there. This quantity is nearly three times the amount of retention estimated were the preceding narrow, partially concreted ditch still been in place.

4. During monitoring thus far the 2nd Avenue SEA Streets project has prevented the discharge of all dry-season flow and 98 percent of the wet-season runoff. Whereas all events in the baseline monitoring period, which occurred mostly in the dry season, created a discharge, only about 10 percent have since the project's construction. The design can fully attenuate 2300 ft^3 (65.2 m^3) of runoff, which represents the volume produced by approximately 0.75 inch (19 mm) of rain on its catchment. For context, the mean storm quantity at Seattle-Tacoma International Airport is 0.48 inch (12 mm). Based on estimates for a street drainage system design according to City of Seattle conventions, the SEA Streets alternative reduces runoff discharged to Pipers Creek in the wet months by a factor of 4.7 relative to the conventional street.

5. On the basis of unit runoff contributing area, the SEA Streets project is at least four times as effective as Viewlands, depending on how the benefit is computed. However, when normalized in terms of the cost per unit catchment area served, the 2nd Avenue NW reconstruction is much less cost-effective than the Viewlands Cascade.

6. Sufficient data are available now for estimating potential hydrologic benefits of future projects of the Viewlands Cascade and SEA Streets types in similar catchments.

References

Miller, A.V. 2001. Hydrologic Monitoring of the Seattle Ultra-urban Stormwater Management Projects. M.S.C.E. thesis, Department of Civil and Environmental Engineering, University of Washington, Seattle, WA.

Miller, A.V., S.J. Burges, and R.R. Horner. 2001. Hydrologic Monitoring of the Seattle Ultra-urban Stormwater Management Projects. Water Resources Series Technical Report No. 166, Department of Civil and Environmental Engineering, University of Washington, Seattle, WA. ■

Salmon or power?

Continued from page 2

more very important factor that has to be taken into account when thinking about the future."

Of particular note is the physics of the model, developed by the National Center for Atmospheric Research in Boulder, Colorado. In general, the model is somewhat conservative with respect to its projections of global warming, in part because of its representation of the thermal inertia of the world's oceans. Also, use of Department of Energy computers allowed evaluation of a broader range of possible future outcomes, in recognition of the chaotic nature of the earth's response to changes in global emissions of greenhouse gases "One implication of this is that this model tends to give climate sensitivities that are toward the low end when compared with some of the other global models," Lettenmaier said. "In other words, one could say that this is an optimistic scenario." ■

Completed theses

The following students recently finished their M.S. theses:

Hydrologic, geomorphic, and biologic influences on redd scour in bull char (*Salvelinus confluentus*) spawning streams
Jeff Shellberg, M.S.

A sediment budget for the Pipers Creek Watershed: Applications for urban stream restoration
Chase Barton, M.S.E. ■

New book

The recent listing of Pacific salmon under the Endangered Species Act has led to substantial interest in the scientific basis for river restroation in the Pacific Northwest. Millions of dollars in state and federal funding have been programmed for habitat restoration efforts to stem the decline of salmon populations in the region. A new book from the Center for Water and Watershed Studies, **Restoration of Puget Sound Rivers**, addresses the need for a solid understanding of fluvial processes and aquatic ecology in order to predict both river and salmonid response to restoration projects.

The eighteen chapters in this volume — presented by the region's experts at a symposium of the Society for Ecological Restoration — examine gological and geomorphological controls on river and stream characteristics and dynamics, biolgical aspcets of river systems in the region , and the application of fluvial geomorphology civil engineering, riparian ecology, and aquatic ecology in the efforts to restore Puget Sound Rivers.

Edited by David R. Montgomery, Susan Bolton, Derek B. Booth, and Leslie Wall, the book is available for $30 from UW Press (http://www.washington.edu/uwpress) and local bookstores. This book will be of interest to civil engineers, planners, aquatic biologists, geomorphologists, and all those interested in the interface of science and policy in addressing one of the fundamental environmental challenges of the twenty-first century. ■

Upcoming events spring 2003

Details for these events can be found at http://depts.washington.edu/cwws/Outreach/Events/seminars.html

6 February	**CWWS Annual Review of Research**, 8:00 am to 6 pm, HUB West Ballroom UW campus
12 February	**Dr. Robert Costanza**, UW Walker-Ames guest lecture,
7 January – 11 March	**Tuesday Morning Seminar Series**, Tuesdays, 8:30 to 9:30 am, 22 Anderson Hall, UW campus
9 January – 13 March	**Monster Seminar Jam**, Thursdays, 11:00 am to 12:00 pm, NMFS, 2725 Montlake Blvd E

Professional development programs
For more information on cost, how to register, and other details, see http://www.engr.washington.edu/epp

5 – 6 February	New technologies and concepts in stormwater treatment
12 – 13 February	How to evaluate and condition wetland and mitigation design plans
4 – 5 March	Geology and geomorphology of stream channels
9 – 10 April	How to imporve stormwater management using low impact development practices
14 – 15 May	Infiltration facilities for stormwater quality control
4 – 5 June	Biolgoical and ecological assessment and habitat

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