The Washington Water RESOURCE

The quarterly report of the Center for Urban Water Resources Management

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Message from the Director

This issue of the Newsletter is yet another casualty of the February 28th earthquake, because of the increased opportunities, and the increased workload, that it brought to all geologically and geotechnically oriented researchers in the region. Although not directly connected to "urban water resources management," several of us who work on such matters *also* have found our hands full with post-earthquake evaluations and studies. Life is only slowly returning to normal, and hopefully the same is true for you. In any case, apologies for the delay in sending out this issue are in order.

Short of the earthquake, the biggest news here is a recommended merger of the Center for Urban Water Resources Management with the Center for Streamside Studies. If you are not familiar with CSS, it is a cooperative program of the College of Forest Resources and the College of Ocean and Fishery Sciences that was established in 1987. Its mission has been to provide scientific information necessary for understanding the relationship between timber land management and the public resources of stream and riparian habitats, and the fish and water quality that are affected by their management. Over the last several years, CSS has been encouraged from several quarters to expand its geographic scope from exclusively timberlands to the surrounding rural, suburban, and ultimately urban landscapes. That broadening has led to a number of highly productive, cooperative efforts between our two centers, most recently the combined Annual Review in February that saw almost 400 people in attendance for a full day of talks here at the University.

CSS has prepared a strategic plan, to be reviewed this spring by interested parties both inside and outside of the University, that recommends a merger of our two centers as the next logical step in our development and interdependence. Neither the current directors nor the centers' advisory boards see negative consequences from this merger to students, faculty, or outside constituents. Funding, financial support, and resources should remain equal or increase, and we expect that opportunities will be enhanced for the center to become a regional focus for water-related studies in the region by having a broader thematic focus and a larger resource base.

Although it is a little early for detailed plans, by the next Newsletter issue it may be a little late…so we are now planning that the 2001 Stream Temperature Survey will occur on Saturday, August 11th. It is being coordinated with a satellite overflight of the region that will be collecting simultaneous stream-temperature measurements, and so the focus will be slightly different from previous years. However, this event has proven to be a valuable source of regional data and a welcomed volunteer event for several stream-management agencies around the Sound, and so we will maintain the same level of logistical support and data archiving as in previous years. We are also moving, though ever-so slowly, towards a full analysis of the first three years' data. The blame for such a delay belongs strictly to me, and I am hoping for a productive, aseismic spring in which to finish our report!

❖ *Derek Booth*

The Washington Water Resource is the quarterly publication of the Center for Urban Water Resources Management at the Department of Civil and Environmental Engineering, University of Washington, Box 352700, Seattle, WA 98195.

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Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts

by Derek Booth, University of Washington; David Hartley, King County Water and Land Resources Division; and Rhett Jackson, University of Georgia

INTRODUCTION

Recent Endangered Species Act (ESA) listings of Puget Sound chinook and bull trout, and the potential for more salmonid listings, have brought new scrutiny to all aspects of the region's watershed protection and urbanization-mitigation efforts. Such increased attention is forcing a better articulation of the goals, the means, and the justification for mitigating the effects of urban development. It also has highlighted the failure of most stormwater mitigation efforts, not only in the Pacific Northwest but also across the country, where well-publicized successes are overshadowed by progressive degradation of once-healthy stream systems. This degradation has continued, despite sincere but ineffectual efforts via structural "Best Management Practices" (BMP's), particularly detention ponds, buffer regulations, and rural zoning.

As part of this reevaluation, a small group of us who worked in King County's Basin Planning Program in the late 1980's and early 1990's have been revisting the history, and the lessons, of watershed-scale efforts at stormwater management. Our purpose here is to diagnose the successes, and the failures, of these historic structural and regulatory approaches so that others can think more creatively and productively about even more promising strategies. We have no panaceas, however; if the problems were easily solved, they would have been so many years ago.

Our approach has three elements:

- to review some empirical relationships between watershed conditions and stream conditions;
- to evaluate the basis for regulating watershed land use, rather than building structural BMP's, to minimize the downstream consequences of urbanization; and
- to recommend an integrated stormwater management strategy based on King County's experience of the past decade.

For decades, watershed urbanization has been known to harm aquatic systems. Although the problem has been long articulated, solutions have proven elusive because of the complexity of the problem, the evolution of still-imperfect analytical tools, and socio-economic forces with different and often incompatible interests. King County, Washington, has been a recognized leader in the effort to analyze and to reduce the consequences of urban development, but even in this jurisdiction the path toward aquatic resource protection has been marked by well-intentioned but ultimately mistaken approaches, compromises with other agency goals that thwart complete success, and imperfect implementation of adopted policies and plans. This experience demonstrates the difficulty of meeting urban and suburban water-quality and aquatic-resource protection goals in the face of competing social priorities and variable political resolve on environmental issues that require sustained, long-term strategies to achieve progress.

This paper focuses on changes in runoff and stream flow because they are ubiquitous in urbanizing basins and cause often dramatic changes in flooding, erosion, sediment transport, and ultimately channel morphology. Hydrologic change also influences the whole range of environmental features that affect aquatic biota—flow regime, aquatic habitat structure, water quality, biotic interactions, and food sources (Karr, 1991). Yet runoff and stream-flow regime, while important, are by no means the only drivers of aquatic health. Consequently, there should be no illusion that *just* addressing hydrologic conditions will necessarily "fix" or "protect" an urban stream.

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Modifications of the land surface during urbanization produce changes in both the magnitude and the type of runoff processes. In the Pacific Northwest, the fundamental hydrologic effect of urban development is the loss of water storage in the soil column. This may occur because the soil is compacted or stripped during the course of development, or because impervious surfaces convert what was once subsurface runoff to Horton overland flow. In either situation, the precipitation over a small watershed reaches the stream channel with a typical delay of just a few minutes, instead of what had been a lag of hours, days, or even weeks. The result is a dramatically changed pattern of flows in the downstream channel, with the largest flood peaks doubled or more and more frequent storm discharges increased by as much as ten-fold (Figure 1).

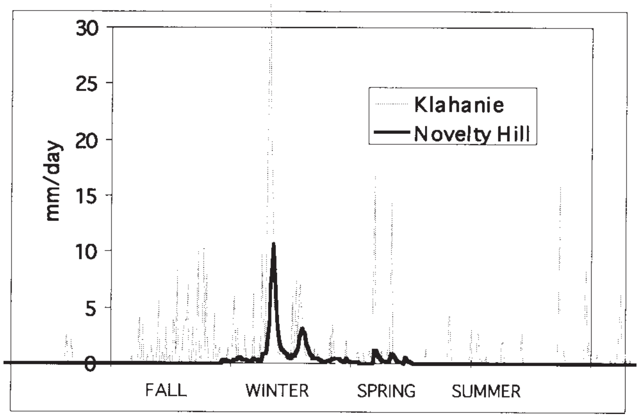

Figure 1. One year's measured discharges for a suburban (Klahanie) and an undeveloped (Novelty Hill) watershed, normalized by basin area (data from Burges et al., 1998)

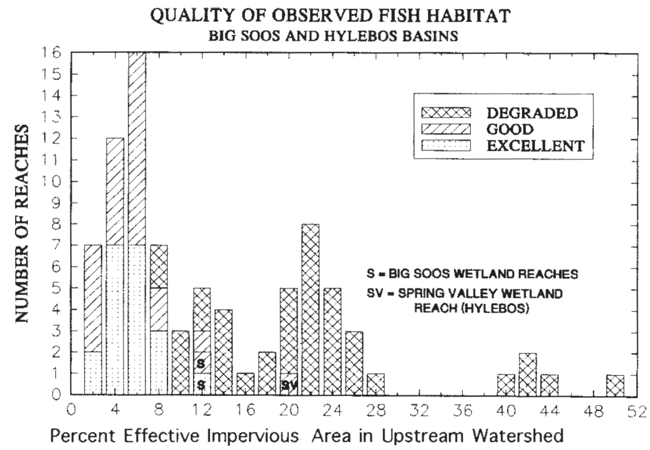

Figure 2. Observed fish habitat quality as a function of effective impervious area in the contributing watershed, based on more than 80 individually inventoried channel segments in south King County (from Booth and Jackson, 1997). "EXCELLENT" reaches show little or no habitat degradation; "GOOD" reaches show some damage to habitat but still maintain good biological function; and "DEGRADED" reaches contain aquatic habitat that has been clearly and extensively damaged, typically from bank erosion, channel incision, and sedimentation.

EMPIRICAL RELATIONSHIPS BETWEEN WATERSHED CONDITIONS AND STREAM CONDITIONS

Correlations between watershed development and aquatic-system conditions have been investigated for over two decades. Klein (1979) published the first such study, where he reported a rapid decline in biotic diversity where watershed imperviousness much exceeded 10 percent. Steedman (1988) believed that his data showed the consequences of both impervious cover and forest cover on instream biological conditions. Later studies, mainly unpublished but covering a large number of methods and researchers, was compiled by Schueler (1994). Since that time, additional work on this subject has been made by a variety of Pacific Northwest researchers, including May (1996), Booth and Jackson (1997), and Morley (2000) (Figures 2 and 3).

These data have several overall implications:

- "Imperviousness," although an imperfect measure of human influence, is clearly associated with stream-system decline. A wide range of stream conditions, however, can be associated with any given level of imperviousness, particularly at lower levels of development.
- "Thresholds of effect," articulated in some of the earlier literature (e.g., Klein, 1979; Booth and Reinelt, 1993) exist largely as a function of measurement (im)precision, not an intrinsic characteristic of the system being measured. Crude evaluation tools require that large changes accrue before they can be detected, but lower levels of development may still have consequences that can be revealed by other, more sensitive methods. In particular, biological indicators (e.g., Figure 3) demonstrate a continuum of effects, not a threshold response, resulting from human disturbance.

THE BASIS FOR REGULATING IMPERVIOUS AREA AND CLEARING

In the realm of physical channel conditions, the data collected from field observations have consistently shown remarkably clear trends in aquatic-system degradation. In this region, approximately 10 percent effective impervious area in a watershed typically yields demonstrable degradation, some aspects of which are surely irreversible. Although early observations were not sensitive enough to show significant degra-

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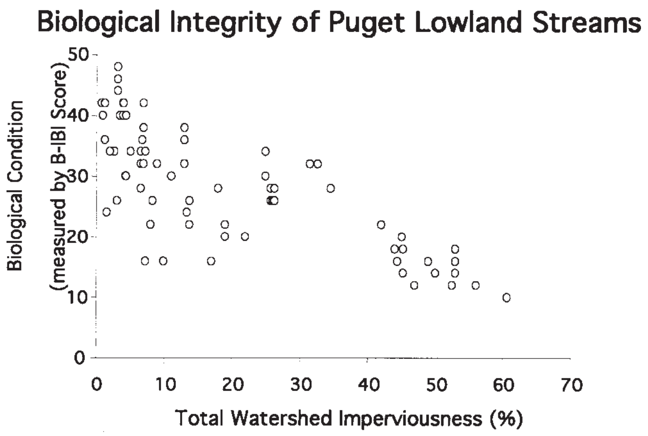

Data from James Karr and others, 1994-1997

Figure 3. Compilation of biological data on Puget Lowland watersheds, reported by Kleindl (1995), May (1996), and Morley (2000). The pattern of progressive decline with increasing imperviousness in the upstream watershed is evident only in the upper bound of the data; significant degradation can occur at any level of human disturbance (at least as measured by impervious cover).

dation at even lower levels of urban development, the basin plans of the early 1990's recognized that such damage was almost certainly occurring. More recently, biological data (e.g. Morley, 2000) have demonstrated the anticipated consequences at these lower levels of human disturbances. Thus "10% imperviousness" is not a threshold; it simply corresponds to levels of degradation that are sufficiently severe to be readily apparent.

Less empirical data have been collected on the direct correlation between forest cover and stream conditions than for watershed imperviousness and stream conditions. In general, the "evidence" has been based on the observed correlation of channel instability to the modeled hydrologic condition of $Q_{2\text{-}cur} > Q_{10\text{-}for}$, coupled with hydrologic analyses that have explored the relationship between forest-cover reduction and peak-flow increases. The first such analyses, for the Issaquah Creek Basin Plan, made a variety of assumptions about "typical" watershed characteristics in that basin and found that 65 percent forest cover with 4 percent effective impervious area closely approached the condition of $Q_{2\text{-}cur} = Q_{10\text{-}for}$. Using more generalized model parameters and a range of effective impervious areas typical of rural areas, 65 percent forest cover is a plausible, but by no means definitive, value for meeting the presumed "stability criterion" of $Q_{2\text{-}cur} < Q_{10\text{-}for}$ in rural-zoned watersheds on moderately (5%-15%) sloping till soils (Figure 4). The analysis summarized in Figure 4 assumes no on-site detention facilities are present because they are often technically (and politically) infeasible in low-density rural areas. Other soils (particularly more infiltrative ones) may yield much greater hydrologic response with even lesser amounts of clearing.

Hydrological analyses suggest that maintaining forest cover is more important than limiting impervious-area percentages, at least at rural residential densities where zoning effectively limits the range of EIA between 2 and 6 percent of the gross development area. Absent clearing limitations, however, forest cover will range between 5 and about 85 percent. Consequently, even if both types of land cover are critical to protect stream conditions, current land-use practices suggest that mandating retention of forest cover is the more pressing regulatory need in rural areas. Degraded watersheds, with less than 10 percent EIA and less than 65 percent forest cover, are common ("cleared rural"); in contrast, we have found no watersheds with more than 10 percent EIA that have also retained at least 65 percent forest cover ("forested urban") (Figure 5).

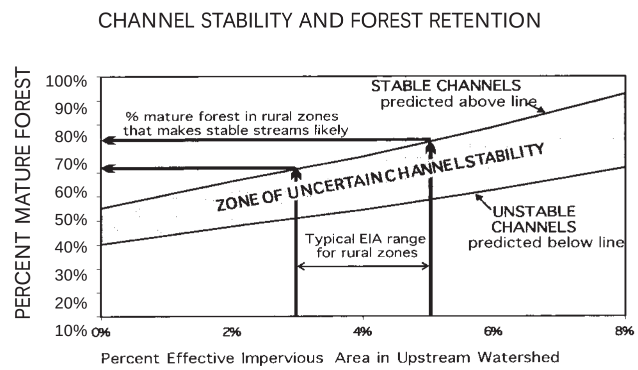

Figure 4. Conditions of forest cover and impervious area in an HSPF-modeled watershed, with moderate slopes and till soils, relative to the channel-stability criterion $Q_{2\text{-}cur} = Q_{10\text{-}for}$. The range of effective impervious areas (3-5%) reflects variation in rural land cover conditions; the "zone of uncertain channel stability" reflects uncertainty

The apparent correlations between stream stability and both impervious-area and forest-cover percentages present a quandary for watershed managers. On the one hand, these correlations point to a tangible, defensible criteria for achieving a specific management objective, namely "stable stream channels." On the other hand, this objective, however worthy, still allows the possibility of serious and significant aquatic-system degradation—and as development is allowed to approach these clearing and imperviousness criteria, degradation is virtually guaranteed. The thresholds implied by these data are simply the "wrong" type on which to base genuine resource protection. They do not separate a condition of "no impact" from that of "some impact;" instead, they separate the condition of "some impact" from that of "gross and easily perceived impact." Hydrologically and biologically, there are no truly negligible amounts of clearing or watershed imperviousness (Morley, 2000), even though our perception of, and our tolerance for,

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many of the associated changes in downstream channels appear to undergo a relatively abrupt transition. Almost every increment of cleared land, and of constructed pavement, is likely to result in some degree of resource degradation of loss. The decision of how much is "acceptable" is thus as much a social decision as a hydrologic one.

These conditions also emphasize the need to develop new approaches to mitigate the consequences of watershed urbanization on streams. If urban and suburban watersheds cannot hydrologically mimic forested ones, no matter how large their associated detention ponds, then reducing the coverage of effective impervious area or the extent of urban development itself is an inescapable consequence of the present desire to "restore" urban watercourses. If those necessary reductions run counter to other, even more pressing social goals, most notably those to accommodate additional population growth, then our goals for aquatic-resource conservation need to be modified in urban areas. By not acknowledging the need for such trade-offs, opportunities to discover the most rational and effective strategy for protecting the condition of once-natural aquatic systems continue to be lost.

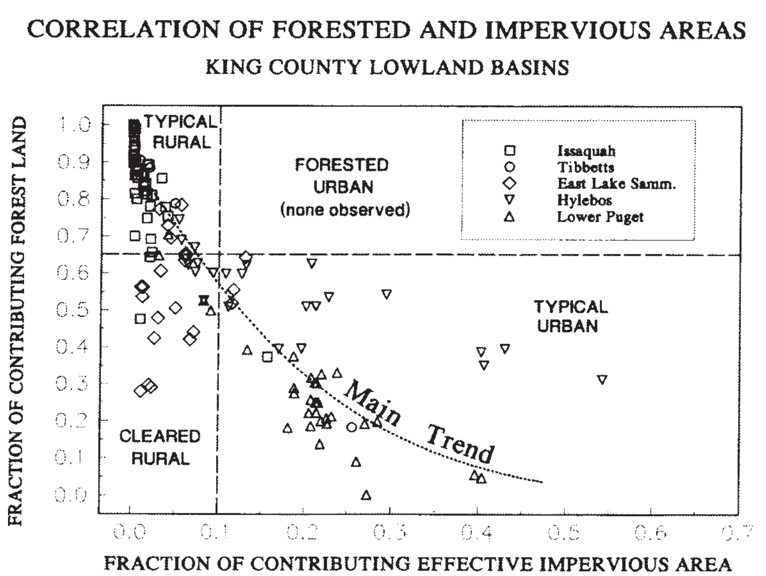

Figure 5. Land cover data from individual subcatchments within five King County watersheds, compiled from King County basin plan land-cover data.
At 65-percent forest retention, EIA £ 10% in all cases, yet with EIA < 10%, substantial clearing is still commonly observed.

MANAGEMENT IMPLICATIONS

Land development that eliminates hydrologically mature forest cover and undisturbed soil can result in significant changes to urban stream flow regimes and, in turn, to the physical stability of stream channels. These changes are manifested in altered stream flow patterns with higher volumes of storm flow, leading to accelerated channel erosion and habitat simplification. Even with stormwater detention ponds, seasonal and stormflow patterns are substantially different from those to which native biota have adapted. These hydrologic changes cannot be completely mitigated with structural measures. Although factors other than hydrologic change (e.g., water chemistry, riparian buffers) can undoubtedly affect the magnitude of urban impacts, the breadth of the existing data suggest that improvements in these other factors can never fully mitigate the hydrologic consequences of overly intense urban development. Under typical rural land uses, the magnitude of observed forest-cover losses affects watershed flow regime as much as, or more than, associated increases in impervious area.

The goals of stormwater detention have become progressively more ambitious as the consequences of urban-altered flow regime have become better recognized and understood. Even the largest detention ponds, however, are limited in their ability to mitigate all aspects of hydrologic change. Twenty years of empirical data display a good correlation between readily observed damage to channels and modeled changes in flow regime that correspond to loss of about one-third of the forest cover in a "typical" western Washington watershed. A similar degree of observed damage also correlates to a level of watershed effective imperviousness (EIA) of about ten percent.

Field observations and hydrologic modeling showed that the watershed plans of the early- to mid-1990's could only hope to meet plan-stipulated goals for resource protection by imposing clearing and impervious-area restrictions. The most commonly chosen thresholds, maximum 10 percent EIA and minimum 65 percent forest cover, mark an observed transition in the downstream channels from minimally to severely degraded stream conditions. At lower levels of human disturbance, aquatic-system damage may range from slight to severe but is nearly everywhere recognizable with appropriate monitoring tools. Not every watershed responds equally to a given level of human disturbance, but some degree of measurable resource degradation can be seen at virtually any level of urban development. The apparent "threshold" of observed stream-channel stability has no correlative in measured biological conditions; for any given watershed, additional development tends to produce additional aquatic-system degradation. However, these impervious and forest-retention percentages have proven to be attractive regulatory thresholds and are being advocated as necessary conditions for mandated protection of rural areas under the Endangered Species Act.

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Development that minimizes the damage to aquatic resources cannot rely on structural BMP's, because there is no evidence that they can mitigate any but the most egregious consequences of urbanization. Instead, control of watershed land-cover changes, including limits to both imperviousness and clearing, must be incorporated (see also Horner and May, 1999). We anticipate needing all of the following elements to maintain the possibility of effective protection:

- clustered developments that protect half or more of the forest cover, preferentially in headwater areas and around streams and wetlands to maintain intact riparian buffers;
- a maximum of 20% total impervious area, and substantially less effective impervious area through the widespread reinfiltration of stormwater (Konrad and Burges, 2001);
- on-site detention, realistically designed to control flow durations (not just peaks);
- riparian buffer and wetland protection zones that minimize road and utility crossings as well as overall clearing; and
- no construction on steep or unstable slopes.

Past experience suggests that each of these factors is important. However, we still lack empirical data on the response of aquatic resources to such "well-designed" developments. Therefore, these recommendations are based only on extrapolations, model results, and judgement; they are tentative at best. Where development has already occurred, these conditions clearly cannot be met and different management objectives are inescapable: many, perhaps all, streams in already-urban areas cannot be truly protected or restored, and a significant degree of probably irreversible stream degradation is unavoidable in these settings.

We can recognize why streams nominally protected under past drainage regulations have experienced severe degradation, we can articulate the kinds of development styles and strategies that should minimize new examples of degraded streams, and we can recognize the role of watershed land-cover regulation in minimizing the consequences of new development; but we cannot find any basis to expect that the full range of hydrological and ecological conditions can be replaced in a now-degraded urban channel. The key tasks facing watershed managers, and the public that can support or impede their efforts, are therefore (1) to identify those watersheds where existing low urbanization, and associated high-quality stream conditions, warrant the kinds of development conditions that may protect much of the existing quality of these systems; and (2) to develop a new set of management goals for those watersheds whose surrounding development precludes significant ecosystem recovery. Following the same strategy in all watersheds, developed and undeveloped alike, simply makes no sense.

REFERENCES

Booth, D. B., and Jackson, C. J., 1997. Urbanization of aquatic systems—degradation thresholds, stormwater detention, and the limits of mitigation. Water Resources Bulletin, v. 33, p. 1077-1090.

Booth, D. B., and Reinelt, L. E., 1993. Consequences of urbanization on aquatic systems—Measured effects, degradation thresholds, and corrective strategies. Watersheds '93, Conference sponsored by U. S. Environmental Protection Agency, Alexandria, VA, March 21-24, p. 545-550.

Burges, S. J., Wigmosta, M.S., and Meena, J. M., 1998. Hydrological Effects of Land-Use Change in a Zero-Order Catchment, ASCE J. Hydrologic Engineering, 3(2), p. 86-97.

Horner, R. R., and May, C. W., 1999. Regional study supports natural land cover protection as leading Best Management Practice for maintaining stream ecological integrity. *in* Comprehensive Stormwater and Aquatic Ecosystem Management, conference papers. New Zealand Water and Wastes Association, 22-26 February 1999, p. 233-247.

Karr, J. R., 1991. Biological integrity: a long-neglected aspect of water resource management. Ecological Applications, v. 1, p. 66-84.

Klein, R., 1979. Urbanization and stream quality impairment. Water Resources Bulletin, v. 15, p. 948-963.

Kleindl, W., 1995. A benthic index of biotic integrity for Puget Sound Lowland streams, Washington, USA. Seattle, University of Washington, Masters Thesis.

May, C. W., 1996. Assessment of cumulative effects of urbanization on small streams in the Puget Sound Lowland ecoregion: implications for salmonid resource management. Seattle, University of Washington, Department of Civil Engineering, Ph.D. dissertation, 383 p.

Morley, S. A., 2000. Effects of urbanization on the biological integrity of Puget Sound lowland streams: restoration with a biological focus. Seattle, University of Washington, M.S. Thesis.

Schueler, T. R., 1994. The importance of imperviousness. Watershed Protection Techniques 1(3), p. 100-111.

Steedman, R. J., 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in Southern Ontario. Canadian Journal of Fisheries and Aquatic Sciences, v. 45, p. 492-501. ❖

The Effects of Alternative Maintenance Practices on the Water Quality Benefits of Highway Road Ditches

By Jay Cammermeyer, Graduate Research Assistant, Center for Urban Water Resources Management, University of Washington

The long-standing attention to improving the water quality of storm runoff has focused mostly on how to design and build facilities that can successfully remove pollutants. Yet vegetated road ditches, although normally considered to be purely for runoff conveyance, should also have the potential to provide the same water quality benefits as swales that are formally constructed for that purpose. On the other hand, eroding ditches could be a significant source of sediments and the other pollutants that they transport. If the potential water-quality benefits of road ditches are to be realized, their maintenance must be consistent with both conveyance and water-quality objectives. Although there are many issues pertaining to the design and maintenance of vegetated stormwater facilities for optimal water quality performance, the goal of this project was focused on determining the maintenance treatment that maximize water quality benefits vs. maintenance costs for highway road ditches.

To accomplish this goal, this study pursued three tasks: 1) to evaluate the sediments, soils, and flow characteristics within vegetated highway drainage ditches; 2) to compare the effects of three maintenance treatments within these ditches on stormwater quality, following sediment removal (cleaning); and 3) to develop simple regression models to predict the quality of storm runoff from a heavily traveled highway.

Three ditch segments were selected; they drain a heavily traveled section of Interstate 405, with an average daily traffic load of roughly 140,000 vehicles, in Bellevue, Washington. Based on the mean influent data from the three sites, the highway runoff concentrations were:

Total suspended solids—109 {mg/L}
Total zinc—243 {mg/L}
Total copper—58 {mg/L}
Total phosphorus—306 {mg/L}
Turbidity—132 {NTU}
Conductivity—84 {mS/cm}

The ditches had been recently cleaned. Following cleaning, three alternative treatments were applied to the ditches. In treatment A (sod+filter), the cleaned portion of the ditch was sodded and an intact grass filter was left undisturbed downstream of the cleaned segment. In treatment B (straw-only), the entire length of the ditch was cleaned and then covered with straw. In treatment C (straw+filter), the cleaned portion of the ditch was covered with straw and an intact grass filter was left undisturbed downstream of the cleaned segment.

Hydraulic residence time dye tests were conducted in the ditches at flow rates equivalent to an extremely high intensity rainstorm (0.32 in/hr). The mean velocities and estimated maximum velocities are presented in Table 1.

One objective of the study was to determine the relative effectiveness of the three treatments for controlling stormwater contaminants. The key findings concerning the effects of the treatments on stormwater quality are summarized below:

- Both treatments A (sod+filter) and C (straw+filter) demonstrated higher removal efficiencies for TSS loads in comparison to B (straw-only).
- While C (straw+filter) was most successful at reducing total phosphorus loads, the other two treatments were also reasonably effective. However, the effluent concentrations of total phosphorus still greatly exceeded Washington State Department of Ecology standards.
- Treatment A (sod+filter) removed over 20 percent of the total and dissolved copper and zinc influent load. The effectiveness of the other treatments for these constituents varied considerably.
- Regardless of treatment, TSS and turbidity could not be decreased below some irreducible minimum level that, depending on receiving body, may still reflect degraded water quality.
- All treatments were a source of soluble reactive phosphorus (SRP) to downstream waters. However, the bulk of the phosphorus in the ditch outflows was not the result of soluble phosphorus loading but rather of particulate bound phosphorus, which accounted for >95 percent of total load.
- The settleable portion of TSS loads was equivalent across the treatments. The sediment retained in the ditches had a mean D50 of 0.25 mm (fine sand) and a mean organic content of 5.3 percent.

Table 1 Flow velocity based on hydraulic residence time dye tests

Ditch: Treatment	Mean Velocity (ft/s)	Estimated maximum velocity (ft/s)
A: Sod+Filter*	0.38	0.73
B: Straw-only	0.71	1.3
C: Straw +Filter*	0.33	0.61

*While both filters consisted of dense, unmowed grass, the filter in ditch C had trapped straw from the upstream treatment, which increased its effective density relative to that of ditch A.

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THE EFFECTS OF ALTERNATIVE MAINTENANCE PRACTICES ON THE WATER QUALITY BENEFITS OF HIGHWAY ROAD DITCHES (from page 7)

Treatment C (straw+filter) is recommended over the other two post-cleaning treatments that were evaluated. A comparison of the load-based removal efficiencies (Table 2) demonstrates that this treatment performs well across the range of sampled constituents, particularly for TSS and total phosphorus.

Table 2 Percent Load Reduction of Selected Water Constituents

Parameter	Treatment A (sod+filter)	Treatment B (straw only)	Treatment C (straw+filter)
TSS	50	13	40
Total Zinc	22	25	24
Total Copper	20	22	23
Total Phosphorus	22	18	52
Turbidity	23	-13	22

In addition to the measured water quality benefits, the straw+filter treatment was judged to be the superior treatment based on the following observations:

- Much of the sod was covered with sediment deposits by the end of the study. In light of the fact that the sod+filter ditch (A) received lower TSS loads than the straw+filter ditch (B), sodding a cleaned ditch is not appropriate for a site receiving high sediment loads, especially when installed during the wet season.
- The uncertain survival and expense of installing sod, combined with the observation that sod+filter neither increased the HRT nor decreased the flow velocity relative to the straw+filter treatment, suggests that straw+filter is the more effective treatment.
- Sod matting may significantly reduce the infiltration capacity of earth-lined drainage ditches.
- Based on a cost-benefit analysis for TSS, total zinc, and total phosphorus, the straw+filter was the most cost-effective maintenance practice following ditch cleaning.

Linear regression models were developed to identify significant relationships amongst the environmental factors and highway runoff pollutant concentrations. The most significant findings were that: 1) the event mean TSS concentration is highly correlated to mean event turbidity and the vehicular traffic during the event, 2) total copper concentration is well correlated with total zinc concentration, and 3) the antecedent dry period has little effect on runoff quality.

RECOMMENDATIONS

The most significant finding of this project was that the retention of a dense, unmowed grass vegetation filter downstream of a cleaned ditch segment can increase the hydraulic residence time (HRT) and significantly improve the quality of the storm flow conveyed through the ditch. The key to reducing the TSS loads of ditch effluent is to retain such an intact vegetation strip downstream of all significant inflows.

In concert with a filter strip, the following additional steps can improve the water quality function of the ditch after cleaning operations:

1) Schedule all cleaning during early spring (late March to May) and early fall (late September to October) when regrowth within ditch is apt to be most rapid. This will reduce the likelihood of having a bare channel during high storm flows.
2) Filters occupying the downstream one-quarter of ditches (total ditch lengths of approximately 200 feet) were found to be effective in this study. While more study is required, it is reasonable to assume that there is a minimum filter length below which water quality benefits are diminished due to hydraulic and sediment loading. Furthermore, the best filter location is likely to be below all point inflows and immediately upstream of the ditch outlet, assuming dense grassy vegetation is present there.
3) Use temporary check structures (cobble dams, straw bales, transverse silt fencing), especially in facilities where no healthy vegetation exists downstream of the cleaned section.
4) While the combination of an intact vegetation strip and check dams was not tested in this study, it may be prudent to install one such dam downstream of each point of inflow to capture larger material that might otherwise fill the ditch bed and inhibit regrowth. This structure tends to dissipate inflow energy that may resuspend settled material or produce localized scour.
5) Avoid creating adverse bed slopes during cleaning activities that could lead to pooling. In particular, care needs to be taken so a lip is not left at the transition between the cleaned segment and the intact vegetation filter.
6) To protect ditch side slopes flatter than 2:1, the placement of 2-in-thick straw cover is suggested. The cover may reduce erosion and rainfall compaction, while promoting grass seed germination. However, straw placed directly in the active flow area is likely to be washed out during storm flows. A thick application of straw on the ditch bed could accumulate at downstream locations where culverts or storm grates exist, creating possible flooding hazards. ❖

On-Site Runoff Mitigation with Rooftop Rainwater Collection and Use

Derek Stuart, Graduate Student Intern, King County WLRD, and Graduate Research Assistant, Department of Civil and Environmental Engineering, University of Washington.

PROJECT PURPOSE

The construction of residential and commercial developments on the previously forested terrain of King County has had negative hydrological impacts on the streams of the region. A forested landscape typically infiltrates precipitation to the subsurface before it reaches a surface channel. After infiltrating, precipitation is both transported as baseflow and also recharges groundwater aquifers. Development creates impervious surfaces such as driveways, roads and rooftops thus causing a greatly increased volume of surface runoff. This increased surface flow causes increased peak flows during storm events and decreased magnitude of low summer flows. This altered flow regime both causes stream channel instability and damages aquatic life.

Historically, King County has managed development impacts by requiring new development to construct plat scale retention/detention facilities. Though these facilities can be effective in reducing the magnitude of large events they require expensive real estate, continuing maintenance costs and do not replicate the natural flow regime.

Recently, after the listing of the Chinook and Bull Trout under the ESA, King County and other municipalities have had increased interest in new "low-impact" development techniques. The goal of low-impact development is to reduce large runoff volumes that traditionally have been created by development. Several on-site schemes for low-impact development are retention systems for use, forest retention, limiting impervious area, dispersion/infiltration systems, soil amendments, alternative landscapes, and permeable pavements. Identifying techniques for reducing runoff impacts from development, such as rainfall collection, could also provide a direct benefit to residents.

SUMMARY OF FINDINGS

In many regions outside the Pacific Northwest, precipitation falls uniformly throughout the year in a pattern allowing for a continuous capturing and usage of rain. However, in the Northwest a majority of the annual precipitation falls between the months of October and June while the highest water demand season is between May and October. This requires that for rainwater to supply a residence during the June to October time period all of the precipitation must be collected during the October to June time period. Even in moderately conservative homes this large volume of water will require a water storage reservoir of greater than 21,000 gallons for all outdoor or indoor usage. An indoor system of this magnitude may cost $24,050 (based on 400 dollar UV purification system, 15,000 dollar subsurface vault, 200 dollars plumbing, 300 dollar pump and pressure tank, and 50 dollar sand column debris filter). This cost is out of reach for most homeowners who are already within close proximity to municipal or public systems. For other rural locations where groundwater may not be easily available or its quality is inappropriate for potable supply, the cost may be more reasonable.

There are large benefits from a rooftop rainwater collection system that is used as a supplement to a municipal or groundwater supply. A 1500-gallon tank system provides adequate supply for a small garden. At a total cost of about $500, this is affordable to many homeowners. With larger systems that significantly reduce municipal water use, savings can approach $150 per year on the annual water bill. In areas with higher water rates the monetary savings could be significantly more.

Besides the monetary benefits to the homeowner, benefits accrue to the ground and surface water systems of the region. By reducing peak runoff and reintroducing the collected rainwater back to the ground through irrigation (outdoor use) or through onsite wastewater system drainfields (assuming that the home is not on a sewage system) a more benign hydrology will exist. Reduced demand on the public water supply, which is likely drawn from surface waters in this region, preserves that much water for instream flow and improves regional hydrology.

RECOMMENDATIONS

Rooftop rainwater collection technology has promise for application in the Pacific Northwest. Large volume systems can provide adequate water supply for small households and reduce demand on regional water supplies. Though sizable costs are associated with large systems, when incorporated into building structures or developments at a large scale some costs may be avoided.

Other benefits from the technology could be reduced sizes of traditional detention facilities. Large and small systems alike when implemented in new developments could reduce the required capacity of traditional detention facilities. Developers could benefit more space for housing lots and possibly reduced demands on conveyance systems. At the present time, local regulations typically do not address rainwater use systems, but this is expected to change.

The full report can be found on the Center's web page as Publication L2. The table of contents of the full report is as follows:

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April 24 and 25, 2001

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Fall 2001

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Publication update of current projects at the Center (with dates of Newsletter articles and available Center publications)

Project	Newsletter Issue	Center Publication
Urban stream rehabilitation:	Su 98	
Riparian buffers in urban watersheds	W 97	
Landsat land cover interpretation	Sp 99, F 00	CUWRM web report
Regional, synchronous stream temperature survey	Su 98, F 98	CUWRM web report & data
Effectiveness of LWD in rehabilitation projects	W 00	K25
Sediment budget of mixed-use watershed	F 99	K23
Rates of stream channel restabilization	Su 99	K24
Urbanization effects on stream biology	Sp 00	K26
Metrics of hydrologic change from urbanization	F 00	
Urban Planned Development monitoring:	F 99	CUWRM web report
Relationship of turbidity to total suspended solids		
Monitoring of ephemeral streams		
Infiltrative parking lot surfaces	W 96, F 96	K19
Stream habitat assessment protocols	W 99	E17 (on CUWRM web)
Puget Lowland geology and geologic hazards	Sp 97, Su 98	linked web site
Water-quality effects of road ditches and swales	F 99, F 00	G15 (on CUWRM web)
Urban stormwater management evaluation	F 99	
Urban Issues Library	F 99	On CUWRM web site
Highway stormwater treatment testing	W 00, F 00	G14 (on CUWRM web)
Remote sensing of stream temperature	W 00	
Review of water reuse case studies		
The impact of urban patterns on ecosystem dynamics		

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