The Washington Water RESOURCE

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Message from the Director

With the end of the academic year, several projects are finishing up while a few more are returning for a second round. In addition to the information currently displayed on the Center's web page (which has now moved to http://depts.washington.edu/~cuwrm/), we will be adding substantially to it over the course of the next month or so, and so I encourage you to revisit this site at your convenience.

First on the horizon is a repeat of the tremendously successful one-day intensive stream-temperature monitoring survey. The Center for Urban Water Resources Management, in cooperation with the Center for Streamside Studies and local stormwater agencies, tribes, and citizen groups, is again planning to coordinate a regional, one-day stream-temperature survey. Last year, over 100 individuals helped us collect over 600 individual measurements and observations in a two-hour period. This year's date will be WEDNESDAY, AUGUST 4th. Once again, our intention is to characterize the range, distribution, and determinants of summertime high temperatures in fish-bearing (and tributary to fish-bearing) lowland stream systems in the Puget Sound lowlands. Whereas last year missed the maximum summertime temperatures of the year, our selected date this year has a much greater probability of lying within a week of that peak. This should provide an even clearer picture of the geographic distribution of maximum biological stresses associated with high temperature and/or low flow. It will also give us a better sense of the inter-annual variability of these data, and the utility (or lack) of any simple criterion for "temperature-impaired" streams.

We are contacting this original set of people in early July in hopes of soliciting their help again, and we also welcome other volunteers and agencies who would like to assist this time around. Contact me directly at dbooth@u.washington.edu.

The results from last year clearly displayed trends in canopy cover and in low summertime flow that contributed to high stream temperatures, particularly in combination with each other. The data also suggested that although typical "urban" effects (such as canopy removal and loss of baseflow) clearly influence stream temperature, generic "urbanization" does not exert any discernable control beyond these two factors. The full data set from last year is posted on the Center's web page and is available for downloading as an Excel spreadsheet. We invite subscribers to the Center and other readers of this Newsletter to explore the information contained in this data set, and to share with us any fruits of your analyses.

Derek Booth ❖

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A Rapid Land Cover Classification Method for Use in Urban Watershed Analysis: Progress Report and Preliminary Results

By Erik Botsford and Kristina Hill

INTRODUCTION

Modifications of the land surface during urbanization can produce tremendous changes in the patterns and the processes of stormwater runoff. These changes result from clearing vegetation, compacting soil, ditching and draining, and finally covering the land surface with impervious roofs and roads. The infiltration capacity of these covered areas is lowered to zero, and much of the remaining soil-covered area is trampled to a near-impervious state. Compacted, stripped, or paved-over soil also has lower storage volumes, and so even if precipitation can infiltrate, the soil reaches surface saturation more rapidly and more frequently. This results in pervasive changes to water quantity, water quality, and the associated ecological function of streams and riparian areas.

In addition to changes in how rainfall is absorbed or runs off of hillslopes, urbanization affects other elements of the drainage system. Gutters, drains, and storm sewers are laid in the urbanized area to convey runoff rapidly to stream channels. Natural channels are often straightened, deepened, or lined with concrete to make them hydraulically smoother. Each of these changes increases the efficiency of the channel, transmitting the flood wave downstream faster and with less retardation by the channel and destroys the habitat for stream biota.

Because of the profound effect of urban development on aquatic systems, characterizing the land cover of a region is critical for a variety of resource-management applications. In the Pacific Northwest, this characterization has been used most commonly to correlate the intensity of human activity with observed stream or wetland conditions, in order to predict the health of the stream system or to guide the allocation of mitigation efforts. For example, measured biological conditions in lowland streams are regularly presented in terms of "impervious area percentage" of the contributing watershed. Land cover is a primary input parameter for numerical hydrologic models (such as the Hydrologic Simulation Program Fortran [HSPF], widely used by the surface-water management agencies of King County, Snohomish County, the cities of Seattle and Bellevue, and the consultants of these and smaller jurisdictions throughout western Washington). Every one of the $20+ million in capital projects planned or under construction by King County Water and Land Resources Division, for example, is designed using HSPF with land cover as a primary, determining input.

Unfortunately, there is little consistency or quality control in how land-cover data are collected and analyzed. Some of this variety is entirely appropriate—the methods and the products for assessing wilderness-area potential in the Cascade Range have little overlap with those used to plan optimal siting of commuter-rail stations, for example. Yet certain applications constantly reemerge, and so typical procedures have been developed but only on an *ad hoc* basis.

The characterization of land cover for purposes of evaluating and assessing aquatic-system conditions is one such application. Yet the imprecision of the methodology currently used to classify land cover belies the significance of the results: typically, recent 1:12,000-scale airphotos (within the last 2–3 years) are manually discriminated by a technician into eight or so different "classes," of which four discriminate urban development of different densities and the remainder characterize the unbuilt areas. Discrimination is at the judgement of the operator, following established guidelines; typical minimum unit areas are one to five acres (about 100 m minimum dimensions); and subsequent ground truthing is nonexistent. Typical analyses require about 1 person-week for a 10 mi^2 area, and once the operator is trained there are no opportuni-

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ties for greater speed—every new area requires an equivalent level of effort. *This* is the procedure against which any alternative method should be compared.

Remotely sensed data from satellites provide an alternative source of information on land cover over very large areas. The traditional approach to classifying remotely sensed data from satellites into discrete classes of land cover involves a lengthy process of automated classification, clustering of spectral signatures, much fine-tuning, and an eventual supervised classification. This process can be both time and resource-intensive. It is also continually being refined, and so the methodologies are not consistent.

We have developed an alternative approach using Landsat satellite imagery to produce the same general type of land-cover characterization as has currently found widespread acceptance and use across the region. However, our methodology does so in a way that achieves maximum utility and consistency for a particular group of users—individuals and agencies needing to assess watershed conditions in the urban, and urbanizing, parts of western Washington. The classes of land cover produced have been chosen to reflect the categories that can be readily distinguished in the satellite data and to have important differences in their associated runoff and watershed characteristics.

The advantages of such an approach are obvious. The algorithm is developed only once; after completion, it can be applied rapidly to any other selected area through GIS software. It does not depend on the discretion of individual operators and so the results are reproducible. These advantages have not been lost on public agencies, but those agencies are not equipped to pursue such efforts systematically, given project-related geographic boundaries, time constraints, staff turnover, and the difficulty of inter-agency communication. With suitable testing and documentation, the release of these data layers through the University of Washington may encourage agencies across the region to adopt a uniform methodology, resulting in a degree of uniformity in data collection, analysis, and reporting of these data that is currently unavailable.

This project is a cooperative effort of the Center for Urban Water Resources Management, PRISM (Puget Sound Regional Synthesis Model), and students and faculty in the departments of Urban Planning and Landscape Architecture. It is still a work in progress, but the results are so promising for a variety of applications that a preliminary report is given here. A more complete description of the methodology and some examples of parts of the classified image in comparison to aerial photography of the corresponding areas are given on the Center's web site. We anticipate placing the full classified image there, available for downloading, as soon as error checking is complete this summer.

METHODOLOGY

The area of this analysis is a portion of the Puget Sound lowlands of northwestern Washington State, extending from the city of Olympia in the south to Everett in the north, and including the entire Seattle-Tacoma-Everett metropolitan area from Puget Sound east to the foothills of the Cascade Mountain range. The study site was chosen to cover a broad range of urban, suburban, and rural areas while excluding those areas with extreme topographic relief and little or no urban development.

Our classification scheme followed a multi-step process that was designed to be intuitive while yielding accurate results. It consisted of:

1. Combination and manipulation of the raw satellite images;
2. Selection of training sites, where different land-cover categories could be defined;
3. Extraction of the "typical" Landsat signatures for each coverage;
4. Classification of the entire image, following the characteristics defined for each class; and
5. Assessment of the classification's accuracy by checking actual field conditions at selected locations.

The final result of this classification is a composite, seven-class image:

Final Classes
Urban
Water
Deciduous vegetation
Coniferous vegetation
Grass/shrub
Forested urban
Grassy urban

Accuracy Assessment

The final step of this process deserves special mention, because it will determine the ultimate utility of the classified images. It entails a pixel-by-pixel error check using the classified images and some source of ground truthing (either DOQQ's or in-field truthing). An error check that examines a larger array of pixels simultaneously will also be used to determine the aggregate accuracy of the images. This step is essential, because *no* method of land-cover classification is error-free. Our experience to date suggests that error rates (*i.e.* percentage of mis-classified pixels) will be less than 10 percent in our chosen region, but we intend to complete this evaluation before releasing the image so that users know the degree of accuracy beforehand. This work is nearly complete as this newsletter is going to press.

FURTHER APPLICATIONS

Although multiple land-cover categories have great utility, there is great appeal to identifying a single "index" variable that characterizes the magnitude of urban development in a watershed. Patterns can be readily displayed, correlations are simplified, and communication between scientists and planners is enhanced. Yet urban development comes in many styles, occurs on many different types of landscapes, and is accompanied by a variety of mitigation measures designed to reduce its negative

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consequences on downstream watercourses. So any simple correlation between any single measure of urbanization and aquatic-system condition is unlikely to be precise.

Past efforts to quantify the degree of urban development have not been consistent. Recent and historical use of the most widely accepted parameter, percent impervious area in the contributing watershed, has been carefully documented in a recent review article (Schueler, 1995) but several issues remain ambiguous. Most significant of these is the distinction between *total impervious area* (TIA) and *effective impervious area* (EIA).

TIA is the "intuitive" definition of imperviousness: that fraction of the watershed covered by constructed, non-infiltrating surfaces such as concrete, asphalt, and buildings. Hydrologically this definition is incomplete for two reasons. First, it ignores nominally "pervious" surfaces that are sufficiently compacted or otherwise so low in permeability that the rate of runoff from them are similar or indistinguishable from pavement. For example, Wigmosta and others (1994) found that the impervious unit-area runoff was only 20 percent greater than that from pervious areas, primarily thin sodded lawns over glacial till, in a western Washington residential subdivision. Clearly, this hydrologic contribution cannot be ignored entirely.

The second limitation of TIA is that it includes some paved surfaces that may contribute nothing to the storm-runoff response of the downstream channel. A gazebo in the middle of parkland, for example, probably will impose no hydrologic changes into the watershed except a very localized elevation of soil moisture at the drip line of its roof. Less obvious, but still relevant, will be the different downstream consequences of rooftops that drain alternatively into a piped storm-drain system, with direct discharge into a natural stream, or onto splashblocks that disperse the runoff onto the garden at each corner of the building.

The first of these TIA limitations, the production of significant runoff from nominally pervious surfaces, is typically ignored in the characterization of urban development. The reason for such an approach lies in the difficulty in identifying such areas and estimating their contribution, although site-specific studies demonstrate that these tasks can be accomplished with simple field methods and the resulting hydrologic insights are often valuable (Burges and others, 1989). Furthermore, the degree to which pervious areas shed water as overland flow should be related, albeit imperfectly, with the amount of impervious area: where construction and development is more intense and covers progressively greater fractions of the watershed, the more likely that the intervening green spaces have been stripped and compacted during construction and only imperfectly rehabilitated for their hydrologic functions during subsequent "landscaping."

The second of these TIA limitations, inclusion of non-contributing impervious areas, is formally addressed through the concept of effective impervious areas, defined as the impervious surfaces with direct hydraulic connection to the downstream drainage (or stream) system. Thus any part of the TIA that drains onto pervious (i.e. "green") ground is excluded from the measurement of EIA. This parameter, at least conceptually, captures the hydrologic significance of imperviousness. EIA is the parameter normally used to characterize urban development in hydrologic models.

Yet the direct measurement of EIA is complicated. Studies designed specifically to quantify this parameter must make direct, independent measurements of both TIA and EIA (Alley and Veenhuis, 1983; Laenen, 1983; Prysch and Ebbert, 1986). The results can then be generalized either as either a correlation between the two parameters or as a "typical" value for a given land use. Alley and Veenhuis found that $[EIA] = 0.15\,[TIA]^{1.41}$ in their highly urbanized watersheds in Denver, Colorado ($r^2 = 0.98$). Using the other approach (i.e., typical land-use values), Dinicola (1989) compiled the findings of these earlier studies to recommend a single set of impervious-area values based on five land-use categories for use in studies of western Washington watersheds:

LAND USE	TIA (%)	EIA (%)
Low density residential (1 unit per 2-5 acres)	10	4
Medium density residential (1 unit per acre)	20	10
Suburban density (4 units per acre)	35	24
High density (multi-family or 8+ units per acre)	60	48
Commercial and industrial	90	86

Because our analysis is being conducted at a fine scale (30-m pixels) and detects only land-cover differences, we can evaluate only *total* imperviousness. Land-use categories, and thus EIA, might be inferred from larger clusters and patterns of individual pixels, but this lies outside the scope of this present effort. Based on detailed measurements of impervious areas at our training sites, we anticipate having median and ranges of TIA values associated with each of the seven land-cover categories at the conclusion of this project.

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Rates of Channel Erosion in Small Urban Streams

By Derek Booth and Patricia Henshaw, Center for Urban Water Resources Management

INTRODUCTION

Stream-channel changes are among the most common and readily visible effects of urban development on natural stream systems in humid environments. Even without any direct human modification of the channel itself, the actions of deforestation, channelization, and paving of the uplands can produce tremendous changes in the delivery of water and sediment into the channel network. In channel reaches that are alluvial, and so capable of responding by adjustment of the channel form and morphology, those responses can be rapid, dramatic, and readily documented. Channels widen, deepen, and in extreme cases may incise many meters below the original level of their beds. Alternatively, they may fill with sediment derived from farther upstream and braid into multiple rivulets threading between gravel bars. In either case, they become aesthetic eyesores and biological invalids; natural populations of benthic invertebrates and fish are decimated, to be replaced by limited numbers and taxa of disturbance-tolerant species.

Consider a watershed of some tens of hectares up to several square kilometers, where development has blanketed the upper watershed and so the headward-most channel(s) are the most fully affected of any in the channel network. Even low levels of land-cover changes, if accompanied by an efficient collection system (*e.g.*, road ditches) can produce significant increases in headwater channel discharges, which in turn will initiate increased in-channel sediment transport. Whether or not the response of the channel to these flow increases is “orderly” (*i.e.* channel-size increases in approximate proportion to discharge increases) or “catastrophic” (*i.e.* rapid incision) is largely independent of the magnitude of the watershed disturbance (see below).

In most cases, channel expansion of at least several times the original cross sectional area accompanies the progression from rural to suburban and urban development. Because such land-use changes typically occur over a period of many years or decades, they tend to produce continuous changes in the downstream channel subject only to the variability of seasonal runoff. Any tendency towards “equilibrium,” either dynamic or static, is completely obscured during this period. Sparse long-term data suggest that true equilibrium may be possible in watersheds with constant land use, over a years-to-decades time lag. We are exploring this issue more fully as part of our ongoing investigations into urban stream rehabilitation. Actually *observing* reequilibration, however, also depends on achieving stable hillslope conditions, which may take many decades or centuries. With these complications, it is not surprising that “reequilibration” may be more useful as a theoretical construct than as a widely observed condition.

The sediment released by this scenario of headwater flow increases may or may not be recognized as it passes through the downstream channel network. The typical channel-network pattern of declining channel gradients generally results in downstream-declining basal shear stress and thus declining sediment-transport competence. The potential input of additional urban-flow-induced sediment from other lateral tributaries will help determine whether sediment, eroded from upstream reaches, can remain in active transport or will accumulate in noteworthy volumes. Curiously, the vagaries of human infrastructure, particularly small roadway culverts that were sized and installed during an earlier pre-headwater-development era when only lower discharges of water (and tremendously lower discharges of sediment) occurred, appear to be one of the strongest single determinants of whether the urban channel change is perceived by citizens and mangers to be mainly a problem of “erosion” or of “deposition.” In fact, both processes are occurring in different parts of the channel network simultaneously.

FIELD INVESTIGATIONS

No single study can cover all settings in which urban-induced channel change is observed. Yet even a geographically limited set of new data can increase our understanding and prediction of this threat to aquatic-system integrity. This study was initiated to provide some of that new data, focused on a part of western Washington state where (and beginning at a time when) the rate of new urban development was accelerating to historically unprecedented rates. It also began when the social and political desire to alleviate the worst environmental consequences of that development far exceeded the concrete knowledge necessary to achieve that goal.

Starting in 1986, 35 stations along an equal number of independent streams were established to monitor long-term channel changes in urbanizing watersheds. The purpose of this ef-

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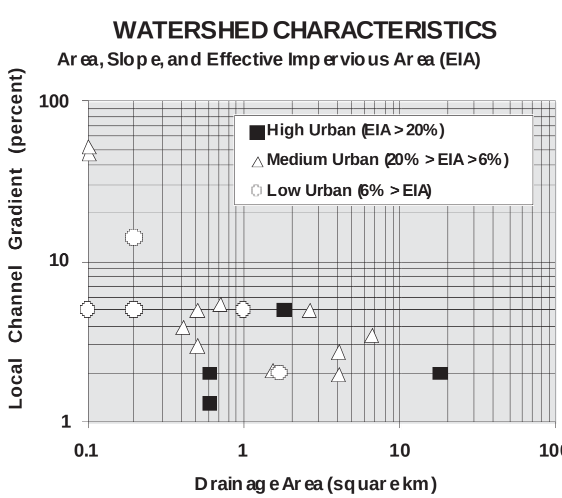
fort was four-fold:

1. To document erosion and deposition rates in a variety of physiographic settings;
2. To test the hypothesis that urban development consistently increases the rate of channel change, and that higher levels of urban development are correlated with faster rates of channel change;
3. To test the hypothesis that certain geologic and/or topographic settings are particularly susceptible to urban-induced channel changes; and
4. To allow prediction of the most susceptible sites *before* development has occurred, and thus before degradation has begun.

METHODS

Study sites. The choice of channel reaches for monitoring began in early 1986, following a particularly large storm in January that resulted in many instances of channel modification and property damage from high discharges. These first sites were chosen because of known stream-channel erosion, reported downstream problems, or knowledge of impending development that might prove problematic. Over the next several years, a number of additional sites were identified, and some unsuitable sites were relocated or abandoned, mainly due to unrepresentative channel conditions but also because of subsequent obliteration by development activity. The selected sites covered a range of channel conditions, particularly slope, degree of upstream development, and geographic location. Previous observations had suggested that channel changes were particularly rapid downstream of recent urban development in small headwater catchments and in channels traversing hillslope deposits of a specific regionally common geologic deposit, so these characteristics were emphasized in the initial site selection.

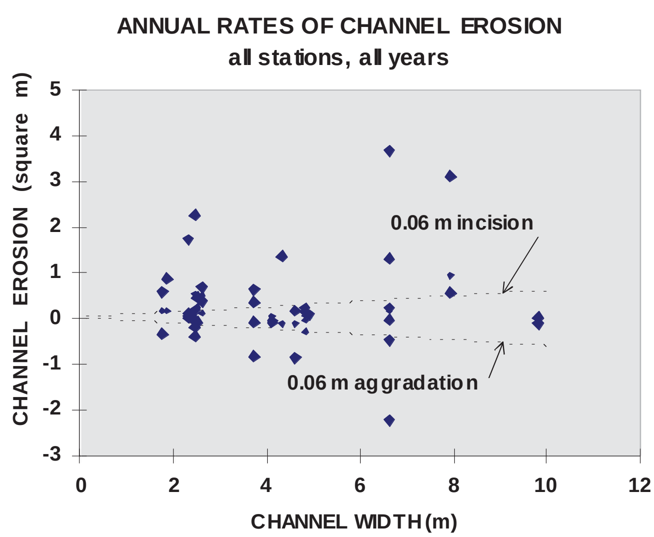
Figure 1. Summary attributes of measurement stations.



Most of the sites were, broadly speaking, *alluvial channels* (Leopold *et al.*, 1964) carved by running water into the very sediment carried by that flow in the past, and that presumably could be carried by that flow in the future. These "self-formed" channels are free to adjust their shape in response to subsequent changes in flow and thus were anticipated to respond most sensitively to future development. However, as the channel changes in response to increased flows (and particularly if it begins to incise) the underlying hillslope deposits commonly become the channel-bounding sediment and the alluvial "character" of the channel can be reduced. In contrast, a channel formed in alluvial sediment but also choked with immovable roughness elements, such as logs, is not strictly "alluvial." Yet if those logs are removed, or if progressive bed erosion strands those logs above the elevation of the flow, the channel will become *more* characteristically alluvial over time.

The sample population explored the influence of the underlying geology by emphasizing sites located on a particularly erodible substrate. Most of the stations had as their underlying substrate a thick and widespread sandy deposit with local concentrations of pebble to cobble gravel, laid down by glacial outwash streams during the last advance of the continental ice sheet (regionally named the "Vashon" by Armstrong and others [1965] and spanning an interval of about 17,000–15,000 years ago). This emphasis was established to quantify rates in what previously had been observed locally to be the most erosion-susceptible deposit. A moderate number of sites with other substrates were also included to test this hypothesis more precisely.

Figure 2. Results of all measurements, expressed as the average change in cross-section area per year between visits. Dotted lines plot the median vertical change of 0.06 m.



RESULTS

Rates of erosion and deposition vary by over two orders of magnitude (see Figure 2). In this population, the minimum amount of annual vertical channel change was below the level of measurement error (about 20 mm); the maximum was about

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1 m per year. Over the 11-year period, 80 percent of all measurements show an annual width-averaged vertical change of less than 0.2 meters, with the median of all measurements at 60 mm/year.

The most consistent pattern is the correlation of rainfall with channel change. This outcome is qualitatively intuitive, although the nature of this relationship is more complex than might be first anticipated. For example, 1990 channel changes are the largest, by a significant degree, at nearly all sites. Although the 1990 rainfall intensities are also the largest in the period as well, they do not exceed other "large" years (1991 and 1996) by nearly as much as the erosion/deposition measurements would suggest.

Most noteworthy of this data set, however, is the overall *absence* of general relationships between measured channel changes and simple, physical parameters of the stream or of the watershed, such as slope or imperviousness. This condition bodes poorly for the kinds of simple predictive methods favored by local governmental jurisdictions in the prediction and avoidance of environmental impacts. Only the role of geologic materials shows any consistency, with cohesive silt-clay substrates generally permitting only low rates of channel adjustment.

The poor correlation between effective impervious area and channel change is quite robust. It is displayed by both the station averages for the period of record and the single-year (1990) data. We therefore reject the first of our initial hypotheses, that urban development systematically increases the rate of channel change, and that higher levels of urban development are necessarily correlated with faster rates of channel change. The following two examples express some common and important trends.

Olympic View Park. This channel is located in a lightly developed parkland, established around the long-protected riparian corridor of the stream. The surrounding watershed has been almost fully developed for several decades, primarily with single-family residences. The ravine that contains the channel and associated park is excavated into deposits of the sandy Vashon advance outwash. Incision has clearly been part of the channel's past history; several hundred meters downstream of the measured cross section, large gabion baskets stabilize what must have been a major vertical knickpoint in the 1970s. Yet the current decade of measurements is noteworthy in the near-perfect uniformity of the channel from one year to the next (Figure 3), although the channel morphology is distinctly unappealing from either a biological or an aesthetic standpoint. It is relatively uniform, slightly sinuous, with virtually no heterogeneity or variability in size, shape, or roughness. Much of this uniformity is surely the result of close human contact—foot traffic up and down the channel (commonly dry in the summertime) is frequent, and any sticks or twigs would be promptly "cleaned up." Yet even where encroaching riparian shrubs likely limit the immediate access of people, conditions are essentially unchanged.

Pepper Creek. In contrast to the modest changes observed at the previous stations, this site has shown tremendously variable conditions (Figure 4). It collects runoff from a watershed in the very earliest stages of urbanization; the major hydrologic changes have been related to channelization and road-ditch interception of shallow subsurface flow (Burges *et al.*, 1989), whereas the total fraction of contributing imperviousness is still quite low. The channel is extremely well protected from direct human intrusion, lying several hundred (very brushy) meters from the nearest structure or public road and entirely on private property. It is eroded into sandy valley-bottom deposits, delivered by episodic landslides from the surrounding hillsides and locally reworked by past fluvial action.

The likely magnitude of channel changes was first suggested by extensive deposition on the downstream alluvial fan of the stream, beginning in about 1980 and coincident with the first extensive road construction and forest removal in recent history. Following first measurements in 1986, two episodes of sig-

Figure 3. All cross section measurement of Station PS4, showing almost no change 1987–1993 and only modest change 1993–1997.

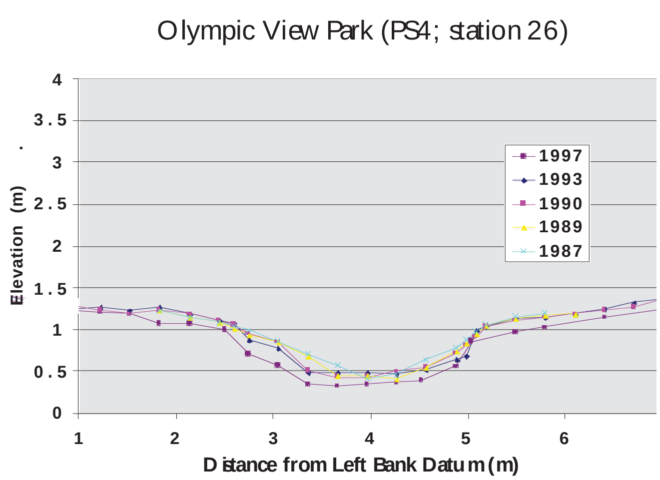
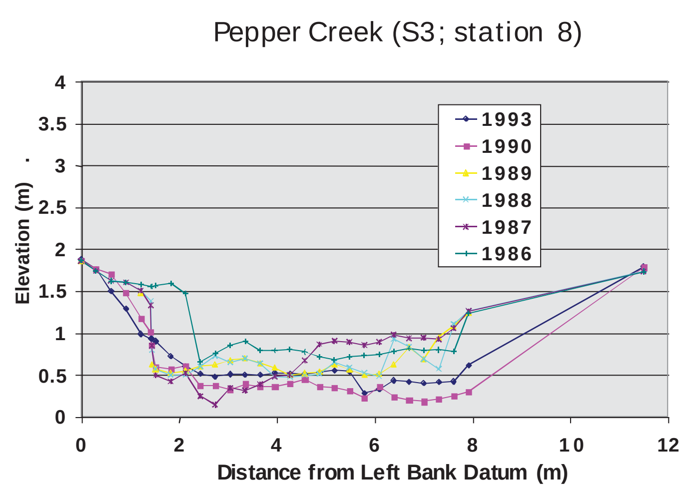


Figure 4. All cross section measurement of Station S3, showing active change in every measurement interval. Vertical exaggeration 2:1 (note expanded horizontal scale).



Professional Engineering Practice Liaison (PEPL) Program

The PEPL (Professional Engineering Practice Liaison) Program, in cooperation with the Center for Urban Water Resources Management, offers a continuing education program in urban water resources management.

As part of the benefits extended to supporters of the Center for Urban Water Resources Management, member organizations submitting five or more registrations for the same course may deduct $30 per registration for a 1-day course, $35 for 1.5-day, $45 for a 2-day course, $50 for a 2.5-day course, and $60 for a 3-day course.

For further information on the *Urban Surface Water Management Continuing Education Program* or on any of the courses on the next page, please contact:

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Professional Engineering Practice Liaison (PEPL) Courses

September 8 and 9, 1999
Use of Constructed Wetlands for Improving Stormwater Quality

September 14, 16 and 21, 1999
Basics of Project Management for Design Professionals

September 15 and 16, 1999
Stormwater Treatment: Chemical, Biological and Engineering Principles

October 13 and 14, 1999
Fundamentals of Urban Surface Water Management

December 3 and 4, 1999
Seismic Site Response Analysis

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nificant erosion were evident: 1986–1987 and 1989–1990. Channel readjustment, but little net erosion/deposition, occurred in 1987–1988. Near-static conditions persisted during the low-rainfall year of 1989. Substantial erosion continued following 1993, but landsliding off the hillside above the right bank, probably in 1996, has now completely obliterated the measurement station.

DISCUSSION

The factors anticipated to influence the annual rate of channel change are generally well represented by the results. They include:

- Abundant rainfall,
- Easily erodible substrate, and
- Presence or absence of watershed urbanization.

These factors resist simple quantification, however, because of the tremendous variability imposed by the multiplicity of local channel conditions, the location of a chosen site in the context of the upstream channel network, and the variety of development styles (*e.g.* residential density, or sewered vs. unsewered). Our population of sample sites was neither varied enough nor large enough to allow a systematic evaluation of every relevant condition. However, several useful observations can be drawn:

1. The average annual rate of change can increase in a single channel by as much as 2 orders of magnitude between dry and wet years (e.g., 1990, in this sample population); more typically, the greatest interannual change is about 5-fold. Because the study years include some of the largest lowland storms in recent memory as well as several quite unexceptional years, this variability is probably representative of most long-term conditions. In virtually all cases, the rate of change returns to nearly equivalent pre-event levels within one measurement interval (typically one or two years).
2. The recognized characteristics of erosion-susceptible channels are broadly correct—moderate to steep slopes, susceptible geologic materials, and significant (and recent) upstream development. The unique factors of any given catchment, however, can greatly influence these predictions. No unconsolidated substrate appears immune from change, given sufficiently severe watershed disturbance. The streams draining large basins are more resistant than those draining small ones. Steep slopes in and of themselves are not critical, but they can increase the magnitude of the response to disturbance.
3. The age of the upstream development appears to be quite significant. In general, channels draining established neighborhoods show low rates of change. Possible explanations include (1) reequilibration of channel dimensions and sediment size with the increased (but now stable) flow regime; (2) removal of all erodible sediment from the channel perimeter, leaving non-erosive bed and banks; (3) cementation of channel sediments, a ubiquitous observation at these sites; or (4) reestablishment of bank vegetation following initial disruption of the channel by increased flows. Each of these explanations applies to certain sites, although (1) and (2) appear to be the most significant in a majority of cases. The reestablishment of equilibrium, however, does not necessarily coincide with a reestablishment of overall stream function or habitat quality: the channel capable of resisting the frequent, flashy discharges that roll out of an urban catchment is generally inhospitable to most aquatic organisms.
4. Results are most unpredictable in the smallest basins (those of a few tens of hectares). In these basins, even a relatively small amount of development can have significant downstream effects if flow concentration occurs as a result of ditches or road crossings. These effects, however, are not well represented by traditional methods of characterizing urbanization, such as impervious-area or disturbed-area percentages.

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RATES OF CHANNEL EROSION (from page 8)

5. The influence of channel slope is not well displayed by this data set. All channels here have slopes of at least 1.3 percent, so true low-slope channels (also correlating, typically, with larger channels) are not represented. Within this data set, there is a crude correlation of increasing slope with increasing rates of change; certainly, the very largest changes (>0.3 m/yr) appear to require a steep slope (4 percent or greater).
6. Finally, the "stability" of a channel, as measured by the absence of change at single cross sections, does not necessarily equate with other desirable conditions, such as high-quality aquatic habitat. The converse statement, however, is generally correct: instability *does* correlate well with low habitat quality. Therefore, only evaluating channel stability will not provide unequivocal information on habitat conditions; if that information is needed, additional monitoring will be required.

MANAGEMENT IMPLICATIONS

These results imply several consequences for watershed management. First, urban development is an obvious force in channel change, yet not all channels respond equivalently. The locations of potential susceptibility can be determined well in advance, at least in the Puget Lowlands of Washington, based on geologic conditions. Finally, channel changes, if and when they do occur, can happen so rapidly after development begins that remediation must occur *prior* to development to be effective.

The results of this study also suggest that channel changes are very responsive to varying rainfall. This source of variability is obviously beyond the ability of surface-water or land-development agencies to control, yet its effects can be as significant as those of urban development. The most extreme effects of high rainfall are felt in the urbanized channels, and so one result of large storms is to amplify the differential response of developed and undeveloped watersheds. This imposes a challenging task for watershed managers: during low-rainfall years, any "warning" of impending channel-erosion disaster is muted, along with the public's concern for such issues. When the large storm arrives, however, the magnitude of channel change in urbanizing watersheds can cause significant damage, and its consequences invariably surprise almost everyone. ❖

Modest Progress on the Long Road to an Effective Water-Resources Management System in Washington

Subtitled: It's a War Zone

By State Senator Karen Fraser

A summary of the May 1999 presentation to the Washington Hydrologic Society (reprinted from the WHS June Newsletter, with permission; for information on membership, contact WHS c/o Llyn Doremus, 10811 36th Ave. SW, Seattle, WA 98146)

Water resources "policy gridlock" evident in the past decade continued in this legislative session. The basis for the current impasse is the foundation of our state's "property-based" water rights system, overshadowing the use of sound science in water policy discussions and decisions. However, the historical trend may be leading towards change in a positive direction. To understand the present situation, it's necessary to view it in light of the historical as well as contemporary "demands" by the state on its water-resource management institutions.

Historically, the Prior Appropriation Doctrine (PAD) creates a "property right" in the actual diversion of water for a beneficial use. The PAD derives from the 1850s gold fields of California, when miners, desperate for water to run sluice systems, violated the existing "riparian" water ownership system by taking water from ranchers and farmers. The miners prevailed in court by arguing that they were taking the risk of investing their capital and putting the water to "good use," therefore they should retain the right to continued water use. The PAD was adopted throughout the west and developed into the familiar system of seniority, "first in time, first in right."

Although the PAD worked moderately well through the end of the 19th and into the first half of the 20th century, concerns about environmental quality initiated in the 1960s initiated change to this system. Washington's water code was amended in the late 1970s to place a "public interest" overlay on the PAD, and comprehensive water-resource planning on a watershed basis was authorized. Minimum flows to protect instream uses were also authorized in statute.

The significant increase in present water-use demands from those of the 1890's, and the PAD "property rights" system together have created a system of "paper" rights on nearly all the major water sources that greatly exceeds the amount of water actually available. With this discrepancy, and the existing "public interest" and "comprehensive planning" statutory authorities merely "overlaying" onto the existing PAD system, it has proven to be impossible to accomplish state water-resource management. Instead, the state has become increasingly mired in an endless effort to "straighten out" who has "property" interests in the state's waters. There are also wildly divergent ideas held on just what the nature of this "property" is. A significant

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MODEST PROGRESS ON THE LONG ROAD (from page 9)

segment of society believes the “paper” rights to water use should be heavily valued. Conflicts over the “property” basis in the state’s water program have overwhelmed efforts to move the program to a “management” system.

However, there is reason to believe that the state, and the Legislature in response, is beginning to shift to a more balanced interest in both the “property” aspect of water institutions as well as the “management” aspects. Federal Laws, including the Endangered Species Act and Clean Water Act, are forcing a more comprehensive approach to management and protection of the state’s waters. Additionally, Washington’s growing communities are interested in long-term water use and management. Municipal water suppliers are seeking a comprehensive understanding of the hydrologic system from which they derive water resources and of the protection required for the aquatic resources impacted in deriving water supplies.

While conflicts within the Legislature over water resources and the PAD dominated the 1999 session, there were some positive outcomes with respect to water management. Conflicts remain over: 1) the definition of a water right, 2) setting instream flows (opposed by those who prioritize out of stream uses), 3) hydraulic continuity (questions of validity), 4) water-law enforcement, and 5) recognition of tribal water rights. However, the 1999–2001 biennial operating budget, signed by Governor Locke, contains funding to significantly assist the state in getting better information about its aquatic systems. So, where will the money be allocated?

- $700,000 for additional hydrogeologic and technical assistance in Ecology’s Water-Resources Program
- $1.7 million to increase Ecology’s Water Resources decision-making staff,
- $1.1 million to increase Ecology’s water-rights and water-quality compliance staff,
- $2 million to the Conservation Commission to assist local salmon-recovery planning efforts in conducting limiting-factors analysis, including water-flow and water-quality factors,
- $1.7 million funding for pilot monitoring systems on 10 rivers around the state to assess salmon-recovery factors,
- $4 million to the departments of Natural Resources, Ecology, and Fish and Wildlife, for technical information, monitoring and rules development to implement the Forestry Module agreement strengthening riparian protection in forest practices.

Additionally, actions by the Legislature in the 1999 session will have other impacts to the states water resources including:

- Creation of a state board to direct how the $112 million of state and federal funds is spent on salmon-recovery projects,
- $1 million budgeted for purchase of water rights to be held instream as a “water trust,” and
- Forestry module legislation increasing protection of riparian areas during forestry activities.

The legislature will also be working between sessions on a variety of other related water-resources issues. These include finalization and implementation of the state’s salmon recovery strategy; developing regional approaches to water-supply management, particularly the RIMA initiative (Regional Integrated Management Area), and a comprehensive cleanup program for the state’s water bodies out of compliance with the Clean Water Act. ❖

Working at a Watershed Level

A one-week course in the basics of watershed management

For the second year, the University of Washington has been funded by the U. S. Environmental Protection Agency’s Office of Water to conduct watershed training in the Pacific Northwest. The UW team includes a set of regionally and nationally known scholars and practitioners covering the full range of watershed management from both scientific and social perspectives, with the participation of two multidisciplinary research centers dedicated to stream and watershed issues, the Center for Urban Water Resources Management and the Center for Streamside Studies. This course provides a basic but very broad foundation of scientific and social principles proven useful in guiding watershed-level activities. The six training units move through a discussion of how watersheds work, how change occurs in watersheds, methods to assess watershed conditions and plan for management, watershed management practices, and the all-encompassing social and cultural context for watershed management.

This course is part of the U. S. Environmental Protection Agency’s *Watershed Academy*. A Federal interagency group (USEPA, U. S. Forest Service, Bureau of Land Management, U. S. Fish and Wildlife) established the overall curriculum; the University of Washington instructional team was selected after a nationwide competition and has developed the specific course materials for this region of the country.

The course is structured for a range of attendees:

1. Entry-level staff with little watershed science background or with a strong background in one or several aspects of watershed management but who lack breadth of knowledge and experience across scientific and social disciplines integral to the watershed approach;
2. Experienced technical staff, who may seek a broader perspective than their narrow specialty or who may desire a comprehensive refresher of watershed approach principles;
3. Managers who cannot afford the time for in-depth technical training yet must direct and evaluate activities that require a sound watershed approach; and
4. Informed citizens involved in working with their own watershed.

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WORKING AT A WATERSHED LEVEL (from page 10)

Out of this course, attendees can expect to obtain a comprehensive overview of the scientific and social elements of watershed management, together with a set of resources that will enable them to pursue any particular technical subject in yet greater depth. The emphasis will be balanced between technical information on physical and biological watershed processes, social and economic realities of watershed activities, and practical examples and experiences of what is and is not successful.

Primary Instructors (partial listing)

Dr. Susan Bolton—Associate Professor of Forestry and Director of the Center for Streamside Studies, University of Washington. Dr. Bolton has a background in ecology, hydrology and engineering. She has studied and worked in interdisciplinary environments for 20 years. Her research has focused on various aspects of the impact of land-use on hydrologic systems, including stream temperature, water quality, snow accumulation, fish habitat and channel migration. She also teaches several courses that deal with ecological impacts of human management activities on the landscape.

Dr. Derek Booth—Director of the Center for Urban Water Resources Management, University of Washington. Dr. Booth spent eight years as senior technical staff (and one year as program manager) in King County's "Basin Planning Program," a multi-disciplinary watershed assessment and rehabilitation team. As director of the University's urban water center, his research focuses on the effects of land-use change on aquatic systems, primarily from a physical geomorphological perspective.

Dr. Clare Ryan—Assistant Professor of Forest Management. Dr. Ryan has a combination of science and policy experience. She has worked for the Washington Department of Ecology and the USEPA on technical and policy issues. Much of this work has involved collaborative planning/problem solving process facilitation and participation in community relations and education.

Dr. David Montgomery—Associate Professor of Geology. Dr. Montgomery is interested in physical processes that affect watersheds and how these processes in turn affect the ecological functioning of the watershed. As a geologist, his primary research interests concern landscape-forming processes and their interactions with other natural systems. Montgomery leads a research program that seeks to develop models of the physical environment necessary for understanding landscape development and ecological response to disturbance.

Logistics

The course will be held September 20–24. 1999. Each day will begin and end at the University of Washington campus in Seattle, although two days will also involve field trips to watersheds and stream-restoration sites in the surrounding region. Because of the commitment of the US Environmental Protection Agency to local-level watershed training, the course fee is only $210 for the entire 5 days and covers all classroom materials, field trip transportation, and lunches. Registration will be limited to 50 attendees.

The University of Washington will be handling registration through the Engineering Professional Programs (EPP) office. Formal announcements and applications will be sent out early this summer to those on the Center's mailing list, but you can request early information and advance registration materials by calling the EPP office at 206-543-5539. ❖

Brief Research Notes

A Meta-Analysis of Cattle Grazing Impacts on Salmonid Stream Habitat Quality: *Dalius Gilvydis, M.S.C.E. Project, Center for Urban Water Resources Management*

The effects of cattle grazing on stream habitat quality has been the focus of intensive study for well over thirty years. These studies usually have very small sample sizes, large variability, and classic problems with "pseudo-replication," all of which make it difficult to detect statistically significant effects. In order to partially overcome some of these problems, this project reports on a meta-analysis of 23 studies concerning cattle grazing impacts on fish populations, stream morphology, riparian vegetation cover, and substrate composition. This analysis shows cattle grazing in the riparian zones of small streams causes salmonid populations to decrease by 0.32 standard deviations (SD) based on 11 studies (n = 11), and non salmonid fish to increase by 1.17 SD (n = 6). Fish biomass (kg/km) data show similar trends with a 0.37 SD (n = 9) decrease and a 4.23 SD (n = 3) increase in salmonid and non-salmonid fish biomass, respectively. Grazing changes the physical habitat by causing streams to widen (2.15 SD; n = 11) and become shallower (-1.64 SD; n = 11). Grazing also reduces the availability of high quality salmonid habitat such as pools (-0.91 SD; n = 4), bank undercuts (-1.71 SD; n = 5), and overhanging vegetation (-2.00 SD; n = 3). The availability of salmonid spawning habitat is diminished by an increase in substrate embeddedness (3.35; n = 4). This analysis shows cattle grazing can have marked impacts on the habitat quality of small streams for salmonid fish, and these changes manifest themselves in lower salmonid and higher non-salmonid fish abundance and biomass. ❖

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