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Riparian buffer function along lowland agricultural streams

Carrie Monohan is a PhD student in Forest Resources.

Non-point source pollution from agriculture is the leading source of impairments to rivers and lakes in the United States (EPA 1996). Agricultural practices that can negatively affect aquatic environments include animal facilities, grazing, plowing, pesticide application, irrigation, fertilizing, planting, and harvesting. There are over 2 million farms in the United States (1997 Census of Ag USDA), and each has unique site characteristics, climate regimes, and ecological features.

Depending on the type of agriculture and its environment, negative effects include the delivery of harmful loads of sediment, nutrients, pathogens, pesticides, and salts to surrounding water bodies. The delivery of excess nitrogen from fertilizer applications can stimulate primary production in nearby aquatic environments, which can lead to eutrophic conditions and degraded habitat for aquatic organisms. Management of agricultural practices for non-point source pollution applied across the nation include improving water use efficiency, implementation of nutrient management plans, integrated pest management techniques, restricting livestock from sensitive areas, and the use of vegetative strips or buffers along streams. Development of best management practices is typically based on the type of agriculture that is being practiced rather than the environment in which it is taking place. Yet strategies for managing non-point source pollution, such as excess nitrogen from fertilizer runoff, may not be applicable from one region to another because of the regional environmental and climate variability.

Riparian buffers along agricultural streams are one of the most widespread management techniques for controlling non-point source pollution. Typically nar-

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Message from the director

Derek Booth

In this issue, we feature two projects that address nutrient cycling, particularly nitrogen, in streams of western Washington. Although the land uses—forestry and agriculture—are different, they share a climate and ecoregion that favor the growth of red alder as the common riparian tree species. Red alder is unusual among riparian vegetation in its ability to fix atmospheric nitrogen and then deliver this nutrient to the stream, through leaf fall, in a bioavailable form. In undisturbed environments this provides what appears to be an important food supply to the aquatic food web; in more human-disturbed areas, however, it may augment already high nutrient loads from adjacent land use.

In both cases, these studies underscore the importance of carefully investigating local processes within the unique context of the Pacific Northwest watersheds. This is exactly the kind of research the Center seeks to highlight and to support; we look forward to the completion of these studies and the application of their management guidance. ♦

Also in this issue

Lowland agricultural streams (cont.)

row forested strips along stream banks, these buffers are surrounded by agricultural fields. These vegetated strips are maintained to filter pollutants, trap sediment, diffuse concentrated water runoff from the fields, and stabilize stream banks. The seminal research conducted by Lowrance et al. (1997) and Peterjohn and Correll (1984) constitutes what is now the classic and widely accepted view of riparian buffer function.

Effective control of non-point source pollution is dependent on the type of pollutant and the hydrologic connection between pollution sources and the stream through the riparian buffer (Lowrance et al. 1997). Peterjohn and Correll (1984) were one of the first scientists to report that plant-uptake by riparian buffers acted as a major mechanism for nitrate loss in agricultural areas. Plant-uptake has become a widely accepted view of how riparian buffers function to remove excess nutrients and protect streams from agricultural runoff. After examining the effects that different subsurface hydrologic connections have on nitrogen removal, Lowrance et al. (1997) concluded that the degree to which nitrate is removed in the riparian buffer depends on the extent to which the groundwater is in contact with the biologically active root zone. They found that up to 90% of the nitrate input from agricultural practices can be removed by vegetation uptake from groundwater moving in shallow flow paths through the riparian buffer. The results from these studies have made riparian buffers a commonly used management practice to control non-point source pollution in agricultural areas across the nation.

The northwest agricultural community

The Northwest agricultural community is currently faced with management decisions to protect water quality and salmonid habitat in lowland agricultural streams, in a region where very little research has been conducted on riparian buffer function. To date, available guidance is based only on research from the Southeast agricultural regions, such as the work by Lowrance et al. and Peterjohn and Correll, or from the Pacific Northwest forestry industry.

In reviewing research on buffer efficiency from the Southeast United States, differences in buffer composition and soils were noted between the Southeast and the Pacific Northwest. Pacific Northwest buffers are primarily composed of red alder *(Alnus rubra)*, a nitrogen-fixing species, whereas the buffers studied in the Southeast are primarily cottonwood and maple. The nitrogen-fixing properties of red alder make it a unique riparian species because it contributes to augmented levels of nitrate in riparian buffer soils and streams (Binkley et al., 1992; Bormann and DeBell, 1981; Cole et al., 1990; Van Miegroet, 1984). As such, riparian buffers comprised of red alder can act as a net source of nitrate rather than a sink, which means that the nitrate-retention attributes of riparian buffers studied elsewhere may not be relevant for riparian buffers in the agricultural areas of the PNW.

Soil texture, another factor influencing nitrogen retention, is commonly fine silt and clay in agricultural areas of the Pacific Northwest as opposed to the sandy or gravel soil in watersheds studied by Lowrance et al. (1997). Fine soils create a unique hyporheic environment connecting the riparian buffer to the stream, in that low hydraulic conductivity may increase the retention time of nitrate-rich groundwater within the biologically active root zone, increasing the potential for nitrate removal via denitrification rather than by plant-uptake. Denitrification is the bacterial reduction of nitrate to elemental nitrogen, which is subsequently lost to the atmosphere. Occurring in soils rich in organic matter, denitrification is generally found under anoxic conditions. The potential for denitrification, and its contribution to nitrate removal in riparian buffers, is especially significant in the Pacific Northwest lowland areas where soils are often saturated and have long residence times compared to the coarse-textured and well-drained soils of lowland agricultural areas of the Southeast. Therefore, the unique biochemical cycling of nitrogen in the Pacific Northwest lowland agricultural streams dominated by red alder means that non-point source pollution management practices in the Pacific Northwest agricultural areas must be studied, and managed, uniquely with respect to nitrate.

Buffers in Pacific Northwest forestry

Riparian buffers in the Northwest have been studied extensively and used in forestry practices to protect salmon-bearing streams from the effects of logging since the 1980s. However, lowland agricultural riparian areas are different from forested riparian buffers. Riparian buffers in forest environments provide recruitment of large wood, shade, stream bank stability, litter-fall, sediment filtration, and support of floodplain processes. Determining buffer widths in forestry can be traced to models developed by the Forest Ecosystem Management Assessment Team (FEMAT 1993), wherein retention of large wood and shade are the dominant factors used to determine buffer widths. Riparian buffer widths recommended by the FEMAT report are largely based on "site-potential tree height," which is indicative of the site's long-term ability to deliver large woody debris to streams. Application of the science from forested riparian buffers to determine appropriate riparian buffer width on agricultural lands, however, has important shortcomings. Most importantly, the parameters used to determine forestland buffer widths, large wood debris delivery, and temperature regulation function differently in agricultural settings.

There is a paucity of research on the role of large woody debris in lowland agricultural streams, which often flow through floodplain environments dominated by deciduous hardwood species. As such, there is considerably less woody debris recruitment in the floodplain environment compared to the forested upper portions of the watershed. Therefore, lowland riparian buffers probably should not be designed to meet large woody debris instream quotas that were developed in mature and/or old-growth upland forests.

The relationship between temperature and riparian buffer widths in lowland agricultural streams also differ from that in conifer-dominated forested streams. Different vegetation and subsequent canopy densities affects the amount of solar radiation that penetrates the canopy and reaches the stream. The low elevation of agricultural streams means that the temperature regime is typically warmer than high-elevation reaches. The elevation-based differences in temperature mean that the role of riparian buffers play in temperature regulation along lowland agricultural streams is potentially of great importance to the maintenance of a habitable temperature regime for salmonids, but appropriate widths may not be predicted by models developed in forested regions.

The future of riparian buffers

In summary, the soil properties of agricultural areas of the Pacific Northwest, the historic floodplains of lowland rivers, differ significantly from the sandy substrates of the Southeast agricultural regions where most existing buffer research has been conducted to date. This has direct implications for the flow of subsurface water and delivery of excess fertilizer nutrients to the stream ecosystem. In addition, the nitrogen input from red alder creates a nitrogen cycle unique to Pacific Northwest streams, which sets these lowland Northwest agricultural streams apart from their hardwood-dominated Southeastern counterparts. The temperature regimes of low-elevation streams, particularly those with riparian canopies primarily composed of deciduous species, means canopy density plays a role in temperature regulation that will not be well-predicted by upland forest research or models.

These differences emphasize the need for individual scientific attention to be placed on agricultural riparian buffer ecosystems in the Pacific Northwest. The objective of my doctoral research is to investigate one aspect of this need, the surface and subsurface water chemistry of agricultural streams under a range of riparian buffer widths in the lowland agricultural areas in Skagit County, Washington. After three years of sampling, the chemistry of waterways that run through areas adjacent to row-crop agriculture and those that run through pasture areas were compared. Results indicate that row crop streams experience more intense fertilizer applications and subsequently had higher levels of ammonium than streams that ran through pasture areas. Among pasture streams there is a range of buffer widths (0, 40, 75ft) and canopy densities primarily composed of red alder. Preliminary results show that instream total nitrogen increases with buffer width and density. This result is drastically different than the observed decrease in nitrate levels with increased buffer width described by Lowrance et al. (1997) and Peterjohn and Correll (1984), and it demonstrates

A newly planted riparian buffer in Skagit County.

the unique biogeochemical cycle of Northwest agricultural riparian buffers and streams. This increase in nitrate with buffer width and density is most likely a result of leaf litter additions from red alder, which are rich in nitrate. Further investigations of the nitrate delivery and processing mechanisms (i.e., denitrification) within riparian buffers along lowland agricultural streams are ongoing, and they should have direct implications for the management of lowland streams in agricultural areas of the Pacific Northwest.

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Red alder on the rise—Making a comeback both economically and ecologically

Carol Volk is a PhD student in Forest Resources.

Two Pacific Northwest (PNW) icons, large coniferous trees and anadromous salmon, have brought this region much attention. The survival of both has merged as we have learned the importance of upland and watershed processes to aquatic ecosystems and salmonid populations. However, red alder *(Alnus rubra)* is also a very prominent tree species in today's watersheds. It is a nitrogen-fixing deciduous species that does not usually achieve top billing as an icon of the PNW. Although this tree has been seen in the past as a trashy, soft-wood species, it is making a comeback—both as a profitable commodity and as an ecologically important species.

The economic value of alder is easy to recognize. With an average domestic market price of $645 per milled log, alder is second only to Western Redcedar ($1000) and surpasses the value of hemlock ($290), spruce ($395), and Douglas-fir ($605). However, the ecological advantages of having alder in the watershed are still under scientific debate.

Two of Volk's assistants scrub algae off rocks.

Over the past five years we have investigated the influence of riparian red alder on the food web of aquatic communities. We have scraped algae off rocks, caught flying and swimming bugs, and fished for four-inch trout in the streams of old-growth forests and adjacent red alder watersheds of the Olympic peninsula—all to figure out if we should pay as much attention to the young, sprightly alder forests as to the ancient old-growth forests.

Red alder has been a part of the PNW landscape for thousands of years, even dominating the forest composition in SW Alaska during the Late Holocene. It is a primary successional species and is currently known for its prominence in floodplain areas and harvested watersheds, as it can quickly regenerate in disturbed areas. For centuries, stands of alder have been known as nutrient-rich islands in the forest, with as much as 50 kg N/ha/year being deposited into surrounding soils. This nitrogen and associated nutrients are commonly utilized by soil microbes and fungi as well as surrounding plants. Recent studies have also shown that these nutrients can be flushed from upland soils and transported into stream and river systems, subsidizing the nutrient cycle of aquatic ecosystems.

In the past few years, we have found that streams with prominent riparian alder populations have increased amounts of both dissolved and particulate nutrients when compared to old-growth coniferous forested streams. This trend has been observed in surface and groundwater and has included higher levels of nitrate, phosphate, total nitrogen and phosphorus, magnesium, calcium, and iron. Specifically, we observed a strong relationship between the percent of alder within the watershed and the surface water nitrate concentration. This trend has also been found in watersheds of coastal Oregon and southeastern Alaska (Piccolo and Wipfli 2002; Compton et al. 2003). These alder-derived nutrients are often available for uptake by microbial communities and algae, both of which are important food resources for a variety of aquatic organisms.

We have also observed that the benthic algal film coating streambed rocks is much thicker in alder streams and also enriched with phosphate, presumably due to the high concentrations of phosphorus within the water column. Increased algal biomass was observed in spring and fall seasons, whereas summer and winter algal biomass was similar between coniferous- and alder-dominated streams. However, many factors beyond nutrient resources, such as light availability and grazing, can also control algal biomass. In the summer sampling, we suspected that high counts of grazing invertebrates controlled algal biomass rather than nutrient limitation. Thicker algae on rocks pose a challenge to the most dexterous of stream ecologists to stay on their feet, but it also can indicate that there is ample food resources for grazing aquatic organisms.

If there is more algae and leaf litter in alder streams, it is probable that the animals feeding on these resources will display increased numbers. We have observed at least 3–4 times the amount of terrestrial and aquatic adult invertebrate populations in alder streams than in old-growth ecosystems (Figure 1). The biomass of drifting invertebrates, a common food resource for fish populations, is also greater in alder than conifer streams. This translates to a buffet of food resources for fish as well as other insectivores, like birds and bats, which prefer to feed in riparian areas. The diversity of aquatic invertebrates is also higher in alder streams, contributing to the idea that plentiful resources promote a plentiful selection of species—which can be useful when disturbances eliminate one set of organisms and functionally equivalent species that survive the disturbance flourish.

Although fish are not quite as sensitive to the biodiversity of alder forests, the higher abundance and biomass of invertebrates also attract the attention of fish populations. Some of our preliminary results suggest that higher levels of specific essential fatty acids are found in fish from alder-dominated streams. The growth rates of fish are still under investigation, but soon we hope to know if fish from riparian alder patches have faster growth rates than coniferous stream-dwelling counterparts.

Both the quantity and quality of aquatic food resources in alder streams make them an important compartment of the habitat network of freshwater ecosystems. These results do not support the logging of old-growth forests and replacement with alder forests, since old-growth forests offer a multitude of resources and habitats for terrestrial and aquatic species, but we do suggest that riparian alder makes an important, functional contribution to aquatic ecosystems and should not be logged or removed simply to replant coniferous species. Recent increases in the price of alder also make it profitable to harvest.

It is still crucial to freshwater ecosystems to have sources of coniferous forest throughout watersheds to provide large woody debris, shade, and upland habitat, yet alder is also a functionally important part of the landscape that should be integrated into forest management plans rather than simply replaced by coniferous forests. While conifers may provide stable large woody debris important in maintaining ample physical habitat for aquatic organisms, riparian alder patches may be providing food resources that are not as available in other sections of the watershed. Allowance of this heterogeneous landscape of alder and conifer provides a variety of habitat resources for aquatic organisms and their predators.

In summary, the nutrients from alder forests appear to supplement aquatic ecosystems, providing an extra boost of nutrients that are not always available in old-growth forests. These nutrients are taken into the food web and translate into more algae and invertebrates, and potentially more and larger fish as well. Alder is just one of the many nutrient resources available to freshwater ecosystems, because nutrients from red alder play a role similar to the salmonid carcasses deposited after anadromous spawning. Alder may not be the complete answer to food resources for anadromous salmon fry, but it is certainly one supplement that may aid anadromous fish fry and resident fish species in making a comeback.

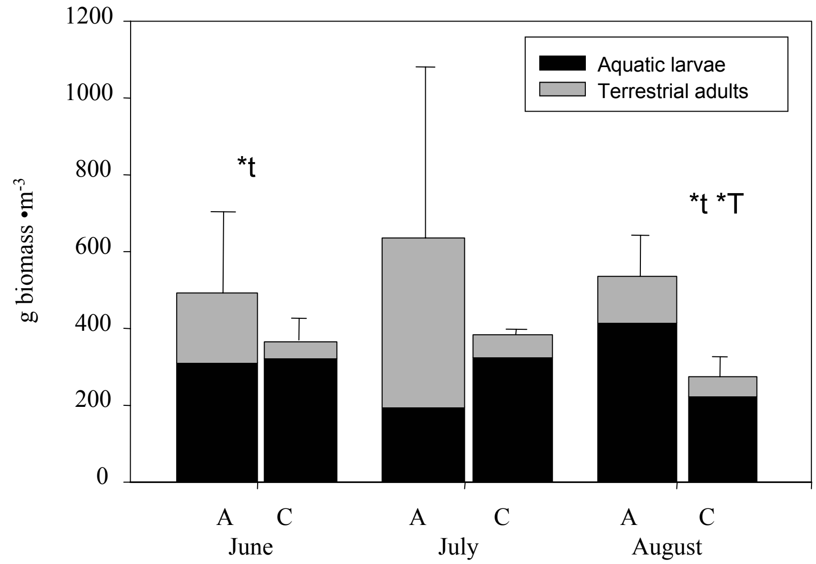

*Figure 1. Drift invertebrate biomass for summer 2001. A=alder, C=conifer. *t indicates a statistically significant difference (p<0.05) in terrestrial invertebrate biomass between alder and conifer streams. *T indicates a statistically significant difference (p<0.05) in total invertebrate (aquatic + terrestrial) biomass between stream type. This figure is an excerpt from a manuscript in preparation (Volk and Kiffney).*

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"Normative flows" in urbanizing watersheds

Derek Booth

Flow regime is a key factor in local and regional efforts to achieve conservation goals for aquatic ecosystems, because the success of habitat protection or restoration actions often depends on a supply of the appropriate amount of water at the appropriate time. Yet human activities have altered the flow regime in many rivers and streams in ways that may jeopardize the efficacy of those habitat actions. "Normative flow" is a way of looking at the suite of flows in a watercourse that stresses the importance of pattern and temporal variation in flow attributes, making the key assumption that the patterns most beneficial to aquatic organisms are those that most closely approximate natural (i.e., "normative") conditions. What distinguishes the normative concept is its emphasis on multiple aspects of the flow regime that create and sustain suitable habitat conditions, in contrast to the emphasis of simplistic minimum (or maximum) flow-analysis approaches.

Since 2002, King County has been exploring the application of normative flow concepts to management of its rivers and streams. In support of this effort, the Center has been facilitating a review team composed of national experts on the normative approach to hydrologic management. Its members are James Karr, faculty member in Fisheries and Biology at the University of Washington; Bob Milhous, hydrologist for U.S. Geological Survey's Stream and Riparian Ecology Section; LeRoy Poff, faculty in Biology at Colorado State University; and Chris Frissell, staff scientist at the Pacific Rivers Council and faculty in Fisheries at the University of Montana. Derek Booth of the Center is also on the review team and acts as its facilitator. The team has met four times since early 2002 and has worked with King County, its various agency cooperators from around the region, and its consultants.

The use of hydrologic metrics to evaluate the quality of a stream ecosystem is not particularly innovative, but most prior efforts have emphasized either a short set of easy-to-measure but ecologically unimportant metrics (e.g., increase in peak flows of a given flood recurrence) or a dramatically longer list of hydrologic metrics that may be very difficult to apply in practice (see, for example, the list of metrics in Poff et al., 1997, BioScience 47(11):769-784). The emphasis in the current project is to find a relatively short and robust list of metrics, easily determined from gage data and/or simulation results, that respond to watershed urbanization and have a credible link to biological response.

At the most recent meeting of the Science Review Team (February 2004), a set of hydrologic indicators for small streams was identified and reviewed in some detail, using both gaged and simulated flows in conjunction with available biological data. Little Bear Creek, a 40-km^2 suburban watershed in south Snohomish and north King counties, provides a useful example of the opportunities and challenges with this approach. Comparing hydrologic simulation results for fully forested and current land-cover scenarios, the major changes visible on an annual time scale are the earlier onset of high flows in the autumn and bigger individual storm peaks. The timing of flows in the late winter, spring, and summer is virtually unchanged. Metrics that evaluate characteristics of individual storm flows (or sequences of flows), however, show strong differences between the two land-cover

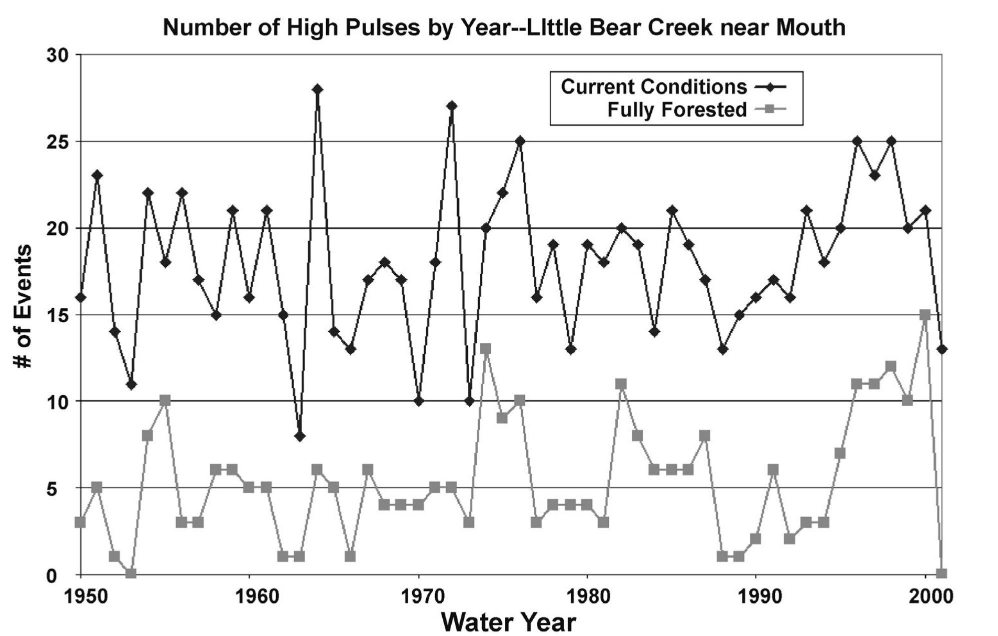

Figure 1. Example of the annual variability of a hydrologic metric, superimposed on the overall change imposed by different land-use conditions. "High pulses" are defined as the number of discrete excursions of the hydrograph above a chosen (and largely arbitrary) threshold—in this example, twice the forested mean annual flow. On average, this discharge is exceeded here about three times more often following suburban development (i.e., "current conditions"), displaying the greater frequency of high peaks common in an urban stream. Hydrologic simulations and graph courtesy of Kelly Whiting, King County.

Snapshot of current research

Above the dam: The ecology of salmon colonizing new habitat

Joseph H. Anderson, MS, Aquatic and Fishery Sciences

Freshwater habitat destruction is a primary cause for declining salmon abundances, because fish make extensive use of rivers and streams for migration, reproduction, and rearing. In many areas, dam construction has blocked adult salmon migration, denying fish access to large stretches of high-quality habitat. Fish ladders, a series of step-pools navigable by migrating salmon, are popular as a means to increase the habitat available to anadromous fish. However, relatively little is known about the ultimate success or failure of these projects. The construction of a fish ladder at Landsburg Diversion Dam on the Cedar River, Washington, provides an incredible opportunity to investigate salmon colonization. In fall 2003, Seattle Public Utilities began passing migrating chinook salmon, coho salmon, and steelhead trout above the dam. With access to over 27 kilometers of habitat above Landsburg, anadromous fish are now being allowed to naturally re-colonize an area closed to them for over 100 years. Research will (1) document the passage of adult salmon colonists above the dam and into the upper Cedar River watershed, and (2) track movements and determine spawn locations of adult coho salmon colonists within the upper watershed via radio telemetry. Initial results are promising, as 79 chinook and 47 coho salmon migrated above the dam in fall 2003. ♦

Chinook salmon passage at Landsburg Dam, Cedar River. Photo © City of Seattle 2003.

Normative flows

simulation scenarios. These include:

1. High pulse count (i.e., the number of excursions of the average daily discharge above a selected threshold) (Figure 1)
2. High pulse start (date of first discharge of the water year above a selected threshold)
3. High pulse end (date of last discharge of the water year above a selected threshold)
4. Fall rate (cfs/day, averaged as the change between days when the second day has a lower discharge than its predecessor)
5. Rise rate (cfs/day) (as above, but with increasing daily flows)
6. Fall count (days/year when the average daily discharge is at least 10% less than that of the day before)
7. Rise count (days/year) (as above, but with at least a 10% increase over the previous day's flow)
8. T_{Qmean}, the fraction of the year that flows are greater than the mean discharge (see the Fall 2000 issue of the Center newsletter).

In addition to exploring the behavior of these metrics under changes in watershed land cover, some investigation has also been made of their correlation with biological data. Using the Benthic Index of Biotic Integrity (B-IBI) to characterize biological health, preliminary analyses suggest that many of the hydrologic variables correlate well with the B-IBI (and better with the full 10-metric B-IBI than with any of the component B-IBI metrics). To date, there is also no suggestion that hydrologic-biological relationships are improved by considering time lags of one or more years—same-year biological and hydrological data show the strongest correlations.

If, as preliminary results suggest, hydrologic factors display a strong relationship to variation in B-IBI scores, a basis for regulating flow in pursuit of non-degraded biological conditions will be established. Regulating for this one factor only (i.e., hydrology), however, does not guarantee non-degradation, because there may be other such factors (such as water chemistry or physical habitat) that influence conditions at other times or at only slightly lower levels of impairment. Improved hydrology is likely to be demonstrated as a strongly defensible management goal, but it will not guarantee improved biological conditions everywhere.

For further information on the Normative Flow Project, see:

♦ http://dnr.metrokc.gov/wlr/BASINS/flows/index.htm

♦ http://depts.washington.edu/cwws/Research/Projects/normativeflow.html ♦

Lowland agricultural streams (cont.)

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Center for Water and Watershed Studies
University of Washington
Box 352100
Seattle WA 98195-2100
cwws@u.washington.edu
206.543.6920