Article 33

Technical Note #109 from Watershed Protection Techniques 3(2)

The Impact of Stormwater on Puget Sound Wetlands

Watershed managers have frequently questioned whether natural wetlands should be used for stormwater treatment. At the same time, wetland regulators have wondered whether upstream development and stormwater runoff might have a negative impact on the quality of natural wetlands. Until recently, these questions were largely theoretical, since very little research had been conducted on the influence of stormwater on wetlands. However, a series of recent research studies from the Pacific Northwest has shed new light on this topic.

A consortium of agencies and universities undertook an intensive eight-year study to investigate the consequences of watershed development and stormwater runoff on freshwater palustrine wetlands in the Puget Sound lowlands ecoregion. The consortium, formally known as the Puget Sound Wetlands and Stormwater Management Research Program (PSWSRP), evaluated how five major structural components of wetlands— hydrology, water quality, soils, plants, and animals— responded to watershed urbanization. Palustrine wetlands were selected because they have historically been altered more than other wetland types in the Puget Sound lowland ecoregion. Palustrine wetlands are freshwater systems that are in headwater areas or isolated from other water bodies and typically contain a mix of open water and other vegetation zones.

The 19 palustrine wetlands studied were relatively small (ranging from 1.5 to 31 acres in surface area) and had contributing watersheds that ranged from 87 to 886 acres in area. The wetland plant communities at the study sites were quite diverse. About 26% of the study wetlands classified as scrub-shrub wetlands, 16% were forested wetlands, 13% were emergent and 5% were bogs or fens. The remaining 40% of wetlands studied were a mix of more than one of these wetland community types.

The study wetlands differed sharply in the amount of development that had occurred in their contributing watersheds, as defined by the indicator of total impervious cover. The wetlands were roughly split according to whether they were largely undeveloped (less than 4% impervious cover), moderately developed (four to 20%) and highly developed (more than 20%). The largely undeveloped wetlands were used as a reference to define the "best attainable" conditions for wetlands within the ecoregion. It should be noted that some of the wetlands experienced rapid growth during the eight years of study, while others remained relatively stable. A detailed summary of the study design and sampling methods used to investigate the wetlands can be found in Azous and Horner (1997).

Hydrology

Wetland hydrology is often described in terms of its hydroperiod: the pattern of fluctuating water levels due to the complex interaction of flow, topography, soils, geology, and groundwater conditions in the wetlands. One of the key characteristics of the undeveloped reference wetlands was that they had relatively

Table 1: Key Factors that Influence Water Level Fluctuation (WLF) in Puget Sound Wetlands

Factor	Range	Mean WLF (feet)	No. of Observations
Forest Cover	No forest cover More than 15% cover	1.15 0.45	97 224
Impervious Cover	less than 3.5% 3.6 to 20% 22 to 55%	0.32 0.53 1.43	105 143 73
Outlet Constriction	low or moderate high	0.44 1.02	198 123
Wetland to Watershed Area Ratio	less than 5 percent more than 5 percent	0.91 0.39	169 152

Table 2: Median Water Quality Concentrations in Wetlands with Different Levels of Urbanization			
Water Quality Parameter	Non-Urbanized Wetlands (N=206)	Moderately Urban Wetlands (N= 177)	Highly Urban Wetlands (N=66)
pH	6.4	6.7	6.9
Conductivity	46	160	132
TSS	2.0	2.8	4.0
NH3-N	21	43	32
NO3 + NO2	112	304	376
TP	29	70	69
Fecal Coliforms	9	46	61
Zinc	5	8	20
all units in ug/l, except conductivity (uS/cm), TSS (mg/l), and fecal coliform (cfu/100 ml)			

low water fluctuations after storm events. Early work by Chin (1996) found that more developed wetlands had a higher water level fluctuation (WLF) after storms, and that this variable was an important overall indicator of the hydroperiod of a wetland. During the course of the study, the team frequently measured the WLF at each wetland site, defined as the average difference between maximum depth and the base depth on a crest stage gage.

Four watershed factors were found to strongly influence the WLF in a wetland (Table 1). The first two factors were strongly interrelated. When watershed forest cover was absent or total impervious cover was high, mean water level fluctuation frequently exceeded a foot or more in the wetland. More specifically, two impervious cover thresholds were identified. The first WLF threshold started at about 4% impervious cover, and corresponded to large lot rural development that begins to clear forest cover and alter natural drainage patterns. The second and more significant WLF threshold occurred at about 20% impervious cover, at which point upstream development increased the peak and volume of stormwater runoff, and began to dominate the hydroperiods of downstream wetlands.

The third factor that contributed to a high WLF was the degree of constriction at a wetland's outlet. Wetlands that had constricted outlets (such as an undersized culvert or embankments) tended to have a greater WLF than wetlands with less constricted outlets (primarily due to backwater effects). The fourth key factor that influenced WLF was the wetland-to-watershed area. Wetlands that were small in relation to their contributing watershed had a greater WLF, and tended to be more dominated by surface inflow. Wetlands that were relatively large in comparison to their contributing watersheds had a smaller WLF, and tended to be more influenced by groundwater.

The study team found that water levels tended to fluctuate by only a few inches in undeveloped wetlands, whereas developed wetlands frequently experienced water fluctuations of a foot or more. But how does a greater "bounce" in water levels actually alter or disturb a wetland's ecology? The major influence is that individual wetland plant species are generally adapted to a fairly narrow and stable range of water depths or soil saturation, and most species favor conditions where water levels rise or fall in a very gradual manner.

When water levels rise frequently, or stay high for extended periods of time, many plant species are stressed. The bounce effect is particularly acute during the early part of the growing season when the shoots and stems are still short, and the plants are fully inundated. Several invasive or aggressive wetland species, such as reed canary grass and cattail, thrive or at least tolerate the bounce effect, and tend to crowd out more sensitive species.

Water Quality

A large number of grab samples were taken from the largest open water pool in the study wetlands (or near the outlet if there was no open water) to characterize water quality conditions. As shown in Table 2, wetland water quality tended to decline slightly when contributing watersheds urbanized. Non-urbanized wetlands in the Pacific Northwest tend to be slightly acidic, but tended to become more neutral as watershed development increased.

Conductivity and nutrient levels also increased noticeably as upstream watersheds urbanized. The same pattern was also observed for zinc and fecal coliform levels. In most cases, the decline in water quality was relatively modest, particularly when these values are compared to typical stormwater runoff or stormwater pond concentrations. The decline in water quality, however, may be a significant factor for certain wetland types, such as bogs and fens, that are highly sensitive to changes in nutrient inputs and increases in pH levels.

Wetland Soils

Multiple sediment samples were collected in the study wetlands to evaluate how their sediment characteristics responded to upstream development. Perhaps the most noticeable difference was an increase in pH in the sediments of bog wetland types. In general, there was a strong tendency for redox to rise in the wetland sediments. Trends in nutrient, organic content and metals levels in wetland sediments were more ambiguous, leading the study team to conclude that, except for the modest increase in pH, there were no obvious signs that the quality of wetland sediments had declined in response to recent watershed development.

Impacts of Urbanization on Palustrine Wetland Flora and Fauna

One of the hallmarks of the study was the long term investigation of how various flora and fauna responded to changes in urban wetlands over an eight-year time span. And indeed, the effect of watershed factors on the wetland flora was a major focus of the study. Some of the key findings are highlighted in Table 3.

The richness or number of plant species was used as an index of wetland diversity. Some 242 plant species were recorded in all of the wetlands studied, but the number of species found in any individual wetland ranged from 35 to 109. The number of species found was not related to the area of the wetland. Instead, the richer plant communities were associated with more complex hydrology and surface topography, which provided more surfaces at different gradients for individual plant species to exploit. More uniform wetlands with simple hydrological patterns had fewer wetland community types, and consequently, fewer species.

Table 3: Influence of Urbanization on Flora and Fauna of Wetland Communities

Wetland Community	Key Findings from the Wetland Study
Wetland Plants	Plant richness was negatively correlated with increasing watershed impervious cover and water level fluctuation (WLF) for emergent and scrub-shrub wetlands (but not forested wetlands). Impact of WLF was greatest when it occurred early in the growing season. Particular losses noted for thin-stemmed species. 62% of urbanizing wetlands lost plant species. Plant richness dropped sharply when water depths were greater than two feet. Plant richness not correlated with wetland area. Several invasive or aggressive plant species were favored when WLF was high (e.g., reed canary grass).
Amphibians	Species richness was inversely related to watershed impervious cover and mean water level fluctuation.
Mammals	Mammal richness was highly variable among and within study wetlands. Mammal richness was most strongly related to the width and complexity of adjacent forest land to the wetland. The presence of large woody debris in the forest land was important. Wetland area and wetland type were not strongly correlated with mammal richness.
Birds	No detectable change in overall bird richness as impervious cover increased. Adapter species flourished, some avoider species declined. Most resident bird species maintained their populations over the study. Richness in bird community more related to complexity of wetland habitat types within an individual wetland.
Macro-invertebrates	Some trend toward decreasing taxa richness with more impervious cover. Shredder and scraper functional species declined as well as odontates.

Table 4: Excerpts from Puget Sound Wetland and Stormwater Guidelines (Azous and Horner,1997)

Provide an extensive vegetated buffer around palustrine wetlands.

Measure existing wetland hydroperiods and estimate future hydroperiods as a result of future development. Based on this analysis, seek to restrict:

Mean monthly water level fluctuation (WLF) of less than eight inches

More than six excursions above six inches in the wetland an average year

Duration of these excursions should not exceed three days in the wetland

Total dry period in the wetland should not change by more than two weeks

More stringent criteria were set to protect bogs and fens. In these systems, WLF should not exceed 24 hours in duration and upstream nutrient controls are required.

Specific land use and stormwater management requirements are then evaluated to meet the WLF criteria.

Plant richness strongly correlated with both WLF and impervious cover. In general, the greater the WLF, the lower the richness of plants found in a wetland. The effect was greatest when a high water level fluctuation corresponded with the early growing season (February 1 to March 31). It was also noted that an increase in WLF from one year to the next saw a decrease in species richness and an increase in exotic invasive species in the succeeding years. The effect of WLF on plant richness was not observed for forested wetlands, but it is possible that several decades of study would be needed to detect any change in such a long-lived community.

Perhaps the greatest effect of watershed factors was observed for amphibians. While the amphibian fauna in the Pacific Northwest is not as a rich as elsewhere in the country, up to seven species of salamanders, frogs, toads and newts are frequently found in undisturbed palustrine wetlands. Richter and Azous, however, found that amphibian communities were less rich in wetlands located in urbanizing watersheds. Species richness was negatively correlated with watershed impervious cover, and in particular, with higher WLF.

Richter had previously discovered that most amphibians have very specialized breeding requirements, and tend to attach their egg masses to thin-stemmed emergent or submergent wetland plants. The direct effect of a high WLF is the stranding of egg masses: water levels are temporarily high when the egg masses are attached, and when they subsequently drop, the egg masses are stranded, leading to desiccation. The indirect effect of a high WLF is a gradual loss of the thin-stemmed species upon which amphibians depend, and eventual replacement with broader-stemmed species (such as the cattail).

The response of birds, mammals, and macro-invertebrate communities to watershed and wetland changes was less clear (Table 3). In the Puget Sound region, over 80% of bird species have been observed to use wetlands. No obvious trends in the richness of bird species were detected, and most resident bird species maintained their populations over the eight years. “Adapter” species that thrive in urban watersheds (crows, mallards, starlings, sparrows) tended to increase in population, whereas rarer residents (known as “avoiders”) declined. Two factors were found to explain much of the pattern of bird richness: the number of wetland community types present in an individual wetland, and the presence of large forest areas close to the wetland. Impervious cover was not strongly correlated with bird richness.

Much the same response was seen for the mammal community. Nineteen native mammal species were observed in the 19 study wetlands, although only one to 13 were captured in any individual wetland. The mammal population was quite variable between and within individual sites. Watershed and wetland factors did not explain the distribution of mammal richness. Instead, this was tied to the width and structural complexity of the forest lands adjacent to the wetland, as well as the presence of large woody debris on the forest floor. Mammal richness appeared to be linked more to the quality of a wetland’s forest buffer, than the complexity of wetland habitat itself.

Strategies to Protect Palustrine Wetlands from Watershed Development

The Puget Sound wetland study has several important implications for watershed managers. Taken together, its results provide a more scientific basis for designing watershed strategies to protect natural wetlands. Indeed, the study team concluded that palustrine wetlands could not be protected by simply regulating development activity within wetland boundaries. Instead, managers must evaluate the changes in land use in upstream watersheds, and predict how this will influence the hydroperiod of a wetland. Other key elements of a watershed approach to protecting wetlands include retaining forest cover, minimizing impervious cover, and maintaining natural storage reservoirs, drainage corridors and forested buffers.

The study team developed a set of management guidelines to protect palustrine wetlands from upstream development (Azous and Horner, 1997). Excerpts from the guidelines can be found in Table 4. In general, they require that an analysis of current and future wetland hydrology be conducted to determine the magnitude, duration and frequency of changes to water level fluctuations in individual palustrine wetlands. This usually entails application of a continuous hydrologic simulation model for the watershed and wetland. The results of this analysis are compared to a set of four target criteria for most wetland types, which were derived from the wetland study (Table 4). Special criteria were developed for bogs and fens, given their sensitivity to changes in hydrology, pH and nutrient inputs.

Many of the protection guidelines are now being incorporated into local watershed and master drainage plans. A prominent example is the East Lake Sammamish Basin Plan, developed by the King County (Washington) Surface Water Management Division. This basin has faced rapid development since 1980, and is being transformed from forest and rural residential land uses to higher density residential and commercial land uses. This growth pressure has raised concerns about the threat to the 40 wetlands within the basin. Continuous simulation models were used to forecast WLF in watersheds that are experiencing rapid growth. Special small watershed plans were developed to protect nine wetlands that were designated as unique and outstanding. Major components of the wetland protection plans included the following:

- Capping total impervious area in the watersheds to 8%, where allowed by zoning
- Requiring that 50% of the existing forest cover be retained in some watersheds
- Encouraging development to be clustered away from hydrologic source areas
- Requiring construction of infiltration basins to decrease runoff volumes in one watershed
- Seasonal clearing limits for construction activi ties that prevent any clearing and grading during the wet season (October through April)

While the specific numerical targets for WLF developed in the Puget Sound ecoregion are probably not transferable to other regions of the country, the broader management concepts are a good starting point for managing stormwater wetlands at the watershed level.

Conditions for Using Natural Wetlands for Stormwater Treatment

The study team developed guidance for a rather narrow set of conditions under which natural wetlands might be used for stormwater treatment. Potential treatment candidates must satisfy three broad criteria. First, the candidate wetland must already be highly altered by watershed development, and meet certain benchmarks for isolation, high WLF, low wetland plant richness, dominance of invasive or aggressive plants and altered hydrology. Second, it must be shown that the wetland site does not contain any unique wetland features (not a peat, forested or priority wetland, no rare or endangered species, no salmon rearing habitat, among other factors).

Lastly, any proposed modification must be designed to restore or enhance the existing wetland. Construction should disturb as little of the wetland as possible, and any stormwater storage provided should not greatly increase surface water elevations or cause permanent inundation. For a complete list of the criteria, please see Appendix A in Azous and Horner (1997).

Implications for the Designer of Stormwater Wetlands

This study also has some implications for engineers that are designing stormwater wetlands located outside of natural wetlands. Specifically, it helps set up some expectations about the level of plant and animal diversity that might be achieved in these systems. Stormwater wetlands, and particularly those that employ extended detention, can expect to have a mean WLF of several feet, and WLF durations that extend for several days. Consequently, wetland plant and animal richness within these constructed systems will probably always be much lower than their natural counterparts. The only technique that designers have to compensate for the ubiquitous WLF of stormwater wetlands is to create complex internal topography that creates a range of depth zones to be exploited.

Summary

The Puget Sound wetland study has produced a much greater understanding of how palustrine wetlands are linked to their watersheds, and how these watershed factors can influence them. The sobering news for watershed managers and wetland regulators is that a relatively small amount of watershed urbanization (>4%) can produce detectable changes in wetland quality, with more severe changes in wetland quality occurring when total impervious cover exceeds 20%. This trend is similar to the strong relationship between impervious cover and stream quality that was previously discovered in the same ecoregion by May *et al.* (1997). It provides yet another example of the fact that individual water resources cannot be effectively protected without managing land use in the watersheds in which they exist.

References

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