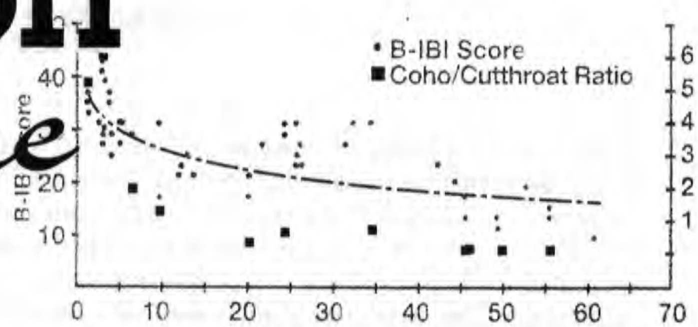
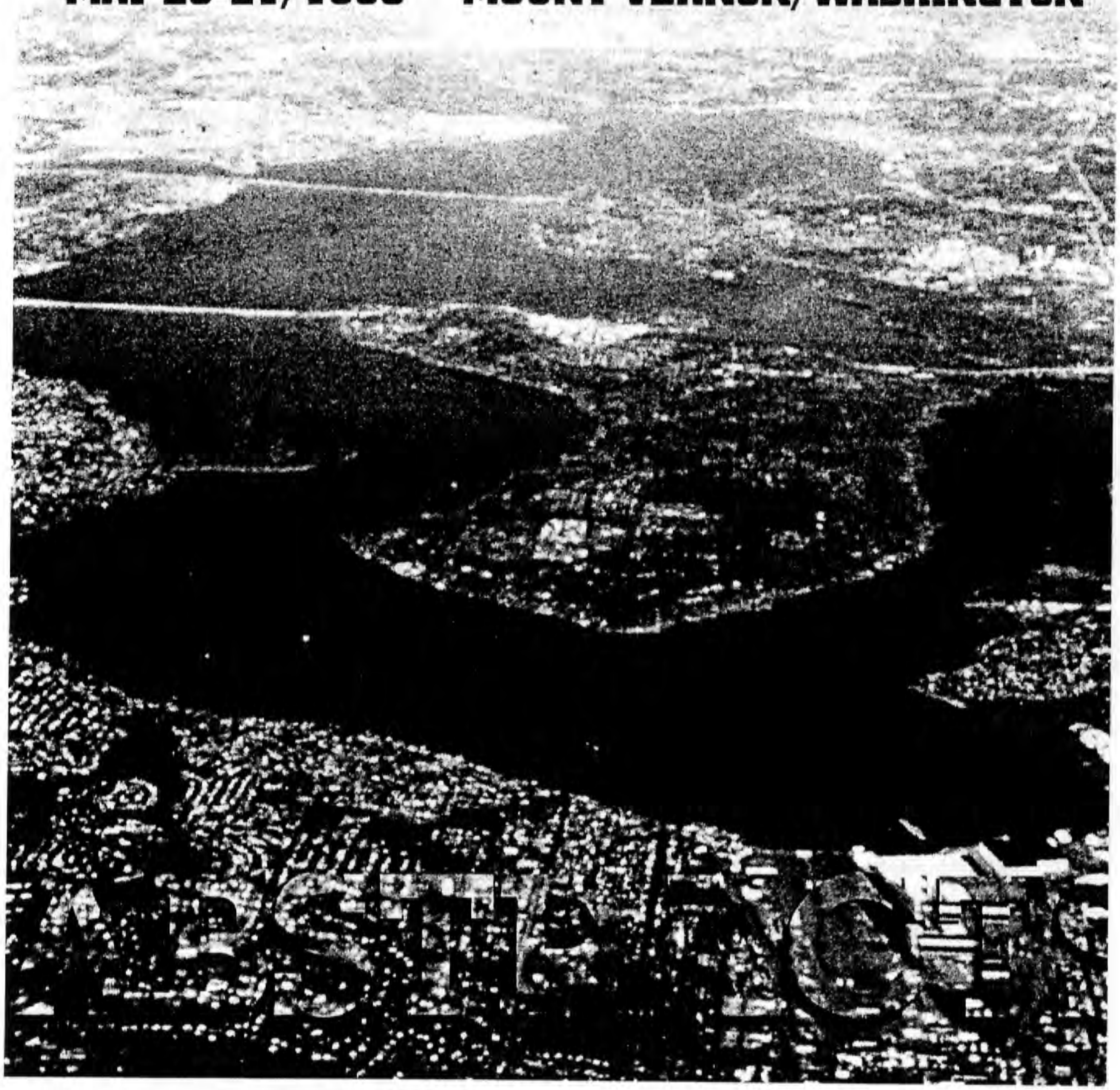
Salmon in the City



MAY 20-21, 1998 MOUNT VERNON, WASHINGTON



FORWARD

In the following pages, speakers at the Salmon In the City Conference inform us that urbanization is damaging fish habitat in small lowland streams in the Puget Sound Basin and British Columbia, and they describe the causes and extent of the damage. On the poor soils that predominate in the area, the damage begins with the first few percent of impervious surface in the basin and, for most such streams, reaches massive proportions when it becomes 20% to 30% impervious. For these urbanizing watersheds, the very high stream flows that accompany traditional development are more critical than the water quality impacts of such development, for in the course of forest conversion increasing flows erode the channel and ruin habitat long before the impacts of water quality degradation are felt.

Speakers point out that good habitat is characterized by a forested watershed that provides fish and other aquatic life with year round, cool, well modulated stream flows, shelter, and food. If the forest is converted to urban uses (in the traditional manner), speakers offer no engineering solutions to replace its functions. However a few speakers suggest that where development and conversion of forests will take place, there may be non-traditional ways to greatly mitigate such new land use and prevent major impacts to streams. These include design and construction methods that retain most of the forest and reduce "effective" impervious surface area to near zero. Because there are no examples where such a condition has been intentionally achieved, a few speakers advocate a demonstration project which, if it has the expected effect, could be used as a model for revision of development standards.

Speakers offer little encouragement for the possibility of restoring damaged urban streams without restoration of their watersheds. A restored watershed, capable of sustaining runs of wild anadromous and native fish, will have 60% to 70% of its area reclaimed as forest, stormwater outfalls removed, most stream crossings closed, large natural buffers reclaimed, and impervious areas reduced to effectively zero. In the short term, such restoration of any thoroughly degraded urban stream is probably not possible because of the staggering costs involved and traditional funding shortages for such activities. Further, speakers warn us that urban stream restoration may not even be wise, in the short term, if such restoration meant that the relatively minor financial resources required to preserve existing, quality habitat were diverted to the prohibitively expensive restoration of even the smallest of urban watersheds.

The data imply that urban watershed restoration, where we choose to do it, is practical only in the long term. Over long periods of time, restoration of urban watersheds (much of which will redevelop with or without a restoration strategy) might be made to pay for itself. The mechanisms for such results are dramatic changes in re-development policy and a redefinition of the term "long range" planning.

The quest to restore urban watersheds brings us into truly uncharted waters. We are asked, like those who built cathedrals in the middle ages, to begin an activity that may show us little benefit in our lifetimes and that only our descendants can finish. Speakers urge that we ask ourselves if we have the vision and the will for such a commitment.

NEEDS OF SALMON IN THE CITY: HABITAT IN THE URBAN LANDSCAPE

By: Robert R. Fuerstenberg

INTRODUCTION

Aquatic habitats critical to salmonids are the outcome of physical, chemical and biological processes acting across various scales of space and time. The environmental conditions that result from these processes provide the habitat requirements for a variety of species and life history stages of salmonids and other stream dwellers. Whether in pristine watersheds or in those most heavily urbanized, the basic requirements for survival of salmonids are the same. Salmonids are temperate and subarctic (and rarely, arctic) zone fishes, well adapted to the cold, clear, waters of Pacific Northwest rivers and streams.

HABITAT

Salmon—at least the anadromous ones—must live in and migrate through three quite distinct aquatic environments: freshwater, estuarine and marine. Within those large environments, however, salmon are apt to be found in particular local environments at particular times during their life history. These local environments possess the combinations of physical, chemical and biological conditions to which salmon have become adapted over the many thousands of years they have occupied the Pacific Northwest. Thus, habitat can be thought of as the set of environmental conditions, variable in space and time, that salmon require for survival; more simply, as those places where salmon are "apt to be found". When considering habitat requirements, it is necessary to keep in mind some important characteristics of salmonid ecosystems (Spence et al, 1996):

Watersheds and streams differ in a variety of physical, chemical and biological characteristics.
Salmonid populations are locally adapted to these conditions and their natural fluctuations.
Specific habitat requirements differ among species and life history stages, and change with the season.
Aquatic ecosystems are dynamic, undergoing periodic cycles of disturbance and recovery.

Everest et al (1985) noted that while it is certainly the case that each species of salmonid differs in its specific habitat requirements, all species share some basic habitat needs. In rivers, all salmonids require cool, flowing water free of pollutants and high in dissolved oxygen; gravel substrates low in fine sediment for reproduction; unimpeded access to and from spawning and rearing areas; sufficient refuge and escape cover; and sufficient invertebrate organisms for food. Bjornn and Reiser (1991) provide a detailed review of freshwater habitat requirements from a variety of field observations and laboratory studies. Pearcy (1992), in his review of ocean ecology of salmonids, discusses estuarine habitat requirements that are functionally similar to those in freshwater: areas of cold, well-oxygenated water; refuge for resting and escape from predators; sufficient food resources; and, unique to estuaries, mixing zones of reduced salinity necessary for making the physiological transition from fresh to salt waters. In the ocean environment, most of the same characteristics are necessary for salmon survival as well, and the various species may migrate great distances to reach areas of the Pacific where these conditions are found. Regardless of the environment, all habitats have physical, chemical and biological components that influence the survival of the various species and life history stages of salmon. Table 1 outlines some of the important features of freshwater habitat for salmonids. Within this basic framework are five classes of features that determine the suitability of aquatic habitats for salmonids.

Table 1. Important Components of Freshwater Habitat for Salmonids

Physical	**Flow Regime** -Depth, velocity, seasonality **Habitat Structure** -Substrate material, size and distribution -Channel Morphology -Channel slope, width, depth -Bedforms: pools, riffles -Large Woody Debris -Cover -Escape, feeding, resting -Riparian structure -Stand composition, age -Temperature
Chemical -Dissolved Oxygen -Anions and Cations (pH) -Dissolved Nutrients -Turbidity	**Water Quality** -Pollutants
Biological	**Interactions among species and life histories** -Competition -Predation -Biological modification -Redd building **Energy Supply** -Riparian inputs -Carcass loading -Instream inputs/macroinvertebrates

This generally simple view of habitat belies the true nature of the complex and dynamic nature of ecosystems. We tend to describe habitat based on that which is most visible and observable; and often impose on it a stability and uniformity that does not, in fact, exist. We must keep in mind that habitat is the product of the interactions among the features in Table 1 and is therefore far more complex than this simple assortment suggests. These features vary over a season, some over decades, and others over centuries. Flow, for example, falls to its lowest in the late summer when streamflow may be intermittent or absent all together in small streams. Runoff during late winter, however, may crest the streambanks and be 20, 30 or 40 times the summer flow. Even at this short time scale, the habitat structure of the system is very different to the species and life stages dwelling there. Habitat structure also varies from place to place across the river landscape. As one travels from headwaters to estuary, flow increases, sediment distribution and bedform change, flood-tolerant species come to dominate the riparian zone, and temperature patterns are altered. Large woody debris, so critical to sediment storage and pool formation in upper and mid-river reaches, tends to function more as refuge or as substrate in the lower reaches, often partially buried in the fine sediments of the river bottom or encrusted with barnacles on estuarine mudflats.

Habitat is the outcome of various processes, each with its own characteristic rates, magnitudes, spatial and temporal scale (Spence et al 1996), and can be usefully characterized as the relationship among process, structure and function within ecosystems (Figure 1). At large spatial and long temporal scales, the dominant processes that shaped PNW landscapes were tectonic and glacial. These processes established the landscape

framework upon which further processes occur. Over periods of decades to centuries, large floods, mass wasting and fires have been the dominant processes shaping riverine ecosystems. These disturbances have caused abrupt changes in habitat conditions: large floods reconfigure the channel, often causing channel migration and abandonment, redistribution of bars and pools, and thus the destruction of existing habitats and the formation of new ones. Changes in the structure may persist for decades or centuries, affecting the relative suitability of these habitats for various salmonid species. This natural disturbance and recovery regime, however, has directed the evolution of life
history characteristics and strategies for salmonids.

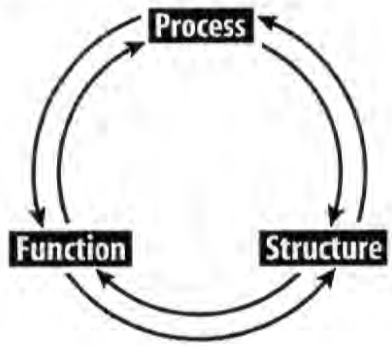


Figure 1.

At the watershed scale, the major physical processes that affect the attributes of habitat are hydrology, sediment transport, energy transfer, nutrient cycling, and delivery of large woody debris. Hydrology is perhaps, the primary "forcing" process at this scale and determines the quantity and timing of streamflow (flow regime) which in turn directly influences sediment transport, channel configuration and habitat availability. Moreover, flow indirectly controls nutrient cycling and energy transfer by affecting the movement of litter, emergence of aquatic insects and the distribution of temperature in the stream environment. The delivery of large woody debris to stream systems illustrates the relationship among process, structure and function quite well. The age and composition of the forest stand (structure) influences the rate of delivery into the stream (process) and also the longevity and interaction of the woody debris with water and sediment (function). The wood, in turn, influences both flow and sediment transport in such a way that pools and riffles are formed, and habitat diversity for salmonids is modified.

An important biological process for Northwest rivers is the migration and spawning of anadromous salmon in our rivers. In the process of spawning, salmon turn over considerable portions of the gravel bed, thus modifying habitat structure to aid survival of their offspring. This activity may also benefit the survival of species that spawn later because fine material is flushed from the stream bed. More importantly, because of our recent glacial history and the presence of our dense coniferous forests, nutrients in our rivers are in short supply. Salmon are a crucial link between oceanic processes and riverine process and structure. Nutrients flushed to the oceans perhaps centuries before are returned in the form of salmon carcasses to nourish bear, mink, elk and deer, and the diversity of aquatic insects that will be food for the next generation of salmon. In fact, recent research has demonstrated that overwintering salmon and trout have significantly higher growth rates in streams where anadromous salmon spawn and die. Some of these nutrients find their way into vegetation within the riparian zone and are taken up by vegetation as diverse as western hemlock and the most appropriately named salmonberry.

The interaction of these processes, at time scales from 1-10,000 years and at landscape scales from reach to region, have produced habitats of unique structure and function suited to a unique family of fishes. The conservation of salmon will ultimately depend upon maintaining and restoring the integrity of these processes at their natural rates and magnitudes or providing structural and functional surrogates for them where ecosystem integrity has been lost.

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RESTORING LIFE IN RUNNING WATERS; PLANNING THAT SEES THE SALMON LANDSCAPE

By: James R. Karr

For more than 100 years, human society in the Pacific Northwest has watched as salmon populations have declined; many stocks are extinct. Although the declines have been much discussed and many actions have been taken to reverse the trend, the trend nonetheless continues. The potential Endangered Species Act (ESA) listing of Puget Sound Chinook adds urgency to the discussion and emphasizes the effects of urbanization on salmon numbers. Efforts to avoid this and other potential listings under ESA proliferate. Because of the long history of failure to reverse long-term trends in salmon numbers, it seems prudent to examine carefully any and all efforts to produce a new generation of "fixes." More important, perhaps, we should carefully examine the theoretical underpinnings, the hypotheses if you will, that have been or will be used to guide efforts to reverse the trend.

One such hypothesis is captured in the subtitle of this symposium, "Can habitat in the path of development be saved?" I suggest that the question itself will lead us astray because it provides for a new generation of narrow conceptions of the challenge. Rather than saving habitat, for example, should we focus on saving salmon, or fish? Better yet should our focus be on the complex living systems that salmon and other fish depend on?

Or should we think more comprehensively about the landscapes that salmon depend on for their survival? That landscape clearly includes rivers, their watersheds, and the ocean environments where salmon reside through much of their life cycle. But the salmon landscape also includes the administrative and political landscapes that salmon must traverse in their migrations. And those landscapes are created by the attitudes and philosophies of the people that occupy the Pacific Northwest. Failure to focus on any of these dimensions of the salmon landscape is likely to limit the success of policies to protect and restore salmon. Clearly, saving habitat in the path of development will not be enough, just as making baby fish or clean water is not enough.

Efforts to protect and restore the salmon landscape, and thus protect salmon populations, should keep several lessons from the pat in mind. First, we must overcome narrow conceptions of the challenge and the legacies that come from those conceptions. Second, we must be realistic. We should strive for better rivers everywhere, not salmon everywhere. Furthermore, we should recognize that we can't repair 100+ years of damage in 5 to 10 years. Third, we should recognize that knowledge is, and always will be, limited. At the same time, we know enough today to do a better job of protecting salmon landscapes and thus salmon. Fourth, we must begin to establish priorities in a more comprehensive and incisive way. Decisions to protect the best (conservation), develop intelligently (development), and restore the rest (restoration), must be guided by thoughtful integration of scientific information, economic consequences, and the values and attitudes of the people.

Decisions derived from this integration should focus on three questions: How do we decide what to do? How do we decide where to do it? How do we decide if it worked? Sadly, the last question has rarely been included in past analyses.

Because a biological endpoint—protection of salmon populations and the life-support systems they depend on-is a core goal, we must do a better job of documenting the biological effects of our actions. That is, we must select appropriate biological indicators as endpoints for monitoring and evaluation. Better biological monitoring is key to the evaluation of past approaches, to the protection of valuable natural resources, and to avoid the waste of economic resources in programs or practices that simply do not work.

Better biological monitoring is key to restoring life in running waters—including salmon. No matter how important for commerce, sport, or even as a regional icon a particular species is to humans, it cannot persist outside the biological context that sustains it. Failing to protect plankton, insects, bacteria, higher plants, or other fish ignores the key contributions of these taxa to health living systems. Salmon depend on healthy living systems.

Human activities—urbanization, grazing, logging, point and non-point pollution, and others—do not just degrade "habitat." Human activity alters water quality, habitat structure, flow regime, sources of energy and nutrients for the aquatic food web, and biotic interactions. Analyses to conserve, develop, or restore must incorporate this broader perspective on the consequences of human actions. Those analyses must focus on biological endpoints.

Because they focus on living organisms—whose very existence represents the integration of conditions around them—biological evaluations can diagnose chemical, physical, and biological impacts as well as their cumulative effects. One biological yardstick is the index of biological integrity (IBI), first developed in 1981 for monitoring water resource condition in Midwestern US streams. The IBI has now been adopted for use in evaluation of the condition of streams in Puget Sound. Like economic indexes an IBI consists of multiple measures—called metrics—each describing one aspect of the biological condition of a site. Each measure should be sensitive to important characteristics of living communities, not narrow indicators of commodity production or of threatened and endangered status. Together, such measures make up an ecological yardstick. Changes in those measures, like the changes in temperature or altered blood cell counts in a human, signal "ecological disease."

Samples of invertebrates from one of the best streams (Rock Creek) in rural King County, Washington, for example, contained 27 kinds (taxa) of invertebrates; similar samples from an urban stream (Thorton Creek) in Seattle contained only 7 taxa. The rural stream has 18 taxa of mayflies, stoneflies, and caddisflies, the urban stream only 2 or 3. When these and other metrics are combined in an index based on invertebrates, the resulting "benthic index of biological integrity" (B-IBI) provides a numeric description of the condition, or health, of a stream. The B-IBI for Rock Creek was 44 (maximum index is 50) and that for Thorton Creek was 10 (minimum 10). Based on our preliminary analyses of these and 25 to 30 other Puget Sound lowland streams, it appears that B-IBI values below about 35 to 38 are not likely to support healthy populations of coho salmon. This numeric index makes it possible to compare steam quality across geographic areas so that citizens as well as managers can establish priorities for protection and restoration. Biological monitoring and assessment in this framework can provide a powerful tool to answer the "how to decide" questions mentioned above.

WATERSHED URBANIZATION AND THE DECLINE OF SALMON IN PUGET SOUND STREAMS

By: Richard R. Horner and Christopher W. May

ABSTRACT

The Puget Sound lowland (PSL) ecoregion contains an abundance of complex and historically productive salmonid habitat in the form of small stream ecosystems, including their riparian forests and wetlands. These watersheds are under intense pressure owing primarily to the cumulative effects of urban development. Urbanization of PSL watersheds has increased impervious areas and decreased forested areas, including a significant loss of natural riparian forests and wetlands. The cumulative effects of a modified hydrologic regime, the loss of instream structural complexity, and the alteration of channel morphological characteristics accompanying urbanization have degraded instream habitat and biological integrity in PSL streams. At very low levels of development there appears to be a rapid decline in biological integrity as well as the physical habitat conditions necessary to support natural biological diversity and complexity. This decline continues as watershed development increases, with no threshold indicated. These results suggest that resource managers should place a high priority on preservation and protection of high-quality stream ecosystems that currently support natural salmonid populations. Mature, riparian forests dominated by coniferous trees should be the long-term management goal. A wide and near-continuous riparian zone appears to be a necessary, although not wholly sufficient condition for a natural level of ecological integrity. Rehabilitation and enhancement efforts should be concentrated on streams draining watersheds with low to moderate development. Restoring the natural hydrologic regime should be a primary goal. At the highest levels of urbanization, natural ecological function may not be possible. Although recovery to near-pristine conditions cannot be expected in all developed stream basins, innovative mitigation efforts should nevertheless continue in an effort to improve stream quality to a level supportive of natural biota. Because of the cumulative effects of past and current land-use practices, some habitat enhancement will be required to accomplish rehabilitation goals in all PSL streams, regardless of present watershed development level. Under current development and mitigation strategies, it is apparent that downstream changes to both the structure and function of aquatic ecosystems is inevitable unless limits are instituted on the extent and distribution of watershed development.

BACKGROUND

In the Pacific Northwest (PNW), as in many areas of North America, urban development is rapidly expanding into areas containing much of the remaining natural aquatic ecosystems. In the Puget Sound lowland (PSL) ecoregion, the natural ecosystems most directly affected by urbanization are small streams and associated wetlands. These ecosystems are critical spawning and rearing habitat for several species of native salmonids (both resident and anadromous), including cutthroat trout (*Oncorhynchus clarki*), steelhead trout (*O. mykiss*), coho salmon (*O. kisutch*), chum salmon (*O. keta*), chinook salmon (*O. tshawytscha*), pink salmon (*O. gorbuscha*), and sockeye salmon (*O. nerka*). These fish, especially the salmon species, are of great ecological, cultural, and socio-economic value to the peoples of the PNW. Despite this value, wild salmonids are in considerable jeopardy of being lost to future generations (Figure 1). Over the past century, salmon have disappeared from about 40% of their historical range, and many of the remaining populations (especially in urbanizing areas) are severely depressed (Nehlsen et al., 1991). There is no one reason for this decline. The cumulative effects of land-use practices, including timber harvesting, agriculture, and urbanization, have all contributed significantly to this widely publicized "salmon crisis."

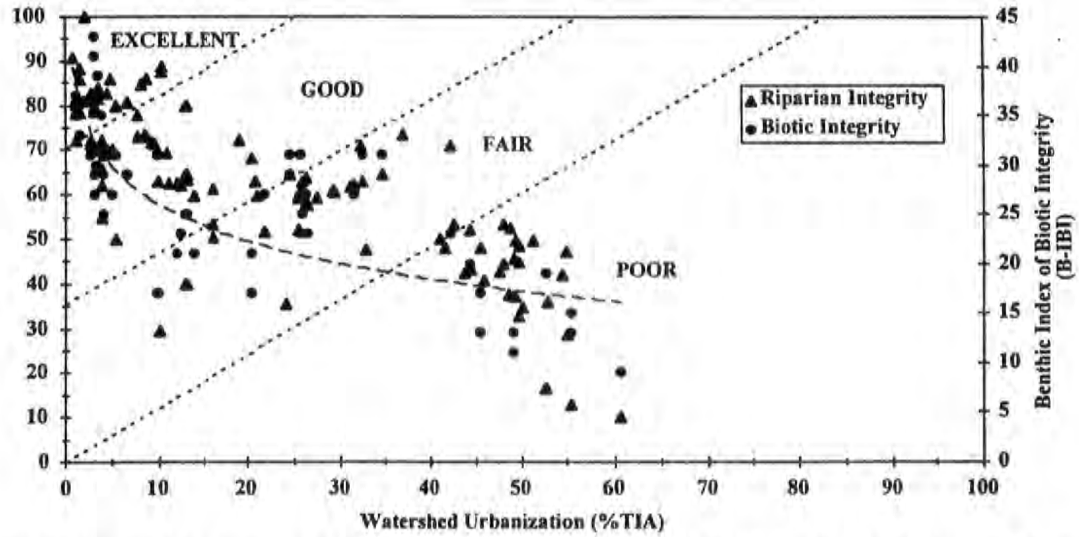

Figure 16. Relationship between basin development, riparian buffer width, and biological integrity in PSL streams

SUMMARY

Results of the PSL stream study have shown that the physical, chemical, and biological characteristics of streams change with increasing urbanization in a continuous rather than a threshold fashion. Although the patterns of change differed among the attributes studied and were more strongly evident for some than for others, physical and biological measures generally changed most rapidly during the initial phase of the urbanization process as TIA rose above 5–10%. As urbanization progressed, the rate of degradation of habitat and biologic integrity usually became more constant. There was also direct evidence that alteration of the watershed hydrologic regime was the leading cause for the overall changes observed in instream habitat conditions.

Chemical water quality constituents and concentrations of metals in sediments did not follow this pattern. These variables changed little over the urbanization gradient until imperviousness (%TIA) approached 40%. Even then water column concentrations did not surpass aquatic life criteria, and sediment concentrations remained far below freshwater sediment guidelines. As urbanization (%TIA) increases above the 50% level, the point where most pollutant concentrations rise rapidly, it is likely that the role of water and sediment chemical water quality constituents becomes more important biologically.

It is also apparent that, for almost all PSL streams, the quantity and quality of large woody debris must be restored for natural instream habitat diversity and complexity to be realized. Of course, prior to undertaking any habitat enhancement or rehabilitation efforts, the basin hydrologic regime must be restored to nearly natural conditions. Results suggest that resource managers should concentrate on preserving high-quality stream systems through land-use controls, maintenance of riparian buffers, and protection of critical habitat. Enhancement and mitigation efforts should be focused on watersheds where ecological function is impaired but not entirely lost.

Alterations in the biological community of urban streams are clearly a function of many variables representing conditions in both the immediate and more remote environment. In addition to urbanization level, a key determinant of biological integrity appears to be the quantity and quality of the riparian zone available to buffer the stream ecosystem, in some measure, from negative influences in the watershed (see Figure 16). Instream habitat conditions also had a significant influence on instream biota. Streambed quality, including fine sediment content and streambed stability, clearly affected the benthic macroinvertebrate community (as measured by the B-IBI). The composition of the salmonid community was also influenced by a variety of instream physio-chemical attributes. In the PSL region, management of all streams for coho (and other sensitive salmonid species) may not be feasible. Management for cutthroat trout may be a more viable alternative for streams draining more highly urbanized watersheds. The apparent link shown here between watershed, riparian zone, instream habitat, and biota supports management of aquatic systems on a watershed scale.

This research indicates that there is a set of conditions that, though not individually sufficient, are necessary to maintain a high level of stream quality or ecological integrity (physical, chemical, and biological). If maintenance of that high level is the goal, then this set of conditions constitutes the standards that must be achieved if the goal is to be met. For the PSL streams, imperviousness must be severely limited, unless mitigated by extensive protection of the riparian corridor and BMPs. Downstream changes to both the form and function of stream systems appear to be inevitable unless limits are placed on the extent of urban development. Stream ecosystems are not governed by a set of absolute parameters but are dynamic and complex systems. We cannot "manage" streams but instead should work more as "stewards" to maintain naturally high stream quality. Preservation and protection of high-quality resources should be a priority. Engineering solutions are useful in some situations in urban streams, but in most cases they cannot fully mitigate the effects of development. Rehabilitation and enhancement of aquatic resources will almost certainly be required in all but the most pristine watersheds. In order to support natural levels of stream quality, the following recommendations are proposed.

- Reduce watershed imperviousness, especially targeting transportation-related surfaces and compacted pervious areas.
- Preserve at least 50% of the total watershed surface area as natural forest cover.
- Maintain an urbanized stream system drainage density that is within 25% of pre-development conditions (i.e., an urban/natural DD ratio < 1.25).
- Continuously monitor streamflow and maintain 2-year stormflow/baseflow discharge ratio of much less than 20.
- Allow no stormwater to drain directly into a stream without first being treated by quality and quantity control facilities.
- Replace culverted road crossings with bridges or by arched culverts with natural streambed material.
- Retrofit existing BMPs or replace them with regional (sub-basin) stormwater control facilities with the goal of restoring the natural hydrologic regime.
- Limit stream crossings by roads or utility lines to less than two per kilometer of stream length and strive to maintain a nearly continuous riparian corridor.
- Ensure that at least 70% of the riparian corridor has a minimum buffer width of 30 m and utilize wider (100-m) buffers around more sensitive or valuable resource areas.
- Limit encroachment of the riparian buffer zone through education and enforcement (< 10% of the riparian corridor should be allowed to have a buffer width of < 10 m).

- Actively manage the riparian zone to ensure a long-range goal of maintaining at least 60% of the corridor as mature, coniferous forest.

- Allow no development in the active (100-year) floodplain area of streams. Allow the stream channel freedom of movement within the floodplain area.

- Protect and enhance headwater wetlands and off-channel riparian wetland areas as natural stormwater storage areas and valuable aquatic habitat resources (buffers).

- Adopt a set of regionally specific stream assessment protocols including standardized biological sampling (e.g., B-IBI).

- Under low-to-moderate basin development, use chemical water quality monitoring sparingly, i.e., only if a chemical pollutant is suspected or in situations where biological monitoring indicates a problem. For highly urbanized streams, sampling should be more frequent but should still be focused on specific constituents of concern.

- Tailor monitoring of instream physical conditions to the specific situation; based on objectives. Salmonid habitat surveys should include a measure of rearing habitat (LWD and/or pools) and a measure of spawning/incubating habitat (%fines and/or IGDO). In addition, standard channel morphological characteristics (pebble count, and streambank condition) should be measured. Scour monitoring should be used to evaluate local streambed stability in association with specific development activity.

The complexity and diversity of salmonid life cycles and stream communities, along with our limited understanding of them, should engender caution in proposing any simple solutions to reverse the cumulative effects of urbanization in streams of the PSL region.

> **"Many of the things that must be done are little things - small things each citizen can do...things little in themselves, but vital, urgent, and far-reaching in cumulative results. Therefore, the matters here discussed are not to be dismissed lightly as the concerns of scientists, engineers, and government alone. Every citizen must understand the problems and play a part in the solution"**
>
> **Person, 1935**

TRADITIONAL ALTERNATIVES: WILL MORE DETENTION WORK?

By: Douglas Beyerlein, P.E., and Joseph Brascher

QUESTION: Will More Detention Work?

ANSWER: No.

For the past 20 years local jurisdictions in the Puget Sound region have required stormwater detention facilities (ponds, tanks, and vaults) to be constructed to mitigate the impacts of development on our streams, rivers, and lakes. Standards were established to attempt to prevent runoff from development from increasing streamflows.

As hydrologists and engineers we participated in setting the standards, selecting the methodologies, and designing and building detention facilities. This was all for the purpose of protecting our aquatic systems while allowing development in our watersheds.

We have failed. With development has come increased winter flood flows, decreased summer low flows, and a general degradation of our stream systems.

We have failed because we are trying to replace the complex interactions of the hydrologic cycle with a pond. It can't be done. Table 1 shows why.

Table 1 shows where our average annual rainfall of 40.70 inches goes.

Table 1.	Surface Runoff (in)	Interflow (in)	Ground-water (in)	Evapotrans-piration (in)
Land Use				
Forest	0.09	8.46	13.40	18.79
Pasture	0.29	13.26	10.15	17.02
Lawn	0.61	16.72	8.89	14.48
Rural Residential (forest)	1.56	10.81	11.05	17.31
Rural Residential (pasture)	1.64	12.73	9.75	16.60
Suburban Residential	9.30	12.37	6.58	12.44
Multi-family Residential	16.66	8.69	4.62	10.72
Commercial	29.37	2.34	1.24	7.74
Impervious	34.05	0.00	0.00	6.64

In the natural forested environment almost half of our rainfall returns to the atmosphere via evapotranspiration. Evapotranspiration (ET) is the combined effect of evaporation of water from surfaces and transpiration of water from the soil by plants.

In the paved environment less than 20 percent of the rainfall becomes ET.

With development we have more water that becomes runoff. We have less natural storage for it because we are putting less water into the ground. It is this groundwater that supplies our streams with water during summer dry periods.

Instead we are increasing surface runoff, which is the water that gets to the streams the quickest. Interflow, the water that travels just below the surface, is not far behind. Together, surface runoff and interflow produce floods.

Stormwater detention is suppose to slow down the runoff from development and make it behave like natural runoff. It isn't working. And it can't work when you look at the numbers in Table 2.

Table 2.	Surface Runoff + Interflow (in)	SR+I Change from Forest (in)	Ground-water (in)	GW Change from Forest (in)
Land Use				
Forest	8.55	0.00	13.40	0.00
Pasture	13.55	5.00	10.15	-3.24
Lawn	17.32	8.77	8.89	-4.51
Rural Residential (forest)	12.37	3.82	11.05	-2.35
Rural Residential (pasture)	14.37	5.82	9.75	-3.65
Suburban Residential	21.67	13.12	6.58	-6.82
Multi-family Residential	25.35	16.80	4.62	-8.78
Commercial	31.71	23.15	1.24	-12.15
Impervious	34.05	25.49	0.00	-13.40

Just the act of cutting down trees and replacing them with pasture increases the bad runoff (surface runoff plus interflow) by 5 inches per year and decreases the good runoff (groundwater) by more than 3 inches. **No detention is required by government agencies.**

Replacing forest with lawn (residential sod) is worse. The bad runoff increases by almost 9 inches and the good runoff decreases by 4.5 inches. **Again, no detention is required by public agencies because no impervious area has been added.**

Detention is required once more than 5000 square feet of impervious area has been added to the development. But is it enough?

No.

In the Puget Sound region the Washington State Department of Ecology (DOE) has set the minimum standard for stormwater detention. The DOE Stormwater Management Manual requires that the runoff from new development (with more than 5000 square feet of impervious area) not exceed the 2-year and 10-year predevelopment floods. For a 100-acre development this produces the pond sizes shown in Table 3.

Table 3.	DOE Required Pond Size (acre-feet)	Actual Required Size (acre-feet)	Increase Needed (acre-feet)	Percent Increase
Land Use				
Forest	0.00	0.00	0.00	0
Pasture	0.00	5.16	5.16	--
Lawn	0.00	8.24	8.24	--
Rural Residential (forest)*	0.63	4.23	3.60	572%
Rural Residential (pasture)*	1.41	5.98	4.57	324%
Suburban Residential	2.85	13.45	10.60	372%
Multi-family Residential	6.88	18.99	12.11	176%
Commercial	10.88	29.59	18.71	172%
Impervious	11.86	33.92	22.06	186%

* assuming more than 5000 sq. feet of impervious area; otherwise, no pond is required.

The DOE ponds are too small.

Even if the ponds were sized to the actual required size (based on HSPF-generated runoff), mitigation based on the 2-year and the 10-year floods does not protect our streams.

Development with ponds increases the smaller flood flows and increases the length of time of flooding. This can be just as destructive to the streams and the salmon as the bigger floods. Controlling flow durations is the key to protecting them.

Flow duration is the percent of time that a particular size of flow is exceeded. For example, if a flow in a stream is greater than 1 cfs (cubic foot per second) for a total of 876 hours in a year then the flow duration for 1 cfs is 10 percent of the time (365 days times 24 hours equals 8760 hours in a year; 876/8760 equals 10%).

The annual flood (1.01-year flood) for 100 acres of forest is 1 cfs. Table 4 shows how often this flow is exceeded for each of the 100-acre developments.

Converting 100 acres of forest to suburban residential development (with a 13 acre-foot pond) still results in 1 cfs (the 1.01-year forest flood) occurring for an additional 549 hours (23 days) a year. The excess runoff has to go somewhere.

RESULTS FROM FOREST HYDROLOGY STUDIES: IS THERE A LESSON FOR URBAN PLANNERS?

By: Susan Bolton and Anne Watts

ABSTRACT: People have been wondering about mountains and hence forests and hydrology for centuries. King Solomon wrote: *All of the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again.* This is essentially a 3000 year old statement describing the hydrologic cycle. The hydrologic cycle can be conceptualized and studied in a variety of ways from careful analysis of each physical process to a more wholistic view of the cycle consisting of a system of storage reservoirs. Studies on individual components have looked at interception, evapotranspiration, infiltration, overland flow, subsurface flow, groundwater and streamflow. There has been considerable research on identifying the impacts of forest land cover changes on streamflow. Research sites have included paired basins, long-term nested basin sites, plot studies or review and synthesis of other studies. This presentation will present basic information necessary for understanding how the hydrologic cycle works, where water is stored, and how streamflow is affected by forest removal. The emphasis will be on what has been learned by researchers studying the effects of timber harvest on forest hydrology. Analogies between forestry and urbanization will be drawn and estimates of the impacts of urbanization will be made. Many of the research papers on the effect of forest management activities on stream hydrology are reported as percent change in annual flow, peak flow or low flow. For urban planners, the change in inches of runoff and not percent may be a more useful unit. The area of emphasis will be the Pacific Northwest coastal forests and only hydrological impacts will be discussed. Keep in mind that land use changes also impact many other physical and ecological processes.

Years of hydrologic research have not resulted in an entirely consistent set of results for predicted impacts of forest harvest on streamflow. However, the majority of studies show increases in peak stream flows and volumes in basins with timber harvest. The increase in flow is most noticeable in small basins from average storm events. The period of record, climate variability and harvesting histories make it very difficult to draw strong conclusions about the effect of harvesting on low frequency, high magnitude storms, especially in large basins. Many urban developments take place in relatively small drainage basin so the analogy between forest studies and expected changes due to urbanization is appropriate.

In small basins, hillslope processes dominate storm runoff processes. Critical hillslope processes are infiltration, evapotranspiration, and soil moisture at the beginning of the storm Timber harvest impacts three main components of the hydrologic cycle. **(1)**Removal of the trees increases snow accumulation and decreases evapotranspiration which combine to increase soil moisture levels. Higher soil moisture leads to saturated subsurface/surface flow which increases the amount of water reaching the channel quickly.
(2) Removal of large woody debris from the stream channels and the lack of large, older trees for recruitment to the channel decreases pool formation (pond storage) and decreases flow resistance, which means less water can be stored in the channel and water moves through the channel faster. **(3)** Road building to access the timber harvest sites compacts the soil in the road pathway which decreases infiltration and increases surface runoff. The cut banks of the roads intercept subsurface flow and turn it into surface flow. The road cut also decreases the soil available for moisture storage. The ditches and culverts along the roads create new channels for overland flow. The effect of roads is to increase the drainage density and hence water delivery to the streams. Water in channels travels much faster than does water flowing through the soil. Each of these three activities push the hydrologic cycle towards faster runoff and greater storm runoff. The forest studies were designed to evaluate changes in streamflows due to total or partial timber harvest. Most studies show that clearcutting in small basins increases storm runoff, especially early fall storm runoffs and winter storm runoff.

Recovery does occur from the three impacts mentioned above when the land is kept in forest usage and trees are replanted. Evapotranspiration recovers in about 5 years as new vegetation pushes roots into the deeper soil layers. Canopy interception may take decades to recover as the trees need go through several stages to form a complex canopy structure. Large woody debris, unless placed by humans, takes at least 60-90 years to recover because trees have to grow, become large and fall over. Roads, even in forests, tend to be relatively permanent changes in the systems. Data are inconclusive as to whether recent attempts at road abandonment and removal are effective. History has shown that the old railroad grades have been colonized by alders on the west side of the Cascades but it does take decades for this to occur.

Table 1 shows differences in the various processes that affect the water balance in different vegetation/climate zones. Annual increases in water yield are important and harvest has been used to increase streamflow. Most planning is done for single precipitation events so it is necessary to see where water is stored in the system, how much water can be stored in different compartments and how long it is stored.

Table 1. Average Annual Water Balance (in inches) for West Coast Forests and Potential Increase in Yield due to Harvesting

Forest Type	Precipitation	Streamflow	Evapotranspiration	Potential Water Yield Increase
Douglas fir/ hemlock/redwood	75	45	30	15.0
Mixed conifers	44	22	22	4.5
True fir	60	36	24	6.0

The hydrologic cycle can be viewed as a system of six compartments with fluxes carrying mass and energy among the compartments.

- energy sphere (the sun)
- atmosphere (wind and precipitation)
- hydrosphere (streams, lakes and ground water)
- biosphere (vegetation)
- terrasphere (soil)
- cultural sphere (human activities)

The sun is the driving force behind the hydrologic cycle and provides the energy that melts snow, condenses water vapor, evaporates water, and drives weather systems. It also drives photosynthesis and respiration in plants that lead to water uptake from the soil by plants. The atmosphere, via weather patterns and global circulation, stores water as vapor and distributes moisture around the globe. The biosphere is the vegetation zone of the earth's surface. On a global basis, the biosphere stores 17 times more water than the atmosphere. Water is stored on and in vegetation as interception or tissue water, respectively. The terrasphere is the soil covering the geologic substructure. Water moves through the soil by gravity except when it is responding to tension gradients exerted by plants and soil particles. Humans have little control over the sun or the weather, but we do alter storage in the hydrosphere, soil, and vegetation.

Water can be stored temporarily in soil depressions in response to a precipitation or runoff event. This water is ultimately either infiltrated or evaporated. Soil detention storage is soil water that drains via gravity and is not held in tension by soil particles. It is seldom held more than 24 hours. Detention storage is the difference in soil water between saturation and field capacity. Soil retention storage is water held by bonds between water molecules and soil particles and can only be extracted by plant roots. Some water is held so tightly by soil particles that it cannot be extracted by plant roots. Retention storage is the difference between field capacity and wilting point. Table 2 shows storage values for two common soil types in Puget Sound. Table 3 uses data from the literature to estimate the amount of water storage in different compartments. Evapotranspiration ranges from 0 to 0.2 inches per day depending on soil moisture availability, weather conditions and photosynthesis rates.

Table 2. Potential Water Storage in Soil (inches per foot of soil depth)

Soil moisture level	Silty clay loam	Sandy loam

Saturation (S)	6.3	5.2
Field capacity (F)	4.7	2.4
Wilting point (W)	2.7	1.4
Detention storage = S - F	1.6	2.8
Retention storage = F - W	2.0	1.0
Total potential soil storage	3.6	3.8

Table 3. How much water can a forest hold?

Trees (Douglas fir)	1 inch
Interception (canopy) - rain	0.01-0.7 inch
Interception (canopy) - snow	0.01-1 inch
Interception (litter) - rain	0.02-0.44 inches
Soil detention storage	sandy loam 1.6 – Silty clay loam 2.8 (in/ft of soil)
Soil retention storage	sandy loam 2.0– Silty clay loam 1.0 (in/ft of soil)

Many PNW precipitation events are low intensity and low volume. Intact forests with thick canopies and deep litter layers can prevent many precipitation events from reaching the soil at all. Water that is stored as canopy interception by the litter layer either evaporates and is lost from the storm event or it drips and moves slowly to the soil and infiltrates. Very little precipitation ends up as overland flow in mature, undisturbed forests. Overland flow occurs on compacted soil areas like trails and roads, in places where undecomposed leaves may bind and form a sheet for water to run over, and in areas where the soil is saturated and cannot store any more water.

Urbanization follows the same pattern as forest harvest in its effects: tree removal, channel cleaning and straightening, and road building. However, the changes tend to be permanent. Soil is compacted or graded and removed, thus reducing soil storage. Vegetation is cleared and replaced with house, lawns, and parking lots. Roads are paved and cover vast amounts of the original soil surface. In periods of low precipitation when water has time to drain, detention storage is still available providing that the water has some way of reaching the soil. If the water is guttered and piped to storm sewers or streams, then very little will reach the soil. Without trees or other deeply rooted plants to remove the soil water bound to soil particles, retention storage may remain almost full and not be available for storm storage. In a two-foot deep soil with very low ET due to lack of deep-rooted vegetation, retention storage may remain almost full. This would decrease available soil storage by 2-4 inches depending on the soil type and depth and presence of glacial till layer.

In summary, studies of forest hydrology give us an understanding of how alteration of the land affects the hydrologic cycle. Changes in urban areas are analogous to those due to harvest but are more severe and more long lasting. To minimize excess storm flow generation in streams, it is crucial to maximize natural areas, provide for infiltration opportunity, and minimize the generation of overland flow. Compared to other regions in the United States and the world, some Puget Sound streams still have some ecological functions intact. Now is the time to recognize that certain activities are impacting these streams and to limit the impacts. The longer we wait, the harder and the more expensive it will be to restore the streams, if it is possible at all.

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Technical Details

The above analysis was performed using the U.S. Environmental Protection Agency HSPF computer program, SeaTac Airport hourly precipitation data (October 1948 through September 1996), Puyallup daily pan evaporation data (same period of record), and U.S. Geological Survey regional HSPF parameter values for Puget Sound lowland watersheds in King and Snohomish counties.

The standard EIA values for rural residential (4%), suburban residential (26%), multi-family (48%), and commercial (86%) development were used. The impervious land use category is 100% EIA. Rural residential with forest assumes 5-acre residential lots with 2 acres of forest remaining on each lot. Rural residential with pasture assumes all of the forest has been replaced with pasture.

DOE pond sizing was computed using the SBUH procedure described in the DOE publication, Stormwater Management Manual for the Puget Sound Basin, Volume III - Runoff Control, February 1992.

HSPF flood frequency analysis was computed using Log Pearson Type III procedures described in the U.S. Water Resources Council publication, Guidelines for Determining Flood Flow Frequency, Bulletin #17B of the Hydrology Committee, revised September 1981.

Flow duration analysis was conducted using the HSPF utility DURANL and 420768 hours (48 years) of simulated flows from each of the nine land use categories.

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Everything else is our fault.

BEYOND INNOVATIVE DEVELOPMENT: SITE DESIGN TECHNIQUES TO MINIMIZE IMPACTS TO SALMON HABITAT

By: Tom Holz, Tom Liptan and Tom Schueler

Recent research indicates a strong link between total impervious area and the degradation of stream and wetland ecosystems, particularly salmon habitat (May et al, 1997). The research indicates that the degradation threshold is passed at about 5 to 10% watershed impervious area in Puget Sound lowland streams. Such a low impervious cover limit present a serious challenge to future watershed development, as nearly all traditional development designs (TDD) will exceed the 5 to 10% limit.

In this paper, we explore four questions. The first question is what kind of minimum watershed functions are needed to maintain on salmon habitat in the eco-region. Second, to what extent can "innovative" development designs (IDD) contribute to maintaining these functions? Innovative development designs refers to new site planning techniques that utilize open space subdivisions, narrower streets, greener and smaller parking lots, stream buffers, stormwater practices and other measures to reduce impervious cover and conserve natural areas. It is argued in this paper that IDD techniques alone, however, will be insufficient to maintain the minimum watershed functions to protect salmon habitat in most future growth areas.

The third question explores "Zero-Impact" Designs-- a series of techniques and practices that have not been widely applied in the Pacific Northwest, but may have potential to sharply reduce the "effective impervious area" of new watershed development beyond what can be achieved by IDD. Examples of ZID techniques include: eco-roofs, roof-gardens, rain-barrels, bioretention, alternative paving surfaces, soil amendments, bioretention, reforestation, filter strips and filter-swale systems. The fourth question asks whether improvements in the design of individual development sites can cumulatively meet minimum watershed functions, and explores what implications this may have for regional watershed management in the Pacific Northwest.

1. Watershed Performance Criteria To Protect Salmon Habitat:

Based on our current understanding of PSL streams, the following general watershed functions appear to be necessary to protect salmon from the effects of watershed development:

1. Preserve a minimum percentage of forest cover in the watershed to maintain some of the pre-development storage and evapotranspiration functions.

2. Preserve and manage a suitable riparian forest buffer zones along the stream network, and ensure that any buffer crossings will not create barriers to fish migration now or in the future.

3. Reduce the effective impervious area of the watershed to as near as zero as possible. This requires the design of a stormwater conveyance system that promotes sheetflow and storage, and discourages the collection and concentration of runoff.

Minimizing Effective Impervious Surface

Reduction of "effective" impervious surface to zero implies more evapotranspiration and infiltration of runoff. But the poor soils in the Puget Sound basin preclude infiltration from "traditional" development with its vast seas of impervious surfaces. If runoff is collected in any significant volume such as from a 60 foot wide road with curb and storm drains, it cannot be infiltrated and there is no place to route it except to surface water. Even a few gallons per minute of concentrated runoff cannot be infiltrated because the target zone for such infiltrate, the thin soils over the impervious till layer, do not have the capacity to store such quantities especially in the wet season.

To accomplish infiltration on poor soils, runoff cannot be collected. It must instead reach the water management "engine" of the forest within feet of where it falls as precipitation. To meet this constraint (and also to maintain sufficient forest cover to preserve predevelopment forest functions), development must take place, literally, between the trees. Examples of this kind of development (designed for totally different reasons) can be found in some older subdivisions in the Northwest. To accomplish this, impervious surface must be reduced to the maximum extent possible; impervious surface must be contained in discreet and unconnected blocks; AND discreet blocks of impervious surface must be buffered by forest. Simply put, we must build between the trees.

2. Innovative Development Design.

It is possible to develop land in a manner that sharply reduces the amount of impervious cover created and the amount of natural cover that is lost. It should be noted that most communities will need to substantively revise and reform their current subdivision and planning codes to allow developers to practice these innovative development techniques. In particular, communities need to feel that concerns about the marketability, liability, maintenance, public safety, parking and homeowner acceptance are fully satisfied before changing from the traditional development patterns. To help guide this process, a group known as the Site Planning RoundTable, representing over thirty national organizations that have a strong influence on how land development occurs, agreed to a set of 22 model land development principles that promote innovative development.

Residential Streets and Parking Lots (Habitat for Cars)

1. Design residential streets for the minimum required pavement width needed to support travel lanes; on-street parking; and emergency, maintenance, and service vehicle access. These widths should be based on traffic volume.
2. Reduce the total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length.
3. Wherever possible, residential street right-of-way widths should reflect the minimum required to accommodate the travel-way, the sidewalk, and vegetated open channels. Utilities and storm drains should be located within the pavement section of the right-of-way wherever feasible.
4. Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce their impervious cover. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should be considered.
5. Where density, topography, soils, and slope permit, vegetated open channels should be used in the street right-of-way to convey and treat stormwater runoff.
6. The required parking ratio governing a particular land use or activity should be enforced as both a maximum and a minimum in order to curb excess parking space construction. Existing parking ratios should be reviewed for conformance taking into account local and national experience to see if lower ratios are warranted and feasible.
7. Parking codes should be revised to lower parking requirements where mass transit is available or enforceable shared parking arrangements are made.
8. Reduce the overall imperviousness associated with parking lots by providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, and using pervious materials in the spillover parking areas where possible.
9. Provide meaningful incentives to encourage structured and shared parking to make it more economically viable.
10. Wherever possible, provide stormwater treatment for parking lot runoff using bioretention areas, filter strips, and/or other practices that can be integrated into required landscaping areas and traffic islands.

Lot Development (Habitat for People)

11. Advocate open space design development incorporating smaller lot sizes to minimize total impervious area, reduce total construction costs, conserve natural areas, provide community recreational space, and promote watershed protection.
12. Relax side yard setbacks and allow narrower frontages to reduce total road length in the community and overall site imperviousness. Relax front setback requirements to minimize driveway lengths and reduce overall lot imperviousness.
13. Promote more flexible design standards for residential subdivision sidewalks. Where practical, consider locating sidewalks on only one side of the street and providing common walkways linking pedestrian areas.
14. Reduce overall lot imperviousness by promoting alternative driveway surfaces and shared driveways that connect two or more homes together.
15. Clearly specify how community open space will be managed and designate a sustainable legal entity responsible for managing both natural and recreational open space.
16. Direct rooftop runoff to pervious areas such as yards, open channels, or vegetated areas and avoid routing rooftop runoff to the roadway and the stormwater conveyance system.

Conservation of Natural Areas (Habitat for Nature)

17. Create a variable width, naturally vegetated buffer system along all perennial streams that also encompasses critical environmental features such as the 100-year floodplain, steep slopes and freshwater wetlands.
18. The riparian stream buffer should be preserved or restored with native vegetation. The buffer system should be maintained through the plan review delineation, construction, and post-development stages.
19. Clearing and grading of forests and native vegetation at a site should be limited to the minimum amount needed to build lots, allow access, and provide fire protection. A fixed portion of any community open space should be managed as protected green space in a consolidated manner.
20. Conserve trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and promoting the use of native plants. Wherever practical, manage community open space, street rights-of-way, parking lot islands, and other landscaped areas.
21. Incentives and flexibility in the form of density compensation, buffer averaging, property tax reduction, stormwater credits, and by-right open space development should be encouraged to promote conservation of stream buffers, forests, meadows, and other areas of environmental value. In addition, off-site mitigation consistent with locally adopted watershed plans should be encouraged.
22. New stormwater outfalls should not discharge unmanaged stormwater into jurisdictional wetlands, sole-source aquifers, or sensitive areas.

While implementation of the RoundTable principles is both economically and environmentally desirable, and a clear improvement over the traditional development designs, available evidence suggests that they still may not reduce stormwater enough to prevent degradation of salmon habitat. This is illustrated by two real case studies, where the innovative land development principles have been applied to "re-design" traditionally developed sites. A simple model was used to compute the reductions in stormwater flows, pollutant loads and construction costs. While the analysis indicates that the application of innovative development principles does result in impressive reductions in all three factors, the reductions are not sufficient to meet the watershed function criteria outlined earlier.

3. Zero-Impact Design.

The primary reason why innovative development designs cannot meet the watershed function criteria is that they still produce large impervious units, in the form of rooftops and roadways that concentrate stormwater flows well beyond the pre-development condition. To achieve a "truly" zero-impact design, it is therefore necessary to convert these large impervious units so that they effectively function as pervious ones. This challenging task requires a fundamentally different approach toward design, and might involve:

Eco-roofs to Reduce Runoff

An eco-roof is a term used in Portland to describe a green living roof of vegetation and soil. This type of roof is European in origin and is referred to in Europe as a "green roof or extensive roof garden." It is a light weight (5-25 psf) roof system consisting of a synthetic waterproof membrane, a drainage layer, a thin soil layer (2-4 inches), and is covered with specific plant species adapted to the extremes of a rooftop environment. The eco-roof is a very low maintenance, self-sustaining plant/soil community without need of irrigation, fertilizers, or pesticides. It is of relatively low cost, about 30% more than a conventional roof, but lasts about 50% longer. Based on a German survey 82 cities in Germany offer some form of financial assistance to building owners who retrofit their rooftops with eco-roofs.

Eco-Roof Application

The eco-roof is mainly intended for its environmental functions and can be applied to retrofit existing buildings and for new construction. If we assume that one third of the impervious surfaces of an urban landscape are rooftops, then a significant opportunity exists for the eco-roof application. For example, the estimated total area of rooftops in Portland is 20 square miles, and at full build-out the rooftops will be about 24 square miles. Total area of the City of Portland is 145 square miles, with the estimated total impervious surfaces projected to 45% at build-out. Considering also that nearly all of these roofs will have to be replaced within the next 30 years, every building owner will be faced with a major capital expense.

Eco-roof Benefits

Are eco-roofs "truly" a zero expense technique? Probably not, but when compared to conventional roofs an eco-roof offers far more environmental and potential economic benefits. These benefits are multi-dimensional. Table A provides a comparison of eco-roofs to conventional roof systems to help provide a better context upon which to judge the characteristics of each. Most of the information has been obtained from sources listed below the table. Some information (indicated with *) is based on BES initial studies and speculation.

TABLE A – COMPARISON OF ECO-ROOFS AND CONVENTIONAL ROOFS

SUBJECT	ECO-ROOF	CONVENTIONAL ROOF
Stormwater:		
Retention:	15-35% wet season	0%
*peak flow:	Mitigates average wet season intensities	0% mitigation
	Attenuates 100% of warm season high intensities	0% attentuation
*temperature	0-35% hot runoff warm season	90-100% hot runoff warm season
	Reduces thermal increase in runoff	Causes thermal increase in runoff
Quality	Retains atmospheric deposition and retards roof degradation; potential for nutrient discharges	Allows atmospheric deposition to runoff and doesn't protect roof materials from degradation
Air quality:	Filters air, stores carbon and releases oxygen	None
Energy:	Approaches predevelopment air/surface energy relationship, allows almost year round evapotransporation of about 60% annual precipitation	Major impervious surface contributor to ozone problem, no transporation, evaporation at about % annual precipitation
***Greenspace:**	Can replace 100% of greenspace lost to building footprint (although greenspace is not of same quality)	None
Habitat:	Provides habitat and for some insects and birds	None
***Livability:**	Buffers noise, eliminates glare, alternative aesthetic	Conventional non-aesthetic
Cost & Life:	About 30% more expensive for construction including retrofits, life span 36 years about 50% longer than conventional roof	Approximately $2-$10 per square foot for new construction and $4 - $15 per square foot for retrofits, average life span 24 years
Maintenance:	After plants are established, once a year to assure drains are not clogged	Once a year to assure drains are not clogged

Sources: Sarnifil Co. Sarnevert Division, Switzerland; Soprema, Inc. Ohio, USA: North American Wetland Systems/Re-natur Minnesota, USA; Garland Co. Ohio, USA; Schoop Co. Switzerland; Grodania Co. Denmark; Bernd W. Drupka (Consultant) Germany; Rasen Co. Germany; Silke Schilling (consultant) Germany;

*City of Portland, Bureau of Environmental Services estimation

Road Runoff Management

Traditional roads and streets provide 12 feet of paving per lane for a pair of vehicle tires that are about 7 inches wide each. The wider pavement strips allow vehicles to travel faster. In quiet neighborhoods, the accommodation of high speed travel is a convenience once provided we often do our utmost to retake through speed bumps and traffic calming devices.

In neighborhoods are the best opportunities for pavement reduction. Streets can be made one way and all but the most minimal driving strips are needed to safely carry the very low volumes of traffic. This road section shows a one-lane street (with parking) where impervious surface has been reduced to 11% of the right of way. The portions of the cross section shown as vegetated are proposed to be paved with lattice blocks which will handle parked cars and carry the occasional "slip" from the driving strips. The road ballast provides storage for 4 to 6 inches of precipitation allowing slow migration of trapped precipitation to the adjacent forest. This road section would produce little or no overland flow runoff.

Higher speed arterials provide a greater challenge for impervious surface reduction but the same principles apply: actual impervious surface reduced to a small fraction of the right-of-way and a forest canopy covering as much of the driving lanes as possible. Ironically for higher speed roads, right-of-ways may have to be wider (goes against the goal for more dense development) to allow adequate buffer of forest necessary for acceptance of the extra runoff generated by the road.

Runoff Reduction Means Native Vegetation in Landscaping

Evapotranspiration from forest is about 50% of annual precipitation. From lawns it is less than half that. Furthermore such artificial landscapes require massive amounts of chemicals to resist nature's intent. If too much of a watershed is converted to lawns and forest buffers around such landscaping are insufficient to absorb the additional runoff, stream discharge increases and water quality decreases until fish habitat is no longer viable.

4. Site Design and Watershed Function:

Can improvements in the design of individual development sites cumulatively meet minimum watershed functions in most watersheds? The answer is probably no, unless they are performed in the context of an overall watershed plan that includes sub-watershed-based zoning, protection of sensitive areas, buffers, erosion and sediment control, stormwater management, non-stormwater discharges and watershed outreach programs. At a regional level, it may well be necessary to direct new growth into subwatersheds that are already well developed, and to manage these more urban systems in different ways.