CHAPTER 2

Scientific Foundation

This chapter presents the scientific foundation that supports the City of Portland's watershed management process. Specifically, it describes the principles and guidelines that will influence the City's watershed restoration efforts and the assumptions on which those principles and guidelines are based. To achieve healthy watersheds, both aquatic and terrestrial components will need to be addressed. The primary ecological principles in this chapter, many aspects of the riverine, wetland and upland principles, and the restoration guidelines apply to both terrestrial and aquatic species and habitats.

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The Importance of a Scientific Foundation

For much of the twentieth century, the City of Portland viewed the Willamette and Columbia rivers, their tributaries, and the natural resources within their watersheds largely as components in the regional economy that contributed to transportation, agriculture, waste disposal and other forms of commerce. For example, throughout the Pacific Northwest, salmon have been viewed as commodities that could be reared in hatcheries. With this conceptual foundation it is not surprising that the response to the continued decline of watershed health and fish and wildlife populations has been to try to "fix" the environment, to engineer new habitats as habitats have been destroyed and even to modify watershed functions so that they help meet economic needs. In many cases, attempts at environmental and natural resource restoration have not been based on sound information and an accurate understanding of watershed and ecosystem functions and the impacts of human activities on those functions.

Although many improvements have been made over the years, many fish and wildlife populations continue to decline, suggesting that a new approach to managing natural resources is needed. Indeed, current scientific evidence suggests that species and their habitats form a complex, integrated ecological system, and that when this system functions successfully the result is both a healthy environment overall and adequate abundance, productivity and diversity of individual species, including those that are of particular economic or cultural interest to humans.

The scientific foundation that will guide the City of Portland's watershed and fish and wildlife restoration efforts is in alignment with this view of species and habitats existing in an integrated ecological system. As defined by the Independent Scientific Group (2000)[1], a scientific foundation is "a set of scientific principles and assumptions that can give direction to management activities." It attempts to summarize the City's understanding of how the

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[1] This was a group of independent scientists that developed a conceptual foundation, review and synthesis of science underlying the Columbia River Basin Fish and Wildlife Program of the Northwest Power and Conservation Council.

ecosystem works and how this understanding can be applied to achieve watershed health goals. A scientific foundation provides a consistent and clearly defined approach to protection and restoration, and it states the assumptions and hypotheses underlying that approach so that they can be scientifically tested and refined over time.

A central tenet of the City's scientific foundation is that reestablishing healthy watersheds will require restoration of ecological functions and conditions. The scientific foundation recognizes that the Columbia and Willamette rivers and their tributaries provide many of the ecological services that are of intrinsic and economic value to humans, such as high-quality water, healthy fish and wildlife populations, safe access to waterways, and recreational opportunities, and that these services also depend on the restoration and maintenance of the ecological system.

Local rivers and streams provide us with valuable services, such as high-quality water, healthy fish and wildlife populations and recreational opportunities. These services depend on the restoration and maintenance of the ecological system.

Scientific information is rarely static, especially in regard to complex ecological systems. Knowledge is gained continually, and new conclusions and directions emerge. For this reason and others, this scientific foundation will be refined over time, through deliberative scientific review. Such review by independent scientists should occur at least every four years, and the scientific foundation should be updated if the scientific review indicates the need for a significant shift in direction.

Scientific Uncertainty and Adaptive Management

The principles presented in this chapter are supported by varying levels of scientific evidence. In some cases, they are supported by an extensive body of peer-reviewed research and apply directly to urban watershed restoration activities. In other cases, the principles represent hypotheses or assumptions that are scientifically plausible and consistent with established scientific principles but that have not been directly addressed by research. While the City's scientific foundation is based as much as possible on previously established principles, many decisions about restoring watershed health will need to be made when there is not enough directly relevant research to guide these decisions unambiguously. A fundamental premise of adaptive management is that encountering such decision points is common. The appropriate response to scientific uncertainty is not to avoid or postpone important decisions but rather to clearly document the assumptions that underlie the decisions and to evaluate the validity of those assumptions by carefully monitoring their results.

As each principle that guides the City of Portland's watershed and habitat conservation efforts is discussed, the level of scientific support underlying that principle is documented and the published sources that support it are cited. This is intended to clearly indicate where each principle lies on the spectrum of plausible hypothesis to well-established scientific principle.

Components of the Scientific Foundation

The principles and guidelines that make up the City of Portland's scientific foundation for achieving watershed health fall into four categories: primary ecological principles; riverine, wetland and upland ecology principles; salmonid ecology principles; and restoration guidelines (see Table 2-1). Many of these—including the primary ecological principles, the restoration guidelines, and aspects of the riverine, wetland and upland ecology principles—apply to the nonaquatic (terrestrial) components of the ecosystem.

TABLE 2-1
Principles and Guidelines Underlying the City of Portland's Scientific Foundation

Category	Principle or Guideline
Primary ecological principles	1. Ecosystems are dynamic, resilient and develop over time. 2. Ecological systems operate on various spatial and time scales that can be viewed hierarchically. 3. Habitats develop and are maintained by processes related to biotic and abiotic components of the ecosystem. 4. The abundance, productivity and diversity of organisms are integrally linked to the characteristics of their ecosystems. 5. Species play key roles in developing and maintaining ecological conditions. 6. Ecosystem function, habitat structure and biological performance are affected by human actions. 7. Biological diversity allows ecosystems to accommodate environmental variation.
Riverine, wetland and upland ecology principles	1. Rivers are not separate from the wetland and upland areas they drain. 2. Watersheds are defined by and operate across the spatial and temporal dimensions of riverine, wetland and upland ecosystems. 3. Hydrologic modification (outside normative flow regimes) and changes in upland conditions, functions and land uses can reduce habitat diversity, decrease native biodiversity, increase nonnative species and exacerbate water pollution, landslides and flooding.
Salmonid ecology principles	1. Life history diversity, genetic diversity and metapopulation organization are ways salmonids adapt to their complex and connected habitats and are the basis of salmonid productivity and salmonids' ability to cope with environmental variation. 2. Sustained salmonid productivity requires a network of complex, diverse and interconnected habitats that are created, altered and maintained by natural physical processes in freshwater, estuarine and ocean environments. 3. Restoration of salmonids must address the entire natural and human ecosystem, encompassing the continuum of freshwater, estuarine and ocean habitats where salmonids complete their life histories.
Restoration guidelines	1. View the whole picture: Watershed restoration efforts need to be placed within the context of the entire watershed; species recovery efforts must be placed within the context of complete life cycles. – 1.1 Define watershed health holistically, by addressing the entire system. Evaluate watershed health in four dimensions: longitudinal, lateral, vertical and temporal. Define watershed health in terms of physical, chemical and biological integrity. – 1.2 Understand the role of the watershed in the landscape. 2. Characterize existing conditions and use the results to inform the entire restoration planning process.

TABLE 2-1
Principles and Guidelines Underlying the City of Portland's Scientific Foundation

Category	Principle or Guideline
	3. When planning watershed restoration actions, prioritize and sequence them to maximize long-term success in meeting the stated objectives for the restoration. – 3.1 Begin recovery efforts by protecting and restoring existing fish and wildlife functions, populations and habitats. – 3.2 Build outward from existing populations, functions, and rare and high-quality habitats. Consider the pattern and connectivity of habitat patches as habitats and functions are built outward. – 3.3 Place priority on controlling sources of degradation before attempting to address the impacts of those sources. – 3.4 In prioritizing restoration actions, first understand how watershed processes affect watershed health. Focus initial restoration actions on the processes that create and maintain healthy watershed conditions and functions. 4. To the maximum extent practicable, use natural processes to achieve ecological functions and societal goals. – 4.1 Minimize the introduction and spread of nonnative plant and animal species, especially into relatively natural habitat areas. – 4.2 Use native species and emphasize natural habitat features and processes whenever possible in restoration activities.

Primary Ecological Principles

The overarching ecological principles are a set of broad, scientifically based statements that describe how the biological and physical features of Portland's watersheds and watercourses form a functional ecosystem and, in turn, how this ecosystem affects the biological performance of species of interest for commercial, cultural or other reasons. These principles are based on a number of principles within the field of ecosystem management, including those of the Northwest Power and Conservation Council's Independent Scientific Group (2000), ecological principles for land management developed by the Ecological Society of America (Dale and others 2000) and those of Quigley and others (1996) for federal land management.

All of the primary ecological principles apply to both aquatic and terrestrial species.

Seven primary ecological principles underlie the City's *Framework*. Principles 1 and 2 deal with the characteristics of ecosystems, Principle 3 deals with habitat-forming processes, and Principles 4, 5, 6 and 7 deal with species' ecological functions and diversity within ecosystems.

The principles are not independent and, in fact, overlap in important areas as a result of the integral coupling of ecosystem components, characteristics and performance. All of the primary ecological principles apply to both aquatic and terrestrial species.

Primary Ecological Principles

1. Ecosystems are dynamic, resilient and develop over time.
2. Ecological systems operate on various spatial and time scales that can be viewed hierarchically.
3. Habitats develop and are maintained by processes related to biotic and abiotic components of the ecosystem.
4. The abundance, productivity and diversity of organisms are integrally linked to the characteristics of their ecosystems.
5. Species play key roles in developing and maintaining ecological conditions.
6. Ecosystem function, habitat structure and biological performance are affected by human actions.
7. Biological diversity allows ecosystems to accommodate environmental variation.

Primary Ecological Principle 1: Ecosystems are dynamic, resilient and develop over time.

Although ecosystems have definable structures and characteristics, their behavior is highly dynamic, changing in response to internal and external factors (Dale and others 2000). The system present today is the product of its geological, biological and human legacy. Natural cycles of change structure biological communities and affect species abundance and distribution (Beamish and others 1999). Disturbance and change are normal ecological processes and are essential to the structure and maintenance of habitats (Bisson and others 1997).

Disturbance can be the result of natural processes such as fire, flood or insect outbreaks, or they can result from human activities, such as the creation of impervious surfaces, development of riparian zones, timber harvest or agriculture. Natural disturbance patterns create a mosaic of habitats across the landscape and through time (Reeves and others 1995). At the same time, ecosystems maintain characteristic features and support definable communities of organisms. Habitat-forming processes—which result from the underlying geology, climate and hydrology and species' ecological functions—impart a degree of resilience to the system, allowing it to accommodate change and maintain essential characteristics (Holling 1973). Once a disturbance dissipates, the ecosystem may come to resemble its previous condition, depending on the type and degree of disturbance and the ecosystem's resilience.

An ecosystem's ability to absorb change and retain its original characteristics is limited, particularly in urban ecosystems, where disturbance is essentially continuous. Under these circumstances an ecosystem may not return to predisturbance conditions even if the disturbance ceases.

However, an ecosystem's ability to absorb change and retain its original characteristics is limited (Holling 1973, Reice and others 1990). Human actions and natural events can dramatically alter ecological systems such that the system is not destroyed but instead shifts into a new configuration in which different species are favored and new biological and physical interactions develop. This is particularly true in urban ecosystems, where disturbance is essentially a continuous rather than episodic event and the resilience of the ecosystem is compromised to the extent that it will not return to predisturbance characteristics even when the disturbance is reduced or eliminated.

A natural ecosystem will show describable, if not generally predictable, patterns of change over time (Odum 1969). For example, a forest, like other ecosystems, may appear stable when observed at one point in time, but it changes over longer time frames. Similarly, a lake or stream matures to have a dramatically different ecological character at various points in time (Cummins and others 1984). Natural disturbances can interrupt succession locally, leading to a mosaic of habitats across the landscape (Reeves and others 1995). More widespread and pervasive disturbance, including many human activities, can stop or reset ecological succession patterns and prevent the formation of habitats and processes that may be essential to the continuation and abundance of some species.

Many natural resource management actions are designed to control the environment, reduce variability, and achieve a stable and predictable yield from a highly dynamic system (Holling and Meffe 1996). For example, dams and other structures are designed to dampen seasonal variation in water flow. In many developed areas, including Portland, river and streambanks are stabilized and diked to minimize out-of-channel flooding during high flow events. Fish hatcheries were conceived, in part, to smooth out natural variation in fish populations and to sustain harvest over time (Bottom 1997). Hatchery production and fish passage measures are timed and engineered to provide a predictable fish migration with minimal conflict with human uses of the river. Fires are suppressed, altering forest succession, species composition and the frequency and severity of insect outbreaks (Quigley and others 1996).

Implications. In accordance with Principle 1, natural resource management programs should anticipate and accommodate both natural and human-induced change. This would be a departure from traditional management, which has attempted to freeze the system in a certain constant state and manage it for constant yields by not allowing natural change to occur. Expectations of constant abundance or yield from natural resources are unrealistic and ignore fundamental features of ecological systems. Similarly, efforts to protect only areas that currently possess desirable conditions, without considering the long-term, dynamic nature of ecosystems, will not result in successful, comprehensive natural resource management. Natural patterns of disturbance should be recognized as events that develop and maintain a diversity of habitats. Efforts to stabilize the environment and reduce disturbance will fundamentally alter habitats to the detriment of the abundance, productivity, spatial structure and diversity of species of management interest, such as ESA-listed salmonids.

Attempts to stabilize and control the natural world through hatcheries, dams and fire suppression run counter to the fundamental nature of ecological systems, which is to be constantly changing.

Given the limited resilience of ecosystems in urban areas, it is not realistic to expect a return to predisturbance conditions. Nonetheless, ecological functions can be restored to some degree. These facts have implications in establishing meaningful objectives, targets and benchmarks for achieving watershed health. Also affecting the establishment of objectives, targets and benchmarks is the expected arrival of an estimated 1.1 million new residents in the Portland metropolitan area by the year 2040.[2] An influx of this magnitude will almost certainly test the resilience of the region's ecological systems and processes and, ultimately, challenge the City's ability to achieve healthy watersheds.

The challenge for the City of Portland will be to allow habitat-forming processes to occur in a built-out environment with high human population densities. The *Johnson Creek Restoration Plan* (City of Portland Bureau of Environmental Services 2001) is one example of an approach that has attempted to do this. The plan calls for buying properties along Johnson Creek to provide flood storage in the floodplain, as well as create off-channel habitat for salmonids. This approach came about as a result of a combination of factors, including strong public support, a history of failed flood control attempts and increased regulatory scrutiny by federal and state agencies as a result of the Endangered Species Act.

Flow regulation in the Columbia and Willamette is one of the most pervasive changes that has been made to these rivers. The confluence of the Columbia and Willamette rivers historically was a site rich in ecological and biological diversity. Flooding, large wood accumulations and tidal influences shaped the factors that aquatic life evolved and adapted to. As the magnitude and rate of flooding have been controlled through reservoirs, habitat-forming processes have been severely altered, if not eliminated. Species such as salmonids and beaver that have evolved complex life history strategies based on the patch-dynamic nature of habitat networks created by disturbance have been forced to use suboptimal habitat patches or move through long stretches of inhospitable habitat. Strategies for the lower Willamette watershed will have to contend with traditional reservoir management of flows and the long history of draining and filling of the floodplains and shoring up the banks with rock, concrete and other structures. Since 2000, the City's Willamette Fish Study, a cooperative effort between the City and the Oregon Department of Fish and Wildlife (ODFW), has been investigating juvenile salmonids' use of bank and near-shore treatments to determine current and future habitat restoration opportunities in the lower Willamette River.

To allow for more natural flow variations, a twofold strategy will be necessary. This strategy will involve adding some controlled habitat-forming flow forces to the traditional management regime of the reservoirs and allowing for some controlled habitat-forming processes to occur in the lower Willamette. The latter will require a regional approach with cooperative agreements among the City of Portland, other local jurisdictions, and state and federal agencies that have jurisdictional authority over flows and the instream, bank and floodplain environment.

Primary Ecological Principle 2: Ecological systems operate on various spatial and time scales that can be viewed hierarchically.

Ecosystems, landscapes, communities and populations are usefully described as hierarchies of nested components (Allen and Hoekstra 1992), with levels in the hierarchies distinguished by different spatial and time scales. A higher level addresses larger areas that fluctuate over relatively long time intervals, whereas lower levels encompass smaller areas

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[2] The Metro-approved *2040 Regional Growth Plan* plans for a population increase of 1.1 million new residents in the region by 2040. Among other things, the plan identifies lands outside Portland city limits that will be used to accommodate this growth.

and vary at greater frequencies. For example, factors such as climate and geology might be addressed at a regional scale, hydrology and water quality might be addressed at the watershed scale and localized habitat components might be addressed on a local, site-specific scale. Expansive ecological patterns and processes constrain, and in turn reflect, localized patterns and processes (Wiens 1989).

The appropriate hierarchy and scale to use for watershed management depend on the question asked (Levin 1992). There is no single, intrinsically correct scale, only one that usefully addresses the issue in question. Conditions at any given level reflect both the cumulative effect of actions at lower levels and the constraints imposed by higher level factors (Allen and Hoekstra 1992). Therefore, to understand conditions at any particular level, it is necessary to consider the higher level constraints (the context) and the lower level mechanisms, both of which influence conditions (Wiens 1989). This suggests neither a top-down nor a bottom-up management approach but rather an integration of both.

Viewing ecosystems as hierarchies is useful in depicting the underlying structure of ecological components. Regional climates, for example, vary through time on scales ranging from millennial to interannual (Greenland 1998). Disturbance regimes within ecosystems can be described at a variety of spatial and temporal scales (Delcourt and others 1983) that can affect life history patterns and genetic structure (Wissmar and Simenstad 1998). Frissell and others (1986) describe a hierarchical classification system for aquatic habitats based on underlying geomorphic hierarchies.

This principle also provides an ecologically based way to structure watershed recovery (Quigley and others 1996). As a necessary first step, the ecosystem is defined at the point in the ecological continuum appropriate to the problem to be solved. The ecosystem at that point reflects both the characteristics of the features nested within it and higher level constraints on performance.

Implications. If ecosystems are viewed as nested hierarchies, it is necessary to define appropriate scales for their management and study (Holling and Meffe 1996). To address problems in the entire Willamette River basin, for example, it may be necessary to filter out local, site-specific data. On the other hand, questions concerning localized components (such as the Willamette's reach within Portland or tributaries to the Willamette, such as Johnson and Tryon creeks) cannot be effectively addressed by looking solely at the entire basin. Understanding basin-level problems requires knowledge of actions and processes that take place in individual reaches and tributaries, while the success of reach- or tributary-level actions may depend on factors operating at basin and regional levels.

Effective restoration of physical, chemical and biological components of the lower Willamette River and tributary streams will require coordination with upstream jurisdictions as well as with agencies that control water flows, water quality and fish and wildlife communities. This will involve working at multiple scales involving both the site-specific and the basinwide context. There will need to be an agreed-upon series of indicators for use in determining current conditions, measuring the progress of restorations actions and monitoring on-the-ground changes to a variety of ongoing operations and maintenance activities. Such a set of indicators is being developed as described in Appendix G, and they will need to be accepted by key stakeholders in the region.

In addition, empirical studies and monitoring will need to be designed and funded to track the progress of restoration actions. The challenge will be in deciding on the priorities for data collection and maintaining a coordinated data system across so many different scales and jurisdictions. The Willamette Partnership (formerly the Willamette Restoration Initiative, or WRI; see Appendix D) may offer the best example yet of how this could occur.

Primary Ecological Principle 3: Habitats develop and are maintained by processes related to biotic and abiotic components of the ecosystem.

Habitat refers to the resources and conditions present in an area that allow a species or a group of species to exist and thrive (Hall and others 1997). From a species perspective, the habitat is the string of conditions encountered over the species' life cycle that contribute to the species' survival and reproduction (Independent Scientific Group 2000). Factors such as geology, climate, geomorphology, soils, hydrology, vegetation and topography regulate habitat-forming processes, which for salmonids include stream flow, contributions of large wood, sediment supply, temperature and channel dynamics (Frissell and others 1986, Imhof and others 1996, Beechie and Bolton 1999). All of these elements act over a range of spatial and time scales to create, alter and maintain habitats (Allen and Hoekstra 1992).

Habitats exist in specific localities, but they are created by processes and factors that extend throughout watersheds, basins and even regions.

Regional-scale climatic conditions determine temperatures and precipitation that are important in the development of habitats. At both the regional and local scales, habitats are created and maintained by hydrologic, geologic and biotic processes that affect other aquatic and terrestrial conditions throughout the watershed. Locally observed conditions often reflect more than local processes and influences; in fact, they often reflect non-local—even regional—processes, including human actions. The presence of essential habitat features created by these processes determines the abundance, productivity, spatial structure and diversity of species and communities (Morrison and others 1998).

The active agent of many aquatic habitat-forming processes is water acting with the underlying geology and topography. Because habitat processes are hydrologically linked, the impacts of actions can manifest themselves downstream. As an example, downstream habitat conditions (such as high water temperature or increased sediment) can be the result of upstream actions and conditions (such as the removal of trees along streambanks or streamside construction). The impacts of these terrestrial actions and conditions accumulate (that is, the water temperature increases continually) as water moves downhill, affecting aquatic habitat conditions downstream.

Terrestrial habitats are often described in terms of food, water and cover. Formation of these features is related to vegetative and biotic patterns that result from the environmental needs of individual plant species, succession and patterns of human-caused and natural disturbance (Whittaker 1975). In turn, the vegetation pattern is related to local geology, topography and climate in the context of the regional climate and other factors. In an urban context, terrestrial habitats are often described in terms of their land uses, levels of impervious surface and vegetative cover.

Implications. Understanding the processes that create and maintain aquatic and terrestrial habitats is key to managing the human impacts on those habitats (Imhof and others 1996, Beechie and Bolton 1999). Even though the perceived problem may be local, it is necessary to consider the habitat-forming processes acting at the watershed or basin level. Often efforts are focused on correcting the symptoms of habitat degradation and loss, rather than on their causes, and problems are addressed with local, technological solutions. Often these efforts prove futile because the process and conditions creating the problem are still in place (Kauffman and others 1997).

Habitats are the result of processes. Restoration efforts are most likely to be successful if they are based on an understanding of the processes that form a particular habitat.

This principle stresses the need to understand and address habitat-forming processes in order to restore and maintain aquatic and terrestrial habitats (Beechie and Bolton 1999). Habitat restoration actions undertaken without appreciation of the underlying habitat-forming processes will not be effective in the long term (Reeves and others 1995).

Land use affects habitats through processes similar to those structuring natural habitats. Understanding the relationship between land use practices and their impacts on ecological processes and functions is key to ensuring that habitats are available to support biological communities and species of interest. For example, one risk to terrestrial species is habitat fragmentation as a result of development. Small patches of fragmented habitat are less likely than large habitat patches or habitat corridors to sustain ecological processes and disturbance regimes that support viable and diverse populations of native plants and animals. As the human population increases in the urban area, the City of Portland will need to identify those habitat patches where habitat-forming processes are still relatively intact so that populations of key terrestrial species, such as western gray squirrel and red tree vole, can be maintained.

In urban areas such as Portland, efforts have been made over the life of the City to control or eliminate the impacts of flooding, with the result that important habitat-forming processes that native aquatic species have adapted to have been altered. Controlling water flows through reservoirs and dams has given many people the sense that rivers can effectively be separated from their floodplains. Activities such as filling floodplains and building flood control bank structures have given human populations the perception that they can safely build next to streams and rivers.

As the population continues to increase in the Willamette River basin, the size and impact of cities located along the river corridor will increase. This will present the challenge of how to allow habitat-forming processes to occur via careful management of high flows, in conjunction with restored bank and floodplain habitat. It also will be necessary to change the management of reservoirs and dams and redesigning fish-friendly bank and near-shore treatments to handle the increased flows while also providing ecological benefits. Given the potential for conflict with regard to historical uses and properties, there will need to be an educational component in addition to coordination to facilitate decisions at site- and basinwide scales.

Primary Ecological Principle 4: The abundance, productivity and diversity of organisms are integrally linked to the characteristics of their ecosystems.

An ecosystem is an organized complex of physical and biological components (Tansley 1935). Physical and biological elements such as minerals, soil, vegetation and animals self-organize into a system that captures and processes energy to produce the observed diversity, abundance and productivity of plant and animal species, including humans (Kauffman 1993, Odum 1993). The characteristics and abundance of individual species reflect their coevolution with other species and their response to their environment. Because of the pervasive impact of human actions on ecological systems (Vitousek and others 1997), achieving goals for individual species of commercial, cultural or other human interest will require managing human activities to support ecological processes (Christensen and others 1996).

Although scientists may have an intuitive feel for what constitutes an ecosystem, management goals and actions frequently focus on individual species rather than on the species' ecosystems—the physical and biological systems that species are a part of, contribute to and depend on. In the past, species of commercial and cultural concern have been given priority, with sporadic success. There is increasing recognition of the need for multiple species management and the integration of land management with fish and wildlife management (Puchy and Marshall 1993, Christensen and others 1996, Dale and others 2000). This means recognizing both the processes that form the habitats necessary for species (processes such as channel dynamics and habitat connectivity) and the functions that species provide to the ecosystem (such as input of organic matter, primary and secondary production and energy flow). For example, many of the flood control dams constructed in the upper Willamette River basin did not provide fish passage, thereby eliminating crucial nutrient cycling. The combination of suitable habitats and needed ecological functions combine to form the ecosystems needed to provide the desired abundance and productivity of specific species.

Local climate, hydrology and geomorphologic factors as well as species interactions strongly affect ecological processes and the abundance and distribution of species at any one place (Dale and others 2000). The life histories, physical features and diversity of individual species are shaped by climate, the physical structure of their habitat and biological interactions. Change in physical or biological features of the ecosystem, either natural or human-induced, affects the capacity, productivity and diversity of fish and wildlife species.

Implications. Management of species or ecological problems in isolation at best provides an incomplete picture and at worst misleads by not accounting for the context and mechanisms that control species abundance, capacity and diversity, or the ecological processes that support these. This principle notes the integral relationship between species and their environment and the role that species themselves play in maintaining that environment. It couples ecological conditions with the productivity and abundance of species, including those of management interest.

Natural resource management, especially fisheries management, often isolates species from their environment to insulate them from habitat loss or other impacts of human actions (Bottom 1997). Insulating species in this manner neglects the role of biological and physical factors of the ecosystem—such as dynamic conditions of flow, habitat and water quality—in shaping individuals, populations and species through natural selection. In addition, this approach does not replace habitats themselves or the ecological functions that species provide, such as supplying nutrients and food to other species. For salmon, hatcheries historically have not been successful. This is not to say that hatcheries do not have a role to play in salmonid recovery, particularly during the stages in which habitat and ecological functions are being restored. Rather, hatchery operations should be conducted with an understanding of the contribution salmonids make to healthy functioning of the ecosystem and the reliance of salmonids on biological and physical characteristics of their environment.

It will be crucial to understand which habitat and ecological functions or processes in the lower Willamette and its tributaries play key roles in providing rearing, feeding, and spawning habitat, and in providing for other needs of native biological communities. The Willamette Fish Study, a fisheries research effort of the lower Willamette River by the City and ODFW, is attempting to do this for juvenile salmonids, but this type of investigation must be extended to other species as well, both aquatic and terrestrial (bald eagles and turtles, for example).

Primary Ecological Principle 5: Species play key roles in developing and maintaining ecological conditions.

Organisms do not act as passive occupants of their habitats. Instead, each species has an ecological function that may be key to the development and maintenance of ecological conditions such as habitat and food supply (Walker 1995). Although not every species' ecological role is well understood, it is clear that each group of species has a distinct job or "occupation" that is essential to the diversity, sustainability and productivity of the ecosystem over time (Morrison and others 1998). For example, plant, animal and bacterial species structure habitats, cycle energy and control species abundance and diversity. Beavers create ponds, plants make the sun's energy available to herbivores (and ultimately carnivores) and bats help keep mosquitoes in check. The existence, productivity and abundance of species depend on functions such as these.

To varying degrees, similar ecological functions may be performed by different species, and having a diversity of species with similar "occupations" enhances the resilience of the entire ecosystem in the face of disturbance or environmental variation (Walker 1995). However, some ecological functions are performed by a limited number of species. The decline or disappearance of these species can have significant impacts on their associated ecological function, the ecosystem as a whole and other species.

A species does not just live in and rely on its ecosystem; it also performs functions that contribute to the healthy functioning of that system, such as shaping habitats, funneling energy from the sun to other organisms and keeping the populations of other species in check.

In Pacific Northwest ecosystems, for example, salmon often play a unique role in cycling nutrients and energy from the ocean to freshwater and terrestrial habitats (Cederholm and others 1999). Salmon carcasses naturally fertilize freshwater systems, providing a unique array of nutrients, lipids and biochemicals to freshwater and riparian food webs. Algae, bacteria, invertebrates and young salmon fry in particular depend on these nutrients—many of them marine-derived—to survive and remain viable throughout the year. In fact, "the watershed fertility once provided by healthy runs of salmon may be essential to recovery of declining salmon stocks" (Pacific Northwest Research Station 2001). The disappearance or decline of salmon stocks in a particular watershed can have far-reaching impacts on coexisting aquatic and terrestrial plants and wildlife; these impacts include changing the nutrient cycle and other ecological functions (Willson and Halupka 1995, Cederholm and others 1999).

Salmon hatcheries may provide harvest benefits to some human users when habitats have been altered or destroyed, but generally hatcheries do not replace the ecological role that salmon play in the ecosystem, such as nutrient cycling. Recent experiments show that placing hatchery-origin salmon carcasses into streams (one carcass per square meter) jump-starts trophic level production and results in accelerated growth rates in fish. Through its Salmon Trout Enhancement Project, ODFW enlists volunteers to place carcasses in streams. Although the ecological impact of these particular carcass placements has not been measured, the strategy of carcass placement remains a potential short-term method for incorporating marine-derived fatty acids and biochemicals into aquatic food webs. (It should be noted, however, that just as some streams have never supported certain fish populations, individual watersheds will respond differently to added nutrient loads, depending on biological, chemical and physical attributes unique to that system. Also, in urban areas it may be necessary to investigate the use of other fertilization techniques to avoid nuisance impacts to local human residents.)

Implications. This principle affirms the need to consider resource management actions in the context of species' ecological functions. In the case of salmon, it is generally understood that spawned-out carcasses provide important nutrients to ecosystems as the carcasses decompose and release minerals. Although scientists do not know the degree to which declines in local salmon runs—and the concomitant changes in nutrient cycling—have affected Portland's watershed ecosystems, the declines have doubtless had an effect. The result can be significant ecological change affecting the presence and abundance of other aquatic and terrestrial species (Cederholm and others 2000).

If a species disappears from an ecosystem, so too does its contribution to the healthy functioning of that ecosystem.

Ill-placed or poorly designed culverts or other fish passage barriers affect the number of salmonids that can return to spawn, the temporal and spatial distribution of salmonids throughout a subbasin and—ultimately—the nutrient balance of that freshwater system. In Portland, there are only two waterways that are "open": Johnson Creek and Tryon Creek. The remaining freshwater systems in Portland either are available to salmonids only seasonally or are totally unavailable. Managing Portland's waterways so that salmonids can return unimpeded to spawn will be critical to reestablishing the nutrient bank in those freshwater systems.

Hatcheries may continue to play a role in natural resource management, but their operation must be changed so that they not only bolster salmon survival but so they restore or replace the functions that salmon provide in the ecosystem and boost the overall carrying capacity and productivity of the environment.

Primary Ecological Principle 6: Ecosystem function, habitat structure and biological performance are affected by human actions.

Humans play an integral role in ecosystems and are subject to the same ecological principles as other organisms are. However, we are unique in that we have the ability to shape our ecological future.

Humans are integral parts of ecosystems, and human actions have a pervasive impact on the structure and function of ecosystems; at the same time, human health and well-being are tied to the condition of the ecosystem (Vitousek and others 1997). Like many other organisms, people structure and control ecosystems for their own needs. In some ecosystems, particularly urban ones, human impacts are major factors controlling the environment. However, unlike other organisms, humans can consciously control their actions to allow needed ecological conditions to develop. While human actions may be unique in the scale of their impact on ecological systems, the method of interaction is not; ecological principles apply to human interactions with ecosystems as much as they do to the interactions of fish and wildlife species with the ecosystem.

It is a reasonable assumption that for most species, the ecological conditions that are most conducive to their long-term survival and productivity are those under which they evolved. But urbanization and associated human actions in the Portland area—as in other similar urban areas—have shifted ecosystems away from their predevelopment conditions, with negative impacts for many native plant and animal species. Some changes are irreversible: the urbanized landscape has been permanently changed; increased stormwater runoff has altered flow, water quality and habitat conditions in stream channels; and nonnative plant and animal species have been introduced that compete with and in some cases displace native species. Even with complete cessation of urban development, the ecosystem would not return to its previous condition. However, the impacts of urbanization and associated human actions on ecosystems can be managed to move the system to a state that is more compatible with the needs of other species.

Implications. Some people view humans as separate and distinct from the natural world—as observers and users rather than as active participants. Principle 6 stresses the integral role of humans in the ecosystem and their unique ability to shape society's ecological future. For millennia, humans have altered the natural landscape in the Willamette River basin and the abundance and distribution of its plants and animals. In intensely developed areas, human activities will continue to dominate the ecosystem. However, it is possible to manage those actions in a manner that is more consistent with the needs of other species and ecological processes.

Human impacts on the ecosystem can be managed to make the system more compatible with the needs of other species.

As scientists learn more about urban ecosystems, there will be more opportunities to incorporate considerations related to ecological functions and processes into traditional urban development and redevelopment objectives. Ecosystem objectives do not have to be incompatible with urban objectives. For example, fish and wildlife-friendly objectives can be incorporated into streambank, near-shore and upland developments and redevelopments along with more traditional objectives, such as flood control. Zoning can establish and protect effective riparian corridors along streams and rivers and upland vegetation to buffer the impacts of humans on the aquatic and terrestrial systems. Stormwater best management practices can be implemented to detain and infiltrate stormwater onsite at existing facilities and redevelopment sites, thus reducing high stormwater runoff flows.

As the more deleterious impacts to Portland's urban streams are addressed, it will be important to track the responses of fish, wildlife and plant communities. An effective monitoring system should be designed to determine whether the City's programs and actions are successful.

In addition to the investigation of City-controlled activities and their effects, studies should also evaluate how state programs, such as ODFW's hatchery and unfed fry release programs, are affecting the City's ability to reach its goals. As the City directs resources to assisting in the recovery of listed salmonid species, it should be determined whether hatchery programs have helped or hindered resident fish populations. As the cumulative impacts of urbanized systems are better understood, hatchery programs should be fine-tuned to assist in the recovery of resident native populations.

Primary Ecological Principle 7: Biological diversity allows ecosystems to accommodate environmental variation.

Biological diversity occurs at a variety of scales: in the variety of life forms across the landscape, in the ecological roles they play and in the genetic diversity within their populations (Odum 1993). Biological diversity develops as a result of various physical and biological processes in response to variability in the physical and biological conditions of the environment (Southwood 1977). Variation in biological characteristics among species, populations and individuals is what drives adaptation in response to environmental variation.

Biological diversity contributes to ecological stability and resilience (Walker and others 1999) at two levels:

- **Within ecosystems.** Resilience is enhanced by the presence of multiple, functionally similar species within a single ecosystem. As the populations of individual species increase or decrease over time, they can alternate in providing essential ecological functions (Morrison and others 1998, Peterson and others 1998, Walker and others 1999). Species that are abundant contribute to ecological function and performance at a particular time, whereas rarer species contribute to ecological resilience over time (Walker and others 1999). Loss of species, particularly those for which there are few ecological equivalents, jeopardizes overall ecological structure and stability (Walker 1995).
- **Within a species.** Genetic diversity contributes to the stability of a species over time by providing a wider range of possible evolutionary responses to the challenges posed by variation in the environment. As the environment changes over time, survival rates vary from one population to the next. As some populations suffer under an environmental extreme such as an El Niño condition, others might fare better. However, the species as a whole survives, bolstered by its ability to respond to the shifting environment (Bisbal and McConnaha 1998).

Human actions often reduce biological variation at both levels (Urban and others 1987, Policansky and Magnuson 1998). As the environment is simplified and its natural variability is decreased, biological variation at the various scales is reduced as well. This leads to the potential loss of organisms as they become less capable of responding adaptively to environmental change. The subsequent loss of ecological functions (functions that the organisms formerly provided) can decrease the stability and resilience of ecosystems.

Biological diversity serves as a natural modulator of ecosystems, helping them remain stable and resilient in spite of environmental changes.

Implications. Activities should be managed to encourage natural expression of biological diversity. While diversity can be quantified, it probably is not possible to determine the "proper" level of biological diversity, partly because it varies over time in response to various physical and biological processes. Furthermore, because future environments or situations cannot be predicted, the level of biological diversity needed to maintain future ecological systems cannot be known. It is not simply that more diversity is always good; in fact, increasing diversity by introducing nonnative species can actually disrupt ecological functions. Rather, it is important that the ecosystem be able to express its own species composition and diversity, so that it remains productive and resilient in the face of environmental variation. The challenge is to manage human activities to encourage the development of compatible native biological communities while at the same time minimizing our impacts on selection so that diversity can develop accordingly.

Riverine, Wetland and Upland Ecology Principles

Ecosystems and fish and wildlife species evolved in response to dynamic patterns and processes occurring along three spatial dimensions of the landscape and one temporal dimension. The spatial dimensions are longitudinal (upstream-downstream), vertical (within the groundwater system and above ground, including tree canopies and the atmosphere), and lateral (across streambanks and floodplains to uplands). To understand watersheds as ecosystems, one must understand the ecological processes functioning throughout the entire watershed, in these four dimensions (Stanford and others 1996). This approach can be used to identify the components necessary to maintain a productive riverine, wetland and upland ecosystem and the processes that control the distribution and health of not only salmon but all biota within Portland's watersheds.

Riverine, Wetland and Upland Ecology Principles

1. Rivers are not separate from the wetland and upland areas they drain.
2. Watersheds are defined by and operate across the spatial and temporal dimensions of riverine, wetland and upland ecosystems.
3. Hydrologic modification and changes in upland conditions, functions and land uses can reduce habitat diversity, decrease native biodiversity, increase nonnative species and exacerbate water pollution, landslides and flooding.

Riverine, Wetland and Upland Ecology Principle 1: Rivers are not separate from the wetland and upland areas they drain.

Riverine Areas. Rivers are not separate from the lands they drain (Hynes 1975). In developing river protection and restoration strategies, it is essential to understand the linkages among terrestrial and aquatic components and processes within watersheds (Stanford and others 1996).

Contemporary river ecology theory is guided by a number of intertwined concepts derived from empirical studies that demonstrate these linkages and apply to all rivers:

- Rivers are networks of surface and groundwater flow pathways that drain watersheds.
- Flowing water constantly reconfigures the physical form of these interconnected flow pathways, primarily through flooding.
- Inorganic and organic materials are eroded upstream and deposited downstream primarily in relation to long- and short-term flow dynamics, the resistivity of geological formations to erosion and dissolution, instream retention structures (such as large wood and boulders) and the geomorphology of the watershed.
- Channel morphologies are determined by the legacy of flooding. Big floods fill channels with inorganic and organic material eroded laterally and vertically at upstream locations, thereby producing (1) a continuum of instream structures, such as pools, runs, riffles, gravel bars, avulsion channels, islands and debris channels, and (2) lateral floodplain terraces in many sizes and shapes.

Wetland Areas. Wetlands can occur in a stream channel, riparian area, floodplain or upland area. All of these wetland environments connect rivers and streams to the lands they drain in a similar manner. They also have similar effects on hydrology and water quality and provide habitats that are crucial to a healthy watershed.

Vegetation and gentle slopes tend to slow water as it passes through a wetland, which forms a transition between aquatic and terrestrial environments. Wetlands perform several important functions within a watershed, and these functions vary with wetland type. During storm events, wetlands slow and temporarily store stormwater, thus reducing peak flood flows and allowing time for infiltration to occur. In this way, wetlands can reduce the risk of downstream flooding and facilitate groundwater recharge. Detention basins, floodplain depressional marshes and wide stream corridors provide important natural flood control.

Wetlands can greatly improve the quality of water passing through them by slowing the flow of water such that sediments have time to settle out. Wetland vegetation and aquatic microbes remove nutrients from the water, reducing the potential for downstream nutrient enrichment. By promoting sedimentation, wetlands also help cleanse water of toxic pollutants because toxic contaminants such as heavy metals and organic compounds often adhere to sediment particles. Riparian vegetation greatly enhances river and stream conditions by providing shade, bank stabilization, stream flow moderation, fine and large woody materials, organic and inorganic debris, terrestrial insects and habitat for riparian-associated wildlife (Hollenbach and Ory 1999, Metro 2002a, City of Portland Bureau of Planning 2001).

Generally, wetland areas provide diverse and productive habitats for many species of fish and other aquatic organisms, amphibians, reptiles, birds, mammals and plants. The vegetation and animals in riparian and floodplain areas, which are a subset of wetlands, are crucial to healthy aquatic environments. For example, functions performed by beaver provide habitat for fish and wildlife. Natural or restored riparian areas provide cavities, woody debris, nesting and roosting areas, food and microclimates for terrestrial wildlife species. By producing vegetation, invertebrates, fish and wildlife, riparian areas contribute significantly to the food web. In the Portland Metro region, 93 percent of all wildlife species regularly use water-associated habitats around streams, wetlands and lakes, and 45 percent are closely associated with these habitats (Metro 2002a). Because the few remaining riparian areas comprise a small portion of the existing landscape, it is important to maximize their conservation for the health of the entire watershed.

Retention or restoration of a sufficient natural riparian buffer with mature, native vegetation has been shown to help sustain functioning aquatic communities in urban areas and can partially ameliorate the adverse effects of urbanization on aquatic wildlife (Horner and others 2002). Large patches of riparian buffer habitat are typically considered more important than smaller ones because large patches tend to include more viable populations of native plants and animals, including species that depend on interior habitat. In addition, large patches are more likely to sustain ecological processes and disturbance regimes. However, small patches also can be important conservation targets because they may contain unique or rare habitat types or species or act as stepping stones between otherwise isolated patches of habitat. Small patches may also provide sufficient habitat for species that do not require large areas, such as frogs and salamanders (Defenders of Wildlife 2003).

Riparian habitats provide corridors for travel and dispersal. These corridors are valuable conservation tools (Beier and Noss 1998), in part because they connect habitats sufficiently to improve the viability of populations in those habitats. Generally, natural landscapes are more connected than landscapes altered by humans, and protection and restoration of corridors can serve as a strategy to enhance or retain some of this natural connectivity. In addition to its connectivity, a riparian area's width and the quality of its habitat affect its value as a wildlife corridor.

Upland Areas. Uplands are those areas that are not riparian, wetland or open-water habitats. Generally, uplands are located uphill of rivers, streams and wetlands and do not have stream channels draining into them; rather, they serve as groundwater recharge areas and also contribute surface water runoff to stream channels.

Natural or relatively undisturbed upland areas provide substrate such as sediments and gravels, nutrients and large woody debris to stream channels via mass wasting on slopes and in ravines and, to a lesser extent, via overland flow (in developed areas with impervious surfaces) and subsurface flow in the soil mantle (in more natural areas). Upland areas also intercept precipitation, slow runoff and filter nutrients and pollutants before they make their way to streams. This is especially important in urban areas, where large portions of the landscape may be impervious (Booth and others 2001). Uplands also provide crucial habitat values for wildlife species at various stages in their life cycle, including breeding, feeding, foraging, dispersal and over-wintering (Hollenbach and Ory 1999). Eighty-nine percent of all terrestrial species in the Portland area, including several bat and owl species, western gray squirrel, and red tree vole, are associated with upland habitats. Additionally, uplands often provide critical migration corridors for a range of terrestrial species, such as western gray squirrel, red and gray fox, and coyote.

Although most upland habitats in the Portland metropolitan area have been altered by human use, considerable amounts of upland habitat resources remain. Important upland resources exist on privately owned lands, but some of the region's upland resources occur on public land. For example, in Portland parks, the following natural vegetation types provide significant wildlife habitat values (City of Portland Parks and Recreation 2005):

- Mixed evergreen-deciduous forest
- Deciduous forest
- Evergreen forest
- Deciduous open woodland
- Mixed evergreen-deciduous open woodland
- Deciduous shrubland
- Perennial grassland vegetation

Forest historically was, currently is, and likely will be, the predominant and largest habitat in Portland parks. In contrast, shrubland is scarce. Although meadows occur in some city parks, they are not natural remnants. Nonetheless, these provide important habitat values.

Implications. Located at the confluence of two sizable rivers—the Columbia and Willamette—Portland was built in large part by separating the wetlands and uplands from the rivers and streams. This was done by controlling floods and baseflow levels. Reservoirs and dams were built, floodplains were drained and filled, "flood-proof" bank treatments such as seawalls were constructed and rainfall was transported as quickly as possible to the nearest waterbodies through an elaborate network of pipes. Upland forests and woodlands were removed to make way for neighborhoods, institutions and commercial enterprises.

In the past, the complexity of issues dealing with flowing waters in an urban area often overwhelmed planners, engineers, biologists and ultimately decision makers. Faced with an array of problems such as flooding, stormwater runoff, water quality health threats, odor, safety issues, recreation demands, increasing domestic water needs and lack of adequate natural environmental amenities, each discipline has responded separately by narrowing and simplifying the problems.

This simplification has had the effect of compartmentalizing the problems in rivers and streams in a way that encouraged isolated, objective approaches such as channelizing streams to move floods through more quickly or combining sewer and stormwater pipe systems to increase efficiency, without a full understanding of the long-term and unintended consequences. Today the cumulative effects of these simplified actions are clearer, and in some cases governments and citizens are paying the consequences (an example in Portland is a court order to reduce combined sewer overflows into the Willamette River by 2011).

It will be important as the City corrects these problems to coordinate current and future actions so that multiple objectives (riverine, wetland and upland) can be addressed. The *Johnson Creek Restoration Plan* (City of Portland Bureau of Environmental Services 2001) is one example of a strategy to manage flooding by reconnecting flood waters with their floodplains for stormwater attenuation. The plan also is intended to achieve additional objectives, such as the creation of off-channel habitat for fish and wildlife.

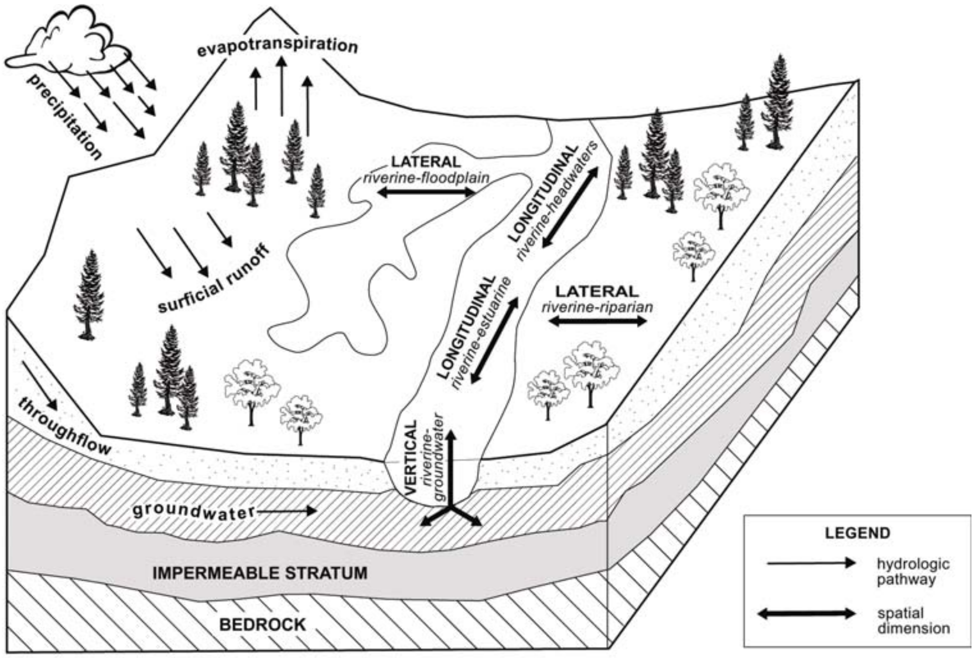
The *Framework* will be the blueprint for coordinating multibureau and interdisciplinary goals and objectives to meet regulatory, watershed health and community goals and needs. As the City continues to examine ways of restoring rivers, watersheds and salmon other populations of native species, it will need to examine how rivers and streams can be reconnected to the wetlands and uplands they drain in a manner that is acceptable and feasible in an urban context.

Riverine, Wetland and Upland Ecology Principle 2: Watersheds are defined by and operate across the spatial and temporal dimensions of riverine, wetland and upland ecosystems.

As a result of fundamental physical processes, three important spatial dimensions operate within watersheds: longitudinal (upstream-downstream, from headwaters to river to estuary), lateral (from river to streamside to floodplain) and vertical (from the river's water column to groundwater) (see Figure 2-1). Each of these spatial dimensions operates on a temporal (time scale) dimension as well. Consideration of dynamic interactions along all four dimensions will improve understanding of the critical components necessary to maintain a productive river.

- **Longitudinal dimension** (upstream-downstream). This includes the occurrence and ecological significance of streamside (riparian) vegetation and fauna in the surficial transition zone from riverine to upland environments, up and down the river. The distribution of blocks of habitat, or "patches," is an important component in wildlife habitat relationships. The amount of habitat, variation in patch size and isolation of certain patches influence species viability and diversity.
- **Vertical dimension** (complex groundwater, or hyporheic, habitats and above-ground structure). This dimension is created by the penetration of river water through the highly porous bed sediments in gravel-bed rivers. The river water saturates the alluvial bedding of the channel and floodplain down to the less porous bedrock. This dimension encompasses vertical variability in conditions in the water column, such as temperature and dissolved oxygen, and it applies to structure—shrubs, trees and buildings—provided by the biotic and physical environment.
- **Lateral dimension** (floodplain). This dimension encompasses both hyporheic and riparian habitats. It acts as the transition zone linking aquatic and terrestrial components of the river ecosystem above and below ground. Dispersal across the landscape through the lateral dimension is an important function for the viability of most species. Although it may not be necessary to connect all patches, in an urban environment it is important to evaluate which species and life stages could benefit from the connection of both large and small patches.

- **Temporal dimension** (time). This reflects the dynamic, changing nature of riverine ecological processes over time, such as daily, seasonally, annually or over centuries. For example, there are diurnal (day-night) fluctuations in water temperatures and seasonal changes in flow, runoff and the migration and life stage development of fish and wildlife.



Modified from Ward and Stanford 1989.

FIGURE 2-1
The Three Spatial Dimensions of Landscapes: Longitudinal, Vertical and Lateral

Rivers that are connected to their floodplains and subject to natural hydrological dynamics, such as flooding, maintain a wider variety of species and food webs than do rivers that rarely or never have scouring floods. Most medium- and low-gradient rivers are naturally flood-prone, such that both the biota and the physical structure of the river ecosystem are controlled by the highly dynamic scouring process of floods. This is consistent with Primary Ecological Principle 1. Floods maintain channel and floodplain habitats and pulse nutrient-enriched waters laterally into backwaters and onto floodplains, as well as downstream into the estuary. Because floods are a continual habitat-forming process, river biota are adapted to the frequency and duration of flood pulses (Junk and others 1989).

Floodplains appear to function as centers of biological and physical structure and organization within the river continuum (Regier and others 1989). Floodplains are likely to be “hotspots” of biodiversity and production that are structurally and functionally linked by the river corridor. The hyporheic and riparian corridor is expansive on alluvial reaches (meaning reaches subject to flooding). Seasonal water temperature patterns vary within the wide array of aquatic habitat that exists laterally from the channel across the floodplain. Food webs are complex and change predictably along the stream continuum in direct response to variations in the strength of interconnections between channel, groundwater, floodplain and upland elements of the watershed.

Urban environments are characterized by built structures, impervious surfaces, reduced forest cover, altered streams and nonnative vegetation. Frequent human disturbance is to be expected in urban habitats, and species that are disturbance-sensitive tend to be absent or reduced in numbers (Marzluff and others 1998). Habitat generalists (northern raccoons and American robins, for example) and nonnative species (such as European starlings and eastern gray squirrels) tend to be most common in urban environments. However, urban environments may also provide habitat to species that require specific and relatively rare micro-habitat features such as cavities, caves, cliffs and rocky outcrops, and ledges (Metro 2002a). For example, peregrine falcons are known to breed on bridges and other artificial structures within the City of Portland, and bridges provide roosting habitat for bats. Portland has several important remnant patches of natural habitat—notably Smith and Bybee lakes, Forest Park and Ross Island—that accommodate a variety of sensitive and common wildlife species.

Most of the riverine, wetland and upland habitat in Portland occurs as patches within a developed urban landscape. Large habitat patches tend to support more biodiversity than small patches, containing more species and individuals than do smaller patches of the same habitat. Typically, large habitat patches consist of interior habitat and an outside ring of edge habitat. These large patches often support both species adapted to edge environments and those adapted to interior habitats. As patch size decreases, the proportion of interior habitat to edge habitat decreases and species adapted to the interior habitats decline, reducing overall species diversity (Dale and others 2000). Large decreases in habitat patch size or increased distance between habitat patches can both reduce or eliminate populations using those habitats and alter ecosystem processes (Dale and others 2000). Also, as interior habitat shrinks, edge-adapted predators have proportionally greater access to interior prey species. Species adapted to edge habitats or that require small habitat areas are able to survive in a matrix of small patches; examples in the City of Portland include coyote and purple finch. Interior-adapted species are less common in Portland but include brown creeper and Douglas' squirrel. (See Metro's Goal 5 report [Metro 2002a] for a more complete discussion of patch size and edge effect.)

Upland habitat in urban areas often is fragmented and intermingled with developed urban land uses (Metro 2002a). It is crucial that upland habitats have some degree of connectivity to aquatic and riparian habitats and to other upland habitat patches. Connections to upland habitat also are important where riparian buffers are not wide enough to meet all of the needs of a species. In a fragmented landscape, habitat corridors can provide connectivity between habitat patches and surrounding, less developed landscapes.

Although corridors foster connectivity of habitats, in some cases they can allow exotic plant and animal species to invade native habitats. (See Metro's Goal 5 report [Metro 2002] for a more complete discussion of habitat corridors and connectivity.)

Implications. As the City comes to understand the site- and basinwide-scale linkages among the physical and temporal dimensions of the ecosystem, it will be important to begin coordinating across scale and across jurisdictions. It is well understood that upstream actions affect downstream jurisdictions such as the City of Portland. If rivers and their lateral floodplain components are reconnected, the associated fundamental physical processes can be used to solve long-standing flooding problems; such reconnections restore many physical and biotic functions in riverine, wetland and upland habitats.

Johnson Creek is an example of the floodplain being intentionally cut off from the stream through channelizing and diking so that flood waters could move through the basin as quickly as possible. As the City has come to learn more about the important functions of floodplains, it has realized that disconnecting floodplains can come at a cost. Reconnected floodplains can result in benefits such as storage and flood attenuation as well as the provision of off-channel habitat for ESA-listed salmonids. Restoring these riverine functions also allows wildlife such as beaver to provide additional functions and habitat that further enhance conditions for fish and wildlife species.

Allowing floods to access historical floodplains will create important physical habitat features that are difficult to create in other ways. Examples of such features are side channels or off-channel pools formed by ascending and then receding flood flows. To allow this to occur in the midst of a crowded urban setting will require careful engineering so that flood forces can access floodplains in a managed and controlled manner. The possibility of returning beaver functions to the floodplain also needs to be addressed to avoid possible conflicts with humans.

Riverine, Wetland and Ecology Principle 3: Hydrologic modification and changes in upland land use can reduce habitat diversity, decrease native biodiversity, increase nonnative species and exacerbate water pollution, landslides and flooding.

Hydrologic and ecological processes and functions link rivers and their biota to their watersheds and downstream waterbodies. As the hydrologic cycles of rivers have been modified, rivers have become degraded. This happens because changes in the hydrologic character of a watershed have acted to reduce the size and complexity of the riparian "fringe" between rivers and uplands, which in effect impairs the hydrologic and ecological links between the aquatic and terrestrial ecosystems. The foundation for understanding current conditions and planning future actions must begin with the recognition of the causes and consequences of hydrologic modification to streams and rivers.

Causes of Hydrologic Modification

Modification of water pathways in a watershed occurs through alteration of all major stages of the hydrologic cycle, including evapotranspiration, throughflow, overland runoff and groundwater recharge. This in turn modifies the ecological processes and functions. In large rivers this modification occurs through flow regulation from dams and reservoirs and the filling and diking of floodplains. In smaller, urban streams, the filling of floodplains and increase in impervious surfaces reduces the watershed's permeability and compacts soils, reducing evapotranspiration, groundwater recharge and throughflow. Upland land uses can have a major impact on both large and small urban streams.

Effects of Hydrologic Modification

Hydrologic modification can reduce habitat diversity by severing the connections among the channel, groundwater, floodplain and upland components of the watershed; causing habitats for riverine biota to become spatially homogenous and limited to the permanently wetted portion of the channel thalweg; and increasing the amount of impervious surfaces in the landscape, thus causing a net decrease in groundwater recharge and net increase in surface water runoff after storms. These effects are discussed below.

Effects of Flow Regulation in Large Rivers. Flow regulation via storage dams and reservoirs is the most pervasive change introduced to large rivers throughout the world (Stanford and others 1996). In large rivers, reservoir storage of peak flows for flood control, navigation, irrigation and hydropower production can sever the ecological connectivity between upstream and downstream reaches and among channels, groundwater and floodplains. This, in turn, often reduces native biodiversity and productivity or allows nonnative biota to proliferate.

More specifically, severing the river continuum can have the following effects:

- Flood peaks are eliminated.
- Daily discharges are more variable, and temperature seasonality may be altered (Stanford and Hauer 1992, Blinn and others 1995).
- The mass transport of water and materials, which are important in the creation of instream and floodplain habitats for riverine biota, is drastically changed.
- Storage of bedload in the reservoir and the constant flushing of clear water downstream artificially deplete gravel and finer sediments in the tailwaters, causing the riverbed to be armored with large cobbles and boulders.
- The amount of floodplain wetland is reduced, which reduces the diversity and viability of species that depend on wetland structure and functions.

Flow regulation can increase baseflows substantially and produce flows that fluctuate so erratically that aquatic biota cannot survive in shallow, near-shore habitats. Peak flows can be insufficient to scour and transport the largest material downstream. With a loss of scouring flood flows and upstream sediment supply, the channel erodes downward, the former floodplain is subject to less flooding and riparian vegetation invades the channel in depositional reaches. The result is habitat simplification and constriction of the channel.

Many restoration actions taken at a particular reach fail to meet objectives because the local effects of flow regulation, which include changes in floodplain inundation and the amount of sediment and wood being supplied from both upstream and upland areas, have caused the river system to become disjointed; the river is no longer functioning as an interconnected ecosystem across the watershed or from headwaters to ocean confluence (Independent Scientific Group 2000). When the dynamic interactive pathways of the river continuum are severed or compromised, the capacity of large river ecosystems to sustain natural biodiversity is reduced.

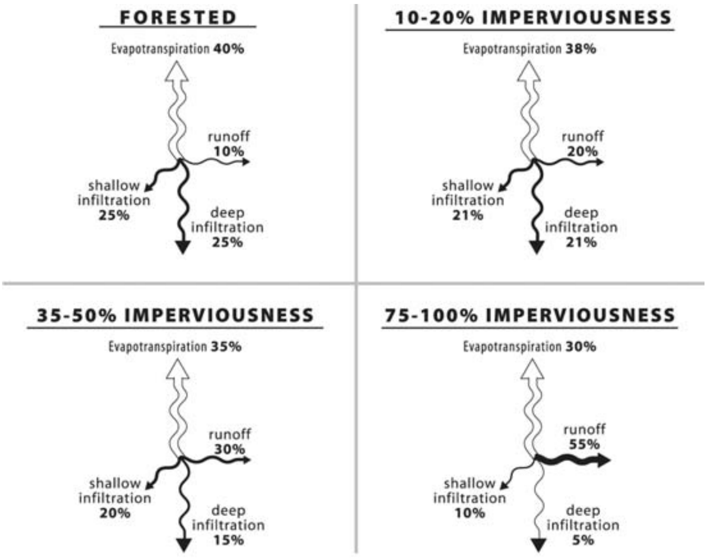
Restoration actions may not meet objectives unless rivers are viewed as interconnected ecosystems that extend from their headwaters to the ocean.

Effects of Hydrologic Modification in Urban Streams. In urban streams, the quantity of physical habitat has been reduced temporally and spatially. Tributary density is reduced through paving, piping and draining as land is developed (Steedman 1987). This effect occurs predominantly in first- through third-order streams and results in a disruption of the riverine-headwater pathway (the longitudinal dimension within a watershed). Because many headwater tributary streams play a role in maintaining stable levels of discharge within a watershed, and because they provide significant spawning and rearing habitat for many fish species, the loss of these systems greatly affects species diversity, the densities of individual species and, ultimately, the productivity of the river (Imhoff and others 1991).

The interactions of the river and its floodplain also are severely impaired by urbanization. During certain times of the year, the biota of rivers rely on the interconnection of the river and its floodplain complex of side channels, backwater areas and wetlands for spawning and rearing habitats (Welcomme 1979, 1985, Sedell and Frogatt 1984, Bacalbasa-Dobrovici 1989, Fremling and others 1989, Lelek 1989). When the river-floodplain pathway is decoupled, productivity and species diversity are fundamentally reduced (Halyk and Balon 1983, Welcomme 1985, 1988; Regier and others 1989).

Effects of Impervious Surfaces. In smaller urban streams, impervious surfaces modify hydrologic pathways. As the amount of impervious surfaces increases, there is a net decrease in groundwater recharge and a net increase in surface water runoff after storms (see Figure 2-2). The following process is typical:

1. Increased stormwater flows change the physical equilibrium of the stream channel morphology. As a greater percentage of stormwater flows into the channel via curbs, gutters, and storm sewers (instead of percolating to groundwater), peak stream flows increase, as does the discharge of sediments into the stream.
2. Larger peak flows alter the river's channel width, depth, sinuosity, bedload transport, bed armoring, down-cutting, riffle-pool sequencing and connection to floodplains.
3. The stream channel is structurally simplified to the point that it lacks the stability and physical diversity to support complex aquatic and wetland communities (Imhoff and others 1991).



(Adapted from Paul and Meyer 2001.)

FIGURE 2-2
Changes in Hydrologic Flows with Increasing Impervious Surface Cover in Urbanizing Catchments

The ecological principles that emerge from this evidence have been corroborated in the growing literature on the ecology of flow-regulated rivers and urban streams affected by impervious surfaces (reviewed by Baxter 1977; Ward and Stanford 1979, 1987; Lillehammer and Saltveit 1984; Petts 1989; Booth 1991; Calow and Petts 1992; Schueler 1994; May and others 1997).

Effects on Groundwater. Reduction in groundwater recharge is another possible effect of hydrologic modification and can have profound effects on river productivity. When infiltration within a watershed is reduced, so too is the recharge of shallow aquifers and wetlands that control and moderate baseflows in adjacent streams. Although the repercussions of increasing surface water runoff are relatively well known, the impacts of reducing groundwater infiltration are less well understood. There is evidence that increasing surface water runoff within a watershed from reductions in infiltration affects baseflow (Hammer 1972, Klein 1979, Steedman 1987). The implications of this are serious because it is baseflow that ultimately controls the maximum potential productivity of a river system, through control of critical living space for fish and aquatic wildlife and native plant communities during the productive summer months.

Reduction in Native Biodiversity and Proliferation of Nonnative Species. The modification of hydrologic regimes and the associated severing of connectivity in the three spatial dimensions of landscapes have reduced both habitat diversity and the biodiversity of native species and contributed to the proliferation of nonnative species. The altered temperature patterns, continual export of very fine organic matter and dissolved nutrients, simplification of channel morphology, stabilization of the bottom substratum and loss of floodplain inundation that can result from hydrologic modification promote environmental conditions to which native species are poorly adapted, giving nonnative plants and animals the opportunity to establish robust populations (Stanford and Ward 1986, Li and others 1987, Pflieger and Grace 1987, Bain and others 1988, Shannon and others 1994).

In an urban environment, competition from nonnative plant and animal species is second only to habitat loss as a cause of native species decline (Defenders of Wildlife 2003). Urban development inherently brings opportunistic weeds, including landscape "escapees" and roadside-adapted species. Ecosystem management requires an emphasis on native species, as they are best adapted to the local climate and ecological conditions.

Nonnative invasive species often have negative effects on native flora and fauna and the functioning of ecological systems, displacing native vegetation and threatening the wildlife that depend on them (Dale and others 2000). Introduced species often find no natural enemies in their new habitat and therefore spread quickly and easily. In the Portland area, English ivy, Himalayan blackberry and the European starling are notorious invasive species that have displaced native wildlife and vegetation. Other, less invasive nonnative species may provide habitat value that is less than a fully functioning native ecosystem would provide but that is still significant. The City should simultaneously encourage native species and discourage nonnatives when possible, while recognizing that in an urban environment much of the functioning habitat will be provided and occupied by nonnatives.

Native species are consistently more abundant in unmodified rivers and streams than in modified rivers and streams.

Additional Effects of Hydrologic Modification. The uncoupling of the three spatial dimensions through hydrologic modifications simplifies the structural diversity of rivers, wetlands and uplands. A river's physical diversity and the biotic communities it sustains, from bacteria to fish, contribute to its ability to assimilate and process nutrients and other materials (Imhoff and others 1991). Therefore, rivers and their biotic communities exert a certain amount of "top down" control on water quality as long as inputs from the terrestrial component of the watershed are not so concentrated as to have a toxic effect on the aquatic community.

In open waterways nutrients circulate through a water column and downstream depending on instream flow dynamics. This dynamic process of nutrient transport in rivers is termed "nutrient spiraling" (Imhoff and others 1991) and varies depending on site-specific and reach-specific flow conditions. For example, headwater streams often have turbulent flows and a high degree of mixing throughout the water column. In flow conditions such as these, nutrients entrained in the water column are readily available to algae, plants, invertebrates and fish. Conversely, in large, deep rivers such as the lower mainstem reaches of the Columbia and Willamette rivers, throughflow—in the form of nonturbulent, roughly horizontal layers—is more characteristic. Although turbulent flow does occur within the water columns of large rivers, turbulent flow does not span the depth of the water column. Under these flow conditions, aquatic vegetation and organisms that occupy perimeter habitats do not absorb nutrients entrained in the water column as readily. Rather, nutrients remain in solution, and their fate is determined by downstream riverine and estuarine hydrologic and hydraulic conditions.

The concept and implications of nutrient spiraling have been discussed for many years in the scientific community (Newbold and others 1981, Elwood and others 1983) in the context of carbon or nutrient flow down a stream channel. But the concept of nutrient spiraling can also be used to illustrate the temporal and spatial mechanisms of nutrient and carbon capture and entrainment in living tissues (Odum 1969, Imhof and others 1991).

For example, the amount of nutrient spiraling and entrainment varies from stream to stream based on the particular stream's relative physical and biotic complexity, which is usually linked to the stream's physical diversity and stability. In theory, the more physically complex a river system, the greater its potential to process nutrients in a manner that maintains water quality by achieving a reasonably stable balance between aquatic productivity and consumption. The corollary of this is that the simpler the physical structure of a river, the poorer the ability to process nutrients, leading to unstable aquatic productivity and consumption. For urban streams, this frequently results in diminished water quality as a result of excessive nutrient and organic matter loads, originating mainly from external sources.

This hypothetical process may explain why many damaged and simplified streams exhibit relatively poor water quality, despite attempts to control point sources of pollution. It implies that the restoration of structural complexity in the stream channel—such as by creating fish habitat in urban areas—could help improve water quality (Imhoff and others 1991).

Effects of Wetland Loss. Human activities have had a large impact over the years on wetland habitat (including riparian areas) and wetland functions in the Portland urban area. The rate of aerial loss of wetlands has declined with the passage of the Clean Water Act and its amendments in the 1970s, but the reduction in wetland functions continues in the wetlands that remain (U.S. Fish and Wildlife Service 2000).

Metro (2002a) presents a detailed discussion of the impacts of urbanization on wetland and riparian habitats and function. This discussion of the effects of wetland loss includes, but is not limited to, converting, altering, and fragmenting habitat; filling or loss of wetlands; reducing biodiversity and rare or specialist species; and contaminating wetlands with a variety of chemicals. Human activities away from wetlands (in the longitudinal and lateral dimensions of the watershed) also can result in the loss of wetland area and function, although such losses often occur more slowly and are not as obvious as discrete actions such as fills. Examples of how human activities away from the wetlands can cause wetland loss include the following:

- Upslope erosion settling out in wetlands, potentially filling them; instream dams inundating wetland vegetation
- Collection of stormwater in uplands, which can reduce the area contributing runoff to wetlands and thus the amount of infiltration into them
- Increased impervious surfaces in uplands, which alters peak and base flows to wetlands
- Increased amounts of herbicides, pesticides, oil and grease from upland development entering wetlands.

Wetlands are the connecting link between riverine and upland components of the watershed. This connecting link facilitates many fish and wildlife interactions (beaver and coho, for example) and hydrogeomorphic functions (Adamus 2004). When these connections are lost as a result of urbanization, the impact on the adjacent riverine environment is obvious to fisheries biologists, who recognize the importance of off-channel wetlands to many species of fish and other aquatic biota that use backwater habitats, such as rearing juvenile salmon. Loss of wetland connection to upland habitats is also obvious to wildlife biologists but less understood by the general public. McGarigal and McComb (1992 and subsequent papers) document the importance of upland habitat to the diversity of birds in streamside habitats and promote landscape-level management actions that consider both streamside and upland habitats. McGarigal and McComb’s recommendation based on bird studies also makes sense for species such as the western pond turtle that require wetland areas for rearing and upland areas for nesting functions (Spinks and others 2003).

The loss of connectivity (that is, fragmentation) along riparian systems and between riverine, wetland and upland habitats is particularly adverse for less-mobile species such as reptiles, amphibians and small mammals (Bolger and others 1997). Bolger and others (1991) found that local extinctions in isolated habitats were common and that recolonization of isolated habitats was rare.

Effects of Upland Loss. Metro (2002a) provides a detailed discussion of the adverse impact of urbanization on upland habitat, with impacts including loss of habitat, fragmentation and disturbance. The fragmentation of upland habitat that accompanied Portland’s population growth has left several areas of unique habitats associated with buttes, cliffs, isolated sloughs in floodplain and steep-slope ravines in locations that are less desirable for development. Wildlife associated with these remnant habitats are a subset of the species normally expected in west-side forests (Ferguson and others 2001), and these remnants may play an important role in maintaining native biodiversity.

As land continues to be developed in the urban environment, the once-dominant west-side coniferous habitat slowly is becoming rare itself. This slow loss of the west-side forest has several consequences: the increasing scarcity of what once was an abundant resource, the loss of upland matrix habitat to connect unique habitats (such as domes and isolated sloughs) that remain from development, and the loss of ecosystem functions (such as nesting and decaying logs) in wetland and riverine habitats. But the loss of mature forest and conversion of upland habitat to agriculture and urban development in the Portland area has also resulted in the loss of ecosystem functions in the uplands that can best be understood by considering the cumulative impact over time. Flinn and Velland (2005) document the loss of plant and animal diversity in post-agricultural landscapes and suggest that current habitats show much reduced species richness and altered composition compared to forests that were never cleared. Furthermore, Flinn and Velland (2005) suggest that post-agricultural habitats depress colonization by plants and animals and that the diversity required to support adequate dispersal may take centuries to restore. Lost functions such as those provided by downed wood in the urban environment may not even be desirable because of the potential for fuel loading and the threat of fire. Just as a properly functioning hydrograph is important to riverine restoration, it is important to understand the upland functions that have been lost in the urban ecosystem when assessing the desirability and feasibility of restoring upland habitats or connecting upland and wetland patches.

Disturbance of upland vegetation and wildlife in the urban environment is a multi-faceted problem, encompassing nonindigenous species, roadways and other developments and human intrusion into sensitive areas. The fact that herbicides and pesticides are used in an attempt to control nonindigenous species—especially in the upland urban environment—illustrates that a solution for one problem can, especially if used improperly, lead to another, such as contaminated stormwater runoff to streams and wetlands. Roads, a necessary component of the urban environment, result in the loss of habitat, prevent dispersal that is important to the life cycle of many upland species, and are a source of road-related chemicals that often are transported to riverine, wetland and upland environments. Innovative solutions to road-related losses are being studied by the University of Wisconsin (see www.deercrash.com). Disturbance in urban environments also includes human intrusion into sensitive areas; this results in trampling of vegetation, noise and litter. Hennings (2001) and others document that certain wildlife species (Stellar's jay, for example) are especially vulnerable to human disturbance in the urban environment. At the same time it is encouraging that other species such as the bald eagle and the peregrine falcon, which were once rare in the urban landscape, now occur within the City limits.

Implications. Modification of historical flows and changes in upland land use can have many unintended and deleterious effects, as has been described above. Many of the actions taken historically by the City were without full knowledge or appreciation of their cumulative effects and consequences, many of which the City of Portland is now having to deal with (combined sewer overflows, flooding in Johnson Creek, declines of native fish and wildlife species and so on). In wetland and upland areas, the habitat loss and fragmentation associated with land use changes have impeded the dispersal of native plants and animals, decreased colonization of isolated habitats and reduced native biodiversity.

To solve these problems, actions will have to be implemented within a broad context that includes working across disciplines and with multiple objectives. Collaborative efforts must be made with an understanding of the size and distribution of upland habitat patches and the terrestrial species that do, or could potentially, depend on them; the effects of upstream actions on rivers and streams; and the impact of modifications of riverine, wetland and upland habitats. Without such understanding, efforts to achieve healthy watersheds that include healthy biological communities are unlikely to succeed. Efforts must be effective at both the site and watershed scales, as well as across jurisdictions.

Salmonid Ecology Principles

The *Framework* includes scientific principles related specifically to salmonids because, as ESA-listed species, salmonids are subject to certain legal protections; their health, abundance and productivity reflect many key watershed processes; and they have special cultural and economic significance in the region. Salmonids and river ecosystems co-evolved in response to dynamic processes that occur in the three spatial dimensions described earlier. In this context, three principles emerge that describe salmonid life history and habitat relationships.

Salmonid Ecology Principles

1. Life history diversity, genetic diversity and metapopulation organization are ways salmonids adapt to their complex and connected habitats and are the basis of salmonid productivity and salmonids' ability to cope with environmental variation.
2. Sustained salmonid productivity requires a network of complex, diverse and interconnected habitats that are created, altered and maintained by natural physical processes in freshwater, estuarine and ocean environments.
3. Restoration of salmonids must address the entire natural and human ecosystem, encompassing the continuum of freshwater, estuarine and ocean habitats where salmonids complete their life histories.

Salmonid Ecology Principle 1: Life history diversity, genetic diversity and metapopulation organization are ways salmonids adapt to their complex and connected habitats and are the basis of salmonid productivity and salmonids' ability to cope with environmental variation.

Salmonid habitat has been described as a "chain of favorable environments connected within a definite season in time and place, in such a way as to provide maximum survival" (Thompson 1959). This "chain" can be thought of as temporal and spatial "pathways" through the freshwater, estuarine and marine ecosystem that salmon use (Independent Scientific Group 2000). Salmonids follow particular pathways, exhibiting unique life history patterns that reflect the salmonids' responses to problems of survival and reproduction. Life history diversity in salmon can be described as the variable use (in terms of time and space) of the chain of available rearing and migrating habitats (Lichatowich and others 1995).

Diverse life history patterns dampen the risk of extinction or reduced production in fluctuating environments (Den Boer 1968). The potential and realized life histories of a population theoretically reflect adaptive capacity—the ability to survive in fluctuating environments.

Spatial and temporal habitat diversity is critical for expression of life history diversity. Habitat degradation, hydrologic modification and the loss of connectivity among habitats has constrained production and suppressed expression of life history diversity within the Willamette River basin, its watershed and its tributaries.

Features of salmonid life histories include such phenotypic[3] traits as age at maturity, mortality schedules, size and growth (Stearns 1976). Salmonid life history traits also include age and size that juveniles migrate within the river system or to the sea, growth and maturity during riverine and lacustrine migrations, spawning habitat preferences, emigration patterns, and age and timing of spawning migration. Salmonids that make use of different chains of interconnected habitat may exhibit variation in important life history traits, such as the age at which juveniles migrate to the sea, the timing of spawning migration and spawning habitat preferences. In several instances multiple life histories have been observed within a single river system (Reimers 1973, Schluchter and Lichatowich 1977, Carl and Healey 1984, Gharett and Smoker 1993, Lestelle and Gilbertson 1993). In the Willamette River ecosystem, life history diversity would be expected to be substantial owing to the ecosystem's large size and number of tributaries, highly variable flow regime, and complex geomorphology, which affects all watersheds in the ecosystem.

For example, in salmon, phenotypic diversity is exhibited over a broad geographic scale in the stream and ocean life history types (Healey and Prince 1995). Stream-type Chinook migrate to sea in the spring of their second year in freshwater, whereas ocean-type Chinook migrate to sea in their first year, usually within a few months of emerging from the gravel (Healey 1991). Stream- and ocean-type fish also differ in other aspects of their life histories, such as oceanic distribution and timing of adult migration (Healey 1991).

Stream and ocean life histories are major life history themes, but within each theme, juvenile migration patterns vary. Continual downstream migration through the lower mainstem of rivers by ocean-type Chinook salmon throughout most of the spring and fall (Rich 1920, Beauchamp and others 1983, Nicholas and Hankin 1988) may represent several discrete migrations of juveniles from different locations in the watershed (Rich 1920). What appears to be a single continuous migration of ocean-type juvenile Chinook salmon may in fact be a diverse assemblage of groups of salmon following somewhat different habitat pathways and thus having somewhat different life histories. Migration patterns also vary among stream-type juvenile Chinook salmon that migrate to the sea in their second year. Some stream-type Chinook salmon remain in headwater areas to rear, while others move into downstream mainstem areas to rear during the winter (Healey 1991).

Steelhead juveniles undergo physiological smoltification within a wide range of ages (from two to seven years) and sizes, depending on population structure, genetic expression and environmental conditions such as temperature, flow and habitat productivity. Some juveniles spend their entire freshwater rearing cycle in their natal stream, while others

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[3] Of, or relating to, the visible or behavioral properties of an organism that are produced as a result of the interaction of the genotype and the environment.

emigrate to lower and more productive river reaches as they grow and require more sustenance.

Before flow regulation and extensive habitat modification, complex and interconnected habitats were created and maintained in the Willamette River basin through natural riverine processes. The availability of these habitats facilitated the expression of life history diversity and contributed to maintaining the production of salmonids. Adaptation of individual populations to specific habitats (and life history pathways) across a mosaic of different landscapes created a diversity of populations that characterized salmonid fishes in the Willamette River basin. Today much of that diversity has been lost as a result of modification of flows and degradation of both mainstem and tributary habitats.

Two additional concepts further elaborate the connections between salmon life histories and riverine habitat: patch dynamics and salmonid metapopulations.

Patch Dynamics. On a watershed scale, salmon habitat can be viewed as a system of "patches," with fish moving among patches for the purposes of rearing, seeking refuge, migrating to spawn (adults) or migrating to the ocean (juveniles) (Murphy and others 1997). In theory, the type of habitat patches varies along the river continuum, corresponding to physical and biological variables, so that the specific types of habitat patches needed at different life stages are distributed in a nonrandom manner. The patches may include spawning areas for adults and a series of spatially and temporally connected areas for summer feeding and winter refugia.

A mosaic of heterogeneous habitats supports species diversity, while a variety of channel and floodplain structures creates a mosaic of habitats for the myriad of plants and animals that make up riverine food webs. The resources needed by an organism at a particular stage in its life history are distributed discretely, in "patches," within this heterogeneous landscape. As flows change seasonally, so does the ability of water to move sediment, gravel, wood and other material. Therefore, to be successful, biota must adapt to resources located in an array of dynamic patches that exist from the local scale (such as in a deep pool downstream of a large boulder in a particular river reach) to the watershed scale (Townsend 1989). As biota attempt to find and use these patches to sustain growth and reproduction over the long term, they must also adapt to the physical forces of water movement (Statzner and others 1988). Therefore, biota are often arrayed in particular locations within the river channel and along the river continuum (Poff and Allen 1995).

A fundamental challenge is to establish quantitative links between the variation in a species' life-history requirements and the variation over space and time in conditions along the river (Schlosser 1991). Because Pacific salmon migrate extensively in marine and freshwater, they are seasonally distributed across a vast ecosystem composed of a chain of favorable geographic habitats (Thompson 1959). A major consequence of land management practices and development in the riparian zone, floodplain and land margins has been the simplification and fragmentation of salmon habitat (Reeves and Sedell 1992). Simplification is a reduction in the number and kinds of habitat types, a decrease in structural materials that make up salmon habitat, such as large wood, and a decline in the indicators of water quality, such as temperature (McIntosh and others 1993). Habitat simplification reduces the number of habitat types, and fragmentation disrupts connectivity and species' ability to migrate at the appropriate time between links in the habitat chain (Lichatowich and others

1995). Even where favorable habitats are retained in undeveloped portions of watersheds, fragmentation may cause those habitats to be inaccessible at the time they are needed by a particular species.

Salmonid Metapopulations. The National Research Council (1996) recommends that salmon be viewed as metapopulations rather than isolated stocks or populations. The Independent Scientific Group (2000) defines metapopulations as groups of local populations linked by individuals that stray from one population to the next, thus facilitating gene flow into larger regional populations that may encompass an entire watershed (Hanski 1991, Hanski and Gilpin 1991). In other words, a metapopulation is a collection of populations in geographical proximity to one another that have a history of interactions via straying and genetic exchange.

Salmonids organize into metapopulations because they display high fidelity in homing to their natal streams (Helle 1981), which allows them to establish local spawning populations. In addition, salmon have relatively low but variable levels of straying (Quinn and Unwin 1993), which creates opportunities for recolonization of habitats where local extinction has occurred. The spatial arrangement of large- and small-scale habitat features within a catchment may serve as a guide for metapopulation organization of fish species (Schlosser and Angermeier 1995).

Metapopulation structure most likely influences the probability of persistence for a species. Metapopulation linkages allow for local extinction of populations that subsequently can be reestablished via colonization from adjacent populations. Recent work suggests that salmonid metapopulations resemble core-satellite metapopulations (Rieman and McIntyre 1993, Li and others 1995, Schlosser and Angermeier 1995). Core populations serve as important sources of colonists that could both reestablish satellite populations in habitat where extinctions have occurred (Harrison 1991, Schoener 1991, Rieman and McIntyre 1993, Harrison 1994, Schlosser and Angermeir 1995) and sustain populations that have been severely depleted. The proximity of populations and favorability of connecting habitats can affect the exchange of individuals between local populations and thus influence the potential for recolonization of habitats where local extinction has occurred. Thus, core populations can buffer metapopulations against environmental change and contribute to the resiliency of regional salmonid production (Independent Scientific Group 2000).

It is likely that spawning populations that could have functioned as core-like populations occurred historically in alluvial segments with well-developed floodplains and gravel bars (Stanford and others 1996). These areas provide a complex habitat mosaic highly suitable for spawning, incubating eggs and rearing juveniles and may have served as centers of habitat stability (Independent Scientific Group 2000).

Implications. The following principle that guided the City, the National Marine Fisheries Service in the National Oceanic and Atmospheric Administration (NOAA Fisheries) and other agencies and stakeholders in the June 1999 “State of the Science on Fish Ecology in Large Low-Gradient Rivers” workshop (City of Portland 1999) helped to determine the City’s role and responsibilities regarding salmon listed under the Endangered Species Act:

> *Complex life history strategies of salmon are a result of evolutionary adaptations to physical, chemical and biological diversity resulting from water and floodplain interactions occurring over a long period of time in the lower Willamette River.*

By investigating a series of hypotheses, workshop participants determined that salmon (particularly juveniles) should be expressing rearing strategies in the lower Willamette. Participants also concluded that, to meet the City Council's resolutions to contribute to the recovery of salmonids (Resolution 35715), research should be conducted to understand more about juvenile salmon behavior in the lower river. The Willamette Fish Study, a four-year fisheries research investigation of the lower Willamette River by the City and ODFW, was the main outcome of these discussions.[4]

The study identified complex behavioral expressions among different species of salmon and among different age classes within the same species; additional studies are needed to understand how and where limiting factors occur. For example, it is important to understand how salmonids are surviving as they migrate through and rear in the vicinity of Portland. Because the City is an important location through which all anadromous salmonid populations that use the Willamette River basin must pass, it will be important to try to understand whether impacts from City activities may limit their survival. Given the importance of this effort, agencies with authority over salmon, water and habitat should be brought in as partners in the Willamette Fish Study.

Salmonid Ecology Principle 2: Sustained salmonid productivity requires a network of complex, diverse and interconnected habitats that are created, altered and maintained by natural physical processes in freshwater, estuarine and ocean environments.

The importance of a complex and dynamic continuum of habitats in a system such as the Willamette River is a central tenet of the scientific foundation. The river continuum concept describes a complex, continuous dynamic gradient of habitat from headwaters to oceanic confluences (Vannote and other 1980). The river provides salmon with access to freshwater, estuarine and ocean environments and associated diverse and high-quality habitats that are crucial for salmonid spawning, rearing and migration; maintenance of food webs; and predator avoidance. Ocean conditions vary and can significantly affect overall patterns of salmonid productivity from year to year.

Connections along the continuum also are important. For example, downstream communities or populations may benefit from activities of populations higher in the watershed, such as the breakdown of leaf litter by aquatic insects living upstream.

Historically, alluvial floodplain reaches have been arrayed along the river continuum between valley segments like beads on a string. These reaches appear to function as centers of biological and physical organization within the continuum (Regier and others 1989). They are likely to be nodes of production and biological diversity that are structurally and functionally linked by the river corridor (Copp 1989, Gregory and others 1991, Zwick 1992, Stanford and Ward 1993, Stanford and Ward 1995). According to the Independent Scientific Group (2000), floodplain reaches and gravel-cobble bedded mainstem segments are

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[4] The Willamette Fish Study is an investigation of how juvenile salmonids are using the variety of bank treatments and near-shore developments in the lower Willamette River. The study began in 2000 and is being conducted by ODFW on behalf of the City of Portland.

particularly important in the Columbia River basin because habitat diversity and complexity are greatest in those locations.

Each species or unique life history type (meaning a stock or population) is most abundant where the resources it requires are most abundant and/or can be obtained most efficiently. Species will be present (and locally adapted) wherever they have enough resources to sustain their growth and reproduction. For some species, resources are available such that the species can maintain its life history without needing to move very much; this results in suites of organisms occurring in zones along the river continuum. Other species have developed adaptations that involve migrating long distances in search of the resources needed at each life stage. In the case of anadromous salmon and trout, this includes migrations to downstream reaches, estuaries and eventually the ocean.

Critical habitats for the various life stages of salmonids need to be interconnected in three important spatial dimensions:

- **Longitudinal (or riverine)**—a continuum of runs, riffles and pools of varying geometry from the headwaters of a river to its mouth
- **Lateral (or riparian)**—an array of habitats from the middle of the main channel through various side and flood channels and wetlands to floodplains and the uplands of the valley wall, including streamside vegetation and associated faunal assemblages
- **Vertical (or hyporheic)**—a lattice work of underground habitat associated with the flow of river water through the alluvium (bed sediments) of the channel

These spatial dimensions correspond to the spatial and temporal dimensions that link watersheds and riverine ecosystems.

Implications. A great amount of effort has been put into controlling the unpredictable nature of flows in major urban centers such as Portland that have been built along rivers and streams. Flow control efforts have included flood control (dams and reservoirs), draining and filling floodplains, and creating hardened bank structures (rock, riprap and seawalls). This has had additional consequences such as the reduction or complete elimination of the habitat-forming processes of flooding that salmonids require for rearing.

To meet the multiple physical and temporal life history needs of salmon that traverse a large geographical area, agencies and jurisdictions must coordinate their restoration efforts. The science of restoration is still in its developing stages. Several papers have raised the issue that watershed and salmonid restoration requires restoring natural processes that create and maintain habitat (Frissel and Nawa 1992) (Roni and others 2002). Much of what constitutes restoration today occurs at the site-specific scale because most jurisdictions, such as Portland, have limited authority to operate outside of their geographical boundaries.

While it can be argued that many limiting factors and bottlenecks can and must be dealt with at the local level, unless watershed-scale processes such as natural seasonal flows are restored, many of the site-specific approaches are at risk of failing (Frissell and Nawa 1992) or of not adequately addressing the fundamental problems at the appropriate scale (Beechie and Bolton 1999).

Thus research and decision making must be designed to work at both the site-specific and watershedwide scales. Only by understanding the limiting factors operating to reduce the diversity and interconnectedness of habitats at both the local and regional scales, and being able to coordinate effective responses at all of these levels, will watershed, river and salmon restoration occur.

Salmonid Ecology Principle 3: Restoration of salmonids must address the entire natural and human ecosystem, encompassing the continuum of freshwater, estuarine and ocean habitats where salmonids complete their histories.

The salmon-bearing ecosystem is characterized by processes that create and maintain a complete array of habitats in which fish species grow and reproduce. Complex habitats with a high degree of spatial and temporal connectivity permit the development and expression of life history diversity, which is an essential component of salmonid productive capacity. Salmonid restoration implies reestablishment of life history diversity, which requires establishment of habitat diversity and connectivity.

Depleted populations of native salmonids cannot be expected to rebuild if any of the habitats required for successful completion of all life stages are compromised. For example, freshwater habitats must provide flow, food and cover for rearing; estuarine environments must allow for continued smoltification and feeding without amplified predatory threats; and the ocean environment must provide opportunities for feeding and migration. In addition to having intact environments that support different stages of salmonid rearing, habitats must be accessible and connected. Thus regionwide restoration efforts must consider the entire life cycle and complex habitat needs of salmonids, or populations will continue to decline over their geographic range.

Although challenging, restoration of salmonids in urban or urbanizing watersheds is feasible if essential ecological processes and conditions exist. The Independent Scientific Group (2000) based many of its tenets on the assumption that an ecosystem that contains a mix of natural and cultural features that typifies modern society can sustain all life stages of a diverse suite of salmonid populations if it provides essential ecological processes and conditions. The Independent Scientific Group referred to this as a “normative” ecosystem. The region, through its policy representatives, will have to decide on the degree to which it improves conditions for salmon (and other species), based on economic and cultural values. Progress toward the restoration goals stated in the introduction to this document requires moving the system from its current degraded state to one that supports improved watershed processes and conditions for salmonids.

The City recognizes that its urban makeup significantly constrains the level of watershed health that it is practical to achieve and sustain. It is not realistic to expect urban-area watersheds to provide the same level of ecological function as a pristine, undisturbed watershed. Nevertheless, Portland’s watersheds provide important habitats for fish and wildlife species, and the City believes that essential ecological functions and processes needed to sustain these biological communities can be maintained or restored in these

Although urbanization constrains the level of watershed health that can be achieved and sustained, Portland’s watersheds are capable of providing essential ecological functions and processes needed to sustain biological communities.

watersheds. Restoration guidelines for achieving these ends are described in detail in subsequent sections of this chapter.

While it is NOAA Fisheries, the U.S. Fish and Wildlife Service (USFWS) and ODFW that have management authority over salmonid populations, the City of Portland does maintain authority over land use decisions that affect habitat and ecological processes through planning, permitting and enforcement. NOAA Fisheries has indicated that while habitat characteristics are not part of the viability criteria it will establish for salmonid recovery (see Appendix E), the effects of habitat characteristics are ultimately reflected in four population parameters for which NOAA Fisheries is setting viable salmonid population criteria: abundance, productivity, spatial structure and diversity (McElhany and others 2000). For example, NOAA Fisheries recognizes that habitat structure largely dictates a population's spatial structure. The City agrees with NOAA Fisheries' assessment and believes that viable salmonid populations can be sustained in the lower Willamette by restoring and protecting habitat functions and processes consistent with a mix of natural and cultural features typical in urban watersheds.

Implications. It is important to recognize and account for the significance of salmon not only as a commodity resource to be harvested for human consumption, but also for salmon's crucial role in supporting overall ecosystem health. Salmon act as an ecological process vector, important in the transport of energy and nutrients among the ocean, estuaries, and freshwater environments. The flow of nutrients back upstream via spawning salmon and the ability of watersheds to retain those nutrients plays a vital role in determining the overall productivity of salmon runs.

As a seasonal resource, salmon directly affect the ecology of many aquatic and terrestrial consumers, and indirectly affect the entire food web. Likewise, many species of wildlife, such as bald eagle, river otter and beaver, play key roles in providing for the health and sustainability of the ecosystems upon which salmon depend. As the health of salmon populations improves, increases in the populations of many of the associated wildlife species also would be expected. Salmon and wildlife are important codependent components of regional ecosystem biodiversity (Cederholm and others 2000).

Salmon life history strategies cover a broad geographic scale, reaching well beyond the City of Portland's jurisdiction. To ensure that the City's actions are effective, a framework for coordinating activities at both local and basinwide scales must be implemented. Regionwide planning efforts that are effective at communicating and coordinating with local jurisdictions will be necessary. NOAA Fisheries' Technical Recovery Team's planning at the evolutionarily significant unit (ESU) scale and the Northwest Power and Conservation Council's subbasin planning efforts are examples of possible forums for this scale of planning. Other examples are the Oregon Plan for Salmon and Watersheds (see Appendix D) and ODFW's native fish conservation activities.

The City of Portland should ensure that local plans and actions are coordinated with these larger regional planning efforts.

Restoration Guidelines

Defining Restoration

There has been considerable debate on the meaning of the phrase "habitat and watershed restoration" and whether it is relevant within an urban landscape. The Society for Ecological Restoration defines ecological restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Society for Ecological Restoration Science and Policy Working Group 2002). This definition is broad enough to encompass restoration efforts within an urban setting, and is used by the City's Bureau of Parks and Recreation in its restoration efforts.

Another commonly cited definition is from the National Research Council (NRC), which defines restoration as "the return of an ecosystem to a close approximation of its condition prior to disturbance". The NRC further elaborates that it includes "functions and related physical, chemical and biological characteristics" and "is a holistic process not achieved through the isolated manipulation of individual elements" (1992, p. 17-18). According to the NRC, restoration is different from processes such as habitat creation, reclamation and rehabilitation, which partially improve one or only a few elements of ecosystem health—often to serve a particular human purpose—and do not entail a holistic restoration of ecosystem structure and function to predisturbance conditions. In this definition the NRC makes it clear that restoration is a high standard and that many projects that have been called restoration projects do not fit this definition.

The problem with the NRC definition is that it is often taken out of context and applied strictly, such that the term restoration is no longer relevant to most or all of the efforts to improve environmental conditions across the planet. In actuality it is virtually impossible to return any ecosystem to predisturbance conditions, if they are defined strictly. Even in landscapes as remote and comparatively undisturbed as the arctic, for example, polychlorinated biphenyls (PCBs) and other contaminants are present in a wide range of native biota (Wolkers and others 1998, Kucklick and others 2002); here and elsewhere, it clearly will not be possible to reestablish predisturbance characteristics for many decades, if at all. Thus if restoration according to the NRC's definition cannot reasonably be achieved even in the arctic, the definition is of little use when planning restoration actions in urban areas such as Portland.

What is often lost in the semantic debate over the term restoration is that the NRC report places as much if not more emphasis on the approach that is taken as it does on the endpoint that is ultimately reached. The NRC report includes an important quote from Berger (1990) in its definition of restoration to underscore the limits to which predisturbance characteristics can be restored:

> *It is axiomatic that no restoration can ever be perfect; it is impossible to replicate the biogeochemical and climatological sequence of events over geological time that led to the creation and placement of even one particle of soil, much less to exactly reproduce an entire ecosystem. Therefore, all restorations are exercises in approximation and in the reconstruction of naturalistic rather than natural assemblages of plants and animals with their physical environments.*

What is often lost in the debate over the term restoration is that the NRC report emphasizes approach as much as the final result.

When a word as important and broadly used as restoration is defined in a number of ways, it is important for entities to clearly define how they are using the term and to maintain consistency in their definition throughout their efforts. While some of what the City of Portland will undertake to recover fish and wildlife populations and watersheds will be consistent with the NRC definition of restoration, it is also clear that the intensity of urban development will keep the City from achieving full restoration at many locations. Thus the City will strive for "achievable restoration," using the restoration guidelines that follow. Achievable restoration means that:

- To the extent that such information is available, predisturbance conditions will be used as a guide to understanding watershed functions and shaping restoration approaches.
- Restoration efforts will focus on protecting and restoring ecological functions and processes that create and maintain watershed health, rather than on merely reintroducing structural elements (such as large wood) without restoring the processes that maintain these elements.
- The City of Portland will take a comprehensive, holistic approach that addresses all important watershed processes, rather than an approach that addresses the isolated end products of those processes (such as fish population numbers and water quality measurements).

The City of Portland is acutely aware of the intensity and severity of watershed degradation resulting from a long history of urban and industrial uses. At many locations, the intensity of urban land uses may overwhelm natural processes' ability to treat, assimilate or otherwise mitigate urban impacts; at such locations technological solutions will be needed to protect or supplement natural processes. For example, the concentration and amount of pollutants running off highways may exceed the ability of riparian vegetation (through overland flow) to treat these pollutants. In this case, technological means of treating the highway runoff (such as by routing it through a treatment swale) might be required to protect the natural processes that maintain water quality. Within the urban environment it is likely that there will be a wide range of situations where technological solutions will be required to protect natural resources and restore watershed function.

The City's "achievable restoration" activities will draw on the comprehensive, process-based approaches and principles inherent in the NRC's rigorous definition of restoration, although the severity of past and ongoing actions may preclude full restoration of all ecosystem functions.

The City of Portland will be engaging in efforts that fall under a broad range of definitions of restoration. Some of the work will fit under the NRC's rigorous definition of restoration. Some of the work will occur in severely altered landscapes, involve the reestablishment of only basic ecosystem functions and thus be more properly classified as rehabilitation. Other efforts may fall under the NRC's definitions of reclamation, enhancement, replacement, protection and creation (National Research Council 1992). Throughout this document, where the term "restoration" is used, it is in the broader sense of "achievable restoration." Activities conducted as part of achievable restoration will draw on the same comprehensive, process-based approaches and principles inherent in the NRC's rigorous definition of restoration, even though the severity of past and ongoing actions may preclude full restoration of all ecosystem functions.

Restoration Guidelines

1. View the whole picture: Watershed restoration efforts need to be placed within the context of the entire watershed; species recovery efforts must be placed within the context of complete life cycles.
    - 1.1 Define watershed health holistically, by addressing the entire system. Evaluate watershed health in four dimensions: longitudinal, lateral, vertical and temporal. Define watershed health in terms of physical, chemical and biological integrity.
    - 1.2 Understand the role of the watershed in the landscape.
2. Characterize existing conditions and use the results to inform the entire restoration planning process.
3. When planning watershed restoration actions, prioritize and sequence them to maximize long-term success in meeting the stated objectives for the restoration.
    - 3.1 Begin recovery efforts by protecting and restoring existing fish and wildlife populations, functions and habitats.
    - 3.2 Build outward from existing populations, functions and rare or high-quality habitats. Consider the pattern and connectivity of patches as habitats and functions are built outward.
    - 3.3 Place priority on controlling sources of degradation before attempting to address the impacts of those sources.
    - 3.4 In prioritizing restoration actions, first understand how watershed processes affect watershed health. Focus initial restoration actions on the processes that create and maintain healthy watershed conditions and functions.
4. To the maximum extent practicable, use natural processes to achieve ecological functions and societal goals.
    - 4.1 Minimize the introduction and spread of nonnative plant and animal species, especially into relatively natural habitat areas.
    - 4.2 Use native species and emphasize natural habitat features and processes whenever possible in restoration activities.

The Four Restoration Guidelines

Four restoration guidelines underlie the City of Portland's efforts to achieve healthy watersheds. They attempt to translate the primary ecological; riverine, wetland and upland ecology; and salmonid principles into effective approaches for restoring watershed functions and conditions. They also describe approaches for setting the scope and scale of watershed management plans, compiling baseline information, prioritizing areas to restore and developing and sequencing specific restoration actions.

Restoration Guideline 1: View the whole picture: Watershed restoration efforts need to be placed within the context of the entire watershed; species recovery efforts must be placed within the context of complete life cycles.

In proposing restoration protocols for rivers, Stanford and others (1996) list the first as "Formalize the problem at the catchment scale" and state "the entire catchment, from headwaters to ocean, is relevant" (p. 404). The NRC (1992) considers stream and river reaches to be parts of a larger integrated riverine-riparian ecosystem that need to be understood, managed and restored as integrated parts of a single ecosystem.

The very concept of a watershed is based on the principle that the "zone of influence" for a particular stream reach extends far beyond its immediate proximity out to the furthest areas that drain to that reach. While restoration projects may not be able to address an entire watershed at once, the entire zone of influence needs to be considered and its impact on the success of any restoration activities understood. The site-specific areas typically addressed in watershed restoration projects develop within the constraints of the larger scale processes, such as climatic changes or watershed hydrology, of which they are part (Frissell and others 1986). As stated by the NRC (1992), "restoration must have a watershed perspective. Changes in any segment are communicated dynamically throughout the system. Downstream restoration can be undone by changes in the watershed, riparian zones, or upstream reaches, and the causes of failure will not be identified if these linkages are not identified and monitored" (p. 175).

An analogous systemwide focus is required for species recovery efforts. Salmonid habitat has been described as a "chain of favorable environments connected within a definite season in time and place, in such a way as to provide maximum survival" (Thompson 1959). This chain of interconnected habitats represents a temporal and spatial "pathway" through the entire ecosystem—freshwater, estuarine and marine (Independent Scientific Group 2000). For a species to complete its life cycle and survive, all components of this pathway must be functioning sufficiently to provide connectivity throughout the system. Recovery efforts that focus only on a small, site-specific portion of a species' life history chain may be unsuccessful unless the conditions and limitations beyond the specific site are understood.

The Ecosystem Diagnosis and Treatment (EDT) analytical approach—an approach used in many salmon recovery efforts across the region—essentially reflects this notion (EDT is described in more detail in Appendix H). EDT maps out the entire life history of a species and evaluates survival across the entire pathway of that life history. As stated by Lestelle and others (1996, p. 33), "ultimately environmental capacity for a population must be considered over the entire life cycle of the animal … Interest in the performance of salmon, whether we view it as a direct or indirect indicator of deliverable societal values, is long-term and most certainly includes the full life cycle."

Implications. The practical implication of this principle is not that watershed restoration activities will fail if they are not completed simultaneously over the entire watershed, but rather that any site-specific restoration activity should be understood in terms of its effects and potential for success in relation to the processes and impacts occurring over the entire watershed. Viewing the whole picture also clarifies what outcomes can realistically be expected to result from restoration actions.

Restoration Guideline 1.1: Define watershed health holistically, by addressing the entire system. Evaluate watershed health in four dimensions: longitudinal, lateral, vertical and temporal. Define watershed health in terms of physical, chemical and biological integrity.

The concept of "view the whole picture" applies not only across the landscape, but also within the dimensions of the watershed as well. Watershed health must be defined holistically, by addressing the entire system, if it is to be restored effectively. As described in Riverine, Wetland and Upland Ecology Principle 2, Ward and Stanford (1995) define four dimensions over which river processes occur: longitudinal (upstream-downstream), lateral (riverine-riparian/floodplain), vertical (riverine water column-groundwater) and temporal. The lateral dimension should also consider upland areas. For restoration activities to be designed appropriately, watershed processes, species interactions and impacts must be evaluated over these four dimensions.

Similarly, watershed health must be defined and evaluated broadly if it is to be restored effectively. Although the goal of the Clean Water Act is "to restore and maintain the chemical, physical, and biological integrity of the Nation's water," the programs and regulations that stem from this act have focused mostly on chemical aspects of water quality, such as temperature and concentrations of metals and organic contaminants. Restoration programs must now focus more broadly on physical and biological components of watershed health, such as flow and habitat, in addition to chemical water quality (Karr and Chu 1999).

Elements of the "whole picture":

- The geographical extent of the watershed
- The range over which the species' life history is carried out
- Upstream, downstream, lateral and vertical influences throughout the watershed
- Hydrology, habitat, water quality and biological communities

The *Framework* proposes four major categories with which to evaluate watershed health:

- Hydrology
- Physical habitat
- Water quality
- Biological communities

Restoration Guideline 1.2: Understand the role of the watershed in the landscape.

"Viewing the whole picture" will require a broad, integrative framework that places rivers and streams, their habitats and their communities in a wider geographic context (Frissell and others 1986; Primary Ecological Principle 2). To fully understand the processes that shape a watershed, the watershed must be viewed and evaluated at a variety of spatial scales. The success of restoration efforts is greatly affected by processes from the broadest landscape scale (such as climate) to the basin scale (such as the Willamette River basin), watershed scale (such as the Johnson Creek watershed), reach scale and below (channel structure and dynamics, for example) (Federal Interagency Stream Restoration Working Group 1998; Primary Ecological Principle 2). No one scale is appropriate for all applications, and while a project may choose to emphasize one scale at which to conduct the most detailed and extensive analysis of restoration alternatives, it is necessary to consider processes at a range of scales for the restoration to be successful.

Stream classification systems often identify important scales to consider—and the important processes that operate over each scale—when evaluating watersheds. Stream classification systems such as that in the *Oregon Watershed Assessment Manual* (Governor's Watershed Enhancement Board 1999) classify waterways according to factors such as shape, size, gradient and dominant substrate and can guide watershed and species recovery efforts in several ways:

- By providing a framework for explicitly addressing important processes at different scales
- By identifying linkages between scales
- By describing expected watershed characteristics and functions
- By identifying the contribution of component reaches and subwatersheds to overall watershed function

Understanding the processes that affect a specific site and placing a site-specific restoration action within the context of "the whole picture" is greatly aided by stream classification systems. To be consistent with practices across the region, the City of Portland will use classification systems widely used throughout Oregon and the Northwest (Governor's Watershed Enhancement Board 1999, Montgomery and Buffington 1993, Rosgen 1994) to guide watershed and species recovery objectives and methodologies.

Restoration Guideline 2: Characterize existing conditions and use the results to inform the entire restoration planning process.

Once the "whole picture" has been defined (by understanding the range over which relevant species' life histories are carried out; the upstream, downstream, lateral and vertical influences throughout the watershed; and the hydrology, physical habitat, water quality and biological communities within a watershed), the existing conditions within the landscape of interest can be characterized. Characterization is one of the most critical initial steps in restoration planning. It is the step at which the scope and focus of restoration begin to become clear. Is the watershed or habitat degraded relative to reference conditions? What problems affect the health of a watershed or species? How do these problems vary in intensity over space and time? How do the characteristics of the watershed or habitat (gradient, climate, soils, land use, infrastructure, etc.) influence these problems, and how should these be accounted for in restoration approaches?

Comprehensively and accurately assessing existing natural and human-made conditions (such as infrastructure) throughout the course of the restoration planning process serves several purposes:

- It is useful in transforming broad and general goals into specific and measurable objectives.
- It identifies existing high-quality habitats that should be given priority for protection.

- It is critical in identifying the scope, severity and dynamics of environmental problems within a watershed. This is a prerequisite for determining the focus and priority of restoration activities.
- It defines the baseline condition against which the future progress and the success of restoration activities can be measured.

For these reasons, the characterization must be accurate, it must be comprehensive in addressing the relevant spatial scales and indicators of watershed health (to the extent possible, given existing data) and it must clearly identify key information gaps.

The solutions developed to restore a watershed will be appropriate and effective only if the nature and dynamics of the problems that degrade the watershed are clearly understood.

In characterizing existing conditions it is important to identify both the attributes of a healthy watershed and reference conditions, meaning the specific level at which each attribute is considered to be healthy or functioning (see Chapter 3 and Appendix G for descriptions of watershed attributes, indicators and target values and how they are used in the City's watershed management process).

Indicators. Following characterization and the establishment of objectives for actions to achieve watershed health, environmental indicators will be established. Developing a set of indicators is essentially a process of converting watershed goals and objectives into specific and measurable components, such as water temperature, the amount of large wood and the abundance and composition of benthic invertebrates. The challenge in identifying a comprehensive set of indicators is to develop a list that truly reflects all aspects of watershed and species health, yet that can be practically and accurately measured. It is important to view watershed health holistically, by addressing the entire system (Restoration Guideline 1.1*)*, and to evaluate the list of indicators against a key question: If objectives for each of these indicators are achieved, are there any significant problems or processes that would be missed? Some of the indicators that can be used to evaluate existing conditions are described in Appendix G.

Reference Conditions. Once a comprehensive set of indicators has been selected, it is important to set specific target values for each indicator. However, before appropriate target values can be set, reference conditions will need to be determined. Reference conditions serve as yardsticks against which existing conditions can be compared and watershed health can be evaluated. One of the critical roles of reference conditions is to provide specific and measurable definitions of such terms as "properly functioning watershed" and "healthy populations." For each indicator, a reference condition represents a level at which the prevailing body of scientific knowledge suggests that the indicator is properly functioning.

Reference conditions may be derived from state water quality standards, habitat benchmarks such as those in the *Oregon Watershed Assessment Manual* (Governor's Watershed Enhancement Board 1999), other available criteria, evaluation of reference areas or historical conditions, or scientific studies. Reference conditions can also be determined at multiple levels, to indicate the degree to which a particular indicator is functioning. For example, NOAA Fisheries uses three levels in evaluating salmon habitat: properly functioning, at risk and not properly functioning (National Marine Fisheries Service 1996).

EDT uses five levels in evaluating salmon habitat (Lestelle and others 1996). The five levels, from 0 (meaning high survival) to 4 (meaning lethal), define salmon survival levels associated with particular conditions of each habitat attribute. Having multiple levels provides additional detail on exactly how degraded a specific indicator is and how far existing conditions are from the intended goal.

Limitations of Characterization. Characterization of existing conditions helps to identify the nature and dynamics of problems that degrade a watershed. Characterization also helps to identify existing populations and high-quality habitats that warrant protection and enhancement because they provide valuable ecological functions, or have the potential to do so in the future.

However, it is important to emphasize that characterization does not by itself identify the most critical priorities or the initial steps that must be taken to restore a watershed or recover a species. Out of the characterization will come a highly complex picture of a range of conditions and problems across the watershed. Translating the results of a characterization into objectives, indicators, target values, benchmarks and then a set of prioritized restoration actions requires additional analysis related to source identification and quantification, evaluation of alternatives and other activities.

Restoration Guideline 3: When planning watershed restoration activities, prioritize and sequence them to maximize long-term success in meeting the stated objectives for the restoration.

The complexity and pervasiveness of environmental problems in watersheds across the country, particularly in urban areas, are such that it is unlikely that all the financial resources to complete all of the actions required to achieve watershed health will be available immediately at the onset of the restoration process. This fact dictates that restoration actions be sequenced, phased or prioritized in a fashion that maximizes effectiveness in meeting watershed objectives and benchmarks. For example, if attempts are made to restore instream channel structure and habitat features before normative hydrology has been restored, excessive peak flows could destroy the restoration project. Also, artificial supplementation to recover salmon populations might not be successful unless there is habitat throughout the watershed that supports rearing, feeding, migration and spawning. Furthermore, introduction of wildlife species such as beaver may conflict with human use of the floodplain, while doing so may also help prevent channel erosion.

Given the range of problems in most watersheds, it is important to determine the most effective order in which to implement restoration actions.

A key question is "What is the most effective order in which to implement the many restoration actions required to address the broad range of problems affecting a watershed?" This approach requires a decades-long process of selecting, designing, funding and implementing a large number of restoration projects.

To determine the sequence in which projects should be implemented, several potentially conflicting criteria must be balanced:

- **Effectiveness Relative to Time and Cost.** Clearly, projects that are highly effective in meeting objectives, relative to the time or cost the projects take to implement, should be implemented early on. This is justified by both fiscal responsibility and the urgent need to reverse watershed degradation and salmon decline. Most restoration and protection efforts acknowledge this criterion, whether they refer to it as selecting the "low-hanging fruit," implementing actions with a "big bang for the buck" or identifying "early actions."

- However, for restoration to be truly comprehensive and effective, it cannot merely be a process of moving from the lowest hanging fruit to the next lowest fruit: some very difficult, costly and lengthy restoration projects will be necessary to reverse the decline of watershed health. This is particularly true within the urban landscape. Thus, additional criteria must guide the sequencing of watershed restoration projects.

- **Optimizing Riverine, Wetland, and Upland Restoration.** Restoration projects that improve riverine, wetland and upland resources can optimize resources by addressing common habitat attributes and functions and encouraging ecosystem-based approaches that benefit fish, wildlife and people. The City already has made considerable investments to conserve and restore habitat values and functions across Portland. For example, the City has acquired and manages approximately 7,000 acres of natural area parks and has established zoning mechanisms to protect or conserve more than 20,000 acres of habitat resources on public and private land. Portland also is investing in an array of programs involving revegetation and restoration projects, education and stewardship activities, and willing-seller land acquisition. Much of the future habitat work in Portland will inevitably involve restoration of degraded sites. However, opportunities to conserve existing high-quality habitats may occasionally present themselves.

  Actions to protect multiple species and/or species assemblages should be considered from an ecosystem management perspective. For example, efforts to protect habitat for bald eagles at Smith and Bybee lakes also will benefit additional terrestrial and wetland-dependent plants, fish and wildlife. Creating a conservation plan at the local level and incorporating it into a local comprehensive plan is one of the most strategic ways to protect biodiversity in urban areas (Defenders of Wildlife 2003).

- **Need.** Projects that address the most severely degraded functions or the most critical limiting factors also should be initiated early on. These projects are identified through the processes of watershed characterization and comparison to optimal values, as described earlier, and through analysis of limiting factors, as described in Appendix H. Other projects that should be considered early on are projects that protect existing healthy watersheds and functions, such as retaining urban growth boundaries and reclaiming sensitive areas via land acquisition.

  The need criterion differs from the effectiveness criterion in that these actions may be quite effective, but they are also likely to be highly complex and expensive and require a long time to implement. It is critical to initiate these projects early on, so that their eventual effectiveness is realized as soon as possible, and to commit to implementing them fully.

- **Effect on Future Projects.** Projects implemented early in the restoration process should not preclude, constrain or otherwise compromise restoration projects that will be required later in the process. While replanting riparian trees is a low-cost effort that addresses many critical watershed problems, restoration programs may not want to invest in replanting a stream reach if comprehensive watershed restoration will soon require that the reach undergo extensive bank and channel restoration to improve connections between the stream channel and the floodplain. On the other hand, if comprehensive restoration is likely to take decades, replanting may be worthwhile.

With these criteria as guidance, the order in which restoration actions should occur is determined by answering the following questions:

- "Where within the watershed should we begin restoration?" (Restoration Guidelines 3.1 and 3.2)
- "Which problems should be addressed first?"(Restoration Guideline 3.4)
- "How should these problems be addressed?" (Restoration Guidelines 3.3 and 4)

Restoration Guideline 3.1: Begin recovery efforts by protecting and restoring existing fish and wildlife populations, functions and habitats.

Species recovery planning efforts should begin by identifying existing populations of the species of interest and protecting and restoring these populations and their habitats as a first priority. The modeling tool EDT prioritizes species recovery efforts through a stepwise process of identifying existing successful life history strategies and their associated habitats (including migration corridors), improving habitats associated with these life history strategies and then improving habitat quality and connectivity to reestablish life history strategies that have been extirpated (Lestelle and others 1996).

There are several reasons why identifying existing populations can provide direction to restoration efforts:

- **As indicators of remaining ecological functions.** Surviving urban fish and wildlife populations are indicators that there are enough habitat and ecological functions being provided across a highly degraded landscape that the species in question can persist locally. If salmon traverse a "chain of favorable environments connected within a definite season in time and place" (Thompson 1959), then a surviving population is an indicator of a chain or set of chains possessing enough basic functions across the landscape that the life history strategy can be successfully completed. Stated another way, these populations are "canaries in the coal mine"; they point to a chain that is at least minimally acceptable, that can be successfully navigated and that can be built upon through restoration efforts. Addressing the key conditions that limit these existing populations is more likely to produce a viable population than attempting to reestablish populations that no longer exist. According to the NRC, "re-establishing new populations through introductions once the local populations have been lost has proved to be extremely difficult. And even if a newly introduced population is initially successful, it might not be adapted to the range of environmental conditions that have happened in the past and can be expected to occur again in the future" (National Research Council 1996, pp. 152-3).

- **As genetic resources.** Surviving urban populations also represent genetic stocks of high value to the evolutionarily significant unit, or ESU. These populations have survived in the face of extensive habitat degradation, and they may have developed adaptations that improve their survival in highly altered landscapes. "One important reason to protect local populations is that they are locally adapted to the streams that support them. In other words, evolution has made a local breeding population better able to survive and reproduce in its home stream" (National Research Council 1996, p. 152).

Restoration Guideline 3.2: Build outward from existing populations, functions and rare or high-quality habitats. Consider the pattern and connectivity of patches as habitats and functions are built outward.

Existing populations and their habitats should be expanded—and linkages to them improved—so that they can serve as "core" populations for subwatersheds without populations. Populations of salmonids and many other fish and wildlife species are best viewed as metapopulations (National Research Council 1996), meaning a collection of nearby populations that interact and can exchange individuals, and many believe that salmonids exhibit a core-satellite metapopulation structure (see the salmonid ecology principles section and citations contained therein). In such a structure, core populations serve as important sources of colonists that reestablish satellite populations in nearby habitats where populations have been extirpated. These populations already have a high probability of being adapted to conditions in nearby habitats (National Research Council 1996).

"Building outward from existing populations" means the following:

- Improving and expanding habitats in which populations currently exist.
- Improving connectivity to nearby favorable habitats to increase the chances of the existing populations straying into these habitats and establishing satellite populations. (This is consistent with the "maximize passage efficiency to allow recovery of metapopulations" restoration protocol in Stanford and others [1996]).

Just as restoring existing populations has a greater probability of success than attempting to reintroduce populations where none currently exist (Restoration Guideline 3.1), protecting existing high-quality habitats is more likely to meet with success than restoring habitats that are in a degraded condition. This essentially implements the first portion of the concept "protect the best, restore the rest." Species recovery efforts should acknowledge that remaining habitats of high ecological value provide critical, irreplaceable functions for species of concern. These critical habitats will be determined by the life histories of the species of concern. For salmonids, for example, habitats of high ecological value might include off-channel habitats, floodplains, islands, springs and confluences; for priority wildlife species such as riparian- or upland-dependent birds, high-quality habitats might include those with the critical combination of food, cover and water. These valuable areas should be given priority for protection, restoration, improved access and expansion. Frissell and others (1986) state that protection of existing functioning habitats is the most urgent and cost-effective habitat conservation measure.

In the long run it is easier to protect existing functioning habitats than it is to create new ones.

However, it is critical to emphasize that, as a priority, “protect the best” is incomplete without “restoring the rest.” Even if all currently existing habitats were protected from any further degradation, the populations of salmon and many other fish and wildlife species would still remain below historical levels, in part because of a lack of high-quality habitat. Local and regional efforts to comply with Statewide Planning Goal 5 for protection of fish and wildlife habitats focus on “protect the best” but not on “restoring the rest.” Restoring conditions and habitats must go hand in hand with protection efforts. For example, while protection of existing high-quality habitats is a necessary and important step, by itself it is insufficient to restore salmon populations because the amount of remaining habitat is inadequate to maintain viable salmonid populations. If the intention of restoration programs is to recover populations rather than merely prevent additional harm or further decline in populations, the restoration programs must improve the functionality of existing habitats or create additional habitats beyond those that currently exist, or do both. Another issue that is central to assisting with the recovery of listed salmonids is that the vast majority of Portland’s highest quality (and fully protected) habitats, including Forest Park and Oaks Bottom, are inaccessible to anadromous fish species.

Given the difficulty of restoring habitat to the quality and functionality of naturally created habitat, one of the most effective ways of increasing habitat functions throughout the watershed is to improve the connectivity of existing habitats by reducing bottlenecks and blockages among them. Bottlenecks and blockages occur in the form of physical barriers, excessive or inadequate flow, water quality barriers or other forms of habitat degradation. The presence of degraded habitat between migratory routes and high-quality habitats precludes or limits access to high-quality habitats; it also reduces or eliminates the valuable functions such habitats could otherwise provide to migratory species. Consistent with the discussion of the riverine, wetland, upland and salmonid ecology principles, improving the connectivity of existing functioning habitats will strengthen existing populations and metapopulation structure (Stanford and others 1996) and promote expansion into favorable but unoccupied habitats.

The distribution of patches of habitat is an important component in wildlife habitat relationships. The amount of habitat, variation in patch size and isolation of certain patches influence both species viability and diversity, with implications for management actions.

Large habitat patches are more likely to sustain ecological processes and historical disturbance regimes than small patches are. In addition, large patches support more viable and diverse populations of native plants and animals, including species such as brown creeper and Douglas’ squirrel that are adapted to interior habitats. Small patches typically support fewer species and individuals than do large patches of the same habitat type, and those species are more likely to be edge-adapted species, including predators such as coyote. However, small patches may also contain rare or unique habitat types or species or act as “stepping stones” between otherwise isolated patches of habitat. When considering management actions, it will be important to evaluate which wildlife species, at which life stages, would benefit from the restoration of large and small patches. Also, it is crucial that upland habitats have some degree of connectivity to other upland habitat patches and to aquatic and riparian habitats. Strategically connecting patches of various sizes could help wildlife species disperse across the landscape, access less developed landscapes and meet those biological needs not satisfied by riparian and aquatic habitats alone.

Restoration Guideline 3.3: Place priority on controlling sources of degradation before attempting to address the impacts of those sources.

Source Identification. Source identification is the step at which the processes degrading a watershed are identified and quantified and is therefore critical for developing and prioritizing solutions. Unfortunately, in the past, both in Portland and elsewhere, many restoration plans attempted to go directly from identifying problems to identifying solutions. For example, if a watershed exceeded temperature standards, oftentimes trees were planted in areas where riparian vegetation was lacking; if there was a lack of habitat supporting spawning, restoration projects were implemented that re-created suitable substrate and instream conditions to support spawning. It is possible with such an approach to identify many actions that may improve degraded conditions in the watershed.

However, the danger of such an approach is that, if efforts are not directed toward understanding the processes that produce the problems, the restoration actions might address only the symptoms of the problems, without solving the problems themselves. For example, knowing that a particular stream reach has insufficient gravels to support spawning is different from knowing whether gravels are limiting as a result of (1) excessive sedimentation, (2) an upstream barrier that impedes gravel transport and "starves" the reach of gravel, or (3) changes in hydrology that alter the transportation and deposition dynamics of the reach. Similarly, knowing that DDT is present in stream sediments at levels that impair ecosystem health is different from knowing whether the DDT (1) originates from past uses and is predominantly stored within aquatic sediments, (2) is attached to upland soils throughout the watershed and is introduced into the aquatic environment through erosion, or (3) is still being used by watershed residents and so has active sources that need to be addressed.[5] In each of these examples there are three possible solutions to what appears to be the same environmental problem. Unless the relative contributions of the different sources are understood, an effective solution cannot be developed.

To the extent possible, protection and restoration programs should place high priority on identifying and quantifying sources or causes of degradation before attempting to address the impacts of those sources within the environment. Money and effort spent on carefully and quantitatively evaluating sources offer multiple benefits:

- Knowledge of which sources it is most important to control
- An understanding of the dynamics of those sources and how best to control them
- An ability to predict quantitatively the benefits that will accrue from controlling each source, taking into account the cumulative impacts of multiple sources
- An ability to avoid creating an "attractive nuisance" that could draw fish or wildlife into habitat where they either cannot be sustained or can be harmed

Insufficient efforts directed toward source identification may result in misdirection of source control efforts. Without a sufficient understanding of source dynamics, the most significant sources may not be addressed and source control policies, programs and technology may be misapplied.

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[5] All three of these sources have been shown to be active in the Columbia Slough, for example (City of Portland Bureau of Environmental Services and Parametrix 1997).

Source Control. Once sources of degradation have been identified and quantified, restoration plans should place priority on controlling sources before attempting to address the impacts of those sources within the watershed. Decades of water quality protection efforts have made it clear that source control is by far the cheapest and most effective path to water quality. The general rule of thumb is that in relative terms it costs $1 to control a pollutant at its source, $10 to treat it at the end of the pipe and $100 to clean it up once it enters the environment. In addition, each step is less effective than the previous one. This is particularly true for certain organic contaminants, which often break down extremely slowly over time and whose chemical properties tend to resist dilution and favor incorporation into sediments and the food chain. Thus the general principle is that restoration plans must control sources of degradation as close to their sources as possible.

In relative terms, it costs $1 to control a pollutant at its source, $10 to treat it at the end of the pipe and $100 to clean it up once it enters the environment.

While the importance of source identification and control has been recognized in connection with water quality programs, its importance and applicability have been less widely acknowledged in connection with protection and restoration efforts that address hydrology, habitat and biological communities. The same principle of addressing causes rather than symptoms applies equally well to these areas. Attempts to restore degraded habitat are never as successful as protecting habitat from destruction or degradation in the first place. Similarly, aggressive efforts to prevent the introduction of exotic species will always be more effective and cheaper than trying to eradicate an invasive species that has already established itself within the ecosystem.

Lack of source control prior to restoration is likely to result in failure of the restoration project. For example, a stream channel restoration that does not address the altered hydrology that causes channel degradation will probably be destroyed by excessive peak flows. Likewise, if contaminated sediments are cleaned up but the source of pollution is not controlled, the sediments will be recontaminated.

It is particularly important to control sources of toxic pollutants before they are released into the environment and enter the food web. Many of the persistent, bioaccumulative pollutants common in urban settings degrade very slowly (if at all) through natural processes, and have adverse impacts on biological populations. Urban wildlife are exposed to a host of chemicals—pesticides, PCBs, heavy metals, and other contaminants—that even at sublethal concentrations can affect survival. In birds, for example, nonlethal and indirect exposure to pesticides can lead to increased susceptibility to predation and changes in avian egg incubation behavior. Repeated pesticide exposure also adversely affects nutrition, reproduction and growth of animals such as gamebirds and waterfowl (Bennett 1992). In addition, being exposed to toxic chemicals can increase terrestrial species' stress, predispose organisms to disease, delay development and disrupt physiological processes such as reproduction.

Although fish and other aquatic species are particularly susceptible to the direct effects of water-borne toxins, terrestrial species that feed on aquatic species also can be affected by toxins through bioaccumulation. This is the case with piscivorous birds such as bald eagles and osprey. Bald eagle eggs from nests in the Columbia Slough area and osprey eggs from nests along the lower Columbia River have been found to contain unsafe levels of DDE (a metabolite of DDT), PCBs, dioxins and other toxins that may affect their productivity.

Restoration actions that would help wildlife avoid exposure to toxic chemicals, either directly or through bioaccumulation, would include those actions that reduce sediment accumulations, or discharges and nonpoint source runoff that may be contaminated.

Restoration Guideline 3.4: In prioritizing restoration actions, first understand how watershed processes affect watershed health. Focus initial restoration actions on the processes that create and maintain healthy watershed conditions and functions.

Restoration actions should be sequenced for maximum effectiveness, considering the importance of hydrology, habitat creation and maintenance, and water quality, which are key, interlinked processes for restoring watershed health.

Regardless of whether restoration is applied to large rivers or small streams, hydrology is one of the most basic and critical forces shaping the structure, dynamics, and function of riverine ecosystems.

Hydrology. Regardless of whether restoration is applied to large rivers, small streams wetlands or uplands, hydrology is one of the most basic and critical forces shaping and shaped by the structure, dynamics and function of riverine and wetland ecosystems (see Riverine Ecology Principle 3). Flow dynamics affect nearly every aspect of ecosystem functioning, including habitat formation and maintenance, the flow of energy and materials, temperature, the fate and transport of contaminants and the composition of biological communities. Stanford and others (1996) emphasize the primary importance of flow in the health of large rivers and regard it as one of the most pervasive impacts on large rivers across the globe. Poff and others (1997) consider flow a "master variable" that regulates the ecological integrity of river ecosystems. In smaller systems, many researchers have documented the strong association of stream health with the amount of watershed imperviousness (Booth 1991, Schueler 1994, May and others 1997), an association that is due partly to the effect of impervious surfaces on watershed hydrology, specifically changes to overland flow and baseflow.

Because of the critical importance of flow in ecosystem structure and function, restoration of other watershed components may be unsuccessful or of limited benefit unless significant elements of normative flow are restored (Beschta 1996, Kauffman and others 1997). Restoration of physical habitat may be destroyed by excessive peak flows or rendered inaccessible to fish by inadequate flows. Restoration of normative flow will have fundamental impacts on elevated temperatures and on the fate and transport of contaminants. Attempts to restore healthy aquatic communities must restore the range and timing of flow to which the species have adapted over evolutionary time.

Even within subwatersheds where existing conditions and constraints preclude the ability to fully restore normative flow, it is important to evaluate the flow regime that ultimately will be attained through the restoration actions planned for that subwatershed. The physical form of the channel; the extent, proximity and composition of riparian and upland vegetation; water quality dynamics; and the composition of instream communities—all will be strongly influenced by the hydrologic regime that the restoration actions ultimately provide. Until a reasonably clear picture of that hydrologic regime and the projects needed to produce it emerges, it will be difficult to know the types of habitat that can be restored in different locations within the watershed.

Restoring water quality also will require an understanding of the flow regime that will be attained through restoration. The assimilative capacity of a stream (meaning the amount of pollution, heat, nutrients and sediments the stream can accommodate before violating the Clean Water Act) is key in planning water quality restoration, and flow regime is a critical component in estimating assimilative capacity. Knowing assimilative capacity and flow regime in turn provide a clearer picture of the conditions that are likely to exist throughout the watershed, and the types of plant and animal communities that will survive in these conditions.

For all of these reasons, some of the first actions to occur in restoring urban watersheds should be (1) evaluation and planning of the restoration actions needed to restore normative flows, and (2) an analysis of the extent to which normative flows can be restored. It is likely that restoring normative flows will require actions throughout the watershed (for example, removal or reduction of impervious surfaces). The extent to which normative flow is reestablished will greatly affect the degree of success in restoring other elements of urban watersheds.

Physical Habitat. Frissell and others (1986) emphasize the importance of physical habitat in the structure and function of riverine ecosystems. When combined with hydrologic restoration, the restoration of physical habitat may address other forms of watershed degradation. For example, stream temperatures can improve dramatically once channel structure, riparian areas and normative hydrology are restored. The importance of wetland and riparian vegetation in nutrient cycling, runoff filtration and determining the balance between autochthonous (instream) and allocthonous (out of stream) primary production makes habitat restoration a key strategy in addressing stream eutrophication. Restoring physical habitat to conditions to which native species have adapted over evolutionary time is key in reducing the dominance of invasive species and recovering healthy biological communities.

Aquatic habitats are created by the interaction of flow, wood and substrata (gravel, sediments, bedrock, etc.) (Naiman and others 1992, Washington Forest Practices Board 1995). Restoring normative flow, restoring and improving connection to riparian and floodplain areas and restoring normative sediment supply processes are some of the key elements required to restore habitat. Given the importance of the floodplain in flow attenuation and storage, habitat processes, provision of refugia and water quality (Stanford and others 1996; riverine ecology principles), restoring river connection to floodplains is a critical element of habitat restoration in floodplain systems. Similarly, understanding how upland habitats are created is important in restoring watershed health.

The following is the City of Portland's prioritization scheme for habitat protection and restoration, adapted from the NRC's habitat management options (National Research Council 1996, pp. 206-210):

1. **The highest quality riverine, wetland and upland habitats should be protected. Fish and wildlife access to these habitats should be evaluated and, wherever possible, restored or improved.** Opportunities for protection and even expansion of these

habitats (such as by improving species' access to adjacent high-quality habitats or restoring nearby habitats) should be investigated. Within Portland, examples of high-quality habitat include Smith and Bybee lakes, Forest Park and portions of Tryon Creek. These areas currently are protected, but aquatic species' access to them is compromised or precluded by culverts or water control structures. Similarly, the City's Environmental Overlay Zones provide some protection to a number of streamside habitats and should be expanded, where warranted. In addition, Metro's Goal 5 Regionally Significant Areas Inventory should be evaluated and expanded within the City of Portland, where appropriate, to address areas of local importance.

2. **Intermediate-quality habitats should be conserved and evaluated for restoration.** Intermediate-quality habitats have been degraded by human activities but have the potential to recover characteristics that would make them functionally equivalent to high-quality habitats. Riverine, wetland and upland habitats in this category that are contiguous with or along migratory routes to high-quality habitats should be given additional priority. Crystal Springs is an example of such a habitat. Located in the lower Johnson Creek watershed, close to the Willamette River, Crystal Springs is used by local fish populations and as off-channel habitat by salmon migrating along the Willamette mainstem. Restoration projects at Crystal Springs could greatly improve its ecological functions because Crystal Springs has large inputs of groundwater and its upper portion is situated among parks, a golf course and a college campus, which reduces constraints to riparian and channel restoration.

3. **The lowest quality habitats should be evaluated for their potential to create "bottlenecks" and to fragment habitat.** Areas that are highly degraded (such as through toxic contamination, habitat destruction, high temperatures or excessive or inadequate flows) may impede or prevent species from reaching higher quality habitats, increase mortality or decrease individuals' fitness as they pass through these degraded areas. Degraded areas that are near or between high-quality areas, or along migratory routes to high-quality areas, should be given additional priority. In a sense, the Willamette River through downtown Portland represents such a habitat. Habitat degradation through this reach may affect fish populations from throughout the Willamette River basin that must pass through the lower Willamette to reach spawning and rearing habitats above Portland.

Water Quality. As discussed previously, restoration of flow and habitat will restore many of the processes that maintain water quality. Attention should then be focused on those components of water quality that are not addressed by reestablishing normative flow and restoring riparian and instream habitats, such as toxic contamination.

The extensive focus of past environmental programs on water quality has provided some valuable lessons that can be generalized to broader forms of restoration. The first of these is that the quality of instream waters is intimately connected to the conditions and activities of the surrounding uplands. Upland areas are an integral and inseparable component of the watershed, and conditions and activities occurring in the uplands are transmitted—often via water quantity and quality impacts—to the streams into which they drain. This concept is captured under the "lateral" dimension in the riverine ecology principles and under Restoration Guideline 1.1. The second lesson learned is that source control, protection and prevention are by far the cheapest and most effective forms of restoration. This is described further in Restoration Guideline 3.3.

Biological Communities. Decisions regarding restoration that involve direct manipulation of biological communities (invasive species control, hatchery introductions, etc.) should evaluate the degree to which degraded flow, habitat and water quality conditions can compromise the effectiveness of these measures. As stated in Primary Ecological Principle 4, "the abundance, productivity and diversity of organisms are integrally linked to the characteristics of their ecosystems." Attempts to reintroduce native species or reduce the dominance of introduced species may fail if the habitat conditions to which native species have adapted are not reestablished (National Research Council 1996). The alteration of these habitat conditions may in fact be the primary factor that gives invasive species competitive advantages over native species (Reeves and others 1987). Thus the highest priority in restoring biological communities should be to address the flow, habitat and water quality conditions that led to the decline of these communities.

Restoration Guideline 3 and its subprinciples provide guidance on how to sequence the evaluation and implementation of restoration actions and how to determine where in the watershed these actions should be implemented first. Restoration Guidelines 3.3 and 4 provide guidance on the restoration actions themselves (that is, the nature and type of restoration actions that should be emphasized in developing comprehensive watershed management plans).

Restoration Guideline 4: To the maximum extent practicable, use natural processes to achieve ecological functions and societal goals. Watershed and species recovery efforts should focus on restoring rather than replacing natural processes to the maximum extent possible (Independent Scientific Group 2000). Stanford and others (1996) emphasize the importance of natural river processes in habitat formation and maintenance under the restoration protocol "let the river do the work." This idea is captured throughout ecological literature in the concept of passive or "self-design" restoration, which is the process of halting activities and removing structures that are causing degradation or preventing recovery and allowing natural processes to restore ecosystem functioning. Beschta and Kauffman (2000) and Kauffman and others (1997) state that passive restoration is the logical and necessary first step in any restoration program.

Restoration Guideline 4 is consistent with and builds upon themes expressed in the other restoration principles:

- Simply reducing or eliminating sources of degradation may be the most important and effective step in restoring degraded watersheds (Restoration Guideline 3.3).
- Restoring existing populations has a greater probability of success than attempting to reintroduce populations where none currently exist (Restoration Guideline 3.1).
- Protecting existing high-quality habitats has a greater probability of success than restoring habitats that are already in a degraded condition (Restoration Guideline 3.2).

Essentially, Restoration Guideline 4 states that natural processes are generally far more effective and cheaper than the technological processes designed to replace them. While some restoration efforts will involve using engineered solutions to allow natural processes to reestablish themselves, wherever possible restoration plans should make use of natural processes to perform ecological functions, rather than rely heavily on technological options—many of which do not have a proven track record of success.

There may be a strong bias against approaches that promote natural processes within the urban landscape, for two main reasons:

- The intensity and pervasiveness of land uses appear to be inconsistent with the space required to allow natural processes to occur.
- Natural processes are inherently dynamic and unpredictable.

However, many of the most innovative emerging restoration approaches—approaches that are showing the greatest potential in terms of effectiveness and cost—are those that embrace the concept of using natural processes to achieve ecological and societal functions.

Example: Flood Control vs. Flood Management. For example, more than 70 years of traditional flood control approaches in Johnson Creek have failed to control floods and, in the meantime, have been detrimental to the ecological health of the watershed (City of Portland Bureau of Environmental Services 2001). As an alternative, the City of Portland has attracted national attention and gained the recognition and support of the Federal Emergency Management Agency (FEMA) by focusing on innovative approaches of flood "management" that have included the following:

- Purchasing and demolishing willing-seller properties within the floodplain
- Reconnecting floodplains so as to reestablish flood storage throughout the watershed
- Re-creating off-channel habitats
- Removing fill and structures within the floodplain

Example: Stormwater Management. Nationwide, the newest and most promising trend in stormwater management is trying to minimize the reliance on traditional conveyance, pond technologies and end-of-pipe systems. These are being replaced by approaches that focus on the following:

- Reducing building and road footprints to reduce the amount of impervious surfaces
- Using permeable surfaces where footprints cannot be avoided
- Using small, decentralized bioretention areas that infiltrate, store and transpire precipitation locally throughout the watershed (Hinman 2001)

These newer approaches make far greater use of localized infiltration and the associated natural process that provide flow and water quality benefits. Initial research indicates that these approaches are more effective than traditional stormwater management approaches with comparable costs, even within highly constrained urban areas (Liptan and Kinsella-Brown 1996). Decentralized bioretention areas also have the potential to play a significant role in flood management; this indicates that effective flood management is not restricted to actions only in the floodplain.

The Role of Technological Solutions. Clearly, the intensity and pervasiveness of urban land uses may overwhelm the ability of natural processes to mitigate all urban impacts. For example, the concentration and amount of pollutants running off highways may exceed the ability of riparian vegetation (through overland flow) to treat these contaminants. In such cases technological solutions will be needed to protect urban natural resources and restore watershed function.

That said, the point of Restoration Guideline 4 is twofold:

- Wherever possible, restoration efforts should include solutions that make use of natural processes within the urban environment.
- Where excessive constraints simply preclude the use of natural processes, technological solutions should be designed to mimic natural processes to the maximum extent possible, with an understanding of the natural processes they seek to replace being reflected in the design. In addition, solutions should be designed to place as few constraints as possible on natural processes.

Restoration Guideline 4.1: Minimize the introduction and spread of nonnative plant and animal species, especially into relatively natural habitat areas. Numerous fish, wildlife, and plant species have been introduced into Portland's watersheds, either intentionally or by accident. These species alter food web dynamics, transmit diseases and parasites, and may outcompete native species, especially if the introduced species have no natural enemies in their new habitat. Introduced species are particularly adept at capitalizing on altered or degraded habitats such as those in urban areas like Portland. Unfortunately, once introduced species become established they are difficult to control or eliminate. They can lead to permanent alterations of the biological integrity of the ecosystem, and their presence, combined with habitat alteration, can deplete or replace populations of native species. In fact, in urban environments, competition from nonnative plant and animal species is second only to habitat loss as a cause of native species decline (Defenders of Wildlife 2003). According to Suter (1993), some of the most severe effects of human activities on the world's biological communities have resulted from the introduction of exotic organisms.

For these reasons, restoration actions should minimize the introduction or spread of nonnative species, to prevent additional disruption of existing ecosystem processes and functions. This is especially important in relatively natural or undisturbed habitat areas that are already supporting assemblages of native plant and animal species (species that, as described in Primary Ecological Principle 5, themselves help develop and maintain healthy ecological conditions).

Restoration Guideline 4.2: Use native species and emphasize natural habitat features and processes whenever possible in restoration activities. Ecosystem management requires an emphasis on native species. Not only are native species best adapted to the local climate and ecological conditions, but they also play an important role in developing and maintaining those conditions. As described in Primary Ecological Principle 5, species provide ecological functions such as cycling energy and nutrients, structuring habitat and regulating the composition of natural communities through interactions with competitors, predators and prey. Although introduced plant and animal species in urban areas such as Portland may provide habitat values and ecological functions, these values and functions often are less than those of a fully functioning native ecosystem. The configurations of habitats and species resulting from the introduction of nonnatives represent a different, less desirable ecosystem than a natural one that supports a full complement of native species. At worst, introduced species disrupt key ecosystem processes and can lead directly to the decline of native species, as described in Restoration Guideline 4.1, and further ecosystem degradation. For these reasons, restoration actions should use native species whenever possible.