APPENDIX G Selecting Indicators of Watershed Health

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For the watershed management process described in the *Framework* to be successful, the City of Portland must be able to measure its progress in meeting the objectives established for each of the City's watersheds. To do so requires having a set of carefully selected indicators of watershed health that can be monitored over time. This appendix presents a rationale for selecting indicators of watershed health and describes various environmental attributes and influences that, together, constitute the suggested indicators for use in the City's watersheds. However, the final list of indicators to be used will be tailored according to the site-specific conditions in each watershed and the objectives established for each watershed. Specific values to be used as targets or benchmarks for these indicators are not suggested. Rather, such values will be developed during the watershed process and tailored to the conditions in each watershed and the watershed process and tailored to the conditions in each watershed and the watershed process and tailored to the conditions in each watershed and the watershed process and tailored to the conditions work.

What Are Indicators?

Indicators are readily measurable attributes that reflect the conditions and dynamics of broad, complex attributes of ecosystem health that may be difficult to measure directly.

Indicators represent the physical, biological and chemical attributes of an ecosystem and can provide a means of evaluating particular components of a complex system.

Indicators are essential in any scientific effort to restore watershed health because they serve as links between goals and actions. A well-designed watershed management plan typically has a set of goals, each of which - to be useful - is broken down into one or more specific, measurable objectives. Each objective, in turn, is defined further by identifying readily measurable indicators and desired conditions for those indicators (desired conditions are often expressed as target values or ranges of values). Over time, conditions can be monitored and compared with the target values, so that progress in meeting the objective can be measured. Also useful in determining progress are benchmarks, which are specific values or conditions to be achieved at various points along the way, before a particular objective is actually met. Benchmarks also can be useful in periodically evaluating and refining the desired condition or target value for an indicator.



As discussed in Restoration Guideline 2, the selection of indicators for characterizing the health of watersheds is critical. The indicators must be comprehensive enough that they

capture the major components and processes that constitute watershed health, yet they must be measurable at a scale and frequency that are practicable. The factors affecting any ecosystem or species are numerous and complex, and it is unlikely that every process and component of an ecosystem can be measured (Barber 1994). The concept of indicators reflects this reality; indicators are an attempt to represent a highly complex ecosystem using a set of defined, measurable attributes of ecosystem health.

For example, watershed managers might measure fecal coliforms rather than the numerous individual human pathogens with which fecal coliforms are associated. Although the presence and

abundance of the other human pathogens may be the most relevant information in protecting human health, these organisms are difficult to measure, and it is believed that the abundance of fecal coliforms is proportional to the abundance of pathogens. Thus fecal coliforms serve as an indicator for broader threats to human health.

Benthic macroinvertebrates such as mayflies and caddis flies are similarly used to evaluate broader aspects of ecosystem health, for several reasons:

- They are useful as a screening tool because their populations respond relatively quickly to a whole suite of environmental attributes, including water quality, habitat and flow.
- Their presence can indicate whether attributes that are expensive or difficult to measure, such as toxic contaminants, are affecting stream health.
- They are useful in evaluating cumulative impacts on stream health that may not be detected by evaluating measured attributes individually. This can be the case even if a large set of environmental measurements is • available.

Indicators often focus on structural and compositional components of the ecosystem, rather than directly on processes or functions (Mulder and others 1999). This is a matter of practicality rather than priority, as it is easier to measure the width, vegetative composition and connectivity of a riparian area, for example, than to measure the myriad complex functions that the riparian area provides, such as maintaining water quality, providing microclimates, supplying organic inputs into

Characteristics of Good Indicators

- They are directly related to objectives.
- They are readily measurable.
- They are comprehensive and accurately reflect watershed health.
- They convey an understanding of how the ecosystem functions.
- They provide insight into the cause-andeffect relationships between environmental stressors and the response of the ecosystem.

the food web, supplying wood and other functions related to habitat maintenance, channel dynamics and stream morphology.

Indicators are readily measurable attributes that reflect the condition and dynamics of broader, more complex attributes of ecosystem health. Indicators are an attempt to represent a highly complex ecosystem using a set of defined, measurable attributes.

Taken together, a set of indicators should convey an understanding of how the ecosystem functions and the components most important to that functioning. As stated in *The Strategy and Design of the Effectiveness Monitoring Program for the Northwest Forest Plan* (Mulder and others 1999), indicators should provide insight into cause-and-effect relationships between environmental stressors and anticipated ecosystem responses. The indicators chosen for a particular characterization or restoration effort should be based on a conceptual model that clearly links stressors, environmental indicators and ecosystem structure and function. The effect of stressors on indicators should be clear, as should the effect of changes in indicators on the ecosystem's structure and function (National Research Council 1995).

Ideally indicators should meet a broad range of criteria (Barber 1994, Reid and Furniss in press), including but not limited to, the following:

- Be relevant to ecologically significant phenomena and closely tied to management goals and objectives
- Be sensitive to stressors
- Have high "signal-to-noise" ratios, meaning that significant changes in an indicator are due to changes in stressors rather than stochastic variability
- Be quantifiable, accurate and precise
- Be representative of the larger resources of concern
- Provide measurements that can be interpreted unambiguously
- Be cost-effective to monitor

Clearly, many indicators used in monitoring programs across the country, and particularly channel habitat indicators (Baur and Ralph 1999, Reid and Furniss in press), do not meet one or more of these criteria. Indicator development is an area requiring a great deal of focused research before all indicators will fulfill these rigorous criteria (National Research Council 1995). The suggested indicators that the City of Portland describes in this appendix attempt to reflect the state of the science on indicators. As the science develops and as the City applies selected indicators to individual watersheds, insights and information will be gained that can be used to refine the selection of indicators.

Suggested Indicators of Watershed Health

This section outlines the conceptual foundation on which the selection of indicators for Portland's watershed planning is based. The indicators discussed in this appendix are presented as a starting place from which to select specific watershed health indicators for each of the individual watersheds. These suggested indicators are consistent with the efforts of the National Marine Fisheries Service in the Oceanic and Atmospheric Administration (NOAA Fisheries), which has developed a tool – the Matrix of Pathways and Indicators (National Marine Fisheries Service 1996b) – to evaluate the effects of human actions on habitat components important to salmonids. As part of the Matrix of Pathways and Indicators, NOAA Fisheries developed the concept of "properly functioning conditions" (PFCs) to describe the habitat conditions required to support salmonids. The document describing the Matrix of Pathways and Indicators (National Marine Fisheries Service 1996b) makes it clear that not all of the indicators in the matrix necessarily apply to

The City has adapted indicators from NOAA Fisheries' Matrix of Pathways and Indicators and developed new indicators that pertain specifically to urban watersheds. The resulting list will serve as the basis from which the actual indicators for each watershed will be selected. watershed types or land uses that differ from the ones for which the original matrix was developed. NOAA Fisheries originally developed the Matrix of Pathways and Indicators for high-gradient, forested landscapes, primarily to evaluate the effects of actions associated with the forest products industry. Evaluating conditions in urban watersheds requires an adapted matrix. NOAA Fisheries is in the process of developing matrices of pathways and indicators for urban land uses and for different types of waterbodies. However, these adapted matrices were not available at the time of publication of the *Framework*. Through a regional workshop sponsored by the City of Portland's Endangered Species Act Program in 1999, the City of Portland has identified indicators

from the original matrix that are relevant to urban watersheds. The City also has developed additional indicators that specifically address the structure of, function of, and impacts to

local urban watersheds, based on what the City has learned about conditions in Portland-area watersheds. It should be noted that the indicators described in this appendix are not the final list of watershed health indicators the City will use; rather, they serve as the basis from which the actual indicators for each watershed will be selected.

The set of indicators suggested by the City of Portland in this *Framework* and those that are ultimately used for measuring watershed health within specific watersheds and subwatersheds (as well as the concepts on which they are based) will be refined

over time. In particular, the concepts underlying the selection of indicators will be developed further to identify in greater detail the mechanistic and functional connections among the identified components of the riverine-riparian ecosystem. Additional indicators for terrestrial species and habitats in the ecosystem will be selected in the future.

A central assumption underlying the set of attributes used in characterization, and ultimately the indicators that the City of Portland will use to evaluate watershed health, is that watershed conditions are defined by three major elements: landscape factors, specific attributes of watershed health, and human influences and activities across the watershed. These three elements are shown in Table G-1 and described in the rest of this appendix.

Landscape Factors

Landscape factors are broad-scale influences such as climate, geology, topography and soils that play a major role in determining the structure, dynamics and function of a watershed. Landscape factors set constraints on, and in many ways determine, the form and function of a watershed. They are characterized and understood through the use of watershed classification systems (Restoration Guideline 1.2) and ecoregional classification (Omernik and Bailey 1997).

The indicators used to measure watershed health within specific watersheds and subwatersheds will be refined over time to better reflect the connections among the components of the ecosystem.

TABLE G-1

Factors That Influence Watershed Conditions

Landscape Factors 🗕	Watershed Health Attributes (Potential Indicators)	Human Influences
Landscape Factors → Climate Physiography Lithology/soils Watershed morphology Hydrology Vegetation	 Watershed Health Attributes (Potential Indicators) Hydrology Hydrograph alteration Floodplain presence and connectivity Groundwater Physical Habitat Floodplain quality and connectivity Riparian condition: width, composition and fragmentation Stream connectivity Channel condition and habitat structure: Habitat types Bank erosion Channel substrate (fine/coarse) Off-channel habitat (tributary and side channels) Refugia (depth, boulders, undercut bank and wood) Large wood 	Human Influences Land use Impervious surfaces Dam impacts Water withdrawals Drainage network Channel alterations Vegetation management Wetland alteration Outfall discharges Exotic species Harassment Harvest Hatchery management Spills and illicit discharges
	Terrestrial habitat (e.g., oak woodland) Wetland habitat Water Quality Water temperature Dissolved oxygen Nutrients and chlorophyll <i>a</i> Total suspended solids Toxic contamination of water, sediments an Groundwater quality Other 303(d)-listed TMDL parameters Other parameters (as determined by weight Biological Communities Biotic integrity Benthic communities Salmonid population structure (abundance, spatial structure, diversity) Species interactions (predation, competition exotic species, etc.) Riparian wildlife Terrestrial wildlife Plant communities	d biota t of evidence) . productivity,

Landscape factors themselves are not environmental indicators, but they are fundamental factors that strongly influence the conditions within a watershed. Therefore, understanding landscaping factors helps in interpreting current and predicted conditions of indicators. Landscape factors are described during the characterization stage of the watershed planning

process to understand historical or properly functioning conditions. Later, they are used when setting watershed health objectives, targets and benchmarks. For example, landscape factors could be useful in determining an appropriate target for stream temperature that accounts for natural local conditions, or in setting targets for the amount of wood desired in a particular stream reach. Information about landscape factors is also useful when planning and implementing actions, such as when determining the type of vegetative community that should be reestablished as part of a restoration project. For example, in high-gradient streams with significant groundwater input, landscape factors might point to conifer-dominated plant communities and a relatively low value for

stream temperature as appropriate objectives, whereas for a large, low-gradient river, landscape factors might suggest higher stream temperatures and cottonwood gallery forests.

Watershed Health Indicators

The *Framework* lays out an approach for getting from watershed health goals and objectives to actions and results. To know whether goals and objectives are being achieved requires

knowing what to measure – that is, the indicators of watershed health. The *Framework* presents watershed health indicators that fall under the four categories of goals – hydrology, physical habitat, water quality and biological communities – and recognizes that healthy watersheds include healthy riparian-riverine *and* terrestrial ecosystems and biological communities. The primary ecological principles in Chapter 2, many aspects of the riverine, wetland and

upland principles and the restoration guidelines apply to terrestrial species and habitats as well as to aquatic.

The National Research Council (NRC) says that "rivers and their floodplains are so intimately linked that they should be understood, managed, and restored as integral parts of a single ecosystem" (National Research Council 1992, pp. 184-185). The NRC defines the general term "riverine-riparian ecosystem" to include both large systems – where large rivers and their floodplains form a single ecosystem – and small systems – where streams and their riparian zones form a single ecosystem.

The *Framework* evaluates the integrity of watersheds through four major categories of watershed health indicators: watershed hydrology, physical habitat, water quality and biological communities. Indicators will be established for each category and will describe the health of the ecosystem in the following ways:

• By identifying the ecological functions currently being provided in the watershed. This information, when combined with information on landscape factors and evaluations of reference areas (that is, sites whose landscape factors are similar but that are subject to

Landscape factors themselves are not environmental indicators, but they strongly influence conditions in watersheds. Therefore, it is helpful to understand landscape factors when interpreting the condition of indicators.

To achieve healthy watersheds, both aquatic and terrestrial components will need to be addressed. fewer human disturbances), can help identify ecological functions lost as a result of human impacts.

- By revealing how the ecosystem responds to stressors, as described by the National Research Council (1995).
- By representing components of watershed processes and habitat functions that are key to supporting healthy watersheds and healthy, self-sustaining populations of salmon and other organisms.

While the watershed health indicators reflect conditions with which many protection and restoration programs are concerned, these indicators are not effective in identifying the causes of any identified degraded conditions. As discussed in Restoration Guideline 3.3, degradation of a component of the ecosystem could be attributable to any number of potential causes. For restoration actions to be effective, careful effort must be directed toward identifying and quantifying the sources of degradation so that appropriate solutions are developed. The indicators of human influences are particularly useful in this effort.

Evaluating the watershed health indicators described below can provide a tremendous amount of insight into the status of a watershed and the types of factors that threaten its integrity. To prioritize stream reaches and degraded conditions that should be addressed through restoration, the City of Portland employs technical methods and analytical tools (described in Appendix H) that make use of the measurements of the following watershed health indicators. It is important to keep in mind the linkages between the indicators described here and the ecosystem functions and processes they represent. These linkages are presented in Table G-6, after each of the watershed health indicators is described.

Hydrology Indicators

Development within urban landscapes has altered the hydrology of urban watersheds extensively. Many of the activities and actions associated with urbanization contribute directly or indirectly to substantial changes in the magnitude, frequency, timing and duration of stream and river flows. For example, the proliferation of impervious surfaces in urban watersheds dramatically increases peak flows (Leopold 1968, Hollis 1975, Booth 1991), which can cause direct mortality of salmonids, force salmonids from rearing areas and degrade physical habitat. Impervious surfaces may also reduce groundwater recharge and thereby reduce summer baseflows, which, in turn, can lead to the dewatering of smaller tributaries and, in larger tributaries, increased stream temperatures and decreased levels of dissolved oxygen.

Flows in the Willamette and Columbia rivers in the Portland area are most affected by alterations in flow from various upriver activities, such as reservoir operations. However, at the local scale, key factors acting on flow in Portland tributaries (as in other urban settings) include replacing natural vegetation with impervious surfaces, altering floodplain storage capacity and the frequency of floodplain inundation, and withdrawing water.

A1: Hydrograph Alteration. As described in detail in Riverine, Wetland and Upland Ecology Principle 3, flow alteration is a key factor affecting the suitability of habitat for salmonids and many other species in all of Portland's watercourses. Flow in tributaries is altered by a wide variety of urban activities, including the proliferation of impervious surfaces, significant diversions or manipulations in flows, channelization or operation of flood

control structures. In contrast, in large rivers the primary influences on flow are various upriver effects, such as reservoir operations, rather than increases in the amount of local impervious areas (although impervious areas do have impacts on other aspects of watershed health, such as water quality). Comparing existing flow conditions to the historical hydrograph (where available) or an estimated "natural, unimpaired" hydrograph (that is, the existing hydrograph adjusted for unnatural flow gains or losses resulting from the effects of storage, diversions, impervious surface runoff, etc.) describes the degree of hydrograph alteration from "normative" river conditions. In this context, "normative" refers to a flow regime that provides characteristics of flow magnitude, frequency, duration and timing essential to support diverse and productive salmonid populations (Independent Scientific Group 2000). Additional information on the use of flow alteration indicators and their meaning is described in two other sources. The Indicators of Hydrologic Alteration (IHA) method (Richter and others 1996) quantifies differences in IHA parameters between "before" and "after" flow regimes. The IHA analysis evaluates IHA parameters to explore changes and effects of watershed development on aspects of the flow regime that correspond to known ecological responses. Metrics to characterize the influence of urban development on storm flow and baseflow patterns have also been developed by the University of Washington's Center for Urban Water Resources Management (Conrad 2000).

A2: Floodplain Presence and Connectivity. The interconnection of an undisturbed stream channel and its floodplain area via periodic flood inundation provides several important functions essential for supporting diverse and productive salmonid populations. These functions include flow detention, groundwater-baseflow recharge, water quality filtration and the provision of side-channel and off-channel refuge and feeding habitats, particularly for rearing juvenile salmonids and native resident species. Two indicators are proposed for assessing floodplain connection: floodplain presence and floodplain inundation frequency. Floodplain presence is used to assess available floodplain presence and size based on typical valley width to channel width (VW:CW) ratios that would be expected under natural conditions according to channel type (Leopold and others 1992, Grant and Swanson 1995, Rosgen 1996). Floodplain inundation frequency is used to assess the frequency of flows that overtop channel banks into the floodplain. These flows provide the hydrologic link between off-channel habitats and the main channel, and they maintain floodplain wetland function and riparian vegetation and function.

A3: Groundwater. Groundwater plays a large role in maintaining the quality and quantity of water in stream and river ecosystems. It is an important source of summer baseflow and provides inputs of cool water that can moderate stream temperatures. Depending on the quality of groundwater relative to surface water, groundwater may either dilute or contribute pollutants to the stream environment. Groundwater also supplies hyporheic flows, which are important for successful salmonid spawning.

Groundwater presents difficulties as an indicator. Measuring the quantity and quality of groundwater entering a watershed is challenging, as is understanding groundwater's effects on the stream ecosystem. In this appendix, groundwater is listed as a potential indicator to emphasize its critical importance to the proper functioning of stream and river systems but with the realization that additional work is needed for groundwater to be practically measured and used in evaluating watershed health.

TABLE G-2

Hydrology Indicators and Metrics

Indicators	Metrics*
A1: Hydrograph Alteration	Peak flow
	Baseflow
	Seasonal patterns in hydrograph (such as mean monthly flows)
	Diel and tidal variability
	Percentage of the time that daily mean discharge exceeds annual mean discharge
	Coefficient of variation in the annual maximum flood
A2: Floodplain Presence and	Area of historically connected floodplain/area of currently connected floodplain
Connectivity	Frequency of overbank flow
A3: Groundwater	[Groundwater metrics are under development.]

*Metrics are the characteristics of an indicator that are measured to evaluate its condition.

Physical Habitat Indicators

Habitat quality and quantity are important determinants of the structure and function of riverine ecosystems (Frissel and others 1986) and of the health of the biological communities within them (Gregory and Bisson 1997). Aquatic habitats in urban and urbanizing areas such as Portland are more highly altered than in any other land-use type in the Pacific Northwest (Gregory and Bisson 1997). Activities and land use changes associated with urbanization significantly alter hydrology, soils and riparian vegetation in ways that can directly affect salmonids through modification or loss of riparian and instream habitats. Habitat can be altered by direct and indirect effects of human perturbations and/or by preventing natural processes from occurring (National Research Council 1996).

The fundamental building blocks of instream habitat are water, substrate, wood and energy (Naiman and others 1992, Washington Forest Practices Board 1995). The processes that supply these building blocks are supported by normative hydrology and floodplain connectivity, healthy riparian zones and good water quality. If these components are intact, the instream components of habitat that aquatic biota require – floodplains, pools and riffles, large wood and appropriate substrate – will be maintained by watershed processes.

The physical habitat indicators address the components of riparian zones that create and maintain habitat, the instream structures that make up physical habitat for aquatic biota and the factors that determine whether existing habitat is accessible. *Indicators for terrestrial and wetland habitat are under development.*

A4: Floodplain Quality and Connectivity. Floodplain presence and connectivity (described previously) emphasize the need to have intact and connected floodplains to, among other things, attenuate flows and moderate normative flows. However, floodplains also provide important habitats for salmon, such as overwintering habitat, refuge from high flows and feeding and rearing areas (Gregory and Bisson 1997). And floodplains contribute organic

matter, substrate and large wood to the stream system. These important functions are associated with floodplain quality.

The floodplain quality indicator addresses the fact that floodplains must have proper physical structure and vegetation to provide these functions. In urban areas, the frequent development of floodplains results in extensive vegetation removal, increased numbers of nonnative species, conversion to impervious surfaces, alterations to landforms through excavation and filling, and soil contamination. These activities ultimately remove the floodplain components that provide valuable ecological functions.

A5: *Riparian Condition: Width, Composition and Fragmentation*. Riparian areas provide multiple functions that are essential for aquatic habitats and wildlife (Gregory and others 1991, Forest Ecosystem Management Assessment Team 1993, Castelle and others 1994). Riparian areas shade streams and moderate stream temperatures, provide overhead cover, filter sediments and runoff, and provide a terrestrial source of organic matter and insects that support aquatic food chains. Riparian areas also provide a source of large wood in channels and control streambank erosion and hillslope sediment production (mass-wasting) (Castelle and others 1994).

There is considerable variability in the definition of an "intact" riparian area. May and Horner (2000) state that important elements of riparian integrity include riparian corridor width, riparian corridor connectivity, vegetative composition and stand maturity. Notably, riparian width varies with local topography, geology and soils (see landscape factors, discussed earlier in this appendix) as well as the type and degree of human use (see human influences, discussed later in this appendix). Thus optimal riparian conditions vary depending on, among other factors, stream size, stream gradient, locale (headwaters vs. confluence), vegetation types and adjacent land use.

Generally, wider and more intact riparian corridors are more desirable than narrow and highly fragmented corridors. The width of the riparian corridor indicates the expanse of vegetative cover extending from both streambanks. This is important for shading the stream corridor and stabilizing streambanks, floodplains and hillslopes.

The composition, age and spatial structure of tree and shrub species are also important to consider when evaluating a riparian area's potential contributions to stream health. Different tree canopy coverages throughout the year encourage the development of different environs for riparian-dwelling species. Notably, the mixed conifer and deciduous forest stands that historically were common in upland habitats of the lower Willamette Valley remain important today. These forest types contribute significant pieces of wood to the stream channel, stabilize streambanks, provide leaf litter to the stream and generally maintain native vegetative communities. In contrast, forest stands dominated by deciduous trees and having few conifers make less significant contributions to the stream. Some deciduous trees are not adapted to aquatic fringe habitats the way certain conifers – such as western red cedar – are, and deciduous trees provide very different leaf litter and large woody debris to streams than conifers do. In addition, hardwoods generally decompose more quickly than conifers. The combination of these effects can significantly affect riparian condition and the benefits it provides to stream health.

A6: Stream Connectivity. Salmonids require a variety of connected habitat types and conditions throughout their lives. Adults need opportunities to migrate upstream and spawn, while juveniles and resident trout require opportunities to move while rearing to find food, avoid predators and seek unique habitat niches. Ideally these opportunities exist year-round, but they are especially important during fall/winter adult migrations, spring emigrations and summer low-flow conditions.

Stream connectivity is affected by natural and artificial features (usually hard and fixed) within and along the stream channel and conditions occurring in the stream. For example, culverts, dams, sewer lines and concrete walls can totally, partially or temporarily (usually seasonally) block fish passage via physical obstruction or by creating hydraulic or hydrologic conditions that impede fish movement. High-water velocities at a culvert inlet or outlet or within a culvert can overwhelm prolonged and burst swimming speeds, thus creating velocity barriers. Shallow water depths (less than 6 inches) within a culvert may limit a fish's ability to swim upstream or downstream, thus stranding or isolating it in specific stream reaches. Depending on the culvert design (high flow vs. low flow), stream flows may delay fish from accessing upstream and downstream sites at critical times and may distribute fish into less than ideal locations. Finally, the height between a culvert outlet and the water surface may exceed maximum jumping heights for salmonids, rearing trout or both.

Habitat breaks or altered boundaries that adversely affect a fish's migratory potential can impair a population's ability to persist and reproduce. Specifically, delayed adults may expend a great portion of their energy reserves, resulting in weakened fish that are more disposed to disease or prespawning mortality or, in females, retention of eggs. Additionally, eggs may be deposited during unfavorable environmental conditions for egg and fry survival; this can leave headwater areas poorly seeded while downstream reaches exceed their stream carrying capacity. In summary, the number, location and type of barriers in a watershed act as a filter that determines the amount of habitat available to each species and age-class of fish (Oregon Department of Fish and Wildlife 1999).

Channel Condition and Habitat Structure

Physical attributes and processes affecting habitat quantity and quality are often interrelated. For example, bank stability influences the amounts and types of substrate entering the creek bed, which in turn affect the amount and extent of silts overlaid on spawning beds. Vegetative composition and size significantly affect stream temperature and bank stability in the present, but they also influence the potential for large woody debris recruitment into the stream in the future. For practical purposes, the channel condition and habitat structure indicators presented below are discussed as discrete topics, but in actuality they are interrelated factors that interact to influence habitat formation and ecosystem dynamics. The indicators that reflect channel condition and habitat structure are as follows:

- Habitat types
- Bank erosion
- Channel substrate
- Off-channel habitat

- Refugia
- Large wood

A7: *Habitat Types*. The amount and type of habitat found in riverine systems affect the biotic potential of that stream. Stream structure and habitat sequencing (pool-riffle sequences vs. pool-glide-pool, for example) are major factors in determining habitat function. Salmonids require different physical environments, such as gravel and cobble habitats, deep pools and – for some species – slack water, throughout progressive stages of their life. Without an adequate amount and proportion of each, physical habitat can limit salmonid productivity within a subbasin.

Gravels and cobbles are predominate substrates in riffles and often in pool tail-outs. These habitats are important to salmonids during spawning, egg incubation, fry emergence and rearing. Additionally, they provide important substrata for production of epifauna and subsequently macroinvertebrates, which are a critical food source for aquatic biota.

Pools are particularly valuable refuge areas for juveniles and migrating and spawning adults in the winter and during storm events. In general, a variety of pool types is required to provide the range of habitat needed by different species and life stages throughout the year. Pools are important to rearing juvenile steelhead, Chinook and cutthroat, which reside and overwinter in deep pools, off-channel pools and slack water. In addition, fish seek deep pools for cover and refuge from predators. Some runs of adult salmon hold in deep pools en route to their natal stream and require deep areas to navigate past barriers such as cascades, falls, debris jams or culverts. Notably, adult spring Chinook hold in deep pools for several months between the time they enter freshwater and the time they spawn, which they also do in pools (of deeper than 0.24 meter). Additionally, some salmonids prefer deep habitats, at higher velocities; as an example, juvenile coho often prefer deep waters (0.3 meter to 1.2 meters) in submerged riffle habitats (U.S. Fish and Wildlife Service 1983). Pool frequency is assessed by the number of pools within a given distance of stream channel length. Under natural, undisturbed conditions, a fairly predictable relationship exists between channel type and the longitudinal distance between pools (Schuett-Hames and others 1994, Montgomery and Buffington 1993).

In addition to deep pools, slack and shallow water habitats are especially important for coho salmon, which often migrate to lower river reaches during their juvenile maturation and seek slack water, side channels or backwater pools in which to overwinter. These environs provide year-round food sources and cover and are generally devoid of other competing salmonids. Co-occurring steelhead, Chinook and cutthroat often overwinter in deep pools on mainstem or tributary reaches.

Gravel and cobbles, deep pools and slack and shallow water are not the only physical habitat types that influence salmonid population structure. The presence and area of other habitat forms, such as steps, cascades, rapids and glides, determine the spatial distribution of both anadromous and resident fish populations. Notably, steps, cascades and rapids can naturally impede fish from moving upstream and thus effectively isolate populations. In addition to these natural habitat forms, piped reaches impede fish passage and lessen the amount of natural creek bed, effectively limiting subsequent biotic production. Especially in urban streams, culverted creek reaches can make up a significant amount of instream

habitat, thus limiting the carrying capacity or productivity that a system would be expected to support.

A8: Bank Erosion. Bank erosion is indicative of a system's ability to withstand erosive flows. Some erosion is natural and expected. However, when erosion is above what is considered normative, banks become unstable and excess sand, silt and organics fall into the waterway. Regular, severe infusions of bank materials into the creek often result in high concentrations of suspended and settleable solids that impair both habitat and water quality. Generally, areas where 30 percent to 60 percent of the streambank consists of bare soil, without root networks and possibly showing signs of sloughing, are considered moderately unstable and have a high potential for future erosion (Barbour 1999).

A9: Channel Substrate (Fine/Coarse). This indicator evaluates the proportion of boulders, cobbles, gravels, sand, silt and organic matter that make up the channel bottom. Gravels and small cobbles are critical for salmon spawning and incubation. The presence of excessive fine sediment in the interstitial spaces of gravels and cobbles (termed "embeddedness") can limit the amount of water – and thus dissolved oxygen – that reaches incubating salmon eggs. It also can impair fry emergence by creating a barrier over the substratum and preventing fry from reaching the water column, and it can limit juvenile rearing opportunities by covering the substratum and limiting the epifauna production and subsequent macroinvertebrate productivity that salmonids depend on. Boulders likewise provide important cover for salmonids and add roughness to a stream channel.

Salmonids require an array of substrate sizes (from 1.3 to 14 centimeters) to successfully spawn in, and consequently for eggs to incubate and fry to successfully emerge and rear. Bed materials cannot be embedded or extensively covered in fine silts and sediments. Rather, they must be relatively loose so that salmonids can successfully dig redds and lay eggs and the eggs can be exposed to adequate flows and oxygenation during incubation. Substrate permeability is critical to the development and emergence of salmonid fry.

Amassed fine sediment (meaning particles less than 0.1 inch in diameter) and extreme silt loads (greater than 25 milligrams per liter [mg/L]) (Bell 1973) can clog fish gills, affecting a fish's ability to absorb oxygen, and can also trap fry attempting to leave the gravel. Additionally, fine sediment covering cobbles and gravels reduces interstitial spaces that are used by aquatic invertebrates, a primary food source for salmonids. Excessive fine sediment content in rivers and streams, particularly in those channel types where such fine sediment content historically was not present, indicates possible sedimentation problems that are often associated with excessive runoff or hillslope and channel erosion.

A10: Off-Channel Habitat. Side channel and off-channel habitats are important feeding, resting and rearing areas and, by providing protected areas with lower flow velocities, serve as key refugia during flood events. Off-channel habitats may provide spawning areas for coho and chum salmon (Cederholm and others 1988, Samuelson 1990), rearing and overwintering areas for many species (a number of studies summarized in Keeley and others 1996) and year-round residence for cutthroat and several non-salmonid fish species (Cederholm and Scarlett 1981, Peterson 1982). Survival in off-channel areas can be at least twice as high as in mainstem habitats during the winter period (Bustard and Narver, 1975). Numerous investigators have shown that coho salmon have strong preferences for off-channel habitats (Everest and others 1985, Glova 1986, Taylor 1988, Bugert and Bjornn 1991), and Nickelson

and others (1992) found that elimination of off-channel rearing areas was a significant limiting factor in coho production in coastal streams. In addition, off-channel overwintering ponds have been shown to be one of the most effective types of salmonid enhancement (Cederholm and Scarlett 1988).

A11: Refugia. Streamside vegetation, undercut banks, boulders, turbulent areas, deep pools and large pieces and clusters of wood provide physical refuge to salmonids. These environs provide important rearing habitat, shelter during high flows, cool water refugia when water temperatures are high and protection from predators. The amount, type and location of instream cover play an important role in salmonids' selection of habitat for spawning and rearing (U.S. Fish and Wildlife Service 1983).

In contrast, in large rivers it is often the lack of shallow water habitats that limits salmonid productivity. Dredging, channelization and the elimination of off-channel habitats have greatly reduced the amount of shallow water habitat in large, low-gradient rivers (City of Portland Endangered Species Act Program 1999). Shallow water provides important rearing habitat for juvenile salmonids (Levy and Northcote 1982, Brown and Hartman 1988) and refuge from larger aquatic predators.

A12: Large Wood. Large wood is one of the most important structural components in forming and maintaining salmon habitat (National Research Council 1996). A number of reviews have concluded that large wood provides a wide range of functions in physical habitat formation, including pool creation, storage of sediment and organic matter and maintenance of a high degree of habitat complexity in streams (Harmon and others 1986, Bisson and others 1987, Gregory and others 1991). Wood in large rivers has an important effect on local channel hydraulics and provides refugia by contributing to the formation of pool and side-channel habitats along channel margins (Abbe and Montgomery 1996, Bisson and others 1987).

Indicators	Metrics						
A4: Floodplain Quality and	Vegetative composition of floodplain						
Connectivity	Amount of fill in floodplain						
	Number of artificial structures in floodplain						
	Ecological risk assessment of contaminants in floodplain						
	Valley width index						
	Stream gradient						
	Entrenchment ratio						
	Land use						
A5: Riparian Condition: Width,	Width of vegetated zone						
Composition and Fragmentation	Species composition (grasses, shrubs and trees), age structure and percentage of tree canopy cover within the riparian area						
	Percentage of native vegetation						
	Number of breaks per reach length						
	Impervious area						
	Bank condition (hardened, landscaped, natural form)						

TABLE G-3 Physical Habitat Indicators and Metrics

TABLE G-3

Physical Habitat Indicators and Metrics

Indicators	Metrics
A6: Stream Connectivity	Number and impact (totally impassable, partially impassable or temporarily impassable) of culverts or other natural and artificial hydraulic breaks (waterfalls, stormwater pipes, flood control structures, etc.)
A7: Habitat Types	Proportion of wetted area composed of pools, glides, riffles, cascades, rapids, steps and piped creek beds
	Pool quality (percentage of pool area or frequency, residual pool depth and pool complexity)
	Riffle quality (percentage of riffle area and substrate composition)
A8: Bank Erosion	Percentage of bank actively eroding
	Bank slope
A9: Channel Substrate (Fine/Coarse)	Substrate size and composition (boulders, cobbles, gravels, sands, fines and organics) by habitat type
	Embeddedness
	Turbidity (total suspended solids, or TSS)
A10: Off-Channel Habitat	Currently accessible tributaries/historically accessible tributaries
	Number of stream miles with secondary channels
	Area of "off-channel" habitat per mile
A11: Refugia	Number of pools per mile (could be broken out by pool types)
	Evaluation of pool quality
	Frequency distribution of depths
	Area of shallow water (less than 20 feet for large rivers)
	Percentage of undercut bank
	Percentage of substrate composed of boulders (in pools)
	Evaluation of large wood
A12: Large Wood	Number and size distribution of wood pieces per 100-meter stream length
	Wood volume per 100-meter stream length
	Key pieces per 100-meter stream length

Water Quality Indicators

Urbanization markedly degrades water quality. Stormwater runoff and combined sewer overflows can discharge nutrients and toxic contaminants from roadways and other surfaces into waterways (Novotny and Olem 1994), while point and nonpoint source discharges and removal of riparian vegetation can substantially increase nutrient and thermal loadings to waterways. Construction activities also can impair water quality via sedimentation. Nearly all of the watersheds in Portland fail to meet their designated beneficial uses (defined by the federal Clean Water Act) because of degraded water quality. The indicators proposed for this category were developed to reflect components of water quality that threaten stream health.

A13: Water Temperature. Temperature affects the survival and growth of stream biota. Increases in temperature can alter metabolism and behavior, reduce survival and reproductive success, and increase susceptibility to diseases and parasites (Poole and others

2001). Increases also can alter the composition and productivity of stream communities and thus alter food supply and species' interactions with competitors and predators (Beschta and others 1987, Bjornn and Reiser 1991). None of Portland's watersheds meet State of Oregon temperature standards during summer months.

A14: Dissolved Oxygen (DO). Oxygen is a critical component in the functioning of healthy aquatic ecosystems. It plays an important role in making energy available for biological processes, and biota within streams and rivers require it for respiration. Microorganisms require oxygen for oxidative processes important in breaking down organic matter and other key processes. In addition, a number of critical chemical processes, including the adsorption and release of pollutants in sediments, are strongly affected by the presence of oxygen (Strobel and Heltshe 2000).

Salmon, which are particularly sensitive to oxygen concentrations, require high levels of dissolved oxygen. Low levels of oxygen (less than 6.0 mg/L) impair the growth and development of embryos and fry and the swimming ability of migratory adults and juveniles (Bjornn and Reiser 1991).

Most monitoring efforts collect data on dissolved oxygen in the water column. This provides important information on the suitability of conditions for salmonids, but it is important to realize that, because oxygen solubility in water is limited, oxygen concentrations can vary greatly through the water column in streams and rivers that are not well mixed. The location at which oxygen data are collected has a large effect on the results. In fact, oxygen concentrations at the interface of substrate and water may be considerably lower than concentrations in the water column (Prescott, unpublished data). Salmon eggs and alevin are highly sensitive to oxygen to accurately reflect the conditions to which salmon eggs and alevin are exposed.

A15: Nutrients and Chlorophyll a. Evaluation of nutrients and chlorophyll *a* illuminates the production dynamics of aquatic ecosystems and can indicate when nutrient and production levels become excessive as a result of inputs from human activities. Excessive nutrients can have adverse effects on aquatic ecosystems. For example, nitrite-nitrogen can be toxic to rainbow trout, and ammonia is toxic to aquatic invertebrates and fish (U.S. Environmental Protection Agency 1986). In addition, high levels of nitrogen and phosphorus compounds may result in eutrophication, wherein algal growth is stimulated to the point that high levels of algal respiration reduce dissolved oxygen levels.

A16: Total Suspended Solids (TSS). Total suspended solids have been selected as an indicator because measures of TSS and turbidity can provide important information about two critical components of watershed health: sediment supply and contaminant dynamics. Human activities that alter sediment supply and dynamics can have far-reaching impacts. Changes in sediment supply can harm habitat for fish and aquatic organisms (see the channel substrate indicator); affect the shape, sinuosity and pool-riffle structure of streams; and have direct physical impacts on aquatic organisms (U.S. Environmental Protection Agency 1991). In addition, because many nutrients and toxic contaminants sorb strongly to sediment particles, runoff of sediments from urban land uses can be a significant pathway by which these contaminants are introduced to the aquatic ecosystem (Novotny and Olem 1994).

A17: Toxic Contamination of Water, Sediments and Biota. Urban areas have the potential to contribute metal and organic contaminants to streams and rivers in amounts that are toxic to aquatic organisms. A number of studies have identified adverse impacts of toxic contaminants on aquatic ecosystems (U.S. Environmental Protection Agency 1983, Meyers and others 1985, Novotny and Olem 1994). Many of these contaminants are hydrophobic and adhere strongly to sediments or bioaccumulate within the tissues of aquatic organisms. Nationwide, the toxic contamination of sediments and organisms is pervasive and in many urbanized areas severe (U.S. Environmental Protection Agency 1997).

Toxic contaminants can directly affect the health of salmonids. Juvenile salmon migrating through urban areas with contaminated sediments may have reduced growth and survival rates and be more susceptible to disease (Varanasi and others 1993) than juveniles migrating through areas without contaminated sediments. Locally the issue of toxic contaminants is an important indicator for restoration because the Portland Harbor area has high concentrations of contaminants known to affect salmon and other aquatic organisms (U.S. Environmental Protection Agency 1998).

A18: Groundwater Quality. As mentioned earlier, groundwater is an important component of stream health, although its effects on the stream ecosystem are difficult to quantify accurately. To the extent possible, the role of groundwater in contributing pollutants – or in providing clean water that dilutes stream contaminant concentrations – should be evaluated.

A19: Other 303(d)-listed TMDL Parameters. The 303(d) list is a list of stream segments that do not meet their designated beneficial uses as defined by the federal Clean Water Act and that have parameters that fail to meet the act's water quality standards. Because many of the designated uses of a waterbody are ecological, the 303(d) list is helpful in identifying water quality attributes that are impairing the ecological health of a watershed. Any 303(d)-listed total maximum daily load (TMDL) parameters not captured by the indicators above should be used as indicators for the health of the watershed.

A20: Other Parameters (as determined by the weight of evidence). Some important contaminants are not addressed by water quality standards. Diazinon, for example, is a pesticide commonly used in urban areas that does not have a water quality standard in Oregon yet has the potential to affect watershed health (Scholz and others 2000). In addition, the complex fate and transport of many organic contaminants in the environment may mean that these contaminants are poorly addressed through existing sediment and water quality standards. For example, emerging research by NOAA Fisheries' Montlake Research Laboratory is finding that fish are adversely affected by polycyclic aromatic hydrocarbons (PAHs) at concentrations below existing standards (Johnson 2000). Where the weight of evidence (biological monitoring, pesticide use studies, emerging research, etc.) indicates that contaminants that are not on the 303(d) list have significant adverse effects on biological communities or ecological functions, those contaminants should be tracked and evaluated as indicators.

TABLE G-4

Water Quality Indicators and Metrics

Indicators	Metrics
A13: Water Temperature	Mean 7-day maximum
	[A metric also needs to be developed to reflect localized variation in temperatures and the presence of thermal refugia (for example, the number, spatial distribution and flow of groundwater seeps).]
A14: Dissolved Oxygen	mg/L DO
	Percent saturation
	Intergravel DO
A15: Nutrients and Chlorophyll a	mg/L of ammonia, nitrogen (nitrate + nitrite), total phosphorus, orthophosphate and chlorophyll <i>a</i>
A16: Total Suspended Solids	mg/L TSS
	Turbidity
A17: Toxic Contamination of Water,	Area with contaminant levels exceeding risk-based effects thresholds
Sediments and Biota	Number of species with tissue contaminant levels exceeding the risk- based effects thresholds
A18: Groundwater Quality	The parameters above applied to groundwater inputs
A19: Other 303(d)-listed TMDL Parameters	Determined by listed parameter
A20: Other Parameters (as determined by the weight of evidence)	Specific to parameter

Biological Communities Indicators

A21: *Biotic Integrity.* Biotic integrity has been defined as the ability to support and maintain a balanced, integrated, adaptive community of organisms having a composition, diversity and functional organization comparable to that in the natural habitats of the region (Frey 1977). A widely used indicator of the integrity of fish communities – and human impacts on them – is the index of biotic integrity, or IBI (Karr and others 1986). Specifically, the IBI reflects important components of an ecosystem, such as taxonomic richness (the number of native families and native species present), habitat guilds (benthic species, native water column species, hider species, sensitive species, nester species and the proportion of tolerant individuals), trophic guilds (the percentages of filter-feeding individuals and omnivores) and individual health and abundance (the percentages of target species and individuals with anomalies). Fish surveys can be queried to derive an IBI rank and subsequent description of biotic integrity.

In addition to absolute IBI scores and what that implies in terms of biotic impairment, data on the presence or absence of fish can be evaluated to determine relative water quality condition, based on an individual family's tolerance for silty, warm and polluted waters. Salmonids tend to be sensitive to water quality conditions, while nonnative species tend to be tolerant of degraded water quality. For example, common carp are omnivorous, are exceptionally tolerant of warm, turbid, silty water and are indicators of seriously degraded habitat conditions (Mebane and others 2003).

A22: Benthic Communities. Biological communities that spend the majority of their life cycle in local watersheds, such as benthic macroinvertebrates, can supplement salmon as a reflection of local conditions. Benthic macroinvertebrates have been used extensively in assessing the chemical, physical and biological health of watersheds and in assessing cumulative effects (see, for example, Karr and Chu 1999). The City of Portland and Portland State University are in the process of developing biological indices for local watersheds that use benthic macroinvertebrates and algal community composition. The metrics that arise from this effort will be used as indicators of biological communities. These and other metrics will be more fully described and justified as the City of Portland and Portland State University work is completed.

Ephemeroptera-plecoptera-trichoptera (EPT) taxa are sensitive macroinvertebrate species that are often used as indicators of macroinvertebrate production and coarse-level stream health. Notably, the number or proportion of EPT taxa are thought to decrease as environmental perturbations increase.

Algae (attached periphyton) also have been used successfully as indicators of stream conditions (Stevenson and Pan 1999) because they have short generation times and they respond rapidly to a variety of physical and chemical variables such as nutrients (Pan and others 1996), pH (Pan and others 1996) and herbicides (Hoagland and others 1996). Algae often are the first group of organisms to respond to both environmental degradation and recovery. In addition, using indicator species at a variety of trophic levels (meaning levels within the food web) can provide insight into energy sources and flows through the ecosystem.

A23: Salmonid Population Structure. Legally, culturally and ecologically, salmon are important indicators of the health of a watershed. In *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units* (McElhany and others 2000), NOAA Fisheries defines four key population attributes that are important to assess in restoring salmon:

- Abundance. Also referred to as population size, abundance is an important measure of a population's health and fitness at various life stages. All else being equal, small populations are at greater risk of extinction than large populations because they have less buffering capacity to withstand severe environmental change or catastrophic loss. Simply put, in large populations, more individuals are likely to remain to repopulate an area after a loss. Viable populations should be large enough to adapt over time to environmental variation, genetic variation, demographic stochasticity and catastrophic events, while maintaining a healthy population.
- **Productivity**. Also referred to as population growth, productivity provides information on how well an individual population is performing (for example, the number of returning adults produced by the parent spawner) in response to its environment. A salmonid population's natural productivity should be sufficient to maintain its abundance above the viable level in the absence of hatchery fish, during poor ocean conditions and across multiple generations.

- **Spatial Structure**. Spatially structured populations are often referred to as metapopulations. According to McElhany and others (2000), "a population's spatial structure is made up of both the geographic distribution of individuals in the population and the processes that generate that distribution." Spatial structure depends on habitat quality, spatial configuration, dynamics and dispersal behaviors.
- Diversity. Salmonids exhibit diverse life history traits within and among populations that affect population viability and persistence. Diversity allows a species to inhabit varying environs, protects a species against short-term catastrophic loss and provides the genetic make-up to allow the species to persist through long-term environmental change. Specific life history traits include anadromy, morphology, fecundity, run timing, spawn timing, juvenile behavior, age structure, size, developmental rate, ocean distributions and molecular genetic characteristics (McElhany and others 2000).

To be consistent with the guidance in *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units* (McElhany and others 2000), the City of Portland's Endangered Species Act Program will be tracking these same parameters in local populations and is developing fish monitoring programs that focus on these parameters.

A24: **Species Interactions**. Species interactions determine the balance among populations of competitors, pathogens, predators and prey and play a critical role in regulating the composition and function of natural communities. Human activities have altered the balance of many species' interactions both directly and indirectly – directly through the introduction of exotic species that prey upon or compete with native species (Li and others 1987) and indirectly through changes in habitat that alter pressures from predation or competition (Reeves and others 1987). Evaluating the composition, relative abundance and spatial distribution of native and nonnative species over time will provide a means of evaluating changes in species interactions over time.

A25: *Riparian Wildlife*. Riparian areas are more biologically productive than any other natural environment, aquatic or terrestrial. The aquatic fringe habitats that characterize riparian areas contain a variety of vegetative species; these species have very different functional values that are adapted to both terrestrial and aquatic or wetland ecosystems. These unique habitats provide important rearing habitats and refuge to terrestrial and aquatic-dwelling species, as well as migratory wildlife. Wildlife use these areas for nesting, rearing, temporary refuge and feeding. As stated by Puchy and Marshall (1993), "if amphibian, reptile, bird and mammal numbers are combined, riparian areas support more species than any other community type" in Oregon. Riparian areas provide habitat for birds and mammals (Castelle and others 1994, Kauffman and others 2001) and herpetofauna (Kauffman and others 2001).

Presuming that wildlife are useful indicators of watershed health, specific indicator or keystone species for riparian wildlife should be chosen. These should include wildlife indicator species that represent the major wildlife guilds that inhabit riparian ecosystems. Species occupying or using both aquatic and terrestrial habitats in their life history expression will be selected as riparian wildlife indicator species.

The primary ecological principles and the riverine, wetland and upland ecology principles presented in Chapter 2 of this *Framework* are relevant to riparian wildlife. However, the City

of Portland has yet to identify potential indicators of riparian wildlife health. Until these indicators are developed, riparian conditions can be evaluated to determine whether they are consistent with high, moderate or low riparian quality and wildlife value. In other words, if the riparian corridor is broad and intact (with few breaks), tree canopy cover and shrub cover are relatively high, the species composition is consistent with habitats and vegetative types of the Pacific Northwest, and stand structure provides horizontal and vertical structure (stand age), then the riparian area presumably has the potential to provide some wildlife value. The City intends to select indicator riparian wildlife species for individual watersheds once characterization has been completed.

A26: *Terrestrial Wildlife.* Because watersheds are geographically defined from ridgetop to ridgetop, achieving and maintaining healthy watershed conditions and functions must address terrestrial as well as aquatic and riverine species and habitats (see Riverine, Wetland and Upland Ecology Principle 1). If wildlife are to be useful as indicators of watershed health, specific indicator or keystone species must be chosen. The selection of indicator species makes apparent the life histories and thus specific habitats and ecosystem functions that are required for healthy populations of the indicator species and associated species with similar habitat needs. Ideally, a manageable set of wildlife indicator species would be identified that represents the major guilds present in the terrestrial ecosystem. The protection and restoration of these species and their habitats would also provide protection for the suite of species present in the terrestrial ecosystem. The City of Portland is in the process of determining how it will select indicator species for terrestrial wildlife in individual watersheds following characterization. Information developed for Tables E-1 and E-2 in Appendix E will be evaluated during this process.

A27: *Plant Communities.* Healthy plant communities serve many important functions: they provide habitat for native wildlife and preserve critical habitat for rare, threatened and endangered animals and plants; enhance air and water quality by trapping airborne particulates and filtering sediments and pollutants from runoff before they enter streams and aquifers; stabilize streambanks and hillside slopes and dissipate erosive forces; ameliorate the local microclimate and reduce water and energy needs; and provide scenic, recreational and educational values which, in turn, enhance Portland's livability.

The City of Portland has not yet selected specific indicators and metrics for plant communities for use in watershed planning as described in this *Framework*. The City is in the process of determining how it will select indicator species for plant communities in watersheds following characterization. In the interim, the City of Portland has adopted a native plant policy that is designed to ensure the continued viability and diversity of indigenous plant communities, to promote the use of plants naturally adapted to local conditions, and to educate citizens about the region's natural heritage and the values and uses of native plants. In support of this policy, the City compiled the Portland Plant List, which now serves as an integral component of the City's natural resource protection program (see http://www.planning.ci.portland.or.us/lib_plantlist.html). Native plants identified on the list are required within the City's Environmental and Willamette River Greenway Zones, and invasive or harmful plants (identified on the "Nuisance" or "Prohibited" plant lists) are prohibited. The list is organized according to general habitat types, including wetland, riparian, forest (upland forested areas with little or no slope), forested slopes (steeply sloping upland forest), thicket (edges of forests and meadows),

grass (open areas or meadows) and rocky upland areas. The list indicates which plant species are found within each of these habitat types. The list further divides plants into three groups: trees and arborescent shrubs, shrubs, and ground covers.

TABLE G-5

Biological Communities Indicators and Metrics

Indicators	Metrics					
A21: Biotic Integrity (fish community structure)	Index of Biotic Integrity (IBI), Benthic Index of Biotic Integrity (B-IBI) and other community metrics (species richness, percentage of intolerant taxa, etc.)					
A22: Benthic Communities	EPT					
	Algal community composition					
A23: Salmonid Population	Abundance					
Structure	Productivity					
	Spatial structure					
	Diversity					
	Presence/absence					
A24: Species Interactions	Native/exotic ratio					
(predation, competition, exotic	Number of exotic predators and competitors					
species, etc.)	Relative abundance and spatial distribution of predators and competitors					
A25: Riparian Wildlife	[Metrics for riparian wildlife have yet to be developed. In the interim, riparian conditions such as width and intactness of the riparian corridor, tree canopy cover, species composition and stand structure can be evaluated.]					
A26: Terrestrial Wildlife	[Indicator or keystone species have yet to be selected and metrics developed.]					
A27: Plant Communities	[Indicators and metrics for plant communities have yet to be developed. In the interim, the City's native plant policy and Portland Plant List will be employed as appropriate.]					

Links Between Potential Watershed Health Indicators and Ecological Functions

As described at the beginning of this appendix, indicators are merely surrogates of underlying ecological functions that maintain watershed health. They are measurable reflections of complex ecological processes that can be difficult to measure directly. It is important to remember, however, that it is the integrity of the ecological processes that is ultimately required to restore and maintain watershed health. The City of Portland will use indicators to evaluate the degree to which ecological processes are functioning properly and as "useful signals of environmental degradation" (Bisson and others 1997).

Table G-6 identifies some of the key ecological functions that maintain watershed health and some of the potential indicators that will be used to directly or indirectly evaluate the nature and dynamics of those functions. The listed functions are a summary of watershed functions identified by the Federal Interagency Stream Restoration Working Group (1998) and the City of Portland (2001).

Human Influences

Human influences are predictive or stress-oriented indicators, as described by the National Research Council (1995). These indicators point to the sources of the problems that are revealed through evaluation of the watershed health indicators. Indicators of human influences also aid in the identification of solutions and opportunities. Essentially, the purpose of the human influences indicators is to identify the stressors on the ecosystem and, to the extent possible, begin to provide information on cause-and-effect relationships between impacts and their potential sources.

For example, human activities and landscape alterations can greatly increase rates of erosion and sediment transport to the point that stream habitat and water quality are adversely affected. Specifically, removal of vegetation, construction activities and soil-disturbing land uses alter soil properties on the landscape and can result in loss of soil or soil compaction.

In addition to land-disturbing activities, changes in the way water flows across the landscape can increase the amount of sediment delivered to streams. Loss of wetland habitats, increases in impervious surfaces and the piping of stormwater runoff directly into waterways eliminate opportunities for stormwater to infiltrate through the subsurface, which naturally removes and stores sediments. Increased amounts of sediment delivered to a waterway can then degrade aquatic habitat, destroy spawning areas, harm fish and other aquatic organisms and result in incised (and unstable) channel condition. In addition, sediments – particularly fine sediments – are a primary carrier of many of the pollutants so common in the urban landscape, such as metals, nutrients and toxic organic compounds (Novotny and Olem 1994).

Characterizing indicators of human influences and urban activities can help identify sources that may impair watershed health, and monitoring these indicators can identify emerging issues before they become problematic to ecosystem functions. The indicators of human influences are described below. The link between each indicator and its impact on components of watershed health is described generally under each indicator and in Table G-7.

B1: Land Use. Land use is a general indicator of the types of human activities that occur across a landscape. In a sense, land use is a catchall indicator that integrates a number of human activities and impacts. Impacts that are strongly associated with land use include impervious surfaces (U.S. Department of Agriculture, Natural Resources Conservation Service 1986; May and others 1997), vegetative characteristics (May and others 1997) and stormwater pollutant concentration (U.S. Environmental Protection Agency 1994). Land use may directly or indirectly affect all four categories of indicators of watershed health: watershed hydrology, physical habitat, water quality and biological communities.

TABLE G-6

Links Between Potential Watershed Health Indicators and Key Watershed Functions

		Indicators																								
	H	ydrolo	drology Physical Habitat									Water Quality							Biological Communities							
Watershed Functions	Hydrograph Alteration	Floodplain Presence and Connectivity	Groundwater	Floodplain Quality and Connectivity	Riparian Condition	Habitat Types	Bank Erosion	Channel Substrate	Off-Channel Habitat	Refugia	Large Wood	Water Temperature	Dissolved Oxygen	Nutrients and Chlorophyll a	Total Suspended Solids	Toxic Contamination	Groundwater Quality	303(d) Parameters	Other Parameters	Biotic Integrity	Benthic Macroinvertebrates	Instream Communities	Salmonids	Species Interactions	Riparian Wildlife	Terrestrial Wildlife
Groundwater Recharge and Storage			•																							
Baseflow	•		٠																							
Flood Storage and Attenuation		•																								
River/Floodplain Interaction		•		•					٠																	
Channel Composition and Dynamics					•	•	•	٠		•	٠									●						
Structural Complexity					•	•		٠		•	٠									●						
Habitat Connectivity		•		•	٠	•														٠						
Refugia		•				•			٠	٠	•									٠						
Shading and Microclimate			•		•						•	•														
Sediment Transport and Storage		•					•	•			•				•						•					
Food Web (primary and secondary production, feeding, respiration, decomposition)		•		•																•	•	•	•	•	•	•
Organic Inputs		•		٠	•																•					
Temperature					٠							٠					٠	•		٠						
Nutrient Cycling		•		•	•									•			•	•		●						
Oxygen													•				•	•		●						
Toxics																•	•	•	٠	٠						
Pathogens																	•	•		٠					•	
Reproduction																				•		•	•	•	•	•
Growth																				•	•	٠	•	•	•	•
Survival																				٠		٠	•	•	•	•
Species Interactions (competition, predation)																				•		•	•	•	•	•

B2: Impervious Surfaces. Impervious surfaces are an important indicator for two reasons:

- They have a direct impact on watershed hydrology and health. As one of the key sources of degradation from urban development, impervious surfaces affect flow, water quality, temperature and stream habitat (Schueler 1994).
- They are a general indicator of human development. Within urban land uses, nearly all types of human development or activities are associated with impervious surfaces. Beyond their flow and habitat impacts, impervious surfaces are also a general indicator of the intensity and spatial distribution of human development and activities and can integrate cumulative effects from a complex range of activities and impacts (May and others 1997).

Clearly, tracking impervious surfaces as an indicator treats all urban land uses equally and does not capture the diversity of activities and impacts associated with various land uses. However, the amount of impervious surfaces is a good general indicator of human impacts and has been used effectively in a number of studies of urban impacts (for example, May and others 1997).

Two measurements are proposed to evaluate this indicator: effective impervious area and total impervious area. Effective impervious area focuses on the hydrologic and water quality impacts of impervious areas. It accounts for the fact that the hydrologic and water quality effects of impervious areas may be partially ameliorated by hydrologically "disconnecting" the impervious surface from the stream by routing pipes through infiltration and detention facilities such as sumps, detention ponds and infiltration basins. Thus not all impervious surfaces have the same impact on hydrology, and this measurement attempts to account for best management practices that reduce the hydrologic and water quality impacts of impervious surfaces. Total impervious area, on the other hand, addresses the second element described above; namely, that impervious surfaces – regardless of whether they discharge directly to streams – are associated with human development and its potential to affect habitat and water quality.

The City acknowledges that, while valuable, impervious area is an imperfect indicator of watershed health. For this reason the City will also attempt to track the effectiveness of various management activities aimed at mitigating the impacts of impervious area. For example, infiltration swales, eco-roofs, constructed wetlands, sumps and other techniques mitigate the effects of impervious area. The City will attempt to account for situations where impervious area drains to these types of facilities.

Impervious surfaces directly affect stream flow, hydrology and water quality; through these impacts they affect physical habitat and biological communities.

B3: **Dam Impacts.** As described in Riverine, Wetland and Upland Ecology Principle 3, dams fundamentally alter the flow, habitat, water quality and biota of riverine ecosystems. Dams are present on virtually every major river in the lower 48 states, and the structure and function of regulated rivers are fundamentally different from those of free-flowing rivers. When dams are present, natural cycles of flooding and the transport of sediment, gravel and other materials are greatly reduced, and channel shape, vegetation and instream biological communities are fundamentally altered (Collier and others 2000). Dams can also block migratory salmons' access to habitat if proper passage facilities are not provided, and

salmon may suffer increased mortality and injury even when passage facilities are provided (National Marine Fisheries Service 1996). Dam impacts affect all four categories of watershed health indicators.

B4: **Water Withdrawals**. The impacts on the health of streams and rivers of removing water for purposes of landscaping, irrigation and water supply include increased water temperatures, increased sedimentation, decreased gravel recruitment, dewatering of previously productive habitat, crowding and increased competition, and reduced productivity (Gregory and Bisson 1997). For salmon, lower baseflows can also increase vulnerability to predation, delay migration, increase stranding and result in the entrainment of juveniles into poorly screened or unscreened diversions (National Marine Fisheries Service 1996). Water withdrawals affect all four categories of watershed health indicators.

B5: Drainage Network. Within the urban landscape, many stream reaches and wetlands have been piped and diverted to allow development on top of former waterbodies and wetlands. This results in direct destruction of aquatic habitats and affects the hydrology of the watershed. For example, in Johnson Creek, 38 percent of former surface waters have been piped (Prescott in prep.). At the same time, development of stormwater drainage systems has dramatically altered the way precipitation flows through the watershed. Prior to development, precipitation predominantly infiltrated into subsurface soil and groundwater zones (Satterlund and Adams 1992). What little surface runoff occurred flowed through vegetation before reaching the stream. In the urban area, a significant portion of precipitation now falls on impervious surfaces (which preclude infiltration), generating stormwater runoff that collects contaminants accumulated on these surfaces; this stormwater is delivered into stormwater drainage systems in far greater volumes than previously. In addition, flow through this artificial drainage network does not provide any of the natural treatment processes that occurred when surface runoff flowed over natural soils and vegetation. The majority of urban runoff, with its associated contaminants from the farthest reaches of the watershed, is routed directly to the stream, with no treatment. The replacement of natural drainage systems with piped drainage systems has had dramatic negative impacts on aquatic ecosystems (May and others 1997). The drainage network affects all four categories of watershed health indicators.

B6: **Channel Alterations**. Human development has significantly altered the structure and function of stream and river channels. Bank hardening, channelization, channel maintenance (such as the removal of large wood), culverts and other stream crossings, and other channel alterations have the following effects:

- They prevent the stream and river from adapting to flow conditions. Rivers and streams normally are highly dynamic environments that change their form in response to variable flow conditions and in the process help form and maintain stream habitat. Structures that attempt to confine a stream into a particular configuration preclude the ability of the stream to adapt to variable flows and impede habitat formation and maintenance.
- They can prevent or decrease the interaction of a river with its floodplain.
- They can create impediments or barriers for salmonids migrating upstream, either in the form of physical constraints or as unsuitable velocities and flows. In these cases,

salmonids can be prevented from using otherwise suitable spawning and rearing habitats. Oftentimes some of the highest quality habitat (for example, Oaks Bottom, Forest Park, and Smith and Bybee lakes) is inaccessible to salmon as a result of culverts, weirs and other instream structures.

• They reduce instream habitat complexity, increase water velocity, degrade instream pool and riffle structure and eliminate large wood.

Channel alterations affect all four categories of watershed health indicators.

B7: Vegetation Management. As described in Riverine, Wetland and Upland Ecology Principle 1, rivers cannot be separated from the lands they drain. This means in part that vegetation and wetlands throughout the watershed affect the quantity and quality of water draining off the land. Evaluating urban impacts on watershed hydrology is more complicated than merely quantifying the amount of impervious surfaces and piped drainage systems. In forested watersheds, very little precipitation reaches the stream through surface runoff because of high rates of evapotranspiration and soil infiltration into organic soils (Satterlund and Adams 1992). Urbanization, on the other hand, often results in vegetation removal and soil compaction (Schueler 1995), which greatly increase the amount of runoff even from areas where pavement and other impervious surfaces are not present. Surfaces such as lawns and parks do not have the density of trees or forest duff layers needed to capture and infiltrate the vast majority of precipitation. In addition, urban lawns and other vegetated areas are often maintained with fertilizers, herbicides and insecticides, which have the potential to contribute to water quality problems. The vegetation removal associated with urbanization affects all four categories of watershed health indicators.

B8: Wetland Alteration. Wetlands throughout a watershed provide stormwater retention, groundwater infiltration, sediment filtration and pollutant removal (Reinelt and Horner 1995). As wetlands are filled and developed, the amount of surface runoff from the watershed increases and the quality of that runoff decreases. Wetland alteration affects all four categories of watershed health indicators.

B9: Outfall Discharges. Intensive land uses in urban areas produce a large amount and variety of pollutants. Road runoff, municipal and industrial processes, construction, erosion, fertilizers and pesticides, deposition of atmospheric contaminants, maintenance and other activities produce a broad range and high concentration of contaminants, including heavy metals, nutrients, particulates, organic contaminants, pathogens, oxygen-demanding substances and heat loads. Many of these contaminants are transmitted to streams and rivers by public and private stormwater outfalls, combined sewer overflows and point source process discharges. Thus, outfall discharges represent discrete points at which the variety of pollutants produced by land uses are introduced into urban streams and rivers. Identifying the location of these outfalls and characterizing the loads they contribute to aquatic environments will provide key information about the impact of urban land uses on water quality. Outfall discharges affect watershed hydrology and physical habitat on a local scale and can have broader effects on water quality and biological communities.

B10: Exotic Species. Some of the most severe effects of human activities on the world's biological communities have resulted from the introduction of exotic organisms (Suter 1993). Human development in and near the riparian zone and in many upland areas has

resulted in the release of domestic animals such as dogs and cats and the introduction of invasive plant species such as Himalayan blackberry, reed canary grass and English ivy. The aggressive nature of these plants has dramatically altered the species composition and habitat values provided by riparian areas. Free-roaming domestic and feral cat populations have an impact on native wildlife, especially birds, while many wetlands are overpopulated with feral domestic ducks and geese. In addition, some sensitive riparian areas have become destinations for dogs that are off leash.

Past fisheries management practices also have resulted in the introduction of a large number of exotic fish species into local aquatic ecosystems. For example, of the 39 total fish species in the lower Willamette River, 19 have been introduced (Farr and Ward 1993). Introduced species include predators such as largemouth bass (*Micropterus salmoides*) and walleye (*Stizostedion vitreum vitreum*) and a large number of competitors tolerant of warm waters and altered habitat conditions. The presence of these introduced species may increase competitive pressures on native species.

Tracking the percentage of invasive species in riparian and aquatic communities is an important component of evaluating the integrity of the riverine-riparian ecosystem and tracking the success of restoration efforts. However, it is also important to exert effort toward tracking and preventing introductions of new species, including invertebrate species. For example, the introduction of green crabs (*Carcinus meanas*) and mitten crabs (*Eriocheri* spp.) has dramatically altered biological communities in California (Cohen and Carlton 1995). These species have not yet been observed locally, but an isolated individual mitten crab was found in the Columbia River. Exotic species affect physical habitat (by way of invasive vegetation) and biological communities.

B11: *Harassment.* The intensity of activities close to rivers and streams in urban areas has the potential to disturb and disrupt salmon. Lights from docks, bridges and other sources; noise from boat traffic, in-water construction and other urban activities; and the close physical presence of humans along trails and at homes and waterfront facilities all have the potential to adversely affect salmon behavior during spawning, feeding and migration. Although the specific effects of harassment on salmon have not been well studied, harassment is included as an indicator of human activity because of the high potential for harassment from urban activities and the opportunity this creates to begin evaluating the potential effects of harassment on salmon. Harassment affects the biological communities indicators.

B12: *Harvest*. Fish harvest can have a significant impact on a fish population's ability to persist over time. The combination of commercial, sport and tribal fisheries effectively reduces the number of adults returning to a stream system and can temporally segregate a population. For example, if overlapping harvest pressure is directed at the beginning of a return period, an unintended consequence is that fish from this earlier return period do not make it back to their natal stream, and life history traits may change or be lost completely (the population could move from an early run to a late run population, for example). The result is that the population as a whole becomes less resilient to environmental change. Although targeted sport fisheries are not necessarily allowed on lower Willamette fish populations (currently only hatchery populations are targeted), incidental harvest undoubtedly occurs. It is likely that harvest affects coho and Chinook populations the most.

B13: *Hatchery Management.* If not properly managed, hatchery programs can negatively affect Willamette fish populations in various ways. Smolts and fry released into areas where natural fish reside and rear can displace wild fish or compete for rearing grounds and food. Furthermore, smolts can prey directly on wild fish or attract predators, which results in higher prey rates on wild fish. In addition to impacts associated with hatchery releases, adult hatchery fish can return to native spawning grounds and compete for space, they may transmit disease, and if spawning is successful they can affect the genetic diversity of a wild population. Also, the abundance of hatchery returns can give the public a false sense that natural populations are healthy and thriving, when in fact the natural populations may be in peril.

However, benefits that can be realized from hatchery programs include supplementation (such as Umatilla steelhead supplementation programs) and reintroduction of native salmonids to rivers and streams in their historical range. If managed well, hatchery programs may be able to provide a benefit to fish populations.

B14: Spills and Illicit Discharges. Outfall discharges are typically permitted and managed through the National Pollutant Discharge Elimination System (NPDES) program under the Clean Water Act. However, spills and illicit discharges are unpermitted and often untreated discharges. Because these discharges typically occur accidentally, inadvertently or secretively, on purpose, it is difficult to apply best management practices or other treatments. Prevention, education and emergency response measures can reduce the potential for and impacts from spills and illicit discharges, but when they occur they have can have significant acute toxic effects. Spills and illicit discharges affect water quality and biological communities.

Indicators	Metrics
B1: Land Use	Percentage of industrial, commercial, residential, open space, etc. within watershed
B2: Impervious Surfaces	Total impervious area
	Effective impervious area (begin to evaluate by tracking downspout disconnects, sumps and other types of disconnections and diversions)
B3: Dam Impacts	Percentage and area of watershed above dams
B4: Water Withdrawals	Amount and percentage of water withdrawn
B5: Drainage Network	Percentage of piped/natural channel
	Number of miles piped/natural
B6: Channel Alterations	Culverts/stream crossings: number of stream miles currently accessible/miles historically available to fish; number, location and passablity of culverts and other stream crossings
	Bank hardening: percentage of "hardened bank" (riprap, seawall, bank with structures)
	Channel modification: channel sinuosity; number and area of instream structures; number and location of structures within the channel meander zone; number of pieces of large wood removed from stream

TABLE G-7

Indicators and Metrics of Human Influences

TABLE G-7

Indicators and Metrics of Human Influences

Indicators	Metrics					
B7: Vegetation Management	Percentage of forest cover in watershed					
B8: Wetland Alteration	Wetland area, location and quality					
B9: Outfall Discharges	Location, pollutant loads and flows contributed by combined sewer overflows, stormwater and municipal and industrial outfalls					
B10: Exotic Species	Number and percentage of exotic species (percentage by area for plants, by abundance for animals)					
B11: Harassment (boat traffic,	Number of boats/day (large and small)					
lights, noise, etc.)	Lumens of light with depth at night					
	In-water decibels					
	Number of people and pets/day					
B12: Harvest	Incidental catch of wild (unmarked) fish in sport, commercial and tribal fisheries (Potential sources of this information are the Oregon Department of Fish and Wildlife and the Columbia River Inter-Tribal Fish Commission.)					
B13: Hatchery Management	Number, location, size and time of hatchery smolts released in the Upper Willamette Basin, Clackamas River basin and lower Willamette River					
	Number, location and time of unfed fry released into Portland watersheds					
	Number of adult hatchery fish spawning in Portland waterways					
B14: Spills and Illicit Discharges	Frequency, magnitude and toxicity of spills and illicit discharges					