City of Seattle
State of the Waters 2007

Volume I: Seattle Watercourses

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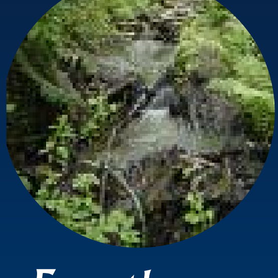

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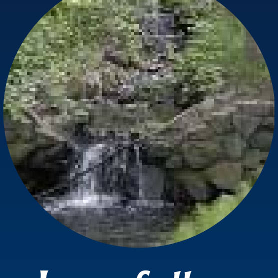

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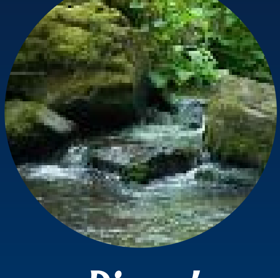

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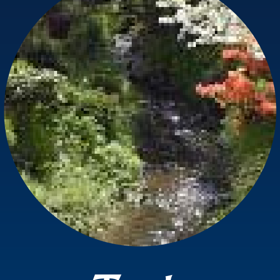

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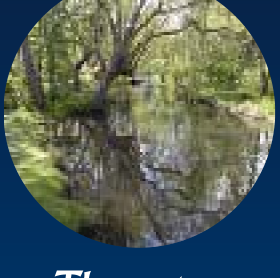

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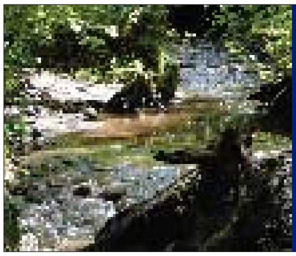

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Acknowledgments

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The State of the Waters report reflects the City of Seattle's understanding of drainage management, starting from a predominant focus on stormwater conveyance and evolving to a more integrated approach addressing water quality, habitat, aquatic biota, and ecological processes of the water bodies connected to Seattle's drainage infrastructure. This report contains decades worth of research and investigation. The combined efforts of many have produced this detailed picture of overall conditions in Seattle's aquatic systems, as well as their connection to the city drainage system.

The research efforts represented in this report fall into three main categories: 1) mapping of the city drainage system (pipes and surface drainage) and its links to receiving waters; 2) mapping and assessing the urban watercourses; and 3) assessing stormwater discharge and water quality.

Initially, the city drainage utility focused on meeting requirements regulating stormwater outfalls in Seattle's major water bodies. In 1993, the former Seattle Drainage and Wastewater Utility was awarded a Centennial Clean Water Fund grant to map the locations of approximately 40 watercourses and to initiate a physical inventory of the five fish-bearing watercourses. In 1998 the City of Seattle launched the Urban Creeks Legacy Program and began rehabilitating the watercourses, and from 1999 through 2003 the Capital Improvement Program/Creek Monitoring Team evaluated performance of these instream projects.

Beginning in 1999, SPU's Urban Creeks Watershed Assessment expanded the existing inventories to provide more detailed data on geomorphology, instream habitat and riparian conditions, and fish use in the five fish-bearing watercourses. In parallel efforts, SPU's Natural Drainage System Program focused on reducing disturbance of stream channels caused by excessive storm flows and improving stormwater runoff discharge and water quality. Drawing on all of these efforts, the State of the Waters report is the product of various multidisciplinary teams and investments over many years. The following people, SPU departments, and companies have made key contributions to this work:

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Contents of the 2007 State of the Waters Report

Volume I of the State of the Waters report focuses on Seattle watercourses. Volumes II and III discuss the small lakes within the city, and the larger aquatic systems including large lakes, estuaries, and marine systems.

This first volume contains the following major divisions:

- Part 1, Introduction, explains the purposes of developing the State of the Waters report and the importance of understanding both historical conditions and present conditions in Seattle's water bodies, and the underlying causes of changes that have occurred.
- Part 2, A Brief Primer on Stream Ecosystems, describes how hydrology, water quality, and physical stream conditions work together to shape stream habitat and the plant and animal communities that use it.
- Part 3, Assessing the State of the Waters, describes the methods used to evaluate conditions in Seattle watercourses for the purposes of this report.
- Part 4, Conditions in Seattle Watercourses, describes the water quality and physical habitat conditions in Seattle watercourses, along with the results of analyses to assess low-quality and high-quality habitat areas. The discussions of existing information on water quality are less extensive than the riparian and instream habitat components of this report.
- Part 5, Seattle Watercourse Summary and Conclusions, summarizes and compares current conditions throughout the city. Part 5 also provides conclusions about the overall state of Seattle watercourses.

A map folio accompanying this report presents watershed maps, and appendices provide additional technical detail about the methods and results of the analyses of aquatic conditions.

Mouth of Piper's Creek at Puget Sound (photo by Bennett)

Executive Summary

Seattle's extensive urban development over the past 150 years has drastically altered the city's watersheds. Previously forested areas and wetlands have largely been converted to residential, industrial, and commercial land uses, with some limited areas of open space. In the course of development, Seattle's watersheds have been covered by buildings, roads, parking lots, parks, and sidewalks. While urban development has created a livable environment for humans, it has brought a decline in the health of city watersheds, the water bodies that drain them, and their non-human inhabitants. By impairing the ecological health of aquatic areas, increasing urbanization continues to degrade the water resources people depend upon for human health, recreation, and aesthetic benefits.

This State of the Waters report describes the current conditions of Seattle's water bodies. Volume I provides a snapshot of overall watershed health within the five major watercourses in Seattle:

- Fauntleroy Creek
- Longfellow Creek
- Piper's Creek
- Taylor Creek
- Thornton Creek.

For clarity, the City of Seattle has adopted the word *watercourse* to refer to the network of pipes, ditches, culverts, and open stream areas that deliver surface water from watersheds to receiving water bodies. This report evaluates conditions in the stream portions (open channels with banks and a streambed) of watercourses in particular.

This report focuses on stream hydrology, water quality, physical habitat, and biological communities, which indicate the ability of Seattle watersheds to perform critical functions and services, such as filtering water, moderating floods, and capturing sediment. The purpose of this report is to condense and organize existing watercourse information to make it readily accessible to City of Seattle staff and interested citizens.

Identifying current conditions is a critical step for preserving and improving ecological conditions within Seattle. Accurate knowledge of existing conditions helps to inform decisions about where current improvement efforts should be continued and where efforts need to be refocused as new problems come to light. It is hoped that the Seattle State of the Waters report will help us all be aware of the role we play in protecting the health of our water bodies, and that awareness will lead to improved conditions for fish, wildlife, people, and the legacy we leave for future generations.

Volume I includes a detailed compilation of habitat and water quality data collected over the past several years. The methods used to collect and evaluate this information are described in Part 3 of this volume. The information collected and its implications are summarized in the individual watercourse sections presented in Part 4. The habitat and water quality information is presented in a variety of formats, including narrative descriptions, and charts and data tables. Summary graphics including watershed graphics and associated maps are included in the map folio accompanying this report. Additional technical information about the methods and results of the analyses of aquatic conditions is included in a series of appendices.

Key Findings

- Both riparian habitat and instream habitat conditions in Seattle's urban watercourses range from relatively good (for an urban area) to poor. There appears to be a high level of correlation between the land use adjacent to a stream section and the quality of its riparian and instream habitat. Stream bank armoring and encroachment into riparian areas by roads and buildings are correlated with degraded habitat conditions on all watercourses, and particularly along Thornton Creek.

- Migratory fish can use only about one-third of the potential habitat in Seattle watercourses due to passage barriers. These barriers prevent fish from reaching some of the highest-quality habitat, particularly on Longfellow Creek and Taylor Creek.

- Physical habitat, stream flow patterns, and water chemistry collectively appear to be having adverse influences on the aquatic invertebrate species inhabiting Seattle watercourses. The results of Seattle Public Utilities (SPU) monitoring show that in most stream reaches the aquatic invertebrate communities are in poor condition compared with other Puget Sound streams. The best habitat conditions appear to be capable of only supporting fair aquatic invertebrate communities.

- Flows in Seattle watercourses appear to be flashy, with sudden high peak flows, although additional flow data are needed to provide a more accurate picture over time. High peak flows are major causes of poor instream habitat, and the adverse impacts are compounded by buildings and armoring along stream banks.

- The available water quality information for Seattle watercourses indicates that many of the chemical parameters generally meet Washington state water quality criteria for the protection of aquatic life in Seattle watercourses. However, at least some of the time, the watercourses that have been tested do not meet state criteria for fecal coliform bacteria, dissolved oxygen, and temperature. Fecal coliform bacteria levels in particular are high and frequently exceed state water quality criteria. Microbial source tracing indicates the main sources are pet and wildlife wastes.

- Metals concentrations in the urban watercourses generally meet state water quality criteria, based on limited sampling conducted mostly during non-storm conditions.

- Accurately characterizing Seattle watercourse conditions is difficult due to the limited data available, particularly for water quality and flow. Implementing a monitoring program to track status and trends for flow, water quality, and habitat, including storm and non-storm event sampling, is important for understanding watercourses, the condition of their watersheds, and the results of Seattle's collective efforts to improve conditions.

- Part 5 of this report provides a comparative summary of relative conditions in Seattle's five major watercourses (see also Figure 34 in Part 5). Conditions are categorized as good, moderate, or poor based on primary indicators, which are discussed in more detail throughout the report.

Factors Affecting Seattle Watercourses

Watercourse conditions are shaped by their upland watersheds, as well as by conditions immediately surrounding their margins. Watershed characteristics such as topography, geology, soils, rainfall patterns, and vegetation influence how water, sediment, wood, and nutrients are moved from land to streams or other watercourses. The hydrology and water quality of a watercourse depend heavily upon watershed conditions.

A watercourse is also affected by local features, such as the riparian corridor, which serves as the interface between the upland, terrestrial system and the aquatic environment in the watercourse. The watercourse shapes and maintains habitat using materials supplied by the watershed and the riparian zone, and provides a home for aquatic animals.

Piper's Creek (photo by Bennett)

Human influences on watercourses and their watersheds affect the interplay among watershed, riparian habitat, and watercourse conditions, resulting in changes in stream habitat and stream communities. Seattle's watershed and watercourse conditions, and their likely impacts on the overall health of watercourses within the city, are summarized below.

Watershed-Scale Conditions

Hydrology

The conversion of forested watershed areas within Seattle to developed areas with impervious surfaces has changed the processes by which upland areas deliver water to their watercourses. These impervious surfaces—roads, buildings, and parking lots—cover more than 60 percent of the land in some Seattle watersheds.

All Seattle watercourses experience high-volume, rapid peak flows (i.e., flashiness) as stormwater rapidly drains from impervious surfaces and enters constructed drainage systems for fast delivery to watercourses and other water bodies. While the Seattle Public Utilities record of flow data is limited—it covers less than the past ten years and includes only a few locations—it illustrates dramatic changes in stream flows compared to expected natural conditions in the watershed. In the five major Seattle watercourses, computer modeling indicates that flow rates and volumes from a common storm event (defined as a rainfall event that occurs on average every 2 years) have increased approximately four or five times over flows expected under forested watershed conditions.

High-volume, rapid peak flows (i.e., flashy flows) damage stream habitat, and that damage is aggravated by stream bank armoring and protection that restricts a stream from using its floodplain. The high flows trigger erosion of unarmored stream banks, which introduces fine sediment into the watercourse. Without a floodplain, there is no release valve for streams under siege from high flows, and as a result, the flows dig into the streambed and erode the gravels and cobbles needed for fish spawning and insect production. This change in stream flows resulting from urban development in the watershed is a major cause of degraded and simplified stream habitat in Seattle.

Water Quality

King County has monitored water quality in three of Seattle's major watercourses: Longfellow Creek, Piper's Creek, and Thornton Creek. Long-term records (covering ten years or more) are generally available for most conventional water quality parameters (i.e., temperature, dissolved oxygen, total suspended solids, turbidity, pH, and fecal coliform bacteria), but information on toxic pollutants such as metals and organic chemicals is fairly limited. The Washington Department of Ecology has also recently begun routine monitoring in Fauntleroy Creek. However, no data are available for other urban watercourses in Seattle (e.g., Taylor Creek and other small watercourses).

The available information indicates that Fauntleroy, Longfellow, Piper's, and Thornton creeks generally meet Washington state water quality criteria for ammonia, suspended solids, turbidity, and metals. However, temperature, dissolved oxygen, fecal coliform bacteria, and nutrients (i.e., phosphorus and nitrogen) can be problematic.

Fecal coliform bacteria levels are high and frequently exceed the state water quality standard in all four of the urban watercourses that have been tested (Thornton, Piper's, Longfellow, and Fauntleroy). Bacteria levels in Seattle watercourses are typically higher under storm flow conditions than under non-storm flow conditions, reflecting contributions from urban stormwater runoff and the effects of nonpoint source pollution. Microbial source tracing conducted in Thornton Creek and Piper's Creek shows that pets and urban wildlife (e.g., rodents and waterfowl) are the largest sources of fecal coliform bacteria. Human sources (e.g., leaking sanitary sewer systems) appear to be minor contributors to high fecal coliform levels.

Water temperature is a critical water quality variable, influencing fish metabolism, as well as dissolved oxygen concentrations. Dissolved oxygen concentrations and water temperature exhibit distinct seasonal patterns. For example, temperatures are generally higher in the summer and lower in the winter, while dissolved oxygen levels decrease in summer months and rise in the winter. During the summer, the lack of riparian vegetative cover and limited base flow likely account for higher temperatures and lower dissolved oxygen concentrations, particularly in Longfellow Creek and Thornton Creek, which frequently fail to meet state water quality criteria for temperature and dissolved oxygen during the summer months. In comparison, Piper's Creek and Fauntleroy Creek, which pass through steep forested ravines with tree canopies that are largely protected from development, do not experience temperature and dissolved oxygen problems.

No state water quality criteria have been established for nutrients. However, total nitrogen and total phosphorus concentrations in Longfellow Creek, Piper's Creek, and Thornton Creek frequently exceed established U.S. Environmental Protection Agency criteria. Exceedances in Longfellow Creek and Piper's Creek generally occur more frequently during storm flow conditions. Thornton Creek experiences occasional exceedances of the nutrient benchmarks under non-storm flow conditions; no data are available for storm flow conditions.

Data on metals and organic pollutants are very limited and have been collected primarily under non-storm flow conditions. The available data indicate that metals concentrations in Seattle urban watercourses generally meet state water quality criteria. Similar to fecal coliform bacteria patterns, most metals concentrations are higher in storm flow samples than in non-storm flow samples due to contributions from urban stormwater runoff. An exception is zinc, which exhibits comparable concentrations in storm and non-storm samples.

Pollutants in watercourses have larger direct effects on the plants and animals than on physical stream conditions. Pollutants can trigger growth in bacteria or algae, or injure or kill plants and animals. For example, too much of a nutrient such as phosphorus can cause algal blooms, which can reduce dissolved oxygen levels and affect the lower levels of the food web, with spiraling consequences to all species in the web. Heavy metals, on the other hand, can injure aquatic life when present in lower concentrations, or can cause death at higher concentrations. Metals can also be ingested or absorbed by animals at the base of the food web and accumulate in larger animals higher in the food web. Water pollution ultimately results in a less diverse aquatic community and could affect human health.

Stream-Scale Conditions

Riparian Habitat

Riparian corridor along Piper's Creek (photo by Bennett)

Riparian conditions along Seattle's major watercourses are heavily influenced by land use. Almost all high-quality riparian areas within the city are found within park areas, where deciduous and coniferous trees provide stream canopy, and where native plants help to stabilize stream banks. These riparian areas are often wide, extending more than 200 feet from the stream. The riparian zones along Piper's Creek and Taylor Creek are dominated by high-quality habitat (along 65 percent or more of these watercourses) located almost exclusively within city parks. However, these riparian areas face challenges from invasive plant species like English ivy and Himalayan blackberry.

Low-quality riparian areas are dominated by grass, invasive plants, and the absence of trees to provide shade and bank stability. These low-quality riparian areas are found near residential and commercial land uses where invasive plants are either allowed to take over or where land owners replace native plants with ornamental species. For example, Thornton Creek, which has the highest percentage of its watershed in residential and transportation uses, also has less than 10 percent of its riparian area in good condition. Low-quality riparian areas, which are more susceptible to stream bank erosion (where banks are not armored), allow sunlight to heat the stream, and disrupt the connections between riparian and instream processes and habitats.

Instream Habitat

Instream habitat quality varies widely among Seattle watercourses and within individual watercourses. In general, habitat quality is challenged by high-volume, rapid peak flows (flashy flows), the lack of floodplain connections to relieve habitat damage caused by high flows, and a scarcity of large instream wood to create diverse habitat and scour pools. These factors lead to simple, uniform stream conditions, where gravel and cobble sediments that support instream biota are scarce and pools are sparse.

Immediately adjacent land uses appear to have substantial effects on instream and riparian conditions. High-quality instream habitat typically is found in open spaces, such as in Carkeek Park in the Piper's Creek watershed, and in Lakeridge Park in the Taylor Creek watershed. Most park areas have limited bank armoring, and buildings and roads are located at a distance from open stream channels, promoting stream and riparian processes that maintain habitat. However, even areas with higher-quality habitat tend to lack the number and quality of pools and woody debris that would be expected in less intensively used watersheds.

Lower-quality instream habitats suffer from bank armoring, nearby encroachment, and degraded riparian areas, which often coincide with adjacent residential and commercial land uses. Both Longfellow Creek and Thornton Creek, which have development along most of the length of the watercourse, have large percentages of lower-quality habitat and rather small percentages of high-quality instream habitat.

Lower section of Thornton Creek (photo by Bennett)

Biological Communities

Chinook salmon (photo courtesy Seattle Municipal Archives)

To help evaluate the biological health of Seattle watercourses, Seattle Public Utilities routinely examines stream-dwelling fish and benthic invertebrates within the five major watercourses of Seattle.

The types of fish using Seattle's major watercourses vary by watercourse and receiving water body (e.g., Puget Sound, Lake Washington, or the Duwamish River). Common fish species include cutthroat trout, salmon, stickleback, sculpin, lamprey, and nonnatives such as sunfish. Fish within Seattle watercourses are limited by passage barriers such as culverts and weirs. Migratory salmon and trout can access about one-third of the potential stream habitat in the five major systems. Some of the inaccessible habitat is of the highest quality, particularly in Longfellow Creek and Taylor Creek.

Seattle watercourses are not in sufficiently good condition to support diverse or abundant fish communities. Many coho salmon die before they are able to spawn, a phenomenon known as coho prespawn mortality. Average coho prespawn mortality rates have ranged annually between 39 and 79 percent, although rates can vary widely from year to year and from watercourse to watercourse. A specific single cause of coho prespawn mortality has not yet been determined; it is possible that many factors, including water pollutants, work in combination to cause prespawn mortality. Habitat conditions, such as the lack of pools and woody debris in streams, limit rearing opportunities for juvenile salmon and other fish.

Because benthic invertebrates are sensitive to human disturbance, as well as being abundant, easy to collect, and nonmigratory, they are used as an indicator of biological integrity in streams. The benthic invertebrate communities of Seattle watercourses are typically dominated by species that can tolerate degraded conditions, such as aquatic worms and midges, and have low diversity. Seattle Public Utilities uses the benthic index of biotic integrity (B-IBI) to measure the health of a watercourse based on the numbers and kinds of stream-dwelling insects present. A comparison of the benthic index results for Seattle watercourses with other streams in the Puget Sound region shows that most Seattle watercourses are in poor condition. Fauntleroy Creek, which is considered to be in only fair condition, received the highest (best) scores among the five major watercourses. Thornton Creek and Longfellow Creek received the lowest scores.

State of the Waters 2007

Part 1 Introduction

Understanding the State of Seattle Waters

The State of the Waters report, prepared by Seattle Public Utilities (SPU), describes the current hydrologic, chemical, physical, and biological conditions in watercourses, lakes, and shorelines located within the city limits of Seattle. These conditions define the overall watershed health and the ability of city watersheds to perform critical functions and services, such as filtering water, moderating floods, and capturing sediment. Based on a number of research, monitoring, and assessment reports, this information has been collectively compiled and organized for the first time to be readily accessible to City of Seattle staff and interested citizens.

Interconnectedness between terrestrial and aquatic environments is among the most important concepts for managing watercourses, lakes, estuaries, and marine environments. Evolving watershed characteristics can lead to impacts in nearby and not-so-nearby areas, sometimes with unintended or unexpected consequences. The unpredictability of impacts on these connections often creates difficult challenges in managing land, drainage, development, and other watershed uses without leading to adverse effects on the ecosystem as a whole. Hence, there is a need to integrate management and stewardship across a watershed at many levels of action—from pesticide use in residential landscaping to stormwater management in large shopping malls. For water resources, this means looking at our actions on land and understanding how those actions affect conditions in our streams, lakes, and Puget Sound. Within Seattle, integrated watershed management is a delicate balance between desired human land uses and equally desired ecological health.

The City of Seattle is committed to restoring, protecting, and enhancing its water bodies, and inspiring citizens and businesses to do likewise. In 2004, Mayor Greg Nickels issued an executive order to create a citywide program that would balance urban growth and development with the benefits of restoring critical water resources. The Restore Our Waters initiative is a long-term effort to protect and restore aquatic habitat, improve water quality, and manage stormwater drainage. Seattle's investments under this program are to be guided by clear goals that are based in science and tracked through time to show progress. This report, State of the Waters 2007, is a critical first step in setting these goals by documenting the baseline conditions of Seattle's surface water bodies.

In addition to documenting Seattle's current, or baseline, conditions, this report serves as an important foundation step for other city efforts and activities that will affect the health of Seattle watercourses in the coming years. The assessment provided in this document was used to develop a companion report, *A Science Framework for Ecological Health in Seattle's Streams* (Seattle Public Utilities and Stillwater Sciences 2007), which outlines what healthy urban watercourses could look like, identifies potential pathways for improvement, and defines a structure for measuring ecological health, based on the best scientific information about urban watercourses.

Downtown Seattle from across Lake Union (photo by Bennett)

The actions of the City of Seattle, citizens, and businesses, individually and collectively, have a large influence over the state of the waters in and around Seattle. It is hoped that the State of the Waters report will enhance public awareness of the role we play in protecting the health of our water bodies, providing a foundation for determining effective and efficient aquatic restoration investments and for integrated management of Seattle's urban watersheds.

Overview of Seattle-Area Water Bodies

Seattle contains four types of aquatic ecosystems that differ in their physical characteristics, the habitat they provide, and the species and human uses they support:

- Watercourses and streams
- Lakes
- Estuaries
- Marine waters.

Watercourses and Streams

Surface water in Seattle is transported to receiving water bodies by a complex system of pipes, ditches, culverts, and open stream areas. For clarity, the City of Seattle has adopted the word "watercourse" to refer to this network. "Watercourse" means the route, constructed or formed by humans or by natural processes, generally consisting of a channel with bed, banks, or sides, in which surface waters flow. Watercourses include small lakes, bogs, streams, creeks, and intermittent artificial components (including ditches and culverts) but do not include receiving waters (Seattle Municipal Code 22.801.240).

This report focuses on those parts of watercourses that are not in culverts, in particular, on watercourse segments where there is an open stream channel with natural habitat.

Species that live in or along stream ecosystems are adapted to changing water flows that produce highly variable and dynamic habitats. The City of Seattle contains five major watercourses, shown in Figure 1:

- Fauntleroy Creek
- Longfellow Creek
- Piper's Creek
- Taylor Creek
- Thornton Creek.

These five watercourses have year-round flow and support salmon and trout. There are also numerous smaller watercourses that do not support salmon and may have only intermittent flow, including Mapes Creek, Puget Creek, Yesler Creek, Fairmount Creek, Madrona Creek, Frink Creek, Arboretum Creek, Wolfe Creek, Blue Ridge Creek, Ravenna Creek, Schmitz Creek, Licton Springs, and 25 other small watercourses.

Seattle watercourses are fed not only from surface water runoff and ground water but also from drainage pipes that convey stormwater from impervious surfaces such as rooftops, roads, and parking lots. A number of Seattle's historical streams are no longer present today as open watercourses, since they have been eliminated from the landscape or entirely confined in constructed drainage systems during development of the city.

Lakes

Lakes are formed in topographic depressions that retain fresh water. Lakes receive inflow from their surrounding watersheds through rivers, watercourses, overland and subsurface flow, and—in developed areas—from drainage pipes. Water typically exits a lake through a watercourse or river, although the outflows of most lakes in Seattle have been channeled into constructed drainage systems. Lakes can range in size from a few acres to many square miles. Plants and animals that depend on lake environments inhabit shallow-water and deep-water areas and interact in a complex food web.

Seattle contains three small lakes: Haller Lake, Bitter Lake, and Green Lake (described in State of the Waters Volume II). The city also contains two larger lakes, Lake Union and parts of Lake Washington. Lake Washington is the second largest natural lake in Washington state.

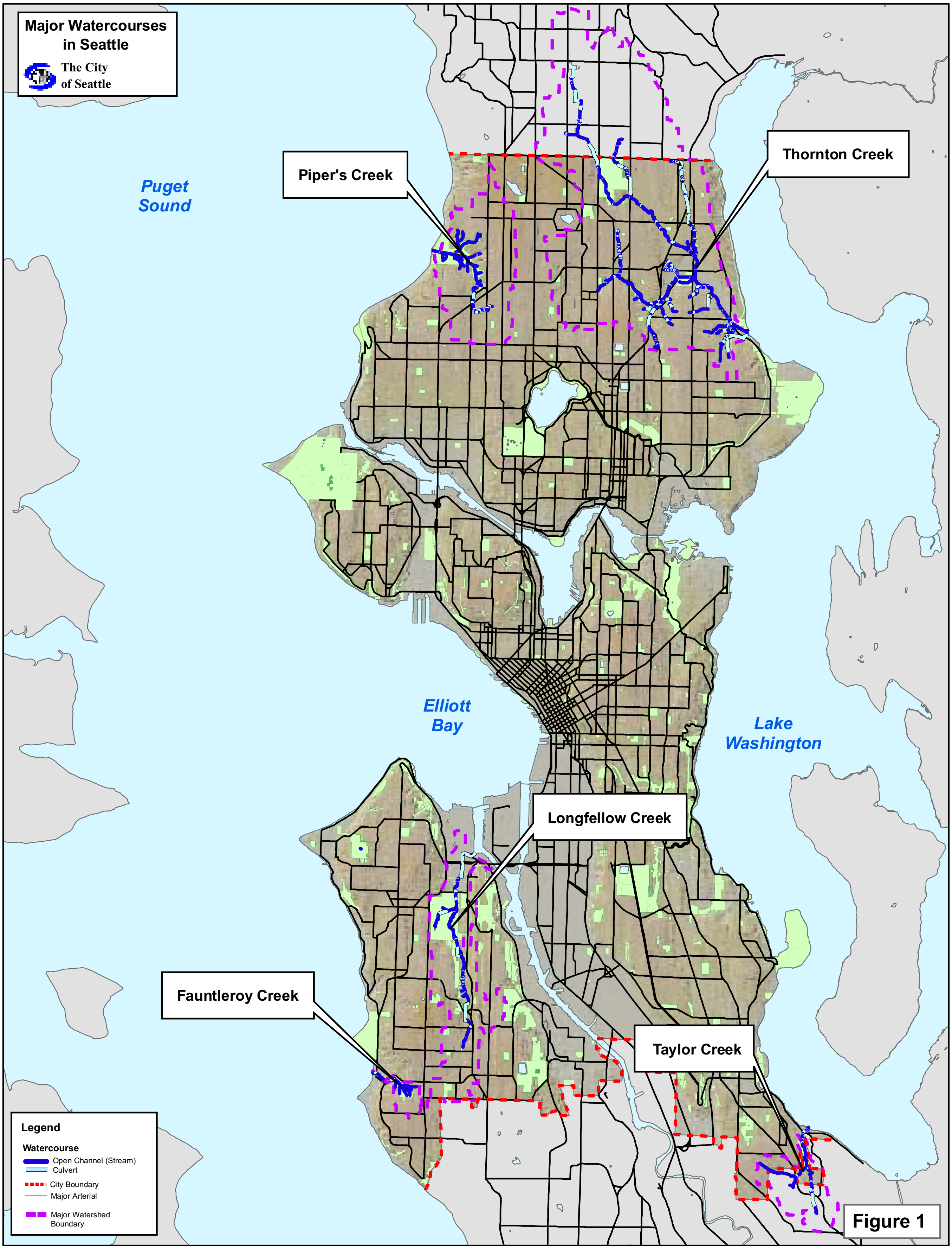


Figure 1. Major Seattle watercourses and regional water bodies.

Estuaries

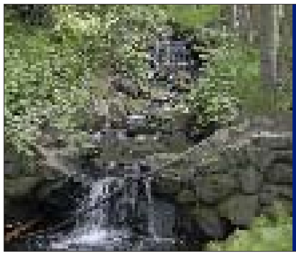
Estuaries are areas where freshwater and marine water mix, on the interface between an ocean and a watercourse or river. These ecosystems are shaped by saltwater tidal fluctuations and freshwater flows. Plants and animals that inhabit these environments must respond to rapidly changing salinity levels and flow conditions. Estuaries are nursery areas for many fish and bird species.

The Duwamish River estuary, which serves as the meeting point for Puget Sound and the Green/Duwamish river system, lies within the City of Seattle. The city also contains the estuary of the Lake Washington watershed at the Hiram M. Chittenden Locks (the Ballard Locks), which was created by redirecting the lake outlet in the early 1900s. The Lake Washington estuary, created by manmade changes, provides limited estuarine habitat.

Marine Ecosystems

Marine waters are areas of saline water, typically connected to or part of the ocean. Marine systems are shaped by tides, currents, sea floor shape, and sunlight. Plants and animals that inhabit marine environments are adapted to high-salinity conditions, and their use of habitats can vary across water depths. Many species are adapted to periods of inundation and exposure with fluctuating tides.

Seattle sits along 30 miles of Puget Sound marine shoreline. While Puget Sound is a saltwater body, it is actually considered an estuary because of the numerous tributary rivers that dilute salinities in the sound to lower levels than typically found in the Pacific Ocean. However, this report refers to Puget Sound as a marine ecosystem, to distinguish it from the smaller freshwater/saltwater interfaces of the Duwamish River and the locks.

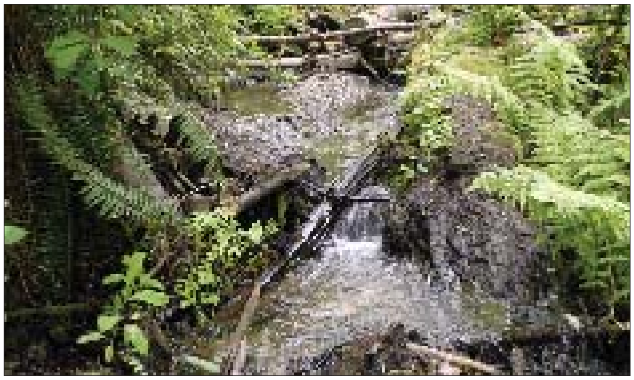


State of the Waters 2007

Part 2 A Brief Primer on Stream Ecosystems

Stream ecosystems (in Seattle, those portions of watercourses that are not ditches, pipes, or culverts) are shaped by a number of physical, chemical, and biological processes. These processes operate over short and long time frames, as well as over small and large areas. Over the past millions of years, long-term and large-scale glaciers, earthquakes, and volcanoes in the Pacific Northwest have created the physical landscape upon which all aquatic systems are based. These factors have shaped watershed characteristics such as topography, geology, and local climate, which in turn have influenced vegetative cover and watershed soils. Collectively, these features determine how water, sediment, wood, and nutrients are moved from land to rivers and streams (Figure 2; Spence et al. 1996), with riparian corridors serving as the interface between upland terrestrial systems and aquatic environments (Gregory et al. 1991).

Using water, sediment, wood, and nutrients from the watershed, a stream is subject to processes both within the stream and in the surrounding riparian corridor that shape its habitat (Naiman et al. 1995). For example, the rate at which surface and subsurface water reaches the stream dictates the flow regime in the stream. The contents of that source water determine the quality of water in the stream. The riparian zone also has many roles that affect a stream, including the following:



Fauntleroy Creek (photo by Bennett)

- Supplying shade that moderates water temperatures
- Providing bank stability by means of plant roots
- Contributing organic litter and large woody debris from vegetation
- Mediating the flow of nutrients
- Controlling sediment inputs to the stream by trapping sediment and filtering surface runoff (Spence et al. 1996).

Processes occurring in the stream and riparian corridor interact with one another, shaping the flow regime, water quality, riparian habitat, and instream habitat. These stream and riparian characteristics collectively influence the biological communities found inhabiting stream environments, including fish, wildlife, and benthic invertebrates. For these animals, all of the features of the stream are important. Biological processes such as organic decay, respiration, and feeding also affect physical and chemical processes and characteristics in the stream, such as water temperature and nutrient cycling.

The working definition of an ecologically healthy urban stream is a stream that exhibits the ecological functions and features necessary to support diverse, native, self-sustaining aquatic and riparian communities. This means that ecologically healthy urban streams have the habitat necessary to support benthic invertebrates and native fish, including salmon and trout during all life stages.

Stream conditions are subject to processes operating at different spatial scales and are also dynamic, changing through time. In some cases, a stream can be altered by large disturbances such as forest fires and floods, which cause the stream to respond to new introductions of sediment, excess water, or changes in the riparian forest. Streams can also be disturbed by local events such as landslides. While disturbances such as these create problems for people, they can contribute to healthier aquatic ecosystems because they create and maintain habitat at different places and different times in a stream system, prompting a continuous renewal of habitat (Naiman et al. 1992).

Human influences on streams and their watersheds also can dramatically alter the ways in which stream ecosystems behave (see Figure 2). People often change the land uses in the watershed. In the Puget Sound lowland, watersheds were once mostly forested, with wetlands and bogs on upper plateaus. Today, the urban watersheds are extensively covered in impervious surfaces like roads, buildings, and paved areas that prevent water from infiltrating the ground. These and other types of human-induced land use changes cumulatively affect many chemical and physical processes that shape stream environments.

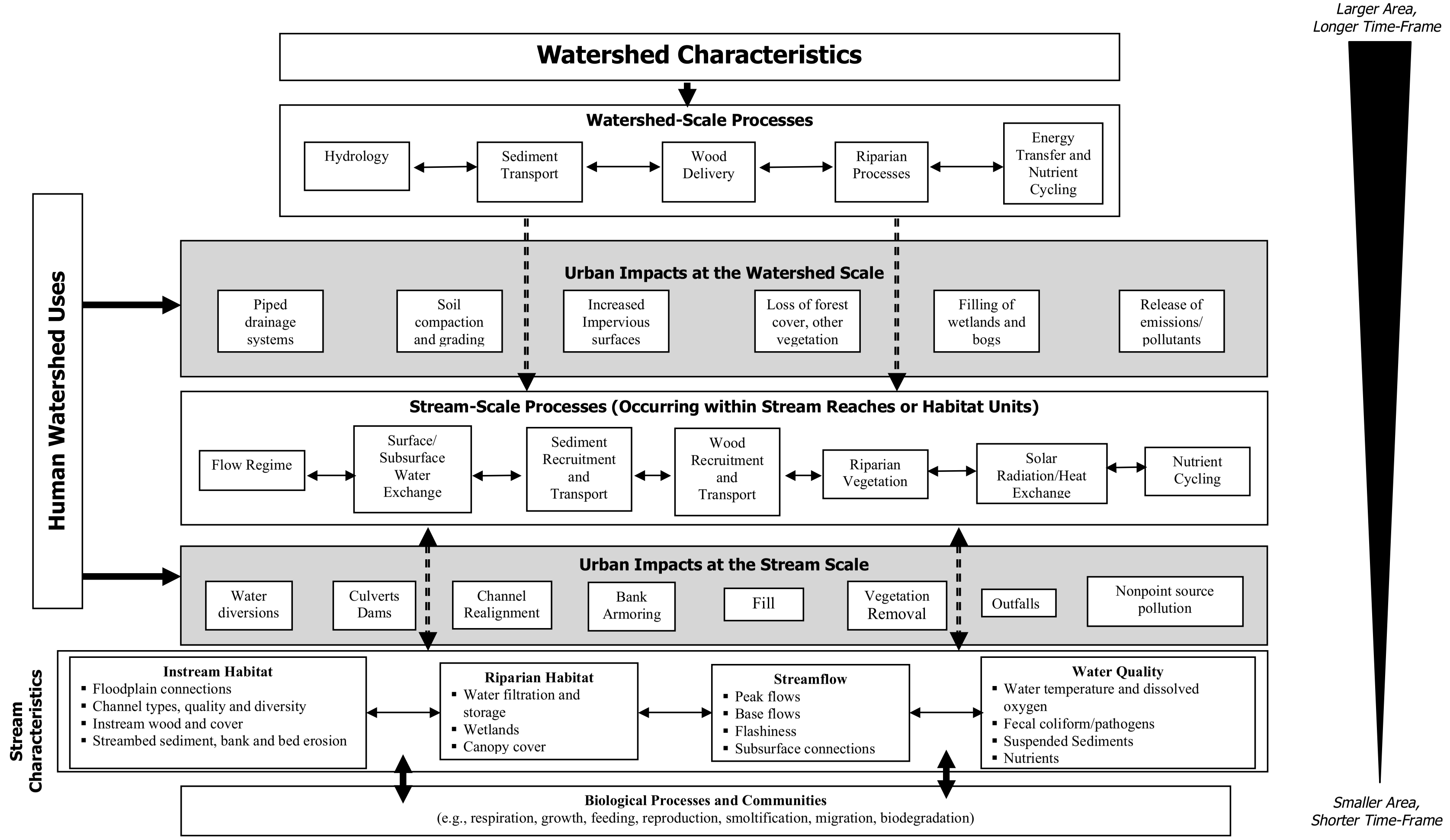
Local changes, like constructing dams or installing stream bank armoring, can also affect stream conditions. These local changes can influence all areas downstream, or become even more problematic when they extend throughout much of a stream system (e.g., bank armoring).

Understanding how stream environments are shaped and maintained is rather complex. An informative description of ecosystem processes and how they shape stream characteristics and biological communities can be found in Spence et al. (1996). The following text highlights those processes and stream features that are important to understanding the conditions specific to Seattle's urban watercourse environment.

This State of the Waters report focuses on five major features of watercourse environments:

- Hydrology (important at the watershed scale)
- Water quality (important at the watershed scale)
- Riparian habitat (important at the stream scale)
- Instream habitat (important at the stream scale)
- Biological communities (important at the stream scale or smaller).

The following discussion generally describes undeveloped conditions for these five major features, as well as the urban influences on these stream conditions.



Note that there are many connections between elements within and among the boxes shown here. Only large arrows between categories are shown, individual arrows have been omitted for simplicity. See Spence et al. (1996) for a good discussion of physical, chemical and biological processes in stream systems.

Figure 2. Conceptual model of a stream ecosystem functioning in an urban environment.

Important ecosystem principles to keep in mind when reading this report include the following:

- The importance of physical, chemical, and biological processes in maintaining healthy stream environments
- The spatial and time scales at which human impacts occur and at which stream consequences occur
- The connections between all components of the stream ecosystem and its watershed.

Conditions at the Watershed Scale

The *watershed scale* refers to the overall watershed, that is, looking beyond the watercourse corridor to evaluate upland activities and environmental features that can influence conditions found within the stream channel. This section explains how watershed conditions can influence stream hydrology and stream water quality, and in turn, how characteristics at the watershed scale can be used to predict conditions at the stream scale.

The next section then discusses how conditions along or within the watercourse corridor—i.e., stream-scale conditions—can also influence stream channel conditions. It is the combination of watershed-scale and stream-scale conditions that ultimately determines the overall condition of a given watercourse; hence these conditions are the focus of typical watercourse assessment efforts.

"Watercourse" means the route, constructed or formed by humans or by natural processes, generally consisting of a channel with bed, banks, or sides, in which surface waters flow.

Stream Hydrology

Surface water hydrology generally refers to the relation between precipitation and stormwater runoff, and in particular, the conveyance of stormwater runoff through natural or manmade systems to downstream receiving water bodies (e.g., streams, watercourses, rivers, canals, lakes, ponds, wetlands, and saltwater bodies). This includes evaluation of the physical processes that affect a droplet of water from the moment it reaches the surface of the earth to the transport of that water over land (including losses to ground water); through pipes, ditches, and streams; to large downstream water bodies.

Stream Hydrology Prior to Urban Development

Stream hydrology is determined by the shape, size, topography, geology, and vegetation of a stream's watershed or drainage area. Watershed geology affects 1) the infiltration of precipitation and the resulting influence on stream flow, and 2) the amount and type of erosion, which determines stream channel shape and substrates.

Rainfall is the major form of precipitation in Seattle watersheds. Rainfall either infiltrates through soils and becomes ground water, or is taken up into vegetation and released back to the atmosphere through transpiration. Very little rainfall runs off the land surface in undeveloped areas. Surface water runoff during storms may elevate stream flows temporarily; however, those increases are gradual, and flow reductions following the storm event are gradual as well. Moreover, the floodplain of a stream and its riparian corridor help to moderate and contain high flows.

The majority of water in surface streams is supplied by subsurface flow from ground water (see Figure 3, upper panel). This subsurface flow provides a consistent and gradual inflow of fresh, cool water throughout most of the year. This region of the stream where ground water and surface water mix is called the hyporheic zone. The hyporheic zone is important for stream hydrology and biological processes as well (Edwards 1998).

The hyporheic zone is a region beneath and lateral to a streambed where shallow ground water and surface water mix and interact, making the hyporheic zone an area of great biological and chemical activity.

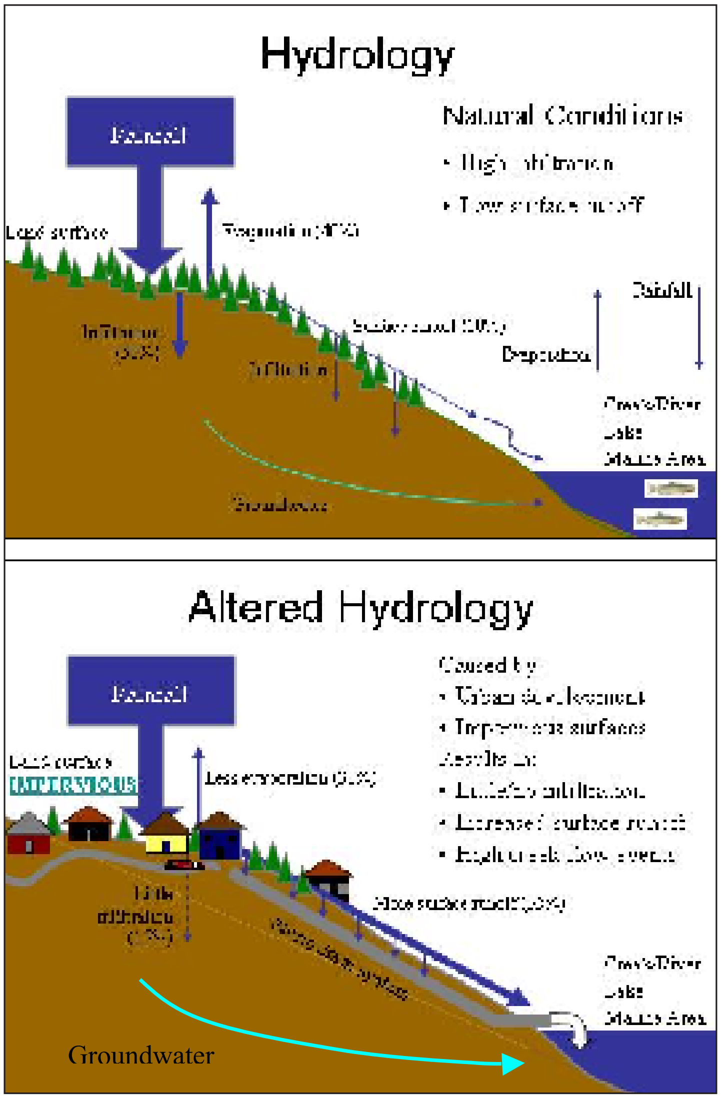


Figure 3. Hydrologic cycle under natural conditions and as altered by urban development.

Urban Impacts on Stream Hydrology

Urban development results in widespread impacts on a watershed's hydrologic regime (see Figure 3, lower panel; Arnold and Gibbons 1996; Center for Watershed Protection 1996). Replacing watershed vegetation with impervious surfaces, roads, buildings, and drainage networks leads to a decrease in subsurface flows and a large increase in surface water runoff. By limiting water infiltration, impervious surfaces reduce ground water recharge, dry-season base flows, and hyporheic exchange.

Reduced ground water and hyporheic flow can also allow stream water temperatures to increase during warmer months. Surface runoff, particularly in warmer months, can be warmed by sun-heated pavement, potentially increasing surface water temperatures during storm events. Surface runoff can further affect the water quality of receiving water bodies by carrying pollutants, such as oils and metals from pavement, to a watercourse.

Flashy flow means a high rate and volume of flow, typical in a developed watershed with impervious surfaces from which stormwater runoff drains all at once. By contrast, in undeveloped watersheds, infiltration and vegetation slow runoff and attenuate peak flows.

Runoff from impervious surfaces can reach watercourses rapidly and in great amounts, creating frequent high and flashy flows that cause problems for instream habitat. While high flows play a large role in habitat creation and maintenance, frequent high-flow events have more damaging effects, especially when coupled with other anthropogenic factors like stream bank armoring and removal of riparian vegetation. Frequent high and flashy flows promote channel incision, where the stream channel increases in depth and width. This channel incision lowers the elevation of the streambed and leads to channel entrenchment below the surrounding land. The frequent high flows also can increase rates of erosion and bank instability. Erosion and bank instability can become even more problematic where the riparian vegetation is insufficient to stabilize stream banks (discussed further below). High stream flows also can scour salmon and trout redds (i.e., nests) from the streambed.

High and flashy flows in watercourses do not operate alone in how they influence habitat. In developed areas where a stream is constrained to an undersized channel or lacks floodplain connections, even moderate increases in flow can damage habitat and cause flooding on surrounding lands. While stream flows can be slowed by in-channel debris or stored within the stream floodplain, these components are rare in urban watercourses. Frequent high and flashy flows along armored stream banks where riparian vegetation has been removed act to reduce or eliminate the ability of a stream to form and maintain complex physical habitat that supports fish and wildlife.

Receiving Water Quality

Local water bodies are used for a wide variety of purposes such as swimming, boating, fishing, and aesthetic benefits, and they also provide valuable habitat and food needed by fish and other aquatic organisms. While humans typically see aquatic ecosystems only from the outside, there are many components of healthy aquatic communities under the surface or at the edge of the water. Streams support a variety of aquatic and terrestrial organisms, including submerged and emergent plants, riparian vegetation, insects, fish, and mammals. Less easy to see but equally important are the microscopic bacteria, fungi, and organisms that provide food for other aquatic animals. A healthy aquatic environment functions in a dynamic fashion to maintain a diverse physical habitat and support the species that reside there. Together, both the human and wildlife uses of Seattle's aquatic systems rely on clean water.

Water Quality Prior to Urban Development

The water quality of a watercourse is determined by watershed hydrology, geology, and vegetation. The watershed characteristics determine whether rain water can infiltrate, as well as the kinds of chemical compounds that may be picked up along the way from watershed soils and carried downstream.

Surface waters contain a mixture of chemical components, biologically important nutrients, and trace elements and compounds. The chemical delivery of dissolved and particulate matter such as nutrients and organic carbon strongly influences nutrient cycling and biological processes in stream ecosystems, including photosynthesis, respiration, and biological growth (Spence et al. 1996).

The abundance of various chemicals in stream water can limit biological processes of plants, microbes, and their consumers. In aquatic systems, nitrogen, phosphorus, and carbon (often available as dissolved organic matter) can be limiting in this way (Spence et al. 1996).

Common indicators of water quality in watercourses include water temperature, dissolved oxygen, nutrients (commonly, nitrogen and phosphorus), suspended solids, and metals. Unlike hydrology and physical habitat, water quality conditions are not usually visible and are highly variable in time and by location. It is important that water quality indicators fall within a range suitable to support aquatic life. Indicator values may vary seasonally, but should not vary beyond a suitable range except for brief periods, usually associated with a storm event or major natural disturbance such as a landslide or fire.

Urban Impacts on Water Quality

Urban development has a wide variety of far-reaching impacts on receiving water quality. Numerous studies conducted during the late 1970s and early 1980s show that stormwater runoff from urban and industrial areas is a potentially significant source of water pollution (U.S. EPA 2002). Stormwater runoff in urban areas, such as Seattle neighborhoods and roads, typically enters a drainage system constructed of pipes and culverts that carries water quickly to receiving waters. Watercourses serve as intermediary receiving waters in Seattle, conveying stormwater runoff from urban watersheds to larger receiving waters, such as lakes and Puget Sound.

The content of urban stormwater runoff is formed by many actions stemming from land use, pesticide use, land management practices, roads and traffic, and industrial activities (USGS 2001). Stormwater may also contain substances that were dumped, leaked, spilled, or discharged into the drainage system. While stormwater influences are thought of in conjunction with storm events, stormwater quality actually is influenced year-round. During dry periods, pollutants can accumulate on impervious surfaces and be flushed into watercourses during later storms. Surface runoff can also include drainage during dry weather from car washing, pavement washing, pavement-cutting washwater, or irrigation (U.S. EPA 2002).

Aerial view of Lake Union and Seattle (photo by Bennett)

Urbanization of a watershed is often characterized by commercial, industrial, and transportation land uses such as airports, smelters, factories, and landfills. These land uses are typically associated with the production of metals, organic compounds, and other toxic wastes that can be entrained in precipitation and runoff (through air pollution or deposition on the ground surface) and ultimately enter aquatic areas. Residential land uses can also produce water quality pollutants resulting from landscaping activities (pesticides and fertilizers), pet waste, and various home and automobile maintenance activities. Metals such as lead, arsenic, and zinc above certain concentrations can be toxic to both aquatic organisms and humans, and exposure can lead to both short-term and long-term health problems (King County 2005a).

Although federal and state regulations have been established in recent years to prevent or reduce the pollution of lakes and watercourses by metals, organic compounds, and toxic chemicals, these constituents often bind readily to the bed sediments. Without cleanup, pollutants can remain at the bottoms of lakes and streams for decades (Davis and Cornwell 1998; Goodyear and McNeill 1999; Mason et al. 2000). Many chemical compounds, such as chlorinated hydrocarbon insecticides, which are now mostly banned in the United States, were originally used because of their persistence and their effectiveness over time. These same characteristics give them similarly long lives in lakes, watercourses, and the flesh of animals that ingest these chemicals (Welch and Lindell 2000). Table 1 summarizes information about compounds that can be toxic to aquatic life.

Table 1. Toxic compounds that may contaminate surface waters.

	Description	Source	Concern
Organochlorine compounds	Polychlorinated hydrocarbons (chlordane and dieldrin)	Pesticides.	Persistent environmental contaminants.
	Polychlorinated byphenyls (PCBs)	Widely used as coolants and lubricants for transformers and appliances. Manufacturing of PCBs was stopped in 1977.	Persistent environmental contaminants.
Semivolatile Organic Compounds (SVOCs)[a]	Polycyclic aromatic hydrocarbons (PAHs)	Combustion of fossil fuels and other hydrocarbon-rich materials. Sources include vehicle exhaust, burning coal, forest fires, tar, and asphalt roads and roofs.	Eliminating PAHs from urban runoff is difficult because of their common and varied sources. They are an environmental concern because some are toxic to aquatic life and are probable endocrine disruptors; several are suspected human carcinogens.
	Phthalates (aromatic esters)	Solvents, plasticizers, and insect repellants.	Environmentally persistent and have become widespread contaminants.
	Phenols (aromatic alcohols)	Derived from coal tar; sources include vehicle exhaust and petroleum refining. Also used as disinfectants.	Absorbed through the skin, they damage most types of cells.
Trace Elements	Metals (arsenic, cadmium, copper, chromium, lead, mercury, selenium, silver, zinc)	Occur naturally from weathering of rocks and mineral soils; human sources such as burning of fossil fuels, industrial discharges, automobile emissions, pesticides and fertilizers, and discharges from wastewater treatment facilities.	Cu, Se, and Zn are essential to animal and plant nutrition but can be toxic at high concentrations. Slow elimination rate of some trace elements from many aquatic organisms can lead to bioaccumulation and biomagnification in aquatic food chains.

[a] SVOCs occur together in the environment, and their effects can be additive.

Similar to receiving water quality, stormwater quality is extremely variable. Differences in the timing and intensity of rainfall affect runoff rates, pollutant washoff rates, in-channel flow rates, pollutant transport, sediment deposition and resuspension, channel scour, and other factors that collectively determine pollutant concentrations and pollutant forms. Pollutant sources can be unpredictable and temporary, such as spills, leaks, dumping, construction activity, landscape irrigation, pesticide application, and car washing runoff. As a result, pollutant concentrations and other stormwater characteristics at a given location fluctuate greatly during a single storm and from one storm to another (U.S. EPA 2002).

Water Quality Indicators

Water quality conditions are usually presented in the form of a *water quality indicator*, which is a metric used to assess the effectiveness of management programs such as pollution prevention and stormwater treatment, as well as to analyze water quality issues associated with discharges from city stormwater and combined sewers. The goal of any water quality program is to protect the beneficial use of the water body, which is often measured by water quality indicators. Because the quality of water in urban watercourses is dominated at times by stormwater-associated constituents, the water quality indicators most often used to assess water quality conditions originate from automotive activities, atmospheric deposition, and other urban sources such as runoff from roofs and landscaped areas. The commonly used water quality indicators and their sources and effects are discussed briefly below.

Water quality indicators are selected chemical and physical parameters and indices that can be used to characterize overall conditions in the receiving water; they also provide benchmarks for assessing the success of watershed management efforts.

Water Temperature

Water temperatures in watercourses are influenced by the amounts and temperatures of surface water runoff, stormwater or other discharges, and ground water, as well as the extent of stream shading provided by riparian vegetation (Spence et al. 1996). Water withdrawals from a watercourse can also influence water temperature.

Because most aquatic species cannot regulate their body temperature, their temperature is determined by water temperature. Water temperature heavily influences the behavior and development of many aquatic species, including salmonids. Water temperature can also affect competition among organisms, predation, parasitism, and disease.

Dissolved Oxygen

Dissolved oxygen is the amount of oxygen dissolved in water and available for uptake by aquatic organisms. Dissolved oxygen levels are highly dependent upon water temperatures, because cooler water can hold more dissolved oxygen. Urban impacts can lower dissolved oxygen through increased water temperature and oxygen depletion. For example, heavy nutrient loading leads to oxygen depletion through plant and algal respiration at night.

Water contains only about 3.3 percent of the amount of oxygen contained in air. Given that aquatic plants and animals depend on oxygen for growth and survival, their efficient extraction of oxygen is critical. Low dissolved oxygen levels can cause stress and even death of organisms.

Turbidity and Suspended Solids

Total suspended solids (TSS) are particulate materials such as eroded soil particles, heavy metal precipitates, and biological solids that are suspended in stormwater runoff and cause surface water to appear cloudy, or turbid.

Particulates readily wash off paved surfaces and exposed soil during storm events. Construction sites, if not properly managed, can be a significant source of suspended solids in many urban environments. Other sources include windblown dust from automobiles and heavy equipment, sand and salt applied to icy roadways, and erosion from agricultural land or residential gardens and lawns. In addition, swift-flowing watercourses can erode stream banks and bottoms, thus aggravating suspended solid problems. Because urban development tends to increase the volume and rate of stormwater runoff, it can contribute to turbidity problems well downstream of the runoff site, where storm drains discharge into natural streams.

Turbid discharge into natural stream (photo by Bennett)

A primary concern with suspended solids is their potential for deposition in ecologically sensitive areas, such as those used for fish spawning. Deposition can also affect the numbers and types of benthic invertebrates that are important components of a water body's food web. In addition, a number of potential pollutants, such as heavy metals and many organic compounds, become associated with suspended solids and tend to accumulate in the receiving waters in areas of suspended solids deposition.

pH Conditions

The pH value of water is a measure of its acidity. The pH value can range from zero to 14; between 6 and 8 is the most desirable range for surface waters. Water with very high pH values (i.e., basic) or very low pH values (i.e., acidic) is corrosive and is toxic to fish and other aquatic organisms. Sources of pH problems in urban runoff include industrial process wastewater; cement used in concrete products and concrete pavement; certain chemical cleaners; and chemicals used by photographic, printing, and graphics businesses.

Heavy Metals

The metals most commonly found in urban runoff are copper, lead, zinc, cadmium, chromium, arsenic, and nickel. Major sources of heavy metals in urban runoff are related to transportation, because metals are components of many vehicle parts, motor oil, tires, and pavement materials. Pesticides, paints, and industrial sites such as scrap yards are other common sources of heavy metals found in urban runoff.

The form of metals that is most toxic to aquatic biota is the free ionic or dissolved state. However, metals in urban runoff are often adsorbed onto suspended solids present in the runoff and are not usually found in large concentrations in dissolved form. Particulate-bound metals are deposited in lakes and Puget Sound and can cause toxicity problems for bottom-dwelling organisms. Research in Puget Sound has shown that metals concentrate in sediments and at the water surface (in the surface microlayer) where they interfere with the reproductive cycle of many biotic species and cause tumors and lesions in fish.

Nutrients

Phosphorus and nitrogen compounds are the primary nutrients of concern in stormwater runoff. These nutrients are used for plant growth or otherwise are altered for incorporation into the food web and can limit aquatic productivity.

Sources of phosphorus and nitrogen in urban runoff include fertilizers, animal wastes, leaking septic tanks, sanitary sewer cross-connections, detergents, organic matter such as lawn clippings and leaves, eroded soil, road de-icing salts, and automobile emissions.

Concerns regarding nutrients, particularly phosphorus, include stimulation of algal blooms and excessive plant growth in lakes and marine waters. When algae and plant material die, dissolved oxygen concentrations in the water can become depleted as the material decomposes. Some forms of algae (e.g., blue-green algae) are toxic to fish and other aquatic organisms and can even kill small animals like cats and dogs when they drink the affected water. Some algal blooms are also harmful to humans and have caused closures of swimming beaches and small lakes. Algae also can cause taste and odor problems in drinking water supplies and can foul water supply intakes.

Ammonia-nitrogen is also toxic to fish and other aquatic organisms. In addition, ammonia-nitrogen can deplete dissolved oxygen concentrations in water systems as it oxidizes to nitrite and nitrate through the nitrification process. Whether caused by decomposition or oxidation, low dissolved oxygen levels can stress or kill fish and other aquatic organisms.

Fecal Coliform Bacteria and Pathogens

Urban runoff often contains high levels of fecal coliform bacteria. These organisms are indicators of fecal contamination from warm-blooded animals and the possible presence of pathogenic (i.e., disease-causing) bacteria and viruses. The primary sources of fecal coliform bacteria in stormwater are pet and wildlife wastes (as well as human waste in areas served by septic systems).

Fecal coliform contamination of surface water supplies can pose a human health risk, consequently limiting the recreational use of a water body. Bacterial contamination has required the closure of swimming beaches in local lakes as well as shellfish harvesting areas in Puget Sound.

Oxygen-Demanding Organic Matter

Organic matter in animal waste, food waste, leaves, and twigs is consumed by bacteria present in receiving waters. Microorganisms use oxygen as they break down organic material such as algae (as discussed in the Nutrients section above). The oxygen consumed in this process is called the biochemical oxygen demand (BOD). Large concentrations of organic matter and their subsequent degradation by microorganisms can deplete oxygen levels in surface water supplies, in turn harming fish and other aquatic organisms.

Other chemicals such as ammonia and many organic compounds also exert an oxygen demand as these compounds are oxidized in water. The oxygen depleted by the chemical oxidation of pollutants present in runoff is known as chemical oxygen demand (COD). Like BOD, COD is an indicator of water pollution. Slow-moving water is particularly susceptible to oxygen depletion by these compounds, because there is little turbulence to reintroduce oxygen into the water.

Toxic Organic Compounds

Pesticides include herbicides, insecticides, fungicides, algacides, and other similar substances.

Organic contaminants are detected infrequently in urban runoff (organic compounds were detected in less than 20 percent of runoff samples analyzed in the Nationwide Urban Runoff Program; U.S. EPA 1983). Organic compounds that are most frequently detected include phthalates (these are plasticizers found in a variety of products including food additives, vinyl and plastic restoration products, and lubricating oils); polycyclic aromatic hydrocarbons (PAHs are components of fossil fuel and may also be formed during any combustion process); and some pesticides.

Most organic compounds are toxic. However, the availability of these compounds to biological systems in urban runoff is difficult to assess because of the close association these compounds have with particulate matter. Many of these compounds are transported primarily as particulates and are deposited in lakes and Puget Sound, where they can be toxic to bottom-dwelling organisms. A recent study conducted by the U.S. Geological Survey found 23 pesticides in water samples collected from urban watercourses in the Puget Sound area during rainstorm events (Voss et al. 1999). The pesticides most commonly detected were 2,4-D (e.g., Weedone), dichlobenil (e.g., Casoron), MCPP (e.g., Mecoprop), prometon (e.g., Pramitol), diazinon, and pentachlorophenol. Concentrations of five pesticides (carbaryl, chlorpyrifos, diazinon, dindane, and malathion) exceeded the maximum concentrations for the protection of aquatic life recommended by the National Academy of Sciences and National Academy of Engineering (1973).

Oil and Grease

Oil deposits on pavement (photo by Bennett)

Oil and grease come from a variety of sources including roads and highways, parking lots, food waste storage areas, garbage collection bins, and areas where pesticides are applied (because pesticides are often applied in a diesel carrier). Oil and grease can be petroleum-based (associated with automotive sources) or food-related (such as cooking oil). These materials are lighter than water and tend to float on the water surface, forming ugly sheens that reduce the aesthetic quality of waterways. When present in sufficient quantities, oil and grease can be particularly harmful to plants (inhibiting germination and growth) and animals (e.g., loss of feather insulation in birds, and general ingestion during cleaning for all wildlife). These substances can adhere to particulate matter and settle out in the receiving water environment, where they can destroy aquatic habitat.

Conditions at the Stream Scale

As noted in the previous section, activities and environmental conditions in the overall watershed play a major role in shaping instream conditions, and thus are useful as a common indicator of stream conditions. This section explains the role played by conditions along or within the individual watercourses in influencing stream channel conditions, and their relative importance in evaluating stream health.

In particular, this section focuses on three key components of stream-scale conditions: riparian area conditions, habitat conditions within the channel itself, and instream biological communities. These components of stream-scale conditions are the primary indicators of stream health and are used extensively to evaluate urban stream conditions in Seattle.

Riparian Habitat

The riparian corridor surrounding a stream plays many roles in shaping stream habitat and biological communities. Riparian vegetation shades the stream, which helps to moderate water temperatures. The condition of riparian areas and their role in aquatic habitat processes are affected by both upland and stream conditions and the integrity of the connections between them (Benda et al. 1998; Naiman et al. 1998).

Riparian Ecosystems Prior to Urban Development

Riparian areas are located adjacent to water bodies and in natural areas of the Puget Sound lowlands; these areas consist of stands of western hemlock, western red cedar, and Douglas fir with an understory of shrubs and ground covers such as salmonberry, Oregon grape, and ferns. The riparian corridor can supply stability to banks and even slow water velocities during high-flow events (Spence et al. 1996). Riparian vegetation also contributes woody debris and litter fall to streams, providing habitat structure and organic materials to fuel the food web. In addition, riparian areas house terrestrial insects that provide prey for fish and other insects.

Riparian forest areas affect water quality by filtering and storing stormwater runoff, and allowing pollutant-laden runoff to infiltrate the sediments before it can reach surface water resources. In addition, certain types of vegetation can actually take up and remove the nutrients and some of the pollutants being transported in stormwater runoff. Forest vegetation shades the stream channel, influences water temperatures, and recycles nutrients deposited by plants and animals using the area (e.g., salmon carcasses) (Gregory et al. 1991; Bisson and Bilby 1998; Hershey and Lamberti 1998; Naiman et al.1998; Suberkropp 1998).

Urban Impacts on Riparian Areas

When urban development encroaches on riparian areas adjacent to streams and replaces natural forests and wetlands with buildings, structures, landscaped yards, or impervious surfaces, it results in a variety of direct and indirect impacts on the habitat quality of streams (Gregory et al. 1991; May 1996).

Removal of riparian vegetation directly results in a reduction in organic material inputs to the stream, which small forested streams rely upon as their principal energy source (Triska et al. 1981). In addition, the sizes and types of woody debris available for recruitment is changed, affecting the ability of the wood to shape instream habitat, as well as the longevity of wood structures in the stream (because decomposition times vary among different types of wood).

Residential encroachment on Taylor Creek riparian corridor (photo by Bennett)

Reduced shading of streams in riparian areas can result in increased water temperatures and reduced dissolved oxygen concentrations, affecting benthic and fish communities. The removal of riparian vegetation reduces the natural filtering properties (discussed in the previous section) that can be important in promoting local water quality (Johnston et al. 1990, Norris 1993). Stream bank instability can also increase where native riparian vegetation is replaced with plants having shallower root systems that cannot hold bank soils together effectively.

Instream Habitat

Instream habitat at the most basic level is shaped by stream flow, channel gradient, surrounding topography, and the riparian corridor. These characteristics affect the introduction and movement of sediment and wood, as well as the connections between the stream and its floodplain. Stream flow and riparian conditions are discussed above, while the following subsections focus on sediment and wood dynamics, floodplain connections, and the resulting instream habitat types.

Sediment and Wood Recruitment and Transport Prior to Urban Development

The size and composition of sediment in a stream and the amount of wood in the channel are important components of stream habitat. Stream flows recruit and transport woody debris supplied by the floodplains and riparian areas of the stream (Bilby and Bisson 1998). Sediment is recruited to the watercourse from hillsides, floodplains, and stream banks through erosion. Once in the channel, sediment and wood are moved by stream flow to shape stream habitat, such as pools, riffles, and overall channel substrate (Montgomery and Buffington 1998). For example, large woody debris traps other pieces of wood, alters and redirects stream flow, and stores sediment (Bisson et al. 1987; Bilby and Bisson 1998).

Urban Impacts on Sediment and Wood in Streams

Wood and sediment dynamics can be disrupted through hydrologic changes and local changes along the watercourse. High flows can wash sediment and wood downstream, causing the channel to incise, widen, and simplify (Paul and Meyer 2001; Figure 4, erosional phase). In urban systems, bank armoring and channelization often disconnect sediment source areas from the stream, so that new sediment cannot be recruited from the stream banks, floodplain, or hillsides (Finkenbine et al. 2000; Pizzuto et al. 2000). Similarly, the lack of wide riparian forests along a stream limits wood recruitment.

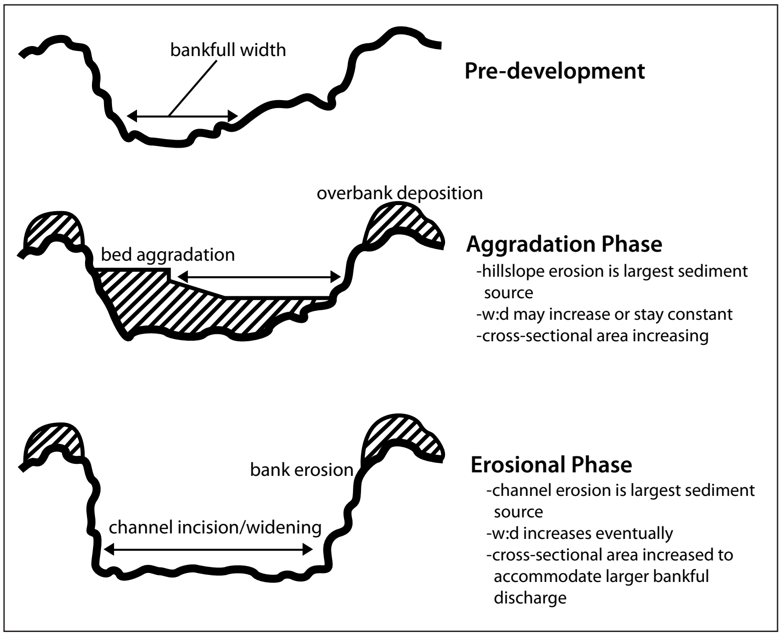


Figure 4. Changes in stream channel sediment dynamics as a result of urban development.

Adapted from Paul and Meyer (2001).

Often, fine sediments become excessive in urban watercourses, as unarmored stream banks, disturbed hillsides, and stormwater runoff introduce silt to the system (Figure 4, aggradation phase). Disruption in the recruitment and transport of sediment and wood in urban areas often leads to an increase in fine sediments, a decrease in coarse sediments (i.e., gravel and cobble), and a decrease in in-channel wood. Collectively, these factors promote simple stream habitat lacking in complexity and diversity.

Sediment and wood dynamics are further affected by infrastructure and road crossings where watercourses are confined in pipes and culverts (Finkenbine et al. 2000). In addition, weirs and dams are commonly installed in stream channels to reduce channel gradient and decrease flow velocity (May 1996). These structures typically are not designed to pass sediment or wood, which consequently are trapped in upstream areas, limiting their ability to contribute to downstream habitat formation. These manmade instream structures often create outfall or velocity barriers to fish passage (WDFW 1999).

Stream–Floodplain Connections Prior to Urban Development

The floodplain of a stream plays an important role in habitat-forming processes. Floodplains are low lying areas adjacent to streams which can fill with water when stream flow increases. This allows water to expand laterally from the channel to occupy a wider area when needed. The floodplain serves as a source area for water storage, wood, and sediment. During high flows the floodplain floods, storing excess water and dissipating high-flow energy. In addition, the channel may migrate across the floodplain to connect to previously formed off-channel and side-channel areas (Junk et al. 1989; Bayley 1991). The floodplain is an essential component of the watercourse, playing a large role in hydrology, wood and sediment recruitment and transport, instream complexity, and riparian connections.

Urban Impacts on Stream–Floodplain Connections

In urban watercourses, many floodplain areas have been isolated from stream channels and removed from their role in stream habitat dynamics. In developing areas, stream–floodplain connections are affected by local actions that, considered cumulatively, can create watercourse-wide impacts. Stream bank armoring, channel incision, and urban encroachment effectively channelize a stream and severely limit its opportunities to connect to its floodplain. This process reduces the stream's access to sediment and wood sources, impairing its ability to form instream habitat. Often it can reduce the ability of the watercourse to manage flood flows and can contribute to downstream flooding problems. Without the floodplain, streams lose habitat complexity, most notably off-channel, channel-edge, and shallow-water refuge habitats.

Stream Habitat and Channel Types Prior to Urban Development

Streams in the Seattle area are Puget Lowland alluvial systems characterized by rather low-gradient channels passing through glacial outwash, where stream flow can downcut and move glacial sediments to form and maintain habitat (Buffington et al. 2004; Naiman et al. 1998). Although streams can be characterized hierarchically (Montgomery and Buffington 1998), only two stream scales are discussed here: the habitat unit, and the reach type (also called channel type or geomorphic type in this document).

Stream Habitat Units

Stream habitat units have distinct characteristics such as depth, water turbulence, water velocity, and substrate. Stream habitat units found in Seattle include the following (Meehan 1991; Spence et al. 1996):

- Pool—Stream area with reduced water velocity, greater stream depth, and typically a smooth surface
- Riffle—Shallow stream area with a rapid current and the water surface broken by streambed sediments such as gravel, cobbles, or boulders
- Glide—Stream segment with intermediate, uniform depth, moderate water velocity, and very little surface turbulence (also called a run)
- Cascade—Stream segment with high gradient, high current, turbulence, and exposed rocks and boulders forming drops in the stream
- Step—Isolated small falls over boulders or large wood in steep, shallow areas, with steeper gradient and shallower water than in cascade habitat unit.

Stream Channel Types

The stream habitats listed above have been used to classify stream channels into reach types (Montgomery and Buffington 1998; Buffington et al. 2003). While these types were first used to characterize mountain stream reaches, the lower-gradient reaches are applicable to Seattle watercourses (Buffington et al. 2003). Listed from higher to lower gradient, these stream types are *cascade*, *step-pool, plane-bed*, *pool-riffle*, and *dune-ripple* (also called *regime*) (Figures 5, 6, and 7).

A Cascade channels are found in steep areas (8 to 30 percent gradient), where the channel is confined by valley walls and contains mostly large substrate such as boulders.

B Step-pool channels are found where the gradient is between 4 and 8 percent, with a moderate amount of confinement from valley walls around the stream. Step-pool channels have small floodplains, if any, and the channel itself typically contains cobbles, boulders, and large woody debris.

C Plane-bed channels develop in lower-gradient areas of 1 to 4 percent, and the channel adopts a rather uniform appearance of riffle and glide habitat with gravel and cobble substrate. A plane-bed channel may or may not have a developed floodplain.

D Pool-riffle channels develop in unconfined, low-gradient areas of 0.1 to 2 percent where the stream can interact with the surrounding floodplain and in-channel woody debris. In some cases, the channel oscillates between pool and riffle areas with some gravel bars, providing diverse habitat.

E Dune-ripple, or regime, channels exist in flat, unconfined areas of less than 0.1 percent gradient with primarily sand substrate. Typically the channel is rather sinuous, with sand bars and potential for multiple stream channels (Montgomery and Buffington 1997; Buffington et al. 2004).

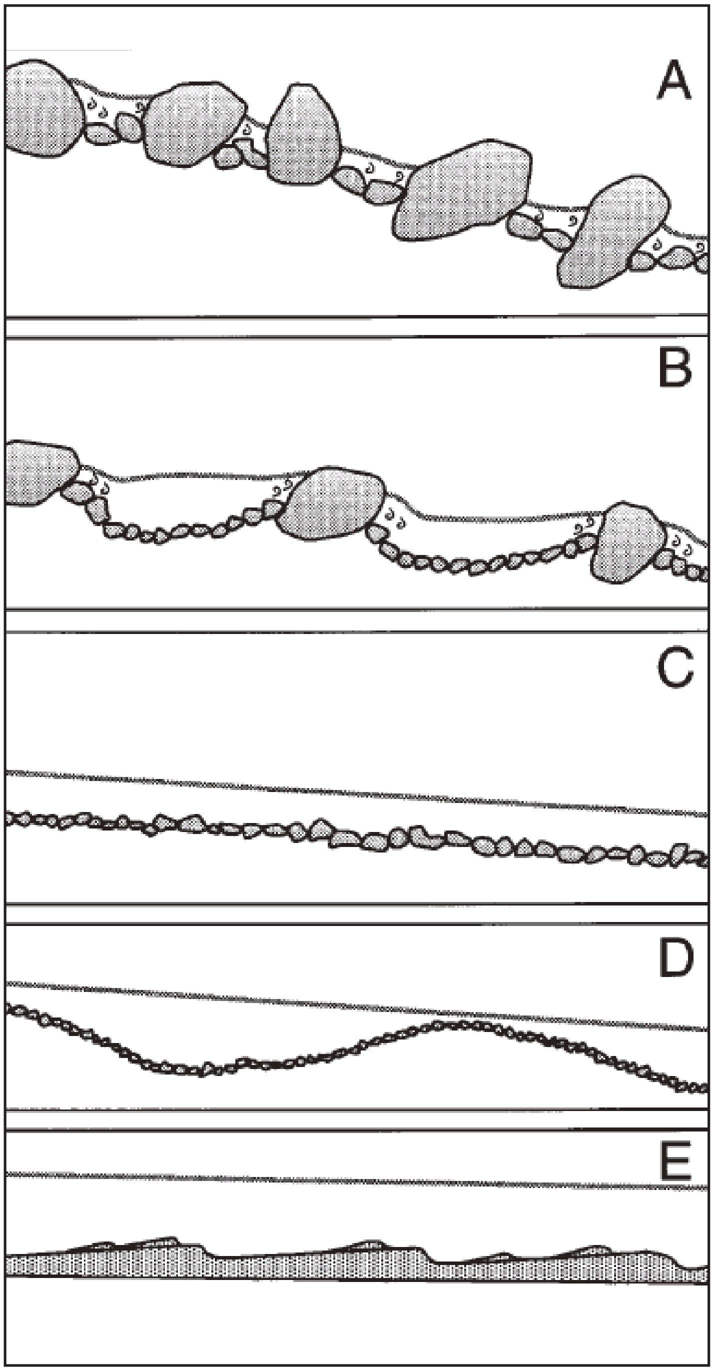


Figure 5. Schematic longitudinal profile view of five stream channel types during low flow, ranging from higher-gradient reaches (cascade form) to lower-gradient reaches (dune-ripple form).

Reprinted with permission from Montgomery and Buffington (1997).

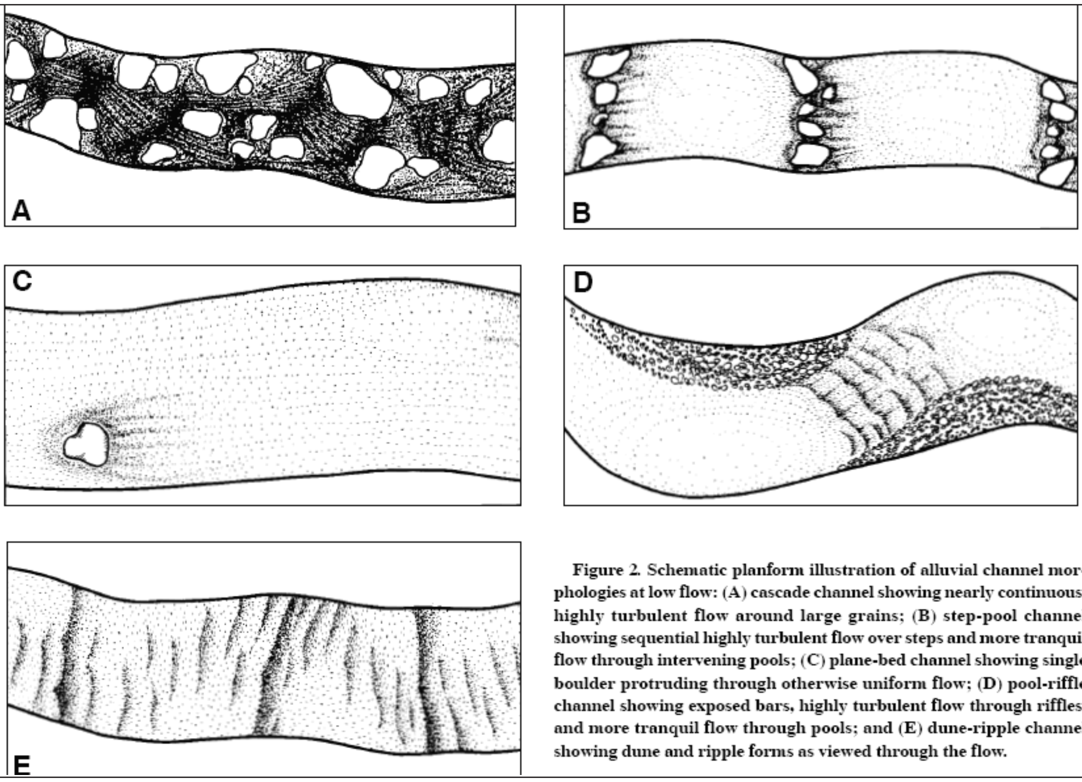


Figure 2. Schematic planform illustration of alluvial channel morphologies at low flow: (A) cascade channel showing nearly continuous, highly turbulent flow around large grains; (B) step-pool channel showing sequential highly turbulent flow over steps and more tranquil flow through intervening pools; (C) plane-bed channel showing single boulder protruding through otherwise uniform flow; (D) pool-riffle channel showing exposed bars, highly turbulent flow through riffles, and more tranquil flow through pools; and (E) dune-ripple channel showing dune and ripple forms as viewed through the flow.

Figure 6. Schematic plan view of five stream channel types during low flow, ranging from higher-gradient reaches (cascade form) to lower-gradient reaches (dune-ripple form).

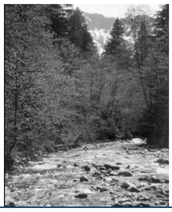
	Regime	**Pool-riffle**	**Plane-bed**	**Step-pool**	**Cascade**
Typical slope	<0.1%	0.1-2%	1-4%	4-8%	8-30%
Confinement	Unconfined	Unconfined	Variable	Moderately confined	Strongly confined
Instream structure	Sinuosity, bedforms, banks	Bedforms, co/bo, lwd, banks	Boulders, cobble, banks	Bedforms, boulders, lwd, banks	Boulders, banks
Typical substrate	Sand	Gravel	Gravel, cobble	Cobble, boulders	Boulder
Sediment sources	Channel, banks, inactive channels	Same as regime + debris flows	Channel, banks, debris flows	Channel, hillslope, debris flows	Channel, hillslope, debris flows
Example picture					

Figure 7. Characteristics of five stream channel types typical of Seattle watercourses.

co/bo = cobble/boulders; lwd = large woody debris.
Figures 6 and 7 adapted from Montgomery and Buffington (1997).

Urban Impacts on Stream Habitat and Channel Types

Stream habitat and channel types are a function of watercourse gradient, confinement by natural features, and instream sediment and wood. In urban areas, expected habitat and channel types are often missing and replaced by simplified channels that lack instream structure and suffer from human-induced confinement. These channels often have eroded streambeds in response to high flows and bank armoring, since there is little accessible floodplain for storing excess water. Often wood and other structures have been removed from the stream to increase conveyance or to prevent possible damage to bridges and culverts, leaving nothing in the stream to store sediment, scour pools, or create habitat complexity. As a result, streams are often plane-bed or regime channels, even where a pool-riffle or step-pool channel type is expected.

Aquatic Biological Communities

A number of aquatic animals depend on healthy stream ecosystems. These species range from salmon, kingfishers, salamanders, and turtles to benthic invertebrates, which are bottom-dwelling organisms such as insects, crustaceans, mollusks, and worms. Salmonids and benthic invertebrates have been chosen as a focus of this report. Both groups use aquatic habitat in Seattle, and both serve as biological indicators of health in watercourses. The City of Seattle collects data to document these species groups. Salmon in particular are culturally, politically, and economically important throughout the Pacific Northwest. Benthic invertebrates are sensitive to human disturbance, as well as being abundant, easy to collect, and nonmigratory. Therefore, they are used as an indicator of biological integrity in streams. A much larger variety of animals inhabit Seattle watercourses and are important components of stream health. However, salmonids and benthic invertebrates are used as indicators in this report and are discussed in detail.

Turtle on Thornton Creek (photo by Bennett)

Salmonids in Aquatic Ecosystems

In this report, the term *salmonid* refers to anadromous and resident salmon and trout. Anadromous fish move between freshwater and saltwater during the course of their lives, using freshwater to spawn and rear, and saltwater to grow and mature. Resident trout (such as rainbow trout) and salmon (e.g., kokanee) stay in fresh water for their entire lives. This report focuses on four species of Pacific salmon (Chinook, coho, sockeye, and chum) and two native species of trout (cutthroat and rainbow or steelhead). Pink salmon are not usually found in Seattle streams.

The life cycle of anadromous salmon and trout (e.g., steelhead and some cutthroat) typically begins when adults migrate into a river or stream to reproduce. In the late fall or spring, females establish a redd, or egg nest, through digging in the gravel of the stream bottom. Male salmon then fertilize the salmon eggs as the female deposits them in the redd. After this act of spawning, the adult salmon die, while some trout may live on to migrate back out to sea and return again. Eggs incubate in the river or stream for about 4 months before emerging as fry. Fry may rear in the stream either for months (ocean-rearing Chinook) or for years (coho, cutthroat, and rainbow/steelhead), or they may head downstream soon after emergence (chum and sockeye). Chum salmon typically head out to saltwater as fry, while sockeye migrate to a lake and spend a year rearing there. Whether in the stream, lake, or marine environment, fry grow into larger juveniles if they find adequate food and refuge from high flows and predators (Bjornn and Reiser 1991; Groot and Margolis 1991).

Juvenile Chinook salmon tend to migrate to saltwater within the first year of life, joined by sockeye, coho, and trout species during their second year of life. While still small, juvenile fish tend to stay close to shore to rear and find refuge in the marine environment. Eventually they grow large enough to head for the open ocean and can travel thousands of miles while they feed and grow. Salmon and trout mature at different ages ranging from 3 years (coho and sockeye salmon) to 6 years (some Chinook salmon). Upon the cusp of maturity they start their migration back to their natal watercourses and rivers. On reaching the river or watercourse mouth, they migrate up to their spawning grounds, depending on sufficient flow, water temperature, holding pools, and spawning habitat to successfully leave their offspring behind.

Sockeye salmon (photo by Doberstein)

Salmon typically spawn in the late fall, and their offspring emerge from the gravel in the early spring. Juvenile fish, after rearing, leave for the saltwater between late spring and summer. After maturing in the ocean, adult salmon return in the late summer and fall season to their natal watercourses and rivers. Trout are late winter and early spring spawners, with young emerging from redds in the summer. The timing of adult returns, spawning, and fry emergence varies based on water temperature, distance of the spawning grounds from saltwater, and other environmental factors. Thus salmon and trout are locally adapted to the conditions of their home system (Groot and Margolis 1991).

Resident salmon and trout have a less arduous journey, living in either a stream, river, or lake for their entire lives. Adult salmon and trout living in lakes are generally adfluvial, meaning they use the lake to forage and grow, but use tributaries draining to the lake for spawning habitat. As with anadromous fish, resident salmon typically spawn in the late fall, and resident trout spawn in the late winter or early spring.

Table 2 summarizes the life history patterns of salmonids in the Pacific Northwest, including those found in Seattle watercourses.

Table 2. Generalized life history patterns of salmon, steelhead, and trout in the Pacific Northwest.[a]

	Adult Return	Spawning Location	Eggs in Gravel [b]	Young in Stream	Freshwater Habitat	Young Migrate Downstream	Time in Estuary	Time in Ocean	Adult Weight (average)
Coho	Oct–Jan	Coastal streams, shallow tributaries	Oct–May	1+ years	Tributaries, main stem, slack water	Mar–Jul (2nd year)	Few days	2 years	5–20 lbs. (8)
Chum	Sep–Jan	Coastal rivers and lower stream reaches	Sep–Mar	Days–weeks	Little time in freshwater	Shortly after leaving gravel	4–14 days	2.5–3 years	8–12 lbs. (10)
Chinook		Main stem of large and small rivers			Main stem large and small rivers		Days–months	2–5 years	
Spring	Jan–Jul		Jul–Jan	1+ years		Mar–Jul (2nd year)			10–20 lbs. (15)
Summer	Jun–Aug		Sep–Nov	1+years		Spring (2nd year)			10–30 lbs. (14)
Fall	Aug–Mar		Sep–Mar	3–7 months		Apr–Jun (1st or 2nd year)			10–40 lbs.
Sockeye	Jul–Aug	Streams, usually near lakes	Aug–Apr	1–3 years	Lakes	Apr–Jun (2nd–4th year)	Few days	1–4 years	3–8 lbs. (6)
Steelhead [c]		Tributaries, streams, and rivers			Tributaries		Less than 1 month	1–4 years	
Winter	Nov–Jun		Feb–Jul	1–3 years		Mar-Jun (2nd–5th year)			5–28 lbs. (8)
Spring	Feb–Jun		Dec–May	1–2 years		Spring & Summer (3rd–4th year)			5–20 lbs.

[a] There is much variation in life history patterns – each stream system having fish with their own unique timing and patterns of spawning, growth, and migration.

[b] The eggs of most salmonids take 3–5 months to hatch at the preferred water temperature of 50–55 degrees F; steelhead eggs can hatch in 2 months.

[c] Steelhead, unlike salmon, may not die after spawning. They can migrate back out to sea and return in later years to spawn again.

Adapted by Pacific States Marine Fisheries Commission. Sources: Ocean Ecology of North Pacific Salmonids, Bill Pearcy, University of Washington Press, 1992 Fisheries Handbook of Engineering Requirements and Biological Criteria, Milo Bell, U.S. Army Corps of Engineers, 1986; Adopting A Stream; A Northwest Handbook, Steve Yates, Adopt-A-Stream Foundation, 1988.

Salmonids in Stream Ecosystems

Watercourses can be used for salmonid spawning, incubation, and rearing habitat. Basic necessities are adequate water temperature (temperatures above 16 degrees Celsius [ºC] or 60 degrees Fahrenheit [ºF] can become stressful for salmonids) and dissolved oxygen levels (dissolved oxygen below roughly 6 mg/L becomes stressful), both of which can be influenced by degraded water quality in stormwater entering watercourses, reduced ground water supplies to feed stream flow, and removal of riparian vegetation.

During adult salmonid spawning, water levels must be sufficient to allow fish access to suitable habitat but not so extreme as to push adults downstream (Bjornn and Reiser 1991; Crisp 1993). Sediment recruitment and sorting are needed to replenish spawning substrates in streambeds, and channel complexity is important in providing resting areas for migrating adults. Moderated flows are also important during egg incubation, which requires sufficient water flow to deliver oxygen to the eggs and carry away waste products (Bams 1969; Leman 1988).

When fry emerge from their redds, habitat complexity is important in providing foraging opportunities and refuge areas from high flows and predators. This complexity is important for rearing and migrating juvenile salmon, as well as juvenile and adult resident trout. At all life stages, salmon need cool water temperatures to control their metabolic rate.

Urban Impacts on Salmonids

Changes in watersheds and watercourses resulting from urbanization can reduce the ability of salmon and trout to successfully reproduce and rear in urban areas. During spawning and egg incubation, high flows can mobilize gravel and scour eggs from the streambed. Fine sediment can smother redds, causing egg mortality, or can irritate fish gills. High water temperatures and low dissolved oxygen levels can induce stress or even lead to death. Once juvenile fish come out of the redds, they also are affected by high water temperatures, low dissolved oxygen levels, and gill-irritating fine sediments (Bell 1986; Chapman 1988; Newcombe and Jensen 1996).

Prey items such as benthic invertebrates can also be smothered by fine sediments. For smaller fish, high flows can displace fish downstream, particularly where there is little accessible floodplain or instream wood and boulders to provide refuge and pool habitat. Instream complexity, created by instream wood, boulders, and pools, is often lacking in urban areas but is important for providing rearing habitat for juvenile fish and resting areas for migrating adults. All life stages of salmonids are affected by toxic pollutants and excess nutrients, which can lead to chronic or acute effects on fish themselves or on their prey.

Benthic Invertebrates in Stream Ecosystems

Salmon fly (photo by Svendsen)

Benthic invertebrates are bottom-dwelling organisms without backbones such as insects, crustaceans, worms, and mollusks that inhabit a stream, lake, estuary, or marine water body for all or part of their lives. They typically dominate the trophic level between primary producers—those organisms that produce energy from sunlight, such as plants and algae—and fish species (Horne and Golman 1994).

In streams, typical benthic invertebrates include mayflies (*Ephemeroptera*), stoneflies (*Plecoptera*), caddisflies (*Trichoptera*), aquatic worms (*Oligochaeta*), scuds (*Crayonyx*), some flies (*Diptera*) such as midges (*Chironomid*), planarians (*Turbellaria*), and leeches (*Hirudinea*). Benthic invertebrates differ in life cycle and length of life, with basic distinctions between insect and noninsect groups. Most noninsect species, such as leeches and worms, spend their entire lives in a stream. Insect species have a more complex life cycle, starting as an egg in the stream, deposited there by a winged, terrestrial adult. In some species such as mayflies and stoneflies, the egg develops into a gill-breathing, insect-like larva that goes through several instars, or developmental stages, as the larva develops. In other insects such as flies, a worm or grublike larva undergoes a complete metamorphosis, developing into a pupa in a protected habitat or cocoon before becoming an adult. All insect invertebrates travel out of the aquatic environment to emerge or molt into winged adults, during which time they disperse, reproduce, and deposit their eggs. The life cycle of most benthic invertebrates spans a year, but some larger invertebrates have life cycles lasting 3 years or more.

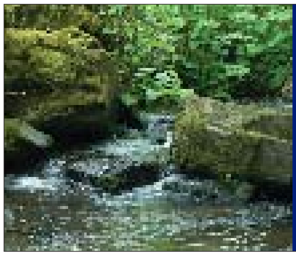
The benthic community is shaped by many aspects of the stream environment, including substrates, flow, water temperature, dissolved oxygen levels, and water chemistry (Hershey and Lamberti 1998). Water temperature, dissolved oxygen, and water chemistry set broad limitations on the types of invertebrates that can inhabit a stream. Some invertebrates require cooler temperatures and moderate flows, while others are more tolerant of a wide range of conditions, including the fine sediments, high temperatures, and high flows common in urban watercourses.

Water velocity and substrate are important at local habitat scales in determining the benthic species present. Because most invertebrates spend their lives attached to sediments, the types of sediment shape the benthic community. For example, coarser sediments provide larger and more numerous interstitial spaces for invertebrates to inhabit than fine sediment can provide. The body shape and other features of benthic species varies, making some suitable for attaching to the sediment (e.g., small or streamlined bodies, rock cases, and suction disks) and feeding in faster-flowing water (e.g., net spinning). The hyporheic zone is important for the benthic community in providing nutrients for primary production and refuge during high flows (Hershey and Lamberti 1998; Edwards 1998).

Urban Impacts on Benthic Invertebrates

Benthic invertebrates can face challenging conditions in urban watercourses. High flows can scour them from the streambed and transport them downstream. Reduced hyporheic zones can limit food sources and high-flow refuge opportunities. The introduction of fine sediment can eliminate suitable areas for certain kinds of benthic invertebrates or reduce their ability to forage effectively (Collier 1995). Loss of connections with adjacent riparian areas may alter the food web or reduce the success of invertebrate species that take refuge in riparian vegetation while adults. Water and sediment pollutants in watercourses or lakes can be ingested by benthic invertebrates, causing mortality, or accumulated in the tissues, resulting in a long-term chronic impact. Because benthic invertebrates are sensitive to human disturbance, as well as being abundant, easy to collect, and nonmigratory, they function well as an indicator of biological integrity in streams.

Caddisfly (photo by Bennett)



State of the Waters 2007

Part 3 Assessing the State of the Waters

Evaluating water quality, sediment quality, and habitat conditions relies on both compiling data and analyzing those data. Data from a variety of sources have been compiled and evaluated for this report. This chapter describes the data compilation and evaluation procedures used to assess conditions in Seattle-area watercourses.

Figure 8 shows the major Seattle watercourses and corresponding watersheds, and identifies the reaches where monitoring data have been collected for water and sediment quality parameters, as well as habitat characteristics.

The 2004 Comprehensive Drainage Plan and other documents issued by Seattle Public Utilities (SPU) have identified limiting factors for Seattle water bodies, that is, major problems that limit the capability of a water body to support fish and other animals, as well as provide clean water and safe opportunities for recreation and other human uses. This State of the Waters report builds upon those previous assessments. To provide connection to that earlier work, the limiting factors are listed in a summary table in Appendix A.

"Watercourse" means the route, constructed or formed by humans or by natural processes, generally consisting of a channel with bed, banks, or sides, in which surface waters flow.

Unnamed creek (photo courtesy Seattle Municipal Archives)

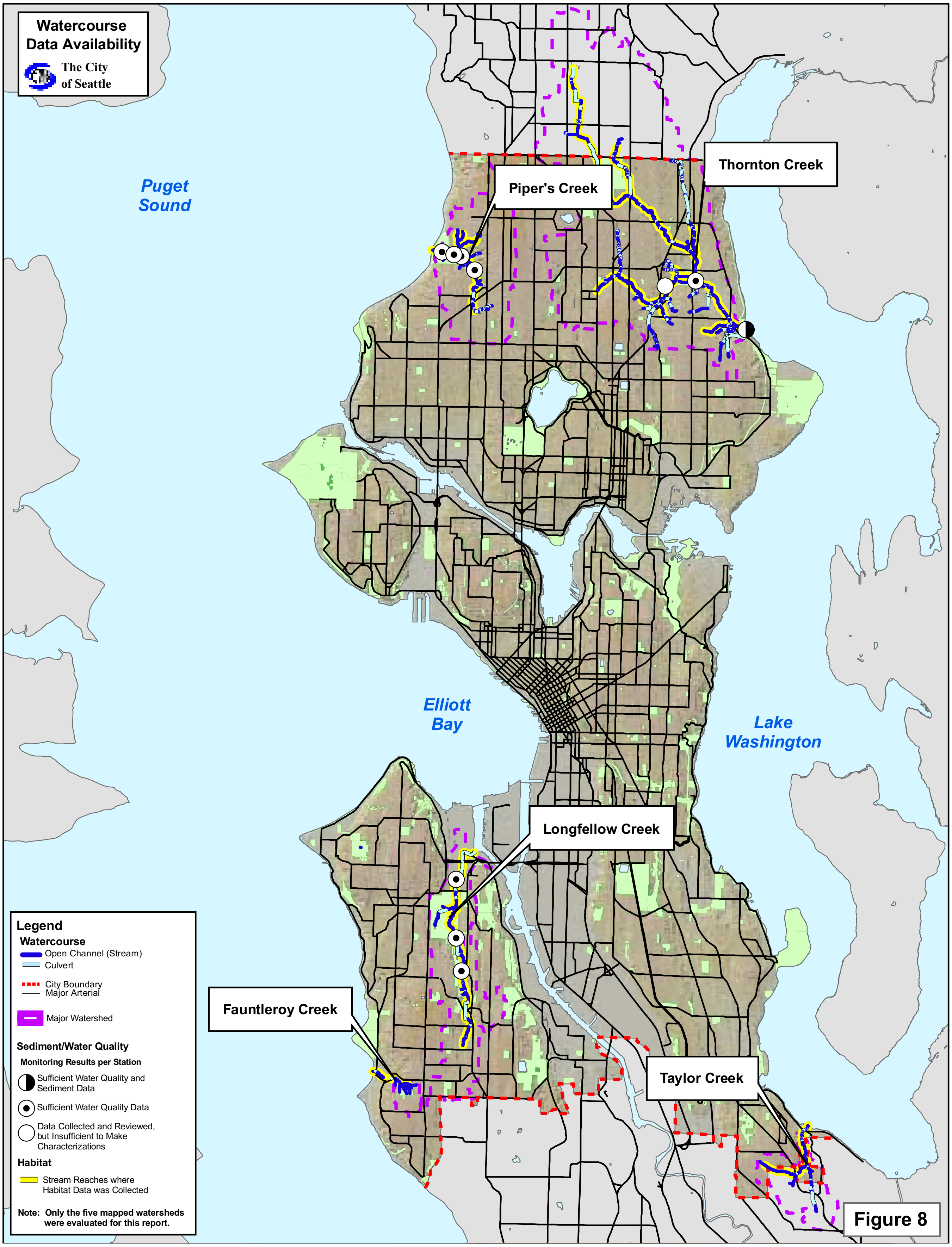


Figure 8. Watercourse habitat surveys and availability of water and sediment quality data.

Evaluating Conditions at the Watershed Scale

This section describes the methods used to evaluate hydrologic and water quality conditions at the watershed scale. Again, the watershed scale refers to the overall watershed conditions, looking beyond the watercourse to evaluate upland activities and environmental conditions that can influence conditions found within the stream channel. The focus of the watershed-scale evaluation is on hydrologic and water quality changes. The methods used to evaluate these two general watershed components are discussed in detail below.

Hydrology Assessment Methods

The following sections discuss the hydrologic data collection and data analysis methods used in this report. The first section covers the main sources of hydrologic data and related watershed hydrologic information used in this assessment. The second section discusses the methods of evaluating stormwater runoff production in each major watershed.

Data Collection and Compilation

- *Flow monitoring* data are available for four of Seattle's five major watercourses (1999–2005), although flow information is not always continuous or available in consistent locations (Hartley and Greve 2005). Data were collected either by SPU or the U.S. Geological Survey. The data were used to generate time series graphs of flow conditions and calculations of mean, peak, and low flows, where such data were available.

- A *subcatchment and outfall inventory* was conducted in 2002 to identify the subbasins delivering stormwater to the five major watercourses. The inventory delineates the specific areas contributing stormwater flows and the discharge point where flows enter each watercourse.

- *Permeability* data identify the ability of subsurface soils to absorb water through infiltration, affecting the amount of runoff that can be generated during a storm. Geologic data for each of Seattle's five major watercourses were obtained from the Pacific Northwest Center for Geologic Mapping Studies at the University of Washington. Permeability data were used for an analysis of runoff production from Seattle watersheds.

- *Seattle topography* data, which provide the relief of the land, were used to calculate slope. This information was also used for an analysis of runoff production from Seattle watersheds.

- *Impervious surfaces* are surfaces that are impermeable to water and prevent water from reaching the underlying soils, such as concrete, asphalt, and buildings. Impervious surface information, based on 2002 LANDSAT data from the University of Washington Urban Ecology Research laboratory (Alberti et al. 2004), was used to assess the degree to which infiltration is possible in Seattle's five major watersheds. This information was used to analyze runoff production from the watersheds.

Data Analysis

Runoff production was analyzed to estimate the potential for a subcatchment (i.e., an area of land draining to a single storm drain outfall in a watercourse) to deliver larger stormwater flows to Seattle's major watercourses at increased rates. The *runoff production potential* qualitative analysis examined relevant landscape characteristics that shape instream flows, including both natural and manmade features. Because the volume and timing of stream flows heavily influence habitat conditions, this analysis was used to identify the areas that may be contributing the most to altered hydrology in the watercourses (although the analysis is not relevant for site-specific evaluations). Currently, these estimates serve as a placeholder until more consistent and comprehensive flow monitoring records are available, to augment 1999–2005 flow information. In addition, because this analysis focuses on both natural and manmade landscape features, some areas could be estimated as having high runoff potential based on natural characteristics such as land slope and geology rather than manmade alterations.

Runoff production is related to both biophysical factors and characteristics of urban development. Physical factors included in the analysis are land area of each subcatchment, geology, and slope. In addition, the amount of impervious surfaces, the presence of detention structures, storm drainage infrastructure (i.e., density and pattern of storm sewers and ditches), road density, and land use (especially commercial use) were also considered for inclusion in the analysis as indicators of urban development. Ultimately, impervious surface area was chosen as the preferred measure of urban development. For the amount of impervious surface, only percentages were included because of limited data availability, given the high degree of overlap between several of the other measures. Therefore, each subcatchment was rated for its runoff production potential based on the following characteristics:

- Impervious surface area (percentage of the total subcatchment area)
- Slope
- Drainage area
- Permeability of surface soils, such as sand, clay, or bedrock.

Each of these factors was ranked on a scale of 1 to 10, with 1 having the highest potential to contribute larger flows or deliver stormwater more quickly, compared to other subcatchments (Figure 9). Individual factor ratings were then averaged to produce an overall *runoff production potential* rating for each subcatchment. These ratings were converted to qualitative categories for reporting in Part 4 of this volume.

The analysis results are presented in a runoff potential and erosion stage map for each watercourse, included in the map folio accompanying this report. The ranking criteria and summary of ranking scores are provided in Appendix F.

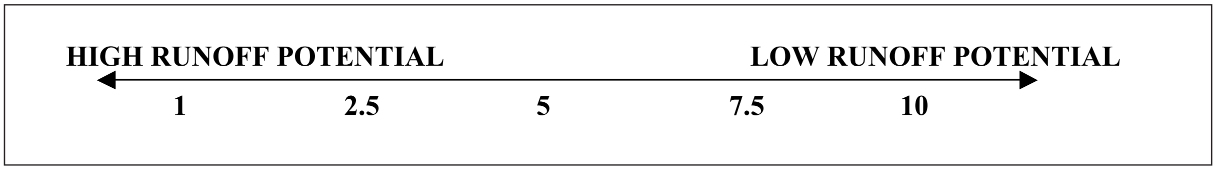


Figure 9. Scoring framework used to rate runoff potential.

Water Quality Assessment Methods

Water quality regulations have been developed both at the state and federal level, and are highly technical in nature. This section is based on these regulations. Water quality data for small watercourses in the Seattle area are fairly limited, and long-term records (i.e., greater than ten years) are available only for the three largest watercourses (Longfellow Creek, Piper's Creek, and Thornton Creek). Sediment quality data are only available for Thornton Creek, therefore this analysis focuses almost entirely on water quality.

The largest source of information is the data from King County's Stream Monitoring Program. As part of this program, King County has been collecting water quality samples each month from four stations in Piper's Creek, one station in Thornton Creek, and two stations in Longfellow Creek since 1988, 1974, and 1973, respectively. All of the data from 1996 through 2005, along with data for select parameters for the entire period of record (including dissolved oxygen, temperature, total suspended solids, turbidity, and fecal coliform bacteria), were compiled and reviewed for this report.

These data generally provide a good record of water quality at these seven stations for several conventional water quality indicators (e.g., temperature, dissolved oxygen, and fecal coliform bacteria). However, metals data from King County are available only for three of the seven stations. Of these three stations, metals are analyzed monthly at the Thornton Creek station and semiannually (twice per year) at the Piper's Creek station near the mouth. King County discontinued metals analysis in Longfellow Creek in 2003. With the exception of the King County data and a few regional studies conducted by the U.S. Geological Survey on Longfellow Creek and Thornton Creek, long-term information on the levels of metals and toxic organic pollutants present in Seattle-area watercourses is generally not available.

Water quality indicators are selected chemical and physical parameters and indices that can be used to characterize overall conditions in the receiving water; they also provide benchmarks for assessing the success of watershed management efforts.

In 2004 and 2005, the Washington Department of Ecology (Ecology) also began to monitor water quality in Fauntleroy Creek, Longfellow Creek, and Thornton Creek. Preliminary data for 2005 from Fauntleroy Creek and final data for 2004 from Longfellow Creek and Thornton Creek have been compiled for this analysis.

Compared to the extensive habitat assessment effort that SPU has undertaken over the past 5 years, SPU's role in monitoring receiving water quality in the Seattle area has been fairly modest. These efforts have consisted of collecting two or three stormwater samples per year from four stations in Longfellow Creek and Piper's Creek since about 1999, along with several small, focused studies to support the ongoing regional coho prespawn mortality investigation, and to assess the performance of stormwater treatment best management practices based on samples collected within the storm drain system, not in the watercourses. These studies have generally focused on several conventional water quality indicators (e.g., temperature, dissolved oxygen, and fecal coliform bacteria), along with pollutants commonly found in urban stormwater runoff (e.g., metals and total petroleum hydrocarbons).

Prespawn mortality occurs when adult salmon returning to fresh water die before they are able to spawn.

For the purposes of this report, the King County and Ecology samples are called non-storm flow samples, and SPU samples are called storm flow samples.

For the purposes of this analysis, data from all sources have been combined to evaluate water quality conditions in Seattle-area receiving water bodies. Sampling techniques and protocols often differ among the various data sources. For example, King County and Ecology generally collect grab samples from streams on a monthly schedule. Samples may be collected during storm or non-storm conditions, and weather conditions during the sampling event are not always recorded. However, a review of rainfall records from the University of Washington rooftop gauge indicate that the 2004–2005 Ecology samples were usually collected on days with little or no rain. For example, 27 of the 40 sampling events occurred on days with no rainfall for the 24 hours preceding the event and during the sampling event. Rainfall exceeded 0.1 inches for only five of the remaining 13 sampling events. King County stream monitoring samples also are often collected on dry days. For the period 1985 to 2000, approximately 85 percent of the routine monitoring samples were collected on days with no rain.

In contrast, SPU samples are collected during storm events and consist of three to four grab samples that are manually composited in proportion to flow to characterize event mean pollutant concentrations (EMC). Although sampling techniques vary, these data are useful in characterizing water quality conditions. Where appropriate, the differences in water quality characteristics under different flow conditions (e.g., storm flow versus non-storm flow samples) are highlighted and discussed.

Water quality monitoring has not been conducted in Taylor Creek or in other small watercourses such as Schmitz Creek or Puget Creek. Consequently, knowledge of water conditions in these watercourses is incomplete. While water and sediment quality are extremely important aspects of aquatic conditions for humans and plants and animals in Seattle, the ability to accurately describe existing conditions is limited by the data available.

Water Quality Indicators

Water quality indicators are selected chemical and physical parameters and indices that can be used to characterize overall conditions in the receiving water, and also provide benchmarks for assessing the success of watershed management efforts. Table 3 summarizes the uses, benefits, and water quality indicators used in this assessment to evaluate the overall conditions in Seattle watercourses. Background information on water quality indicators is provided in Part 2, A Brief Primer on Stream Ecosystems.

Table 3. Uses and benefits of Seattle aquatic resources and their water quality indicators.

Use	Benefit	Key Water Quality Indicators
Contact recreation	Providing suitable water quality and sediment quality for human use of surface waters for contact recreation, including swimming, wading, snorkeling, and diving.	Fecal coliform bacteria
Passive recreation	Providing opportunities for people to enjoy walking and hiking, playing, observing wildlife and connecting with nature.	Total petroleum hydrocarbons (e.g., visible sheens)
Human consumption	Providing suitable water quality and sediment quality for fish and shellfish harvesting.	Metals and organic compounds
Aesthetics	Preventing visual and odor-related degradation of surface waters to protect their aesthetic value.	Total petroleum hydrocarbons
Aquatic health	Providing water quality and sediment quality conditions to support valuable aquatic species.	Conventional parameters (dissolved oxygen, temperature, pH, nutrients), metals, organic compounds

Data Compilation

Information for this assessment was obtained from the following sources:

- King County data for Thornton Creek, Piper's Creek, and Longfellow Creek from the Stream Monitoring Program (King County 2006b), as well as a microbial source tracing study in Thornton Creek (King County 2001).
- SPU stormwater sampling in Longfellow Creek and Piper's Creek (Reed et al. 2003)
- U.S. Geological Survey investigations of water and sediment quality in Longfellow Creek and Thornton Creek (Voss and Embrey 2000; MacCoy and Black 1998; Voss et al. 1999)
- A Department of Ecology source tracing study in Piper's Creek (Olsen 2003)
- Department of Ecology data for Fauntleroy Creek, Longfellow Creek, and Thornton Creek (Ecology 2006d).

Table 4 lists the data sources used in this report. Monitoring station locations are shown on the surface water monitoring station map for each watercourse, included in the map folio accompanying this report.

Data Quality Assurance Review

To identify the data sources of acceptable quality for the purpose of assessing water quality conditions, the available data were subject to a data quality assurance review prior to use. Electronic data files were examined to verify that the data had been checked for quality and accuracy (i.e., quality assurance and quality control [QA/QC] verification). Where possible, written reports were also examined to characterize the level of data quality and accuracy review performed.

Table 4. Water quality sampling stations in Seattle watercourses.

Location	Reference	Station ID	Storm Flow	Non-storm Flow	Type of Sample	Sediment	Period of Record	Frequency (samples/year)	Quality Assurance Category	Temperature	Dissolved Oxygen	Coliform Bacteria	Nutrients	Other Conventional Parameters	Metals, Total	Metals, Dissolved	Petroleum Hydrocarbons	Organic Compounds
Thornton Creek																		
Multiple stations	4	TH1-TH15		√	G		April–May 2001	1	1			√						
Near mouth	1	0434		√	G		1976–present	12	1	√	√	√	√	√	√	√		√[a]
Near mouth	6	12128000			C[g]		5/14/1998	1	1								√	√
Near mouth	7	12128000			–	√	Sep–95	1	1								√	√
North branch below golf course	6	12127700		√	C[g]		5/14/1998	1	1								√	√
South branch at 30th Ave NE	6	12127800			C[g]		5/14/1998	1	1								√	√
South branch at NE 107th St	2	08M070	√	√	G		2003–present	12	1	√	√	√	√	√	√	√		
Longfellow Creek																		
24th-25th Ave SW	2	08J090	√	√	G		2003–present	12	1	√	√	√	√	√	√	√		
SW Graham St	3	LF-Graham	√		C[g]		1999–2001	2-3	2	√	√	√	√	√	√	√	√	
SW Brandon St	1	J370	√	√	G		1979–present	12	1	√	√	√	√	√	√[b]			
SW Brandon St	6	12113488		√	C[g]		5/14/1998	1	1								√	√
SW Yancy St	1	C370	√	√	G		1979–present	12	1	√	√	√	√	√	√[b]	√[c]	√	
SW Yancy St	3	LF-Yancy	√		C[g]		12/01–2/04	2-3	2	√	√	√	√	√	√	√	√	
West Seattle Golf Course	3	LF-98B	√		C[g]		2004–present	2-3	2	√	√	√	√	√	√	√	√	√[f]
Piper's Creek																		
Upstream of orchard	3	Piper-UP	√		C[g]		2000–present	2-3	2	√	√	√	√	√	√	√	√	
Upstream of treatment plant	1	KTAH01		√	G		1988–present	12	1	√	√	√	√	√				
Upstream of Venema	1	KTAH02		√	G		1988–present	12	1	√	√	√	√					
Downstream of Venema	3	Piper-DN	√		C[g]		2000–present	2-3	2	√	√	√	√	√	√	√	√	
Near mouth	1	KSHZ06		√	G		1993–present	12	1	√	√	√	√		√[d]	√[e]		
Venema Creek	1	KTAH03		√	G		1988–present	12	1	√	√	√	√					
Venema Creek	3	Venema	√		C[g]		2000–present	2-3	2	√	√	√	√	√	√	√	√	
Multiple stations	5	PI1 - PI18		√	G		7/7/03	1	1			√						
Fauntleroy Creek																		
Mouth, 45th Ave SW, SW Barton,head	8	–		√	G		1988	2				√						
Near mouth	2	09K070		√	G		2004–present	12	1	√	√	√	√	√	√	√		

G = grab sample C = composite sample

[a] Organic compounds analyzed in select 2002–2003 samples.

[b] Discontinued in 2002

[c] Discontinued in 2003

[d] Total metals analyzed quarterly

[e] Dissolved metals analyzed semi-annually

[f] Organic compounds analyzed during 3 storms in October and November, 2004

[g] Flow-proportioned composite comprised of 2–3 grab samples collected during storm event

1. King County (undated) and Frodge (2006)
2. Ecology (undated)
3. SPU (undated)
4. King County (2001a)
5. Olsen (2003)
6. Voss and Embrey (2000)
7. MacCoy and Black (1998)
8. Kendra (1988)

Based on this review, the compiled data from each source were placed into one of three categories:

- *Data of known and acceptable quality (category 1)*: Quality assurance information from field sampling and laboratory analysis is included in the summary report for the particular source. This quality assurance information has been reviewed against specific, predefined objectives for assessing data quality. Based on this review, qualifying remarks are assigned to those data that do not meet quality assurance objectives. Data having minor quality assurance issues are identified in summary tables and analyses. Data having severe quality assurance issues are excluded from all data summaries or analyses.

- *Data believed to be of acceptable quality (category 2)*: Qualifying remarks are assigned to specific data to indicate the presence of quality assurance issues. However, the specific quality assurance objectives for the data are not clearly identified, and quality assurance information from field sampling and laboratory analysis is not presented along with the data.

- *Data of unknown quality (category 3)*: Qualifying remarks are not assigned to any data to indicate the presence of quality assurance issues. No information is presented on the specific quality assurance objectives for the data, and quality assurance information from field sampling and laboratory analysis is not presented along with the data.

Data sources assigned category 1 and 2 classifications are included in this summary report, while category 3 data are excluded. Based on this review process, data collected prior to 2000 by SPU are excluded from further analysis here. The more recent SPU data are included, although these data are assigned a category 2 classification because they have not been fully verified; that is, quality assurance information exists but has not yet been fully reviewed. The categories assigned to the respective data sources are listed in Table 4.

Data Analysis

The data compiled for this report were used to conduct the following analyses:

- Comparison of sample results to Washington state water quality standards and other applicable criteria to evaluate overall toxicity to aquatic organisms

- Plotting of time series graphs to check overall trends in water quality conditions for key water quality parameters

- Calculation of summary statistics (including arithmetic mean, median, minimum, maximum, confidence limits, and box plots)

- Comparison of storm flow versus non-storm flow data to evaluate the impacts of urban runoff on stream water quality.

Water quality standards, plotting of time series graphs, and summary statistic calculations are discussed separately in the following subsections.

Comparison to State Water Quality Standards

The Washington state water quality standards (Washington Administrative Code [WAC] 173-201A) provide benchmarks for evaluating water quality conditions in Seattle-area receiving water bodies. The state standards assign both quantitative and qualitative criteria to a water body, for protection of public health and aquatic life in freshwater and marine water systems, based on specific or designated uses. Established designated uses of water bodies include public recreation (e.g., fishing, boating, and swimming), aesthetic benefits, commerce, and navigation, as well as the propagation and protection of fish, shellfish, and wildlife.

The state freshwater standards apply to Seattle-area urban watercourses and lakes (including Lake Washington and Lake Union), while the marine standards apply to Puget Sound and the estuarine portion of the Duwamish Waterway. Standards have been established for many conventional water quality indicators (including temperature, dissolved oxygen, turbidity, pH, and fecal coliform bacteria), as well as toxic substances (e.g., metals, organic compounds, and radioactive materials).

Exceedance of a criterion within a water body does not necessarily mean that the water quality standard has been violated. Often, other polluting conditions must exist for a watercourse segment to be in violation of water quality standards. For example, if the natural conditions of a water body fail to meet the established water quality criteria, then the natural conditions are accepted as the water quality criteria for that water body. In addition, the Department of Ecology requires more than a single exceedance of a water quality criterion before a water body is formally listed as impaired (under Section 303(d) of the federal Clean Water Act; see additional details below).

For toxic substances, two levels of protection have been established to prevent injury or death to aquatic organisms: the acute toxicity criteria and chronic toxicity criteria. The acute toxicity criteria are based on short-term exposures. Depending on the chemical, the acute criterion can be the instantaneous maximum concentration that cannot be exceeded at any time, or a 1-hour average concentration, or a 24-hour average concentration. The chronic toxicity criterion reflects the long-term exposure limit, which can range from 24-hour duration up to 4-day duration. For this analysis, samples are compared to both the acute and chronic toxicity criteria.

Ecology revised the state water quality standards in 2006. The 2006 rules are used in this report where the samples were collected appropriately to allow comparison to the 2006 revised criteria. The 1997 rule is used where the existing data are not directly comparable to the 2006 rule. For example, the temperature criterion in the 2006 rule is based on the 7-day average of the daily maximum temperatures, while the 1997 rule is based on a single measurement. Most of the available data for water temperature were collected on a monthly basis and therefore cannot be compared to the 2006 criterion. Consequently, these data are compared to the 1997 temperature criterion. The beneficial use designations that apply to Seattle watercourses under the 1997 and 2006 rules are listed in Table 5.

Under Section 303(d) of the Clean Water Act, water quality standards must be used to identify threatened and impaired water bodies. Category 2 (threatened) water bodies are those that occasionally exceed water quality standards, while category 5 (impaired) water bodies are those that frequently exceed standards. Impaired water bodies are required to be evaluated to identify the pollutants and sources responsible for the water quality problems. *Total maximum daily load* (TMDL) values are then established and allocated to specific pollutant sources in order to reduce pollutant discharges and move toward meeting water quality standards. Table 6 shows the water bodies in the Seattle area that currently are included on the state 303(d) list.

Table 5. Beneficial use designations applicable to Seattle watercourses under state water quality standards.

	1997 Standards			2006 Amended Standards												
				Aquatic Life				Recreational Use		Water Supply Uses			Miscellaneous Use			
	Class AA	Class A	Lake Class	Char	Core Summer Habitat [a]	Spawning, Rearing and Migration [b]	Rearing and Migration Only [c]	Extraordinary Contact Recreation	Primary Contact Recreation	Domestic Supply	Industrial Supply	Agricultural Water Supply and Stock Watering	Wildlife Habitat	Fish Harvesting	Commercial/Navigation	Aesthetics	Boating
Fauntleroy Creek	✓				✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Longfellow Creek		✓				✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
Piper's Creek	✓				✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Taylor Creek	✓				✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓
Thornton Creek	✓				✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓

[a] Summer (June 15–September 15) salmonid spawning or emergence, adult holding; used as important summer rearing habitat by one or more salmonids or foraging by adult and sub-adult native char; spawning outside the summer season; rearing and migration by salmonids.

[b] Salmon or trout spawning and emergence that occurs only outside the summer season (September 16–June 14); rearing and migration by salmonids.

[c] Used for rearing and migration only, not used for spawning.

Table 6. Clean Water Act Section 303(d) list of threatened and impaired watercourses in the Seattle area.

	Category 2 (Threatened)	Category 5 (Impaired)
Fauntleroy Creek	–	Fecal coliform bacteria
Longfellow Creek	Dissolved oxygen, temperature, pH	Fecal coliform bacteria, dissolved oxygen
Piper's Creek	Turbidity (Venema Creek)	Fecal coliform bacteria [a]
Thornton Creek	pH, mercury	Fecal coliform bacteria, temperature, dissolved oxygen

Source: Ecology 303(d) list query tool: http://www.ecy.wa.gov/PROGRAMS/wq/303d/2002/2002-index.html.

[a] Classified as category 4A for a water body with an approved TMDL. In 1992, EPA issued a programmatic total maximum daily load (TMDL) for fecal coliform bacteria in Piper's Creek based on the 1991 Watershed Action Plan.

It has not always been possible to conclusively assess water quality conditions in Seattle-area watercourses for ammonia toxicity and dissolved metals because of the following factors:

- Water quality criteria for ammonia vary with pH and temperature, and for some metals the standards are based on hardness. Because these ancillary parameters have not been analyzed or reported for all samples, it is not always possible to make a direct comparison with current water quality criteria.

- Although reporting detection limits (RDLs) have generally improved over the years, they often vary among laboratories. However, the detection limits for some pollutants (e.g., cadmium, mercury, selenium, and silver) often exceed the numerical water quality standard. This means that lower levels of these metals may not show up during testing, even though the lower levels may be above the regulatory criteria. As described below in the summary statistics section, these data are censored, or qualified, and are flagged with either a *U* or a *<RDL* qualifier. It is difficult to evaluate water quality conditions when a majority of the data are censored, particularly when the RDL is higher than the water quality standard.
- In 1992, the context for the state water quality criteria for metals was changed from a total recoverable basis to a dissolved fraction basis. Sampling protocols often were not immediately modified to reflect this change. As a result, it is often difficult to compare metals results to current water quality standards, because dissolved metals were not analyzed in all of the samples.

Criteria and Benchmarks for Nutrients

Phosphorus and nitrogen compounds are the primary nutrients of concern in stormwater runoff. Their sources in urban runoff include fertilizers, animal wastes, leaking septic tanks, sanitary sewer cross-connections, detergents, organic matter such as lawn clippings and leaves, eroded soil, road de-icing salts, and automobile emissions.

Concerns regarding phosphorus include stimulation of algal blooms and excessive plant growth in lakes and marine waters. When algae and plant material die and begin to decompose, dissolved oxygen concentrations in the water can become depleted. Some forms of algae are toxic to fish and other aquatic organisms.

Ammonia-nitrogen is toxic to fish and other aquatic organisms. In addition, ammonia-nitrogen can deplete dissolved oxygen concentrations in water systems as it oxidizes to nitrite and nitrate through the nitrification process. Low dissolved oxygen levels can stress or kill fish and other aquatic organisms.

The state water quality standards (WAC 173-201A-240) list ammonia as a toxic substance. Numerical standards for ammonia are based on water temperature and pH. The most stringent criterion protects spawning, core rearing, and migration of salmon and trout, as well as other associated aquatic life.

Total ammonia includes the un-ionized component of ammonia (NH_3), which under specific conditions of temperature and pH can be toxic to aquatic life, plus the ionized form (NH_4^+), which is not toxic. The un-ionized component of ammonia increases with higher pH and temperature values. Un-ionized ammonia is degraded to nitrates through biological processes.

Table 7 provides total ammonia toxicity criteria for protection of aquatic life, correlated with typical pH values measured in Seattle-area surface waters and based on the state water quality standard for temperature (17.5°C). The acute toxicity criterion is applicable to the presence or absence of salmonids; the chronic toxicity criterion is applicable to the presence or absence of salmonid habitat.

The acute criterion is applied as a one-hour average concentration of total ammonia nitrogen (in milligrams per liter [mg/L]) not to be exceeded more than once every 3 years on average. The chronic criterion is applied as a 30-day average concentration of total ammonia nitrogen (in mg/L) not to be exceeded more than once every 3 years on average. The highest 4-day average within the 30-day period should not exceed 2.5 times the chronic criterion. The temperature used to calculate the water quality standard is based on the 7-day average of the daily maximum temperatures.

Table 7. Total ammonia water quality criteria for protection of aquatic life.

	Acute Toxicity (mg/L)[a]			Chronic Toxicity (mg/L)[a]		
Instream pH Level	**6.5**	**7.5**	**8.5**	**6.5**	**7.5**	**8.5**
Salmonids						
Salmonids present	33	13	2.1	–	–	–
Salmonids absent	49	20	3.2	–	–	–
Salmon Habitat						
Existing or designated use	–	–	–	2.1	2.1	0.43
Not designated salmon habitat, and other fish early life stages present	–	–	–	7.4	2.7	0.10
Not designated salmon habitat, and other fish early life stages absent	–	–	–	7.4	2.7	0.10

[a] Based on the maximum aquatic life temperature criterion in fresh water for salmon and trout spawning, core rearing, and migration, of 17.5°C (WAC 173-201A-200(1)(c)). The acute toxicity criterion is applicable to the presence or absence of salmonids, and the chronic toxicity criterion is applicable to the presence or absence of salmonid habitat.

mg/L = milligrams per liter.

Additional nutrients of significance for which state water quality standards have not been established are total phosphorus and total nitrogen. While no state standards currently exist for these parameters, associated water quality criteria have been developed by the U.S. Environmental Protection Agency (U.S. EPA) to address human-induced eutrophication. (Eutrophication refers to the addition of nutrients, especially nitrogen and phosphorus, to a body of water, resulting in high organic production rates that may overcome natural self-purification processes.) The total phosphorus and total nitrogen criteria, which are protective of aquatic life and recreational uses, are empirically derived to represent conditions in surface waters that are minimally affected by human activities (U.S. EPA 2000). In Pacific Northwest lakes, phosphorus is usually the limiting nutrient (i.e., when phosphorus is exhausted, plant growth ceases), but in general, higher nitrogen concentrations are also associated with more biologically productive lakes. Phytoplankton growth in lake waters of temperate lowland areas is generally phosphorus-limited (King County 1999). Nitrate, nitrite, and ammonium are forms of nitrogen used by phytoplankton. Nitrogen in its various forms is considered to be the limiting nutrient in marine waters (King County 2006a). Table 8 lists the available water quality benchmarks for total phosphorus and total nitrogen used in this report.

Table 8. Total phosphorus and total nitrogen benchmarks for assessing water quality conditions.

Nutrient	Benchmark (mg/L)	Source
Total phosphorus	0.10 [a]	U.S. EPA (1976)
Total phosphorus [b]	0.0195	U.S. EPA (2000)
Total nitrogen [b]	0.34	U.S. EPA (2000)

[a] A desired goal to prevent nuisance plant growth in streams or other flowing waters not discharging directly to lakes or impoundments (U.S. EPA 1976).

[b] For sub-region 2, Puget Lowlands, based on the 75th percentile concentration for all reference streams in the region.

mg/L = milligrams per liter.

Benchmarks represent interim water quality criteria used solely for this analysis. Because these benchmarks represent surface water quality conditions that are minimally influenced by human activity, exceeding a benchmark does not necessarily indicate a violation of the water quality criterion.

When evaluating water quality conditions, it is important to select appropriate guidelines and thresholds. Because state standards have not been established for total phosphorus or total nitrogen, alternative guidelines are needed. For the purposes of this analysis, the higher of the two total phosphorus criteria (i.e., 0.1 mg/L, from U.S. EPA 1976) is used as a benchmark to evaluate water quality conditions in Seattle watercourses. This higher level is expected to be most useful in identifying the urban watercourses that are most severely affected by nutrient over-enrichment. Lacking alternative criteria for total nitrogen, the U.S. EPA (2000) value of 0.34 mg/L is used as a benchmark in this analysis, although it is recognized that background total nitrogen exceeds this level in most Seattle watercourses.

Metals Criteria

The U.S. EPA has identified 14 metals as priority pollutants, with recommended water quality criteria for the protection of aquatic life and human health in surface water: antimony, arsenic, beryllium, cadmium, chromium (III and VI), copper, lead, mercury, methylmercury, nickel, selenium, silver, thallium, and zinc.

The water quality standards for surface waters of the state of Washington (WAC 173-201A-240) list ten toxic metals with criteria established for protection of aquatic life: arsenic, cadmium, chromium (III and VI), copper, lead, mercury, nickel, selenium, silver, and zinc.

The state water quality standards provide metals criteria expressed in terms of the dissolved fraction in the water column, except for the chronic exposure level for mercury and the chronic and acute exposure levels for selenium, which are expressed in terms of the total fraction in the water column. The criteria recommended by U.S. EPA for protection of human health in surface waters are also expressed in terms of the total metal in the water column. Both the WAC and U.S. EPA criteria are referenced in this report.

Table 9 lists water quality criteria for priority pollutant metals, including the most stringent criterion when a criterion is recommended for protection of aquatic life and human health.

As noted previously, the toxicity of seven of the metals (cadmium, chromium [III], copper, lead, nickel, silver, and zinc) is hardness-dependent. That is, the specific toxicity of that metal depends on the hardness of the surface water at the time of sample collection. Figure 10 illustrates this relationship using dissolved copper as an example. The water hardness values measured in Seattle watercourses generally indicate that non-storm flow samples have higher hardness levels than storm flow samples and are therefore less toxic than storm samples. The higher hardness values in non-storm flow samples are attributed to the greater influence of ground water contributions.

Table 9. Metals water quality criteria for protection of aquatic life and human health in surface waters.

		Protection of Aquatic Life [a,b]		Protection of Human Health
	Parameter (µgL)	Chronic Exposure Level [c]	Acute Exposure Level [d]	Consumption of Water + Organism
Dissolved Metals	Arsenic	190	360	
	Cadmium	0.79 [c]	1.4 [d]	
	Chromium (VI) [e]	10	15	
	Chromium (III) [e]	132.9 [c]	264 [d]	
	Copper	8.37 [c]	7.4 [d]	
	Lead	0.47 [c]	16 [d]	
	Mercury		2.1	
	Nickel	116 [c]	670 [d]	
	Silver [f]		0.683 [d]	
	Zinc	47.1 [c]	51.5 [d]	
Total Metals	Antimony			5.6 [g]
	Arsenic			0.018 [g]
	Beryllium			4 [h]
	Mercury	0.012		
	Selenium	4.6	18.4	
	Thallium			0.24 [g]

[a] State water quality criteria for metals (WAC 173-201A-240).

[b] Water quality criteria for metals are based on the dissolved fraction except for selenium and the chronic toxicity criteria for mercury.

[c] The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. The value given here corresponds to the 15th percentile hardness (70 mg/L as $CaCO_3$) for non-storm flow conditions.

[d] The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. The value given here corresponds to the 15th percentile hardness (40 mg/L as $CaCO_3$) for storm flow conditions.

[e] Due to difficulty meeting holding times and method detection limits, chromium, total measured as dissolved is use as a surrogate for chromium (VI) and chromium (III). Should chromium, total measured as dissolved, exceed 10 µg/L, additional analysis may be needed.

[f] An instantaneous concentration not to be exceeded at any time.

[g] These criteria are published pursuant to Section 304(a) of the Clean Water Act (CWA) and provide guidance for states and tribes to use in adopting water quality standards.

[h] This criterion is from the State Drinking Water Maximum Contaminant Level (WAC 246-290-310).

µgL = micrograms per liter.

mg/L = milligrams per liter.

Time Series Analysis

Time series analyses are simple graphs of chemical concentration through time. These graphs are used in several instances in this report and its appendices. The overall scatter and distribution in the chemical values provide an indication of general trends and variability in the sample population. Where appropriate, water quality criteria are shown on the time series graphs. A special notation is used on the graphs for water quality criteria that are calculated based on other parameters; for example, criteria for some metals are based on the hardness of the water and ammonia, which is pH- and temperature-dependent. A sample result that exceeds a calculated criterion is shown with an asterisk (*) adjacent to the data point. A sample result that exceeds a criterion that is not calculated can be identified by its location with respect to the benchmark or water quality criterion indicated on the graph.

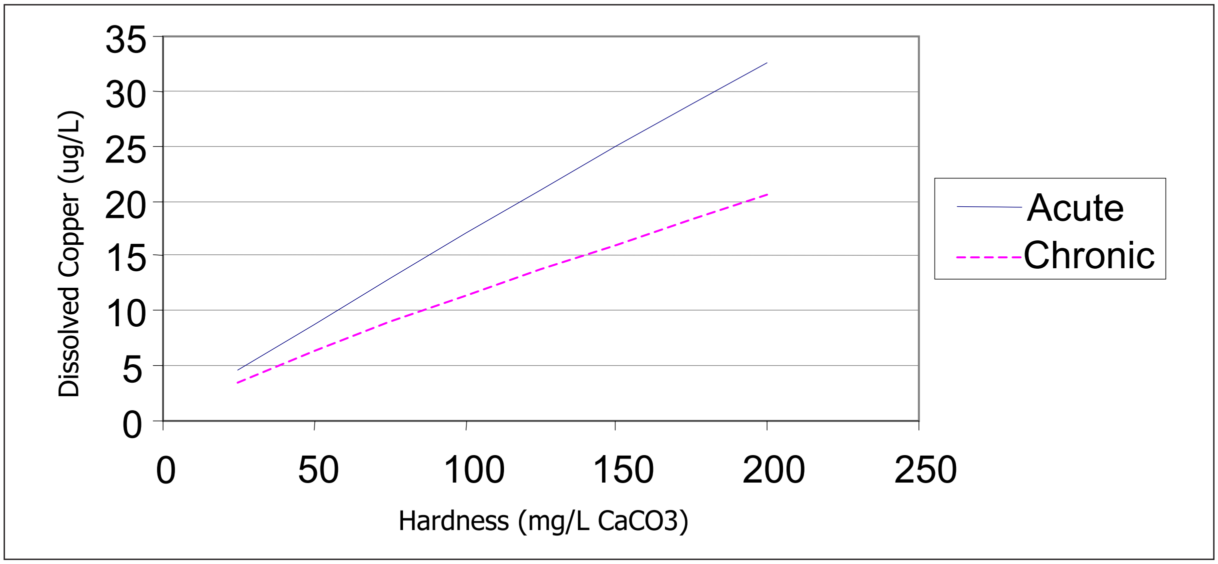


Figure 10. Dissolved copper water quality criteria correlated to water hardness.

The hardness-dependent chronic toxicity water quality criteria for cadmium, copper, lead, nickel, silver, and zinc shown for each sampling date are determined using the minimum hardness for samples collected on that sampling date. If a hardness value is not available for a sampling date, the chronic toxicity criterion is calculated using the minimum hardness value for all samples. The metals concentration is an exceedance only where noted with an asterisk.

The pH- and temperature-dependent total ammonia chronic toxicity water quality criterion shown for each sample date is determined using the maximum pH and temperature values for the samples collected on that sample date. If pH or temperature data are not available for a sample date, the maximum pH and temperature values for that station are used to calculate the criterion. If that information is not available, a pH value of 9 and temperature of 16°C are assumed. The ammonia concentration is an exceedance only where noted with an asterisk.

Summary Statistics

A set of summary statistics was calculated for each water quality indicator to enable qualitative comparisons among Seattle watercourses. Summary statistics are provided in Appendix B. The following statistics were used in this analysis:

- Measures of central tendency or typical values (i.e., mean, median, and trimmed mean)
- Measures of sample spread or variability (i.e., overall range, interquartile range, and standard deviation)
- Extremes (i.e., minimum and maximum values, and 5th and 95th percentiles).

Special consideration is given to undetected values as they affect the summary statistics. Concentrations of toxic pollutants in receiving waters are sometimes below the analytical laboratory's ability to detect them. These data are classified as censored and require special consideration.

- For some of these censored data, the analytical laboratory reports the result as undetected and includes an estimated value less than the reporting detection limit (RDL). The estimated value is used in these cases.

- In some cases the analytical laboratory reports the result with a < symbol preceding the RDL. The RDL value is used in these cases.

- In some cases, historical data were collected and reported with a very high RDL. These data are not included when it is clear that they may cause erroneous conclusions.

Concentrations below the laboratory's detection limits are classified as censored and require special consideration.

All outliers (i.e., values widely divergent from the main grouping of values) are currently classified as suspected values; these were determined by visual examination of box and whisker plots. Figure 11 shows the format of a box and whisker plot, which is explained below.

A box plot is useful in summarizing large quantities of data to only five numbers—the median, upper and lower quartiles, and minimum and maximum values. The box plot provides a quick visual summary that easily shows center, spread, range, and any outliers, or outside values.

- The bottom of the box, or lower hinge, represents the first quartile and is that point above which three-fourths and below which one-fourth of the values lie.

- The top of the box, or upper hinge, represents the third quartile and is that point above which one-fourth of the values lie and below which the other three-fourths of the values lie.

- The height of the box is called the H spread; it is approximately equal to the interquartile range (i.e., width of the central region of the data set, encompassing approximately one-half of the values).

- The step size is defined as 1.5 times the H spread.

- The line that extends above (or below) the box is called the upper (or lower) whisker.

- The upper (or lower) whisker extends to the highest (or lowest) value that is less than or equal to one step away from the box.

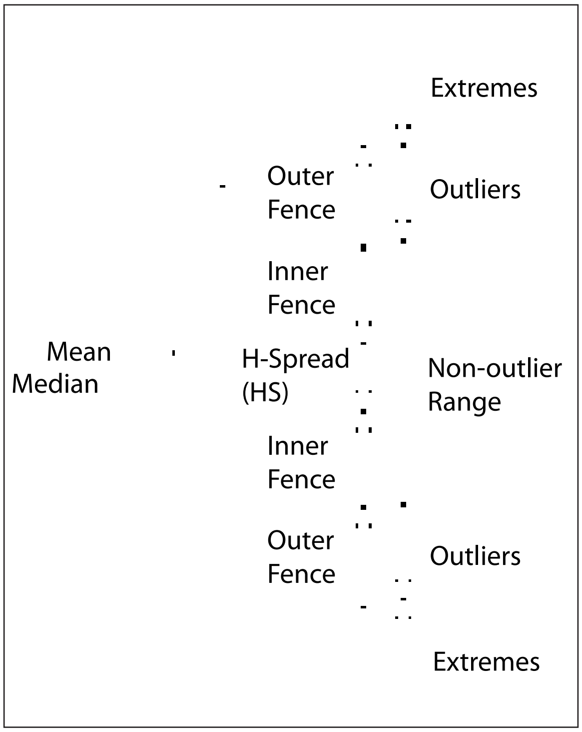


Figure 11. Standard box and whisker plot format summarizing data center, spread, range, and outside values.

- Outside values are those between one and two steps away from the box; they are each marked with an asterisk (*).

- Far-outside values are those that are more than two steps away from the box; they are each marked with an **o** symbol.

Comparison to Available Sediment Quality Standards

In addition to water quality analysis, sediment quality was also assessed for this report. However, among the five major Seattle watercourses, only Thornton Creek has sufficient data for assessment of sediment conditions. Sediment conditions in the other watercourses are not discussed here.

Washington state has not established standards for freshwater sediment. For the purposes of this analysis, Thornton Creek sediment data are evaluated based on comparisons to the following sediment quality criteria and guidelines.

Ontario Ministry of the Environment Sediment Quality Guidelines

Sediment quality guidelines have been established to protect bottom-dwelling (i.e., benthic) organisms. The following three threshold levels are defined (Persaud et al. 1993):

- No-effect level—The concentration at which no toxic effects have been observed in aquatic organisms
- Lowest-effect level—The concentration at which the majority of benthic organisms are unaffected
- Severe-effect level—The concentration at which pronounced disturbance of the sediment-dwelling community can be expected.

National Oceanic and Atmospheric Administration Freshwater Sediment Quality Guidelines

These guidelines, which are based on a compilation of sediment chemistry and biological effects in freshwater sediments, were developed as a preliminary screening tool for evaluating sediment quality (NOAA 1999). The guidelines establish the following three threshold levels:

- Threshold-effects level (TEL), which provides an estimate of the concentration at which adverse effects are expected to occur only rarely, is calculated as the geometric mean of the 15th percentile concentration of the toxic effects data set and the median of the no-effect data set.
- Probable-effects level (PEL), which provides an estimate of the concentration at which adverse effects are frequently expected, is calculated as the geometric mean of the 50th percentile concentration of the toxic effects data set and the 85th percentile of the no-effect data set.
- Upper-effects threshold (UET) provides an estimate of the concentration at which adverse effects would always occur based on the lowest adverse effects threshold (AET) from a compilation of endpoints analogous to the marine AET endpoints; the UET is based on 1 percent total organic carbon content in the sediment.

Consensus-Based Standards for Freshwater Sediment

Developed by MacDonald et al. (2000), these guidelines establish two threshold classifications, each calculated as the geometric mean of all the values assigned to that threshold classification:

- Threshold effects concentrations (TEC), concentrations below which adverse effects are not expected to occur
- Probable effects concentrations (PEC), concentrations above which adverse effects are expected to occur more often than not, based on a compilation of available sediment quality guidelines reported in the literature.

Washington Department of Ecology Proposed Freshwater Sediment Quality Values

Cubbage et al. (1997) proposed values using the probable apparent effects threshold (PAET, calculated as the 95th percentile of stations exhibiting no biological effects based on the Microtox bioassay) for organic compounds, and the marine sediment management standards for metals.

The Department of Ecology is currently working to develop freshwater sediment quality standards. Although much progress has been made in evaluating AET values calculated using the updated freshwater sediment data, Ecology has not yet proposed freshwater sediment standards (Avocet 2003). For the purposes of this report, the 1997 proposed freshwater quality values are used to evaluate sediment data for Thornton Creek, the only watercourse with sediment data available.

Evaluating Conditions at the Stream Scale

This section discusses the methods used to evaluate riparian, instream, and biological conditions at the stream scale. Again, the stream scale refers to conditions along or within the watercourse corridor and streambed. The methods used to evaluate riparian, instream, and biological characteristics are discussed in detail below. The evaluations focus on the five largest watercourses within Seattle.

Seattle watercourses are classified into channel types for this analysis, based on watershed and channel conditions. Alluvial channel types have been defined in the Pacific Northwest based on the factors that shape stream morphology (or channel form), such as channel gradients, confinement, substrates, and flows (Montgomery and Buffington 1997, 1998). While most channel classification work has focused on mountain channels and watersheds, Buffington et al. (2003) relate previous work to channels in the Puget Lowlands, which include the Seattle area. Hence, channel types are used in these assessments to compare the formerly natural stream conditions to those that exist today (see Part 2 for a description of channel types and habitat units).

SPU biologist along Thornton Creek (photo courtesy Seattle Municipal Archives)

The channel classifications, coupled with the results from data compilation and collection efforts, have been synthesized to identify current habitat conditions. Habitat types, stream sediments, riparian vegetation, stream corridor encroachment, stream bank armoring, and several other features are discussed for each watercourse.

This report evaluates riparian and instream habitat conditions using indicators to measure the degree to which aquatic habitat processes and attributes are disrupted in Seattle watercourses. The purpose of these analyses is to evaluate the integrity of aquatic ecosystem processes as they are currently functioning in these urban watercourses. Each of these analyses is briefly discussed below, with more detailed information provided in the appendices.

Riparian Habitat Assessment Methods

Data Collection and Compilation

Riparian assessments were conducted in 2003 to evaluate the conditions of riparian vegetation along Seattle's five major watercourses. The continuous survey collected data on riparian extent, canopy and understory composition, canopy density, stream shading, slope, and land use type.

Data Accuracy and Limitations

For this report, data were analyzed primarily at the reach scale, which is well within the criteria for precision of each survey. However, the riparian surveys were conducted in 2003, and riparian improvement projects installed since that time are not reflected in the analysis, mapping, and reporting in this document. More detailed descriptions and information about data accuracy are provided in Appendix D.

A reach is a portion of the watercourse exhibiting homogeneous characteristics and functions.

Data Analysis

The purpose of the riparian habitat quality assessment is to identify riparian areas of high and low quality. The riparian conditions assessment uses data from the riparian surveys to evaluate the integrity of riparian ecosystem functions. As described in Part 2, these functions include providing a source of instream structure and nutrients, stabilizing stream banks, increasing the sediment/water storage and filtration capacity in the floodplain, regulating water temperatures, and providing wildlife habitat for terrestrial species. These analyses were conducted at the reach scale.

The integrity of each of these functions was evaluated through an assessment of the following characteristics:

- Riparian width
- Riparian connectivity
- Understory and canopy composition
- Canopy density
- Stream cover.

To assess overall riparian conditions, each of these factors was assessed on a scale of 1 to 10, with 10 representing the best condition (Figure 12). These individual rankings were then averaged to produce an overall riparian condition score for each reach, with riparian width, connectivity, and canopy composition weighted twice as heavily as the other factors. Based on score distributions and sample reaches, thresholds were developed to rank riparian quality as good, moderate, or poor. Appendix F provides information on ranking criteria and reach scoring for riparian features. Assessment results were then converted into qualitative categories; these are presented in Part 4 and illustrated in a habitat quality map for each watercourse included in the map folio accompanying this report.

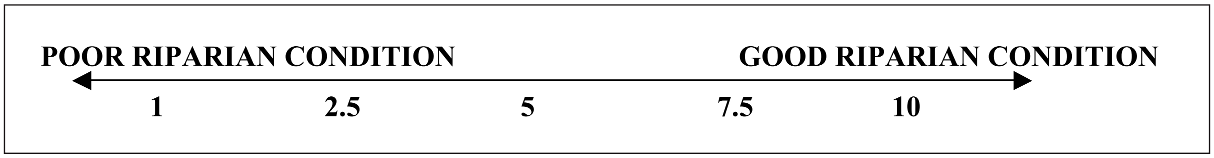


Figure 12. Scoring framework used to rate riparian conditions.

Instream Habitat Assessment Methods

Data Collection and Compilation

Data on stream habitat conditions were collected through a series of studies, from which information in this report is drawn, as briefly described below. More detailed descriptions and information about data accuracy are provided in Appendix D.

Stream Typing and Water Typing

Stream typing and water typing were conducted in 1999 and 2005 to identify fish-bearing and non-fish-bearing waters in compliance with state regulatory requirements governing water bodies and their riparian areas. The typing is based on a Forest Service protocol that evaluates a series of measures, including presence of fish, existence of fish barriers, basin size, gradient, and stream flow. This stream typing information is used in this report to assess fish access potential for each watercourse.

Fish Passage (Barrier) Assessment

Culvert assessments were conducted (1999–2000, updated in 2001 and 2002) to identify barriers to fish passage associated with piped segments within Seattle watercourses. These assessments are based on factors such as height of the culvert outfall above the streambed, capacity (i.e., size/width of the culvert relative to stream width), gradient, flow velocity through the culvert, residual pool depth at the outlet, and accessibility. Weir height and condition were also noted.

Habitat Assessment

Habitat assessments were conducted (2000–2004) to inventory stream channel conditions within Seattle's five major watercourses. Data collected and recorded continuously along the stream segments include instream habitat units (e.g., pools, riffles, and glides), potential fish spawning and rearing habitat, substrate composition, and stream bank integrity (in particular, location and type of stream bank armoring).

Geotechnical/Geomorphological Assessment of Channel Conditions

Channel condition assessments performed in 2001 on the five major Seattle watercourses examined the key factors affecting how the streams recruit, store, transport, and deposit sediment as the building blocks of instream habitat. These key factors include watershed geology, land form, watercourse valley shape, and gradient, as well as land use practices. Specific measures recorded include channel confinement and width, bank height, erosion stage and activity, and bank armoring.

Data Accuracy and Limitations

The individual inventories and studies described above vary in the accuracy of the data collected. For this report, data have been analyzed primarily at the reach scale, which is well within the criteria for precision of each survey. Because many of the surveys were conducted between 1999 and 2004, any recent changes in habitat conditions (since the time of a survey) are not reflected in the maps and analytical results presented in this report.

Data Analysis

The purpose of the instream habitat quality analysis is to identify stream areas of high and low quality. The analysis involves comparing observed physical characteristics of the stream to expected characteristics of a functional stream, based on gradient and channel type (see Figure 5 for descriptions of channel types). Each major Seattle watercourse was examined at the reach scale. The instream habitat assessment synthesizes data on geomorphology, habitat, and fish use to evaluate the integrity of the primary instream habitat-forming processes:

- Channel morphology and shape
- Sediment transport and delivery
- Biological function.

Where the observed channel characteristics closely approximate expected functional conditions based on channel type, the reach is designated as having *good habitat condition* and assigned a score of 10. If the observed channel characteristics are significantly altered from the expected condition, the reach is considered to have *poor habitat condition* and assigned a score of 1. Stream reaches in which observed attributes partially approximate expected conditions are considered to have *moderate habitat condition* and assigned a score of 5 (Figure 13). A more detailed description of the instream habitat assessment methods, as well as a summary of individual factors and reach scores, is provided in Appendix F. The results of this analysis have been converted to qualitative categories for reporting in Part 4 of this volume and are illustrated in a habitat quality map for each watercourse included in the map folio accompanying this report.

POOR HABITAT CONDITION **GOOD HABITAT CONDITION**

◄ **1** **2.5** **5** **7.5** **10** ►

Figure 13. Scoring framework used to rate instream habitat conditions.

Biological Assessment Methods

Data on stream habitat conditions were collected through a series of studies. Information presented in this report is drawn from these studies, as briefly described below. The reports generated for each study contain additional information about data accuracy, limitations, and analysis.

Fish Surveys

Fish presence surveys were conducted in 1999 and 2005 to identify major Seattle watercourse areas containing fish, in conjunction with stream typing surveys. Captured fish were identified, and their size, general condition, and relative abundance in the immediate area were recorded. Data were compiled using computerized geographic information system (GIS) mapping. Data on the extent of fish use in each watercourse are used in this report.

Spawning surveys have been conducted from 1999 to the present to record the numbers and locations of spawning salmon and trout, and their redds (i.e., egg nests). These surveys have been conducted on an annual basis in all five major Seattle watercourses. These data are used in this report to illustrate salmon redd locations and the upstream extent of watercourse use by various salmonid species.

Instream fish survey (photo by Herrera)

Smolt trapping has been conducted annually since 2001 in Thornton Creek and Longfellow Creek to identify the types and numbers of juvenile salmon leaving these two watercourses.

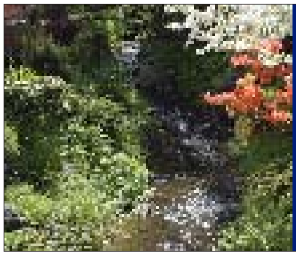
Benthic Invertebrate Sampling

Benthic macroinvertebrate sampling identifies small insects, crustaceans, mollusks, and worms that inhabit Seattle watercourses. Beginning in 1994, the sampling has been conducted every other year at sites in the major stream basins (shown on the active surface water monitoring stations maps, included in the map folio accompanying this report). SPU uses the benthic index of biotic integrity (B-IBI), calibrated for this Puget Lowland region, to interpret benthic invertebrate data. The B-IBI is a multimetric index that rates the degree of human impact on streams based on measurement of different factors, including number of species present and composition, tolerance and intolerance to disturbance, functional feeding groups, and life cycle length (see Appendix C). The index rates streams on a scale from 10 to 50, with 50 representing the absence of human impact (Table 10).

The number of individuals collected in an invertebrate sample influences the number of taxa counted because the more individuals collected, the higher probability of detecting a new taxon (Larsen and Herlihy 1998). To accurately measure taxa richness, a 400-count sample is preferred.

Table 10. Benthic index of biotic integrity scoring system.

B-IBI Scores	Inferred Condition
10–16	Very poor
18–26	Poor
28–36	Fair
38–44	Good
46–50	Excellent



State of the Waters 2007

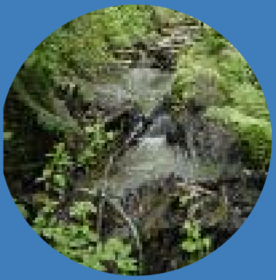
Part 4 Conditions in Seattle Watercourses

This part of the State of the Waters report provides detailed information regarding the present-day hydrology, water quality, physical habitat, and biological communities of each of the five major watercourses in Seattle. The information presented below for each watercourse begins with key findings and a watershed graphic, followed by a brief description of the watershed. The subsequent sections summarize hydrology and water quality conditions in each watercourse, including descriptions of available water quality data. Next, the physical habitat is described for each watercourse, dividing the watercourse first into reaches, and then into smaller segments within each reach, to provide the reader with an in-depth look at how conditions vary in different parts of the watercourse and why. The last section describes biological communities in each watercourse, focusing on fish and benthic macroinvertebrates. These aquatic community groups are the ones the City of Seattle has been most active in monitoring and has the most information about. Although other biological communities, such as amphibians and riparian-dependent birds, are also important components of Seattle's watercourse ecosystems, very limited information about them has been collected by the city.

At the time this State of the Waters report was generated, the available hydrologic and water quality information was rather limited relative to the information available for physical habitat. Consequently, compared to the habitat information, the hydrology and water quality data are presented with less detailed interpretation for Seattle's watercourse conditions. Moreover, much of the water quality information was collected and compiled several years before the date of publication of this document. Appendix G provides this detailed—but outdated—compilation of water quality data analyses. The main body of this report presents a summary of that information with appropriate updates to changes in applicable regulatory standards. Readers interested in more detailed water quality data and analyses can find them in Appendix G.

"Watercourse" means the route, constructed or formed by humans or by natural processes, generally consisting of a channel with bed, banks, or sides, in which surface waters flow.

This chapter concludes with a brief description and discussion of the many smaller watercourses in Seattle. Finally, additional details on hydrology, water quality, and habitat are presented in the associated appendices to this report.



Fauntleroy Creek

Fauntleroy Creek Key Findings

Fauntleroy Creek provides beneficial conditions in several areas and for several water quality components (based on limited water quality data). In general, physical habitat is in good condition in the Fauntleroy Park area, while downstream areas suffer from a number of problems that are absent in the upper portion of the watercourse (Figure 14). Water quality and habitat highlights are outlined below.

- *Dissolved oxygen and temperature* conditions are good. Samples collected between October 2004 and December 2005 consistently met state water quality criteria.
- *Concentrations of toxic materials* (metals and ammonia) over the short period of record are relatively low under non-storm flow conditions. Only one of eight samples (12 percent) exceeded the chronic toxicity criterion for total mercury, while eight of eight samples exceeded the human health criterion for total arsenic.
- *Concentrations of total phosphorus* are relatively low; one of 15 samples (7 percent) exceeded the benchmark for total phosphorus under non-storm flow conditions.
- *Floodplain connections, riparian forest and wetlands, and good instream structure* exist within the Fauntleroy Park reach. These habitat components allow the stream to store sediment, provide woody debris, stabilize stream banks, respond to high flows and occasional landslides, and enhance stream conditions.

The ability of Fauntleroy Creek to function is compromised in downstream areas by the following conditions:

- *Altered hydrology* induced by urban development in the upper watershed has increased the 2-year storm event runoff fourfold over predevelopment conditions. High and flashy flows in the watercourse are causing channel incision and widening.
- *Fecal coliform bacteria levels* have declined significantly since 1988 (geometric mean of 1,300 colony-forming units per 100 milliliters [cfu/100 mL] in 1998 to 130 cfu/100 mL in 2005). However, the annual geometric mean (130 cfu/100 mL in 2004–2005) continues to exceed the water quality criterion for extraordinary primary contact recreational use (50 cfu/100 mL).
- *Floodplain connections, instream structure, and riparian forest* are lacking downstream of the Fauntleroy Park reach. This area is dominated by bank armoring, fill, invasive plants, lawns, landscaping, and encroachment by buildings, resulting in little instream structure and no pools.
- *Fish passage barriers* at 45th Avenue SW and California Avenue SW prohibit anadromous fish from reaching about 65 percent of potential fish-bearing habitat in the watercourse.
- *Benthic index of biotic integrity (B-IBI) scores* indicate fair conditions, although scores range from poor to fair (20–36).
- *Coho prespawn mortality rates* (the lowest within Seattle watercourses) average 39 percent.

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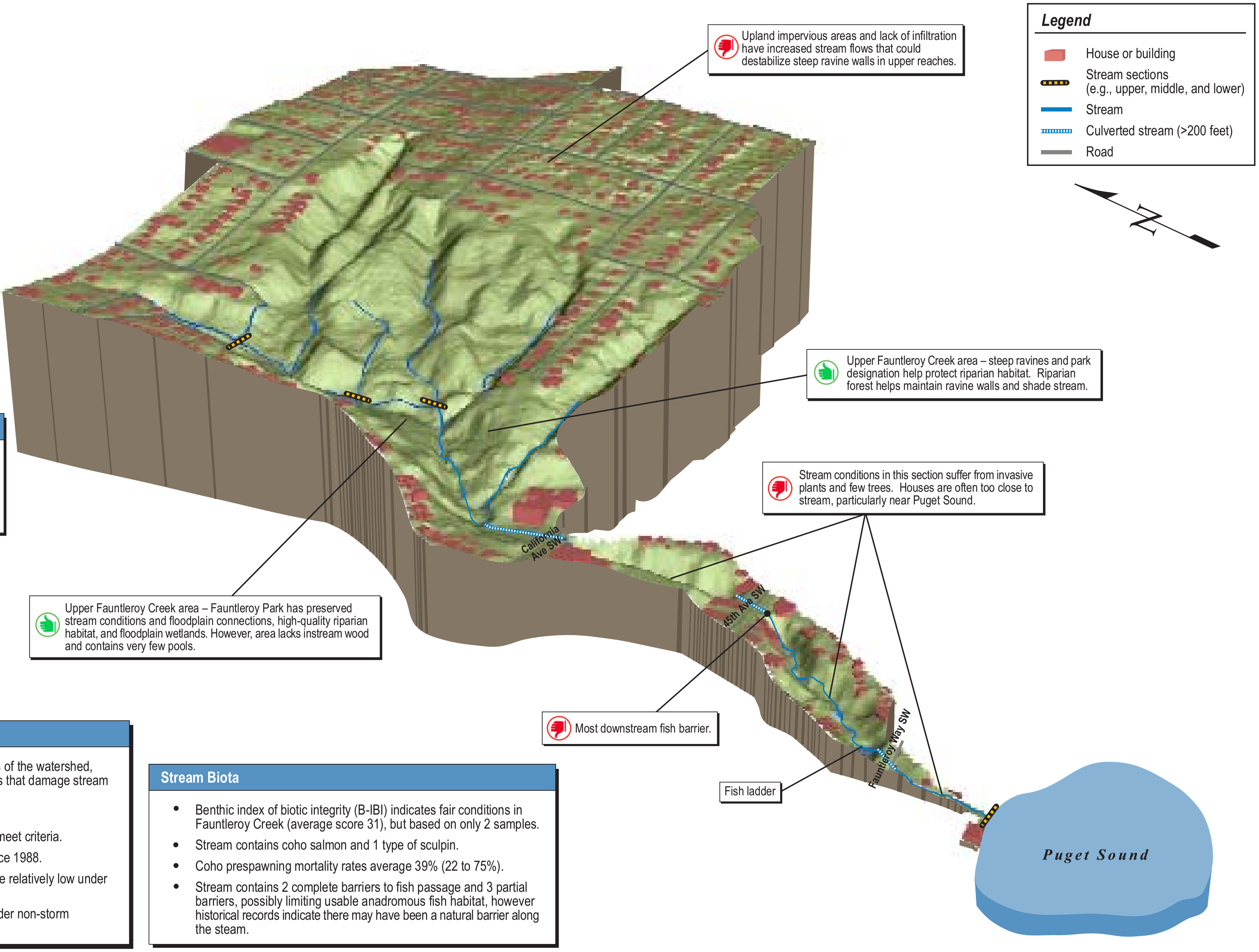
Unique Conditions

- Smallest watershed of Seattle streams (0.23 mi^2).
- Fauntleroy Park covers a large proportion of the watershed.
- Mostly residential land use.
- Drains to Puget Sound.



Upland impervious areas and lack of infiltration have increased stream flows that could destabilize steep ravine walls in upper reaches.

Upper Fauntleroy Creek area – steep ravines and park designation help protect riparian habitat. Riparian forest helps maintain ravine walls and shade stream.

Stream conditions in this section suffer from invasive plants and few trees. Houses are often too close to stream, particularly near Puget Sound.

Upper Fauntleroy Creek area – Fauntleroy Park has preserved stream conditions and floodplain connections, high-quality riparian habitat, and floodplain wetlands. However, area lacks instream wood and contains very few pools.

Most downstream fish barrier.

Fish ladder

Watershed Conditions*

- Buildings, roads, and other impervious surfaces cover 38% of the watershed, substantially increasing stormwater runoff and stream flows that damage stream habitat.
- Stormwater outfalls average 5.6 per stream mile.
- Dissolved oxygen and water temperature levels generally meet criteria.
- Fecal coliform levels exceed criteria, but have declined since 1988.
- Concentrations of toxic materials (metals and ammonia) are relatively low under non-storm conditions.
- Concentrations of nutrients (total phosphorous) are low under non-storm conditions.

Stream Biota

- Benthic index of biotic integrity (B-IBI) indicates fair conditions in Fauntleroy Creek (average score 31), but based on only 2 samples.
- Stream contains coho salmon and 1 type of sculpin.
- Coho prespawning mortality rates average 39% (22 to 75%).
- Stream contains 2 complete barriers to fish passage and 3 partial barriers, possibly limiting usable anadromous fish habitat, however historical records indicate there may have been a natural barrier along the steam.

Note: Information here is based on limited stream flow and water quality data - more data that ranges both storm and non-storm events are needed.

Figure 14. Current conditions of Fauntleroy Creek

The Fauntleroy Creek Watershed

Mouth of Fauntleroy Creek (photo by Bennett)

Fauntleroy Creek, the smallest of Seattle's major watercourses, is located in southwestern Seattle and drains a 149-acre (0.23-square-mile) watershed. The total watercourse length is approximately 8,500 feet or 1.6 miles, including the main stem channel (4,600 feet in length) and six small tributaries. The topography of the watershed is composed of an upland rolling plateau with dense residential development, an area of steep ravines located in parkland with second-growth forest, and a lower valley containing dense residential development. The lowest portion of the watercourse crosses a low-gradient depositional beach area before discharging into central Puget Sound near the Fauntleroy ferry terminal.

The subsurface geology of the Fauntleroy Creek watershed is composed mainly of consolidated sediments with low permeability in the upland plateau, and sand and gravel deposits in the watercourse valley and tributary ravines, which are susceptible to erosion (Troost et al. 2003, 2005). Landslides along the steep valley walls of upper Fauntleroy Creek and its tributaries are major sources of sediment input into the watercourse (Stoker and Perkins 2005). The sand and gravel introduced from the upper ravine walls provide the gravel substrate to the stream. Sand dominates the sediment supply from the middle and lower valley walls, resulting in finer substrate in lower reaches. The stream has eroded into dense glacial silt and clay deposits in lower Fauntleroy Park. These clay deposits are rather impermeable to water and are associated with small wetlands. Artificial fill—a mix of silt, sand, gravel, concrete and other materials—has been used to fill the valley between the downstream boundary of Fauntleroy Park/45th Avenue SW and the watercourse mouth (Troost et al. 2005).

Similar to other Seattle watersheds, the historical Fauntleroy watershed was heavily forested (Stoker and Perkins 2005). Residential development within the basin occurred between the 1920s and 1970s at a rate of about 20 percent of the basin per decade (King County 2005b). This development occurred in conjunction with construction of a formal stormwater drainage system in the upper watershed. Today nearly 70 percent of the basin has been developed into residences and street rights-of-way (Figure 15). These land uses create impervious surfaces such as roads, buildings, and parking lots that limit stormwater infiltration.

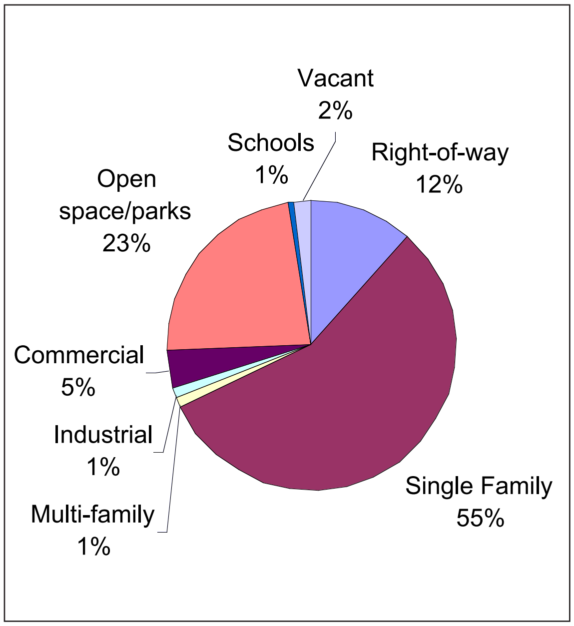


Figure 15. Land uses in the Fauntleroy Creek watershed.

Aside from residential and transportation land uses, the remaining land use in the basin is composed of parks and open space (23 percent). The majority of the watercourse channel length (75 percent) is located within these open-space and park land use designations. In comparison to the other Seattle watersheds, the Fauntleroy watershed contains a relatively low impervious surface area (38 percent) due to the large area of parks and open space (Alberti et al. 2004). Excluding park areas and accounting only for areas drained by the formal stormwater drainage system, impervious surfaces cover 50 percent of the land area in the Fauntleroy watershed (Map 1 in the map folio accompanying this report).

In areas with formal drainage systems, stormwater runoff enters a pipe or ditch and is quickly carried to a watercourse, causing large amounts of water to be discharged to the watercourse over a short time period.

Watershed-Scale Conditions

Fauntleroy Creek Hydrology

A 2-year storm event occurs every 2 years on average, or has a 50% chance of occurring in any given year.

Fauntleroy Creek flows year-round, with an average flow rate estimated at 1 cubic foot per second (cfs) at the mouth and a 2-year peak storm flow estimate of 9 cfs, based on hydrologic models and extremely limited flow information (Hartley and Greve 2005). The magnitude of the 2-year storm event runoff is estimated as four times greater than under predevelopment conditions. The 25-year and 50-year storm event flows are roughly estimated from the model at 17 and 22 cfs, respectively (Hartley and Greve 2005).

Nine storm drains (5.6 outfalls per watercourse mile) discharge stormwater to the upper reaches of Fauntleroy Creek and its tributaries, mostly within or immediately adjacent to Fauntleroy Park (Map 4). The watercourse does not contain any combined sewer overflow (CSO) outfalls. Four of the stormwater outfalls drain upland subcatchments of about 20 acres, the largest within the watershed. However, all Fauntleroy subcatchments have similar impervious surface coverage, low-permeability geology, and gradual slopes, resulting in small differences among estimates of subcatchment runoff potential. Downstream of the park, stormwater reaches the watercourse only through small amounts of surface runoff and through ground water recharge. The hydrologic characteristics of Fauntleroy Creek are generated primarily in the upland plateau above the watercourse.

Fauntleroy Creek Water Quality

Few samples have been collected in Fauntleroy Creek to characterize water quality conditions, and data to evaluate sediment quality conditions are not currently available (Map 2). Available data are summarized below. Beyond the available data, water quality conditions in Fauntleroy Creek are expected to be most similar to conditions in Piper's Creek and Taylor Creek—as opposed to Longfellow Creek and Thornton Creek—because of similar land use patterns. Like other urban watercourses in the Puget Sound area, Fauntleroy Creek has experienced coho salmon prespawn mortality, and water quality is currently being investigated as a potential contributor to the problem. Coho salmon prespawn mortality is discussed later in the Fish section.

The following subsections describe existing water quality conditions in Fauntleroy Creek in general terms, based on available data. More detailed tables and summary statistics for all water quality data are presented in Appendix B.

The Department of Ecology included Fauntleroy Creek on the 2004 list of threatened and impaired water bodies under Clean Water Act Section 303(d), listing the watercourse as a category 5 water body for fecal coliform bacteria. Accordingly, a total maximum daily load (TMDL) limit was required for Fauntleroy Creek based on demonstrated exceedances of the state water quality standard (Ecology 2004). This listing is based on samples collected on June 15 and August 29, 1988, at four sites along Fauntleroy Creek, in addition to earlier sampling conducted by King County (Kendra 1989). Fecal coliform bacteria in the 13 samples collected by Ecology in 1988 ranged from 590 to 2,700 colony-forming units per 100 milliliters (cfu/100 mL), with a geometric mean of 1,300 cfu/100 mL.

In October 2004, Ecology (2006b) began monitoring water quality near the mouth of Fauntleroy Creek. Grab samples are collected each month. Data from October 2004 through December 2005 (15 samples) are presented in the following discussion. Summary statistics from the preliminary results for conventional water quality indicators are presented in Table 11, and the results for each indicator are discussed separately in the following subsections.

Conventional water quality indicators include dissolved oxygen, water temperature, turbidity, total suspended solids, pH, and fecal coliform bacteria.

Table 11. Fauntleroy summary statistics for conventional water quality parameters measured near the mouth.[a]

	Dissolved Oxygen (mg/L)	Temperature (degrees C)	Fecal Coliform (cfu/100 mL)	pH	TSS (mg/L)	Turbidity (NTU)
Minimum	9.8	6.5	23	8.0	3	1.5
Maximum	12.4	15.4	390	8.3	33	19
Median	11.1	10.6	87	8.2	10	5.2
Mean	11.1	10.8	145	8.2	13	6.2
5th percentile	9.8	6.9	27	8.0	3	1.5
95th percentile	12.2	15.1	341	8.3	33	13
Criteria [b]	9.5	16	50	6.5–8.5	–	–

[a] 15 samples collected between October 2004 and December 2005. Most samples were collected during non-storm conditions. Rain occurred during 6 sampling events, and except for December 13, 2005 (0.33 inches), rainfall ranged from 0.02 to 0.07 inches.

[b] Established criteria from WAC 173-201A.

Dissolved Oxygen and Temperature

The measured data for dissolved oxygen and temperature in Fauntleroy Creek consistently met state water quality criteria during the 1-year monitoring period. Fauntleroy Creek is designated as core summer salmonid habitat. For this use designation, the dissolved oxygen criterion is 9.5 mg/L for a daily minimum, and temperature is 16°C for a 7-day average daily maximum. During the 1-year period of record, the lowest dissolved oxygen concentration was 9.8 mg/L, and the maximum temperature was 15.4°C. These very limited data (based on only 15 samples) indicate good conditions for dissolved oxygen and temperature.

In typical urban watersheds, dissolved oxygen levels and water temperatures can be affected by several factors. Inputs of relatively warm stormwater runoff can cause temperatures in watercourses to increase above naturally occurring levels. In addition, channel simplification (resulting from such actions as levee construction, bank hardening, channel straightening, dredging, and woody debris removal) can reduce the hyporheic exchange that helps to promote lower water temperatures. Hyporheic exchange refers to the mixing of surface water and ground water beneath the active stream channel and riparian zone. Finally, reduced shading in streams due to removal of the riparian canopy can cause water temperatures to increase.

Turbidity and Suspended Solids

Fauntleroy Creek total suspended solids (3 to 33 milligrams per liter [mg/L]) and turbidity (1.5 to 19 nephelometric turbidity units [NTU]) are low, reflecting primarily non-storm flow conditions. The highest total suspended solids concentrations (33 mg/L) occurred during two non-storm flow sampling events (June 18 and August 15, 2005). Although particulate levels are expected to increase during storm conditions due to the erosive material present in the Fauntleroy Creek channel (i.e., sandy soil), total suspended solids concentrations in the six samples collected under rainfall conditions ranged from only 4 to 24 mg/L.

For the purposes of this report, the King County and Ecology samples are called non-storm flow samples, and Seattle Public Utilities samples are called storm flow samples.

Background turbidity conditions can be difficult to establish in Seattle's urban watercourses. Typically, background conditions are determined from samples collected upstream of a particular source input to a watercourse, such as a construction site, storm drain outfall, or municipal or industrial discharge. Background samples are then compared to samples collected downstream of a specific source input to determine compliance with the turbidity standard. Because the monitoring stations in Fauntleroy Creek are not located upstream and downstream of specific source inputs, these data are not suitable for assessing compliance with the turbidity standard.

Increases in turbidity and suspended solids typically result from larger storm flows associated with urbanization in the watershed. Larger peak flows tend to erode the streambed and entrain particles more effectively than smaller, less frequent storm flows. In addition, urban stream banks typically erode more easily as riparian vegetation is removed or modified, resulting in increased turbidity and suspended solids downstream, particularly during storms. Finally, turbidity and suspended solids tend to increase downstream in urban watercourses due to unnaturally high inputs of turbid water resulting from urban upland construction activities and ground disturbance.

pH Conditions

The pH level in Fauntleroy Creek (8.0 to 8.3 pH units) is on the high end of the range observed in other urban watercourses in Seattle (6.0 to 8.4 pH units), although it consistently met the state water quality criterion of 6.5 to 8.5 pH units.

Fecal Coliform Bacteria

Results from monthly samples collected in Fauntleroy Creek between October 2004 and September 2005 indicate that fecal coliform levels have declined since 1988 when a preliminary data set of 13 samples was collected by King County (Table 12). The geometric mean in 1988 was 1,300 cfu/100 mL, and the geometric mean in 2004–2005 was 130 cfu/100 mL. Despite this decline over time, recent samples continue to exceed the 2006 water quality standard for extraordinary primary contact recreation (i.e., a geometric mean of 50 cfu/100 mL, with no more than 10 percent of the samples exceeding 100 cfu/100 mL). In 1988, 100 percent of the samples exceeded these criteria, whereas recent samples exceeded the criteria 58 percent of the time.

Table 12. Fauntleroy fecal coliform bacteria comparison between 1998 and 2005 data.[a]

Fecal Coliform Bacteria (cfu/100 mL)	1988	2005
No. of samples	13	15
Range	590–2,700	23–390
Geometric mean	1,300	130
Greater than 100 cfu/100 mL	100 percent	58 percent

cfu/100 mL = colony-forming units per 100 milliliters.

[a] 1988 data collected by Kendra (1989); 2005 data collected by Ecology (undated).

Potential sources of fecal coliform bacteria in urban watercourses are wildlife and pet wastes, leaking wastewater systems, failing septic systems, wastewater treatment plant effluent, and combined sewer overflow events. Stormwater runoff from urban development can easily wash bacteria from these sources into urban watercourses. The exact source of bacteria in Fauntleroy Creek is unknown; however, data from other microbial source tracing studies in Seattle urban watercourses (i.e., Piper's Creek and Thornton Creek) have identified the primary source as pet and wildlife wastes.

Metals

Fourteen priority pollutant metals with recommended water quality criteria for the protection of aquatic life and human health in surface waters (see Table 9) were reviewed for Fauntleroy Creek. No sample results are available for storm flow conditions, and non-storm flow results are not available for dissolved mercury, total antimony, total beryllium, total selenium, or total thallium. Although the record is limited, the quality of the data is relatively good. Appendix B contains detailed summary statistics and time series plots for all metals analyzed.

Overall, metals concentrations in Fauntleroy Creek appear to be relatively low. For dissolved metals, eight samples were collected between October 18, 2004 and December 13, 2005 at station 09K070 (Map 2). Dissolved metals (e.g., copper and lead) were either undetected or detected at levels below the acute and chronic toxicity criteria for aquatic.

In Fauntleroy Creek, total mercury exceeded the chronic toxicity criterion in one of eight samples (12 percent); none of the samples exceeded the acute toxicity criterion. The total mercury chronic criterion of 0.012 micrograms per liter (µg/L) was exceeded on June 13, 2005, with a sample result of 0.014 µg/L. The one mercury exceedance is considered an outlier (i.e., it falls beyond the step spread, as described under Summary Statistics in Part 3); hence additional data are needed to show whether the sample is truly representative of water quality conditions in the watercourse.

The total arsenic human health criterion of 0.018 µg/L was exceeded in all eight samples. This drinking water criterion applies to human consumption of water and organisms (see Table 9). Therefore, the risk to human health is minimal if people do not drink the water or consume fish living in the watercourse. Although the human health criterion for arsenic is frequently exceeded, the aquatic life chronic and acute toxicity criteria are seldom exceeded. As noted earlier, most of these samples represent non-storm flow conditions. Only one sample, collected on December 13, 2005, was collected during a significant storm event (0.33 inches).

Metal pollutants accumulate on impervious surfaces in urban watersheds and are washed off during storms. In addition, some metals are bound to sediments; so as storm flows entrain soil and sediment, metals are more easily transported to watercourses. Sources of metal pollutants include wear and tear of vehicle parts (e.g., brake pads, tires, rust, and engine parts), atmospheric deposition, common building materials (e.g., galvanized flashing and metal downspouts), and roof maintenance activities (e.g., moss control).

Nutrients

Nutrient levels in Fauntleroy Creek are relatively low (Table 13). Fifteen samples were examined for ammonia-N, nitrate-nitrite, and total phosphorus; these were compared against criteria and benchmarks representing surface water quality conditions that are minimally affected by human activity. (Total nitrogen data are not available.) Of those 15 samples, only one (7 percent) exceeded the benchmark for total phosphorus (see Table 8 for nutrient benchmarks). The total phosphorus benchmark of 0.1 mg/L was exceeded on August 15, 2005 with a sample result of 0.864 mg/L. However, this sample result is suspect until additional data have been collected. Of the total of 15 nutrient sample results available, 73 percent were detected values. Appendix B provides nutrient summary statistics and time series plots.

Phosphorus and nitrogen are common pollutants in urban watercourses. Sources include fertilizer applications, increased soil erosion, nutrients from washwater (e.g., car and boat cleaning), failing septic systems, pet wastes, and improper dumping of yard wastes. All of these sources can result in increased nutrient concentrations in stormwater runoff. This is of particular concern for the larger water bodies such as freshwater lakes and Puget Sound. Elevated nutrient levels can lead to eutrophication, a process in which rapid growth of algae may overcome natural self-purification processes in the water body. The resulting algal blooms degrade water quality as the decomposing algae reduce the dissolved oxygen concentrations in receiving waters. Ultimately, increased nutrient concentrations can reduce survival opportunities for salmonids, which rely on oxygen-rich waters.

Table 13. Fauntleroy summary statistics for nutrients.

	Ammonia-N (mg/L)		Nitrate+nitrite (mg/L)		Total Nitrogen (mg/L)		Total Phosphorus (mg/L)	
	non-storm	storm	non-storm	storm	non-storm	storm	non-storm	storm
Fauntleroy Creek station 09K070								
No. of samples	15	ND	15	ND	ND	ND	15	ND
Minimum	0.01	ND	0.71	ND	ND	ND	0.047	ND
Maximum	0.02	ND	1.3	ND	ND	ND	0.86	ND
Median	0.01	ND	0.93	ND	ND	ND	0.055	ND
Mean	0.011	ND	0.96	ND	ND	ND	0.11	ND
5th percentile	0.01	ND	0.75	ND	ND	ND	0.047	ND
95th percentile	0.014	ND	1.2	ND	ND	ND	0.33	ND
Benchmark [a]	0.43 – 2.1		–		0.34		0.1	

[a] Ammonia chronic toxicity criteria are pH-dependent, and the given range is for a pH of 6.5–8.5. All nutrient criteria and benchmarks are described in more detail in Part 3 of this report.

mg/L = milligrams per liter.

ND= no data collected.

Organic Compounds

To date, available stormwater and sediment data are insufficient to evaluate the presence and impacts of organic compounds in the Fauntleroy Creek watershed.

Other Water Quality Indicators

The area offshore of the Fauntleroy Creek outlet to Puget Sound frequently has odor problems during the summer. Studies have found that the odor is caused by hydrogen sulfide generated by decaying seaweed that accumulates along the beach from offshore algae beds (WDOH 2001). Seaweed growth normally is limited by the availability of nitrogen, and by midsummer there is usually insufficient nitrogen to support large growth. However, the nutrient-rich discharge from Fauntleroy Creek is believed to support seaweed growth throughout the summer, which contributes to the odor problem (WDOH 2001). This seaweed growth is related to the eutrophication process described above.

Stream-Scale Conditions

The Fauntleroy Creek channel is very steep and narrow. Within a narrow floodplain and channel migration zone, the stream maintains a relatively static single channel with minimal meandering (Stoker and Perkins 2005). Surface and ground water drainage from the uplands has been gradually cutting into the glacial deposits, leading to channel erosion and landslides that have widened the steep ravine walls of the middle watershed and have supplied large amounts of outwash sand and small amounts of gravel to the main channel (Stoker and Perkins 2005).

Although the gradient of Fauntleroy Creek averages between 2 and 8 percent, the upstream reaches exceed a 10 percent gradient (Map 3). The steepest parts of the watercourse are the upper main stem and its tributaries, which flow through steep-sided, forested ravines in Fauntleroy Park exceeding 8 percent gradient. Fauntleroy Creek is characterized mostly by a simple, single-channel drainage pattern with a steep gradient and a moderately confined, short channel (Seattle 2005).

Based on watershed and channel characteristics, the Fauntleroy stream channel classification under more natural conditions would be cascade and step-pool habitat, particularly where large wood from the adjacent riparian forest would add structure to the channel. One exception is near the mouth where the low channel gradient and tidal beach would promote sediment deposition.

Given the high energy of Fauntleroy Creek and the sediment coming into the system from the ravine walls, an important role of Fauntleroy Creek is to transport sediment to the shoreline of Puget Sound, supporting the creation and maintenance of marine habitat in addition to habitat within the stream.

For the following discussion, Fauntleroy Creek is divided into two major reaches (Map 3). Stream codes, shown on the watercourse maps, consist of two letters of the watercourse name (FA for Fauntleroy) and the number of the stream segment, starting with 01 at the mouth and increasing in the upstream direction:

Watercourses are divided into reaches, reaches are divided into segments, and segments are divided into sections.

- The Fauntleroy Park reach (FA05–FA04)
- Lower Fauntleroy Creek downstream of Fauntleroy Park to the mouth (FA03–FA01).

Fauntleroy Park (FA05–FA04)

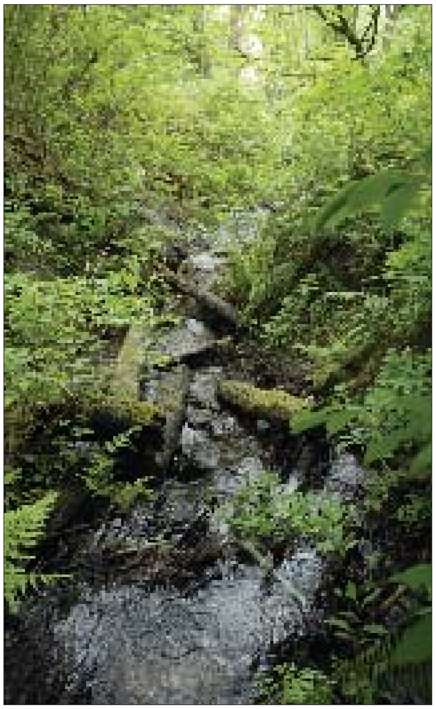
While the watercourse headwaters are located on the rolling upland plateau, the open channels of Fauntleroy Creek begin in the upper valleys primarily contained within Fauntleroy Park. Fauntleroy Creek and its tributaries drain through steep ravines, greater than 8 percent gradient, before reaching the main stem valley floor where the gradient is between 4 and 8 percent (Map 3). The main stem channel in this reach is approximately 1,390 feet in length, in addition to roughly 3,900 feet of channels in six tributaries.

Watercourse codes (also shown on the watercourse maps) consist of two letters of the watercourse name (FA for Fauntleroy) and the number of the stream segment, starting with 01 at the mouth and increasing in the upstream direction.

Riparian Habitat

The riparian corridor within Fauntleroy Park contains a mixture of deciduous and coniferous trees with a primarily native understory (Map 5). The riparian corridor through this reach is continuous, exceeding 100 feet in width and even 200 feet in some areas. The deciduous and coniferous trees provide a full, dense canopy to shade the stream. The stream bank vegetation helps to stabilize banks and prevents excessive bank erosion. The mix of mature deciduous and coniferous trees provides protection to the channel through forest regeneration, as well as providing potential recruitment of large wood to the stream. The forest contains invasive English ivy, particularly in the lower segment of this reach (FA04).

The steep, unstable valley walls and park land use have limited urban encroachment into the stream riparian area and protected its vegetation. The area is dominated by single-family houses, which are set more than 100 feet from the stream (Map 6). A single pedestrian bridge is the only structure along the stream. With the existing forested riparian condition and lack of urban land uses near the stream, the riparian quality of this reach is ranked high (Map 7).



Riparian habitat in Fauntleroy Park, Fauntleroy Creek (photo by Bennett)

Instream Habitat

The channel width within Fauntleroy Park is relatively narrow, averaging less than 5 feet, and is confined by the valley walls and landslide deposits. Historically, the steep tributaries and valley walls have been important source areas for sediment and large wood introduced into Fauntleroy Creek. Historically and today, the main stem occupies a narrow floodplain, with wetlands where tributaries join the main stem (Seattle 2005).

Instream woody debris in Fauntleroy Park, Fauntleroy Creek (photo by Bennett)

Fauntleroy Creek within the park has relatively high instream habitat quality (Map 7). The main stem's narrow floodplain areas and associated wetlands in clay deposits tend to reduce the impact of the high flows on the structure of the stream. Limited deposits of large wood in the channel were not sufficient to create much pool habitat until more wood was added in 2005. Riffle habitat dominates this reach, which contains only two pools representing one percent of the available habitat (Map 5). Given the steep gradient, instream habitat should consist of cascade and step-pool channel types; however, the channel exhibits mostly step-pool and pool-riffle morphologies.

Even with connections between the stream and narrow floodplain, segments of the stream channel within this reach are widening and degrading as a result of increased flows resulting from watershed urbanization and the lack of wood in the channel (Map 4). Hydrologic changes are generated by impervious surfaces and stormwater drainage systems on the upland plateau of the upper watershed. Some stream segments are storing sediment, increasing bed elevation through aggradation, and decreasing the overall gradient of the channel, primarily in areas where stream–floodplain connections and in-channel wood exist to slow water velocity and trap sediment (Stoker and Perkins 2005). The majority of the stream sediment comes from the ravine walls, and some sediment is also eroded from gravel deposits stored along the narrow valley bottom.

Aggradation is the raising of streambeds or floodplains through the deposition of sediment eroded and transported from upstream.

Culverts under 45th Avenue SW and California Avenue SW prevent migratory salmon and trout from using this reach, although students participating in the Salmon in the Classroom program release coho fry into the Fauntleroy Park reach each spring.

Lower Fauntleroy Creek (FA03–FA01)


Mouth of Fauntleroy Creek at Puget Sound (photo by Bennett)

Downstream of Fauntleroy Park, the watercourse flows 2,340 feet (or 0.4 miles) through mostly residential neighborhoods within a narrow valley that is reduced in width by past filling and land grading. The gradient of the watercourse ranges between 4 and 8 percent, characteristic of a step-pool channel type, with a lower-gradient mouth where the watercourse discharges into Puget Sound (Seattle 2005).

Riparian Habitat

The riparian corridor downstream of Fauntleroy Park becomes narrow and is dominated by landscaping and invasive plants. Within Kilbourne Park (FA03b), the riparian corridor averages about 75 feet in width where the surrounding houses are located outside the watercourse ravine (Map 6). This area contains mature deciduous trees that provide a canopy, although the canopy is sparse in some areas (25 percent cover; Map 5). The area is also dominated in the understory by invasive plants, particularly English ivy. Near the mouth (FA02), the riparian corridor is dominated by lawns without canopy cover, and houses are located directly adjacent to the stream, within 25 feet of the banks. These stream segments have poor riparian habitat (Map 7).

In the middle segment of this reach, between Fauntleroy Way SW and 45th Avenue SW (FA03a), the riparian corridor provides moderate habitat quality. The vegetation community is dominated by deciduous and coniferous trees that provide good cover to the stream (averaging greater than 50 percent). The steep ravine also contains a mixed understory of native and nonnative English ivy, located primarily in areas that have a broken canopy due to tree fall. The watercourse ravine has limited the proximity of surrounding houses, which are situated from 20 to 75 feet away from the stream.

Instream Habitat

Historically, Fauntleroy Creek contained large wood that trapped sediment and formed steps and pools in the stream. Today, the lower portions of the watercourse lack instream structure, resulting in plane-bed morphology. The watercourse contains a few pool-riffle and step-pool areas where instream rehabilitation structures have been installed; pool habitat should improve where logs have been added in the upper segment of this reach (FA03; Stoker and Perkins 2005). The active channel width varies from 5 to 10 feet, with a fair amount of confinement by the valley walls between 45th Avenue SW and California Avenue SW. Downstream of 45th Avenue SW, the valley widens and natural confinement within the ravine is reduced (Stoker and Perkins 2005). However, filling, culverts, a fish ladder, and bank armoring have confined segments of the channel, causing incision and limiting stream–floodplain connections and gravel retention (Seattle 2005; Map 6).

Habitat quality ranges between low and moderate within this reach of Fauntleroy Creek (Map 7). Similar to the upstream reach in Fauntleroy Park, the lower reaches of the stream channel are dominated by riffle habitat (about 90 percent), although 25 pools with depths greater than 0.5 feet have been identified (Map 5). However, ten of the pools are created by a fish ladder constructed in the late 1990s at the upstream end of the Fauntleroy Way SW culvert, and the limited area of these created pools does not produce the slow-flowing refuge habitat expected from such habitat types. The lack of structure and large amount of encroachment contribute to degraded instream habitat. Within Kilbourne Park, large woody debris has been added to the stream, which should increase the quality of habitat and channel conditions over time. The lowest segments of the watercourse (FA01 and FA02) are confined to a narrow, simple channel with residential lawns and buildings along both banks.

Encroachment into the stream corridor, coupled with increased flows from the developed upland plateau, have degraded the stream channel (Map 4). Without instream structures to store sediment, sand and gravel from upstream areas are transported to the Puget Sound beach. This export of sand and gravel benefits the marine environment, because sediment is critical to the creation and maintenance of marine shoreline habitats. However, the lack of instream sediment retention affects the creation of stream habitat.

The degradation and further entrenchment of the stream promotes instability of the stream banks, except where banks are armored. Exceptions to this process can be found in the stream near culverts, which store sediment just above their upstream ends and where wood has been added by restoration projects (Map 9). Channel aggradation occurs at culverts under 45th Avenue SW and California Avenue SW, which also block fish passage (Map 8). The new depositional zones upstream of these culverts provide backwater areas, which are different from the riffle habitat that would develop if the culverts were not present.

Use by Fish and Benthic Invertebrates

Fish Access

Based on historical records and accounts dating back to the 1920s, salmon were not present in Fauntleroy Creek until the last decade or so (Trotter 2002). There are anecdotal records of historical use of the mouth and lower watercourse by sea-run cutthroat trout (Washington Trout 2000; Lantz et al. 2006). Today, coho salmon, the occasional chum salmon, and staghorn sculpin use the watercourse (Lantz et al. 2006).

Currently, coho salmon are the primary salmonids using Fauntleroy Creek (Table 14). An average of 26 adults enter the watercourse to spawn each fall, although annual numbers vary widely. Carcass counts represent a minimum level of salmonid use, and the actual number of adult spawners is certainly higher. Roughly 40 percent of the adults using Fauntleroy Creek are hatchery fish that either were released into the watercourse as juveniles or strayed from nearby hatcheries. In addition to coho, one chum salmon carcass was documented in the watercourse in 2001, although no chum redd was found. Based on the small size of the watercourse and the rather large size of chum salmon, Fauntleroy Creek is not expected to be a chum spawning area, or to support Chinook, pink, or sockeye salmon.

Table 14. Fauntleroy salmon spawning survey results based on carcass and redd counts.

	Chinook[a]		**Coho**		**Sockeye**[b]		**Chum**	
Year	**Carcasses**	**Redds**	**Carcasses**	**Redds**	**Carcasses**	**Redds**	**Carcasses**	**Redds**
1999	–	–	28	4	–	–	0	0
2000	–	–	43	9	–	–	0	0
2001	–	–	63	16	–	–	1	0
2002	–	–	3	1	–	–	0	0
2003	–	–	0	1	–	–	0	0
2004	–	–	1	1	–	–	0	0
2005	–	–	44	9	–	–	0	0

Sources: McMillan (2005); SPU unpublished data. Values in table are averaged between the two data sources.
Survey conducted in the lower reach of Fauntleroy Creek up to 45th Avenue SW.
[a] Chinook do not use Fauntleroy Creek, as the stream is too small to allow for spawning activities.
[b] Sockeye salmon are not expected to use the stream, as they need a lake environment for rearing.


Culvert entrance along Fauntleroy Creek (photo by Bennett)

Adult coho spawn in the lower reach of Fauntleroy Creek up to 45th Avenue SW, where a culvert acts as a barrier to upstream migration. Removal of the barrier at the Fauntleroy Way SW culvert in 1998 was important in increasing the amount of accessible habitat in the watercourse (800 feet). Today, the remaining barriers at 45th Avenue SW and California Avenue SW prevent anadromous fish from using high-quality habitat within Fauntleroy Park, although use of the upper portions of the watercourse is also limited by the size and gradient of the watercourse.

Coho redds have been counted annually since 1999 during SPU spawning surveys. Community volunteers monitor the number of juveniles emerging from redds and also operate a smolt trap located just upstream of Fauntleroy Way SW. This trap captures coho fry (less than one year old) that are flushed downstream during high-flow events, along with coho smolts that are actively out-migrating to Puget Sound after spending one year in the watercourse. It is not known what proportion of the fry and smolt catches are naturally produced by coho adults spawning in redds, because hatchery-raised fry are released into Fauntleroy Creek as part of Seattle's Salmon-in-the-Classroom program.

The average number of coho smolts caught in the Fauntleroy smolt trap from 2003 through 2006 ranged between 10 and 37 (Table 15). Fry captured in the trap have varied between 37 and 721. Given that few coho redds are recorded in the watercourse each year, and that typically over 1,100 coho fry are released into Fauntleroy Creek, these numbers indicate extremely low juvenile coho survival. Inadequate spawning habitat and poor-quality rearing habitat probably limit the success of coho salmon in Fauntleroy Creek. Gravel substrates appropriate for spawning are available only to adult coho in a small area 400 feet in length upstream of Fauntleroy Way SW. The lack of pools in Fauntleroy Creek also may limit successful juvenile rearing in the watercourse. The importance of pool habitat is reflected by juvenile coho (hatchery releases) in the stream, which tend to congregate in step-pools within the park (Washington Trout 2000). The few pools that exist are small and shallow, with median depths of 0.6 to 0.9 feet, and some of the largest pools are found in the fish ladder in turbulent conditions.

Table 15. Fauntleroy annual coho smolt trapping and fry release counts.

Year	Monitoring Period	Total Smolts	Smolt Size Range	Total Fry	Released Hatchery Fry
2006	4/9 to 5/18	23	105 mm – 155 mm	121	1,633
2005	3/16 to 5/27	10	100 mm – 135 mm	37	1,138
2004	3/3 to 6/10	11	97 mm – 123 mm	572	1,534
2003	4/2 to 6/16	37	(used different method)	721	1,254

Source: Linde (2006)

Coho prespawn mortality (PSM) may be another factor in poor fry and smolt production. The coho prespawn mortality rate in Fauntleroy Creek averages about 39 percent overall (Table 16). This average is lower than rates in other Seattle watercourses; however, spawning conditions are sometimes uncertain due to scavenging (62 percent of carcasses). The cause of coho prespawn mortality is not known, although combinations of water quality, sediment quality, and other environmental factors are under investigation. No underlying biological causes (such as infection, disease, or parasites) have been identified.

Table 16. Fauntleroy coho female prespawn mortality.

Year	Number of Spawned Females	Number of Unspawned Females	Number of Unknown Spawning Condition	Total Number of Female Carcasses	Total Number of Females of Known Spawning Condition	PSM (%)
1999	0	3	5	8	3	–
2000	9	3	8	20	12	25
2001	8	3	20	31	11	27
2002	1	0	0	1	1	–
2003	0	0	0	0	0	–
2004	0	0	1	1	0	–
2005	1	3	15	19	4	75
Totals	19	12	49	80	31	39

Sources: McMillan (2005); SPU unpublished data. Values in table are averaged between the two data sources.
PSM = prespawn mortality.

Benthic Invertebrates

Fauntleroy Creek has nine years of benthic invertebrate data, collected almost every year between 1994 and 2004, sampled from a site in the middle reach of the watercourse (Map 2, FA03; Table 17). Overall, the biota in Fauntleroy are among the healthiest in Seattle, with benthic index (B-IBI) scores ranging from 20 (poor) to 36 (fair; see Appendix C). Unfortunately, only two of the nine samples met the minimum target threshold of 400 macroinvertebrate individuals; in 1995 the index score was 36, and in 2002 the score was 26. Sampling in 1998 came close to the minimum target threshold (305 individuals), receiving a score of 26. Samples without sufficient numbers to meet the threshold scored between 20 and 28, averaging 27 (n = 5). The scores for samples meeting the minimum threshold averaged 31 (n = 2).

The number of individuals collected in an invertebrate sample influences the number of taxa counted because the more individuals collected, the higher probability of detecting a new taxon (Larsen and Herlihy 1998). To accurately measure taxa richness, a 400-count sample is preferred.

Table 17. Fauntleroy average benthic index scores.

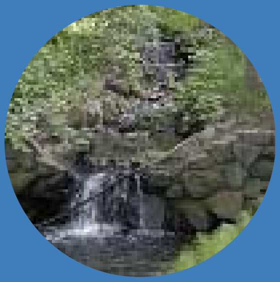
Reach	Collection Sites	Years Sampled	Average B-IBI Score [a]	Range (all samples)
FA03	FA01, FA02, FA03	1994–1996, 1998–2002, 2004	31	20–36

[a] Average of samples with numbers greater than the minimum threshold.
B-IBI = Benthic index of biotic integrity.

Based on the detailed data associated with the benthic sampling, Fauntleroy Creek appears to have some characteristics distinguishing it from other Seattle watercourses. Fauntleroy Creek contains more benthic predator species and stoneflies, fewer clinger species, and a lower percentage of species tolerant of degraded conditions (10–35 percent, as opposed to 40–60 percent in some of the lowest B-IBI-rated sites on Thornton Creek, which indicates better habitat conditions). These benthic invertebrate community characteristics indicate a generally positive biological condition. Also notable are some differences seen among the tolerant species found in Fauntleroy Creek. Some common tolerant species (e.g., leeches and planaria) were not found in Fauntleroy samples; however, two other tolerant species that tend to be rare in other Seattle watercourses were found in Fauntleroy samples: the burrowing fingernail clams *Sphaeridae* and *Pisidium*. In 2004, a moderately tolerant mayfly that requires good stream flow and water quality conditions (*Rithrogena*) was also found for the first time on record in a Seattle watercourse.

Benthic index scores:

10–16	*very poor*
18–26	*poor*
28–36	*fair*
38–44	*good*
46–50	*excellent*



Longfellow Creek

Longfellow Creek Key Findings

As shown in Figure 16, Longfellow Creek overall is in rather poor shape, with a heavily urbanized watershed. However, it provides a few beneficial physical stream conditions:

- *Habitat restoration projects along the watercourse* have increased instream and riparian habitat quality in some locations, have reduced flooding, and have increased open space.
- *The 800-foot instream wetland* within the West Seattle golf course stores sediment, improves downstream water quality, and helps to retard flows.
- *Riparian vegetation* within the golf course provides shading to the stream and provides some bank stability.
- *Concentrations of toxic materials* (metals and ammonia) in the watercourse are generally low.

Water quality and stream conditions in Longfellow Creek are degraded in several ways:

- *Altered hydrology* induced by urban development in the watershed has increased the 2-year storm event runoff by fivefold over predevelopment conditions. These high flows contribute to bank and streambed erosion and flooding.
- *Conventional water quality indicators* exceed water quality criteria. Fecal coliform bacteria levels exceeded the criterion for primary contact recreation (100 colony-forming units per 100 milliliters) in all but one of the last ten years (100 to 1,100 cfu/100 mL). Water temperatures and dissolved oxygen levels are problematic in summer months; over the past 14 years, 2 to 4 percent of water samples exceeded the temperature criterion, and 2 to 3 percent exceeded the dissolved oxygen criterion.
- *Concentrations of toxic materials* (metals) are relatively low under non-storm flow conditions. However, 100 percent of non-storm flow samples (12 samples) and storm flow samples (one sample) exceeded the human health criterion for total arsenic.
- *Concentrations of nutrients* (total nitrogen and total phosphorus) frequently exceed established benchmarks (100 and 9 percent exceedances, respectively, for total nitrogen and total phosphorus under non-storm flow conditions, and 91 percent exceedance of the total phosphorus benchmark under storm flow conditions).
- *Lack of floodplain connections and instream structure, and a highly fragmented riparian forest* along most of the watercourse have led to insufficient refuge or pool habitat, bank instability, flooding, elevated water temperatures, and lack of instream gravels.
- *Fish passage barriers* within the golf course limit anadromous fish to the lower 26 percent of the watercourse.
- *Benthic index of biotic integrity (B-IBI) scores* are poor, ranging from 12 to 18.
- *Coho prespawn mortality rates* are high, averaging 71 percent.

Unique Conditions

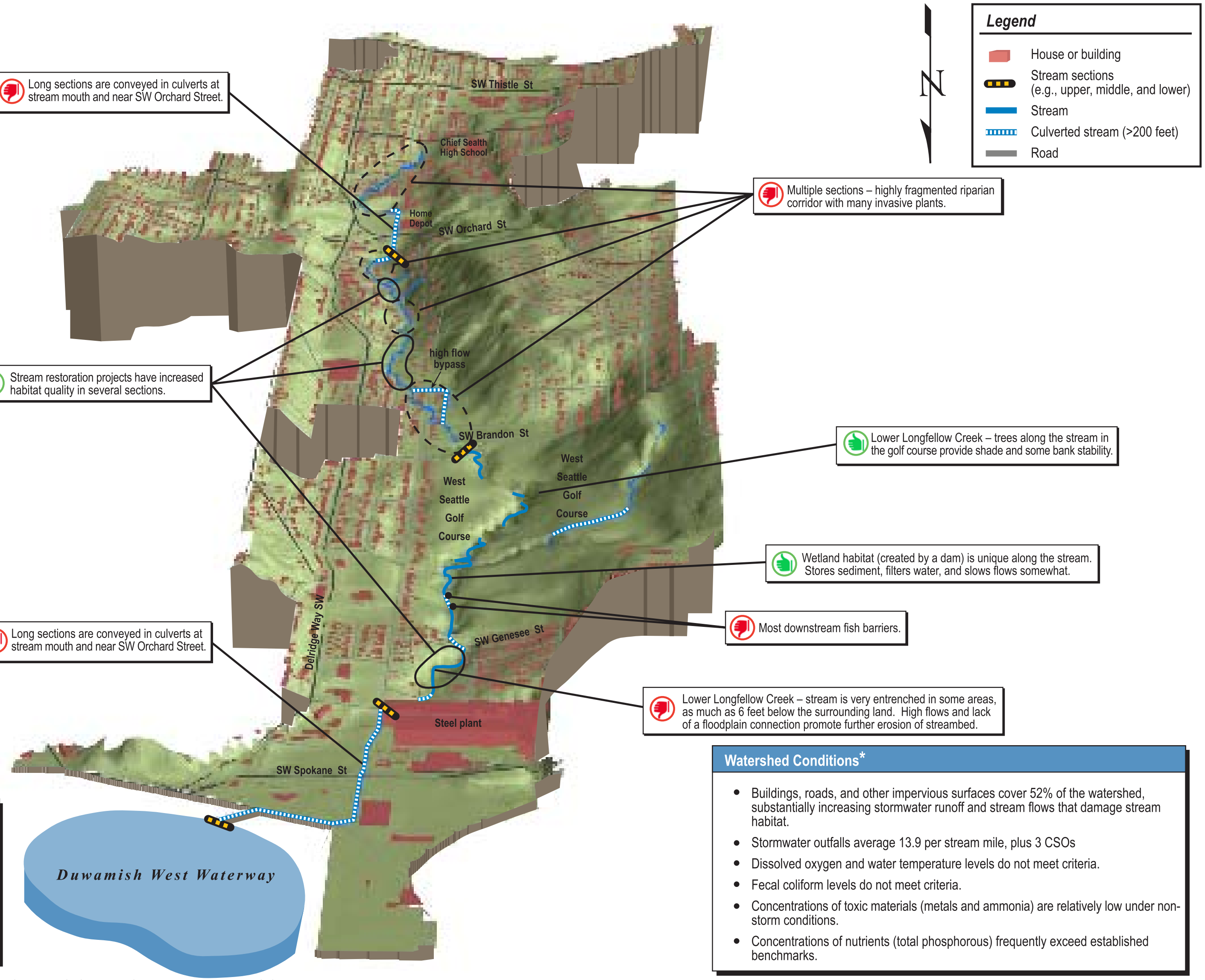
- Second largest watershed of Seattle streams (2.7 mi^2).
- Long, narrow watershed with gentle slopes and a few short tributaries.
- Residential, commercial, and industrial land uses.
- Drains to Duwamish River.
- Only Seattle stream that receives combined sewer overflows (CSOs).

Stream Conditions

- Little high-quality instream habitat.
- Lack of floodplain connections, instream wood, and gravel contributes to erosion of streambed and banks and poor instream habitat.

Stream Biota

- Benthic index of biotic integrity (B-IBI) indicates very poor conditions in Longfellow Creek (average score 15).
- Stream contains coho and chum salmon; rainbow trout; threespine stickleback; and 2 kinds of sculpin.
- Coho prespawning mortality rates average 71% (54 to 82%).
- Stream contains 7 complete barriers to fish passage barriers and 3 partial barriers, limits usable anadromous fish habitat to 2,200 feet.



Long sections are conveyed in culverts at stream mouth and near SW Orchard Street.

Multiple sections – highly fragmented riparian corridor with many invasive plants.

Stream restoration projects have increased habitat quality in several sections.

Lower Longfellow Creek – trees along the stream in the golf course provide shade and some bank stability.

Wetland habitat (created by a dam) is unique along the stream. Stores sediment, filters water, and slows flows somewhat.

Most downstream fish barriers.

Long sections are conveyed in culverts at stream mouth and near SW Orchard Street.

Lower Longfellow Creek – stream is very entrenched in some areas, as much as 6 feet below the surrounding land. High flows and lack of a floodplain connection promote further erosion of streambed.

Watershed Conditions*

- Buildings, roads, and other impervious surfaces cover 52% of the watershed, substantially increasing stormwater runoff and stream flows that damage stream habitat.
- Stormwater outfalls average 13.9 per stream mile, plus 3 CSOs
- Dissolved oxygen and water temperature levels do not meet criteria.
- Fecal coliform levels do not meet criteria.
- Concentrations of toxic materials (metals and ammonia) are relatively low under non-storm conditions.
- Concentrations of nutrients (total phosphorous) frequently exceed established benchmarks.

*Note: Information here is based on limited stream flow and water quality data - more data that ranges both storm and non-storm events are needed.

Figure 16. Current conditions of Longfellow Creek

The Longfellow Creek Watershed

Seattle's second largest watershed, the Longfellow Creek basin, is located in West Seattle. The Longfellow watershed covers 1,729 acres, or 2.7 square miles, with 4.6 miles of watercourse length. The structure of Longfellow Creek is very different from the other major Seattle watercourses; the watercourse is dominated by a single channel with a few short tributaries. The watercourse includes 3.9 miles of main channel, one-third of which (6,350 feet) is piped, and 0.7 miles of tributaries.

Also in contrast to other major watercourses in Seattle, Longfellow Creek has limited areas with steep ravines and high watercourse gradients. The watercourse flows through a broad valley (Delridge Valley), which historically, prior to urbanization, would have allowed wide meandering of the stream and extensive valley bottom wetlands (Seattle 2005). Longfellow Creek flows from south to north, dropping 250 feet in elevation from its headwaters near the southern city limits to its mouth at the Duwamish River near Harbor Island. The watercourse discharges to the Duwamish River through a 3,250-foot culvert.

The surficial geology of the upper portion of the Longfellow Creek watershed consists of till that is dense and compact, with predominantly low infiltration rates (Troost et al. 2005). Historically, the till substrates coupled with peat and wetland deposits created large wetlands and peat bogs in the upper basin (Seattle 2005). The watercourse flows through deposits of clay and silt through the middle portion of the watershed, which are moderately permeable to water. The lower watercourse reflects the geomorphic history of the basin, which has been slowly eroding and washing glacial sediment downstream (Stoker and Perkins 2005).

Downstream of the southern boundary of the West Seattle golf course, the stream has eroded through the valley floor, creating inner valley walls about 30 feet high within the wider Delridge Valley. This inner valley bottom mostly contains sediment eroded from upstream areas, primarily sands and gravels. While Delridge Valley abuts some steep valley walls, they do not contribute much sediment to Longfellow Creek, because the valley is too wide for landslide material to reach the channel. Historically, the stream would have meandered across the floodplain to recruit sediment, but today most of the sediment comes from erosion of the channel bed and stream banks. The watercourse mouth, historically underlain by tide flat deposits of Elliott Bay, today contains artificial fill. Fill has also been used in a majority of the headwater wetlands and in the West Seattle golf course area to create conditions suitable for development.

Development in the Longfellow Creek basin has occurred at a slower rate than in most other areas of Seattle. While initial development at the mouth of the watercourse began in the 1880s, it was not until 1905 that the community of Youngstown was developed to support a local steel mill built on the shore of Young's Cove. Urbanization followed the extension of trolley lines up the eastern and western sides of the Longfellow Creek valley (Trotter 2002). Although the upper portions of the watershed were logged early on, wetlands on the Delridge Valley floor deterred both logging and development in the stream floodplain. Urbanization in the upper valley occurred mainly in the 1960s and 1980s (Longfellow Creek Watershed Management Committee 1992).

Today, residential neighborhoods comprise roughly 32 percent of the Longfellow watershed, while transportation infrastructure such as streets, parking lots, and rights-of-way total 22 percent of the basin area (Figure 17). Industrial and commercial uses are concentrated near the mouth of the watercourse (where the steel mill is still in operation) and comprise 21 percent of the land use in the basin. Commercial uses also include several large shopping centers at the southern end (headwaters) of the watershed.

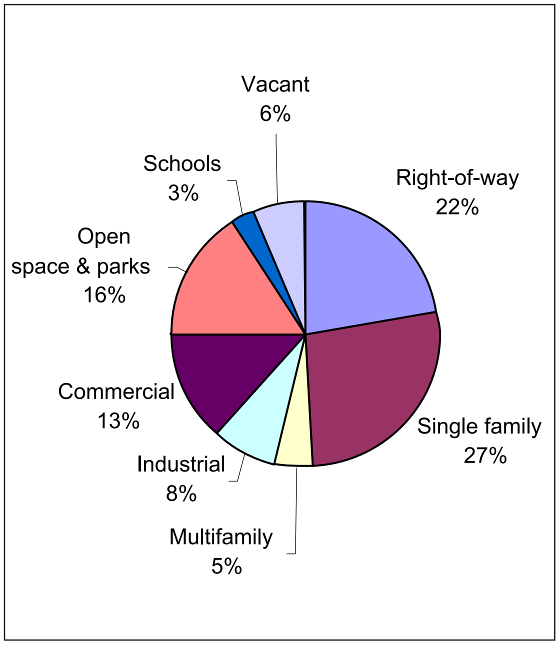


Figure 17. Land uses in the Longfellow Creek watershed.

Approximately 16 percent of the watershed is undeveloped, mostly preserved as park land or open space. Nearly 50 percent of this open space is located adjacent to the stream channel. Overall, 52 percent of the watershed is covered by impervious surfaces such as asphalt, concrete, and buildings (Alberti et al. 2004). The impervious surfaces are concentrated in the upper watershed and at the watercourse mouth (Hartley and Greve 2005), both of which are associated with fill and a higher level of commercial and industrial development (Map 10 in the map folio accompanying this report). Almost the entire Longfellow Creek watershed drains to a formal drainage system (99 percent).

In areas with formal drainage systems, stormwater runoff enters a pipe or ditch and is quickly carried to a watercourse, causing large amounts of water to be discharged to the watercourse over a short time period.

Watershed-Scale Conditions

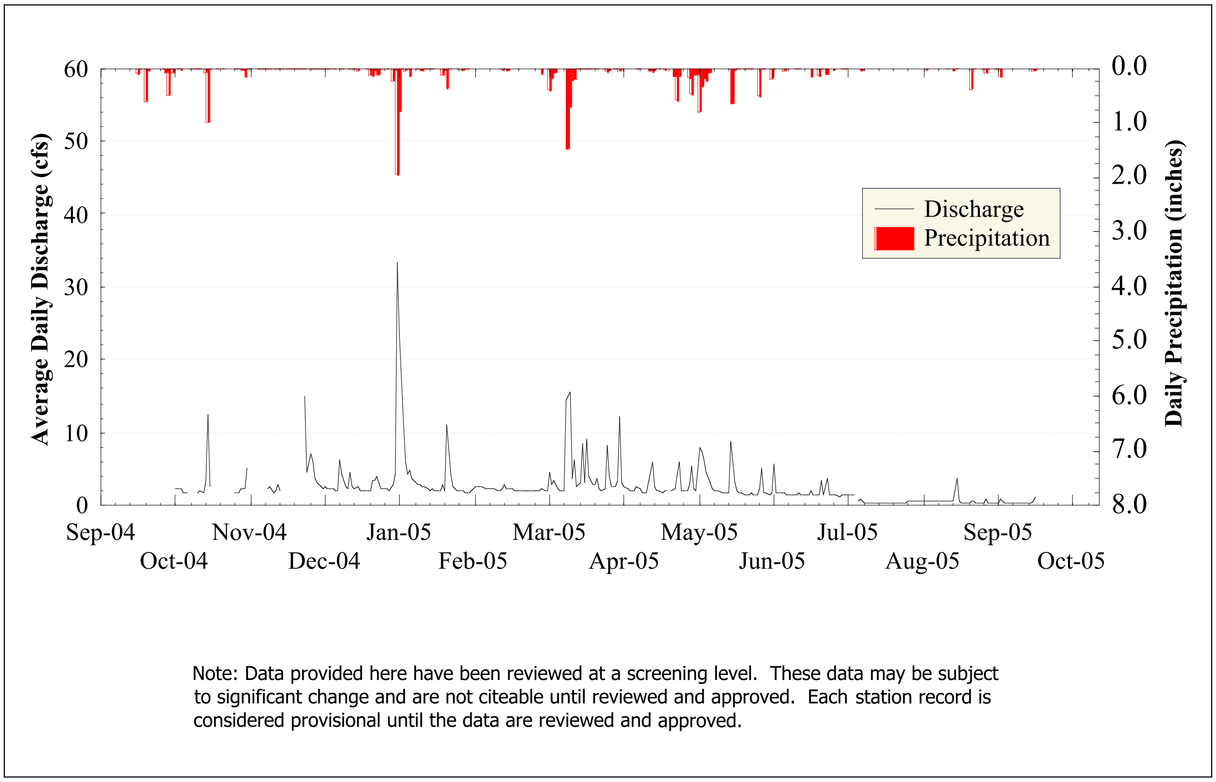
Longfellow Creek Hydrology

A hydrograph is a plot that shows changes in flow over time, such as increasing flows associated with storm events.

Longfellow Creek flows year-round; however, available hydrologic data are insufficient to accurately characterize flow conditions. The most complete data set for Longfellow Creek stream flow, which includes some data gaps, was collected from November 2004 through December 2005 (Figure 18). From this limited data set, the highest flow recorded on Longfellow Creek was 45 cubic feet per second (cfs) with a 7-day low-flow level of 0.4 cfs. In general, the hydrograph of the watercourse shows typical characteristics associated with urban development in the watershed.

A 2-year storm event occurs every 2 years on average, or has a 50% chance of occurring any given year.

Urbanization increases the amount of impervious surface area in the watershed, which drains stormwater to watercourses more quickly and causes higher than normal peaks in flow. These peaks rise and fall rapidly and produce a characteristic flashiness in the watercourse's hydrograph. This flashy behavior is evident in Longfellow Creek during the November 2004 through December 2005 period of record (Figure 18). It is estimated from hydrologic models that the magnitude of the 2-year storm event runoff has increased approximately fivefold over that expected under forested conditions at the mouth of the watercourse (Hartley and Greve 2005).



Note: Data provided here have been reviewed at a screening level. These data may be subject to significant change and are not citeable until reviewed and approved. Each station record is considered provisional until the data are reviewed and approved.

Figure 18. Longfellow mean daily flows recorded at West Seattle golf course gauge, November 2004–December 2005.

Historically, the Longfellow Creek watershed drained an area of 2,810 acres, or 4.4 square miles. As the basin has become developed, drainage from much of the watershed has been redirected away from the watercourse, either through storm drains connected to the wastewater system, or through drainage infrastructure that directs flow out of the basin. Today the area draining to the watercourse is about 60 percent of the size of the former basin. Similarly, the stream channel is shorter than it was historically, reduced from 4.9 miles of main stem channel to 3.9 miles today.

Currently, 64 storm drains discharge stormwater runoff directly to Longfellow Creek (13.9 outfalls per watercourse mile). Three additional outfalls infrequently deliver combined sewer overflows (CSOs) to the watercourse. Overflows occur in the combined sewer system during large storm events when the combination of stormwater and wastewater flows exceed the capacity of the pipe. Under these conditions, excess flow is discharged to nearby receiving water bodies to prevent wastewater backups. These discharges—known as combined sewer overflows—contain a mixture of stormwater and untreated wastewater, although stormwater usually constitutes the majority of the flow.

The areas that have the highest potential to contribute large storm flows quickly are located in the upper portion of the basin (Map 13 in the map folio accompanying this report). Although the upper portion of the basin has the lowest gradient, it is characterized by high levels of impervious surfaces and some areas with low permeability.

Webster detention pond along Longfellow Creek (photo by Bennett)

Due to the long, narrow shape of the Longfellow Creek basin, there are few unusually large subcatchments or large tributaries contributing flow to the watercourse. Therefore, instream flows would be expected to increase gradually from the headwaters of the watercourse to its mouth. However, flooding occurs along the watercourse due to its altered hydrology caused by urbanization. In order to minimize flooding, an overflow pipe has been installed in the watercourse between SW Juneau Street and SW Findlay Street, along with an instream detention pond at SW Webster Street. A natural drainage system project has been completed at Highpoint (near 35th Avenue SW and SW Juneau Street) to control stormwater runoff and increase onsite detention for approximately 120 acres.

Longfellow Creek Water Quality

Water quality in Longfellow Creek has been affected by urban activities in the watershed. Sediment quality data are not currently available. Stormwater runoff from urban areas can contain elevated concentrations of nutrients, bacteria, metals, pesticides, and other organic pollutants such as petroleum hydrocarbons and phthalates. These chemicals, which wash off roadways, yards, and roofs during rainfall events, come from a variety of sources, such as fertilizers and pesticides used on lawns and gardens, pet waste, cleaners and paints, and automobile emissions.

In addition to urban stormwater runoff, Longfellow Creek receives combined sewer overflows from three separate outfalls. To reduce these overflow events, Seattle Public Utilities (SPU) installed a 199,000-gallon storage tank in 1983 and two 1.6-million-gallon storage tanks in 1984. It is estimated that the storage tanks are large enough to control flow and prevent overflows up to and including runoff from a 10-year storm event. However, as shown in Table 18, overflows continue to occur. SPU is currently working to improve the accuracy of the combined sewer overflow monitoring system and to reduce the number of overflows to Longfellow Creek, focusing on improving maintenance and operation of the storage systems. A major water quality problem associated with combined sewer overflows is an increase in levels of bacteria resulting from inputs of untreated sanitary wastewater.

Table 18. Combined sewer overflows to Longfellow Creek, 1998–2005.

Year	Overflow Frequency (events/year)	Total Overflow Volume (gallons/year)
1998	5	2,304,800
1999	1	208,500
2000	0	0
2001	5	7,423,500
2002	0	0
2003	4	757,200
2004	6	6,916,300
2005	11	127,000,000

Although clear connections and thresholds are difficult to demonstrate, degraded water and sediment quality may affect aquatic organisms in Longfellow Creek. Water quality is being investigated as a potential contributor to the unusually high rates of coho salmon prespawn mortality reported in urban watercourses in Puget Sound since 1999, as discussed later in this chapter.

The following subsections describe existing water quality conditions in Longfellow Creek in general terms, based on available data. More detailed tables and summary statistics for all water quality data are presented in Appendix B.

Table 19 presents summary statistics for conventional water quality indicators based on monthly samples collected by King County between 1979 and 2005. All water quality data summary statistics and time series plots are provided in Appendix B. The results for each indicator are discussed separately in the following subsections.

Conventional water quality indicators include dissolved oxygen, water temperature, turbidity, total suspended solids, pH, and fecal coliform bacteria.

Table 19. Longfellow summary statistics for conventional water quality parameters, collected by King County.

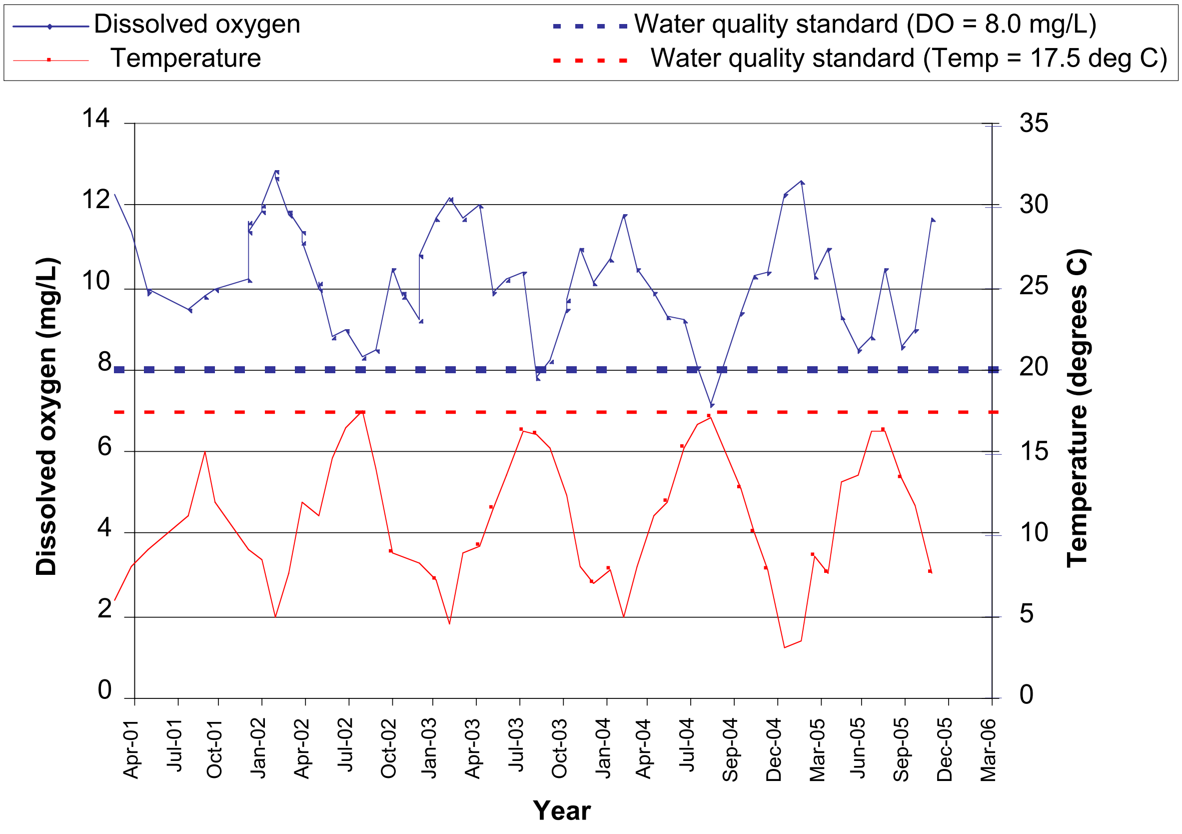
	Dissolved Oxygen (mg/L)	Temperature (degrees C)	Fecal Coliform Bacteria (cfu/100 mL)	pH	Total Suspended Solids (mg/L)	Turbidity (NTU)
Longfellow Creek at SW Brandon Street (J370, upstream station collected 1979–1982; 1990–2005)						
No. of samples	168	158	168	165	139	170
Minimum	6.5	3.0	10	5.2	0.5	0.5
Maximum	14	19.2	39,000	8.9	203	93
Median	10.2	10.9	410	7.7	2.1	2.5
Mean	10.2	11.0	1,346	7.6	7.2	5.7
5th percentile	8.7	6.0	59.05	6.9	0.8	1.0
95th percentile	12	16.0	6,000	8.2	20.1	20
Criteria [a]	8	17.5	100	6.5–8.5	–	–
Longfellow Creek at SW Yancy Street (C370, downstream station collected 1992–2005)						
No. of samples	217	197	214	215	182	221
Minimum	7.1	1.2	9	6.3	0.3	0.5
Maximum	15.0	20.2	25,000	9.4	463	160
Median	10.6	11.0	350	7.8	3.5	3.8
Mean	10.6	11.1	1,258	7.7	12.5	9.8
5th percentile	8.6	5.0	46	7.0	1.1	1.5
95th percentile	13.0	17.0	6,000	8.5	33.8	41
Criteria [a]	8	17.5	100	6.5–8.5	–	–

[a] Established criteria from WAC 173-201A. See Part 3 of this report for more details.
Data source: King County (undated).
mg/L = milligrams per liter.
cfu/100 mL = colony-forming units per 100 milliliters.
NTU = nephelometric turbidity units.

In 2004, the Department of Ecology included Longfellow Creek on the list of threatened and impaired water bodies under Clean Water Act Section 303(d), listing the watercourse as a category 5 water body for fecal coliform bacteria. Accordingly, a total maximum daily load (TMDL) limit for fecal coliform bacteria is required for Longfellow Creek based on demonstrated exceedances of the state water quality criterion (Ecology 2004). In addition, Ecology has identified Longfellow Creek as a water body of concern (i.e., category 2) for dissolved oxygen, temperature, and pH.

Dissolved Oxygen and Temperature

Dissolved oxygen and temperature have been measured monthly by King County during the period of record on Longfellow Creek at an upstream location (near SW Brandon Street) and a downstream location (near SW Yancy Street). At both locations, dissolved oxygen and temperature followed seasonal patterns, with temperature readings lowest in winter and highest in summer, and dissolved oxygen concentrations highest in winter and lowest in summer (Figure 19). These patterns are typical; as temperature increases, dissolved oxygen concentrations decrease based on changes in the solubility of oxygen.



Reference: Station C370. King County (undated).

Note: The areas between the two dashed lines show the samples that do not meet state water quality standards.

Figure 19. Longfellow dissolved oxygen and temperature measured near SW Yancy Street.

During the summer months, Longfellow Creek periodically fails to meet the dissolved oxygen and temperature criteria for the watercourse's designated uses of salmonid spawning, rearing, and migration. Over the entire period of record, dissolved oxygen failed to meet the criterion of 8.0 mg/L in approximately 3 percent of the samples at the upstream location and in approximately 2 percent of the samples at the downstream location. During this same time period, temperature was recorded on a monthly basis only; consequently, these data are not directly comparable to the revised temperature criterion, which is based on the 7-day average of the daily maximum temperature. Therefore, based on the 1997 temperature criterion of 16.0ºC, water temperatures measured between 1992 and 2005 exceeded the criterion in 1 to 2 percent of the upstream and downstream samples, respectively.

During the 2001–2003 period, SPU monitored temperatures in Longfellow Creek at 30-minute intervals to evaluate temporal patterns at the downstream location. These data can be compared to the Ecology (2006a) amended temperature criterion, which is based on the 7-day average of the daily maximum temperature. The updated temperature criterion for Longfellow Creek (17.5ºC) was exceeded from mid-June into September (Figure 20). This pattern corresponds to approximately 7 percent of the samples collected between October 2001 and April 2003. A summary of dissolved oxygen and temperature sample statistics and time series plots is provided in Appendix B.

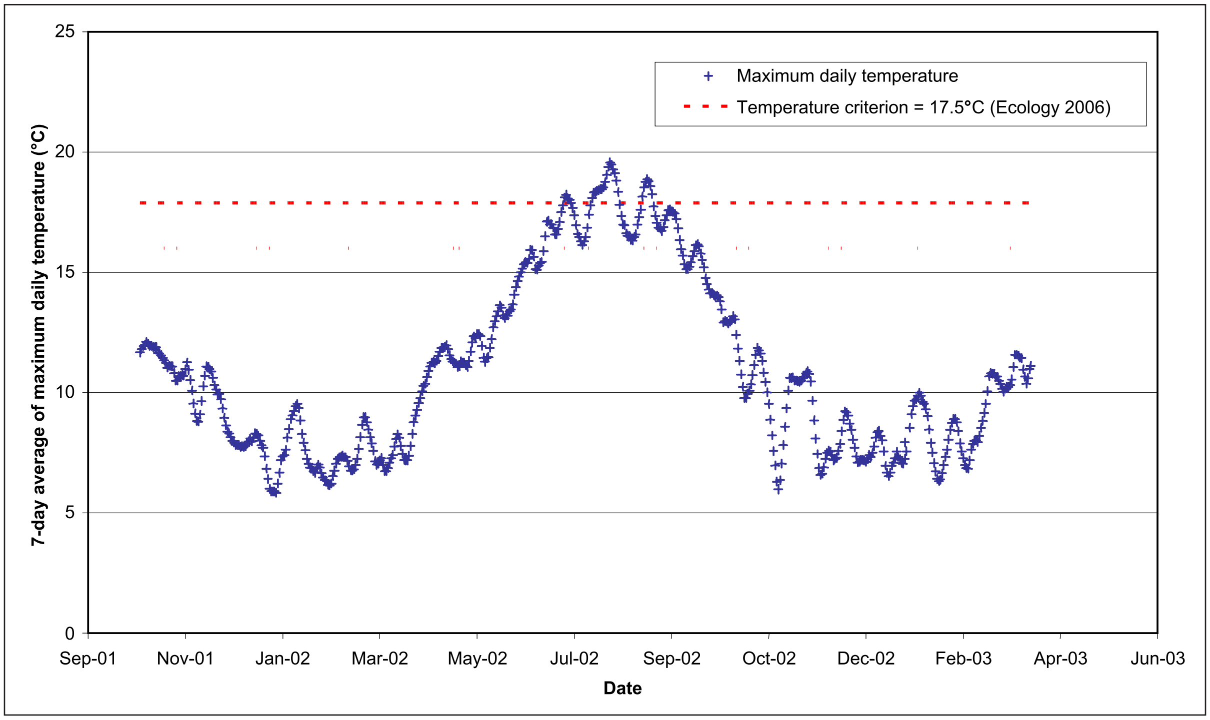


Figure 20. Longfellow temperatures measured near SW Yancy Street.

Dissolved oxygen levels can be influenced by several factors. Inputs of relatively warm stormwater runoff can cause temperatures in watercourses to increase above naturally occurring levels. In addition, channel simplification resulting from such actions as levee construction, bank hardening, channel straightening, dredging, and woody debris removal can reduce the hyporheic exchange in streams that helps to promote lower water temperatures. Hyporheic exchange refers to the mixing of surface water and ground water beneath the active stream channel and riparian zone. Finally, reduced shading in streams due to removal of the riparian canopy can cause water temperatures to increase.

Turbidity and Suspended Solids

Historical data for turbidity and total suspended solids, summarized in Table 19, indicate that particulate levels in Longfellow Creek generally increase between the upstream station at SW Brandon Street and the downstream station at SW Yancy Street. For example, the median values of suspended solids and turbidity at SW Yancy Street (3.5 mg/L and 3.8 nephelometric turbidity units [NTU], respectively) are greater than those measured at SW Brandon Street (2.1 mg/L and 2.5 NTU, respectively). A summary of turbidity and total suspended solids statistics and time series plots is provided in Appendix B.

Background turbidity conditions can be difficult to establish in Seattle's urban watercourses. Typically, background conditions are determined from samples collected upstream of a particular source input to a watercourse, such as a construction site, storm drain outfall, or municipal or industrial discharge. Background conditions are then compared to samples collected downstream of a specific source input to determine compliance with the turbidity standard. Because the monitoring stations in Longfellow Creek are not located upstream and downstream of specific source inputs, these data are not suitable for assessing compliance with the turbidity standard.

Increases in turbidity and suspended solids typically result from larger storm flows associated with urbanization in the watershed. Larger peak flows tend to erode the streambed and entrain particles more effectively than smaller, less frequent storm flows. In addition, urban stream banks typically erode more easily as riparian vegetation is removed or modified, resulting in increased turbidity and suspended solids downstream, particularly during storms. Finally, turbidity and suspended solids tend to increase downstream in urban watercourses due to unnaturally high inputs of turbid water resulting from upland construction activities and ground disturbance.

pH Conditions

The pH levels in Longfellow Creek at SW Brandon Street and SW Yancy Street rarely exceed the state water quality criterion (i.e., pH greater than 6.5 and less than 8.5). For example, over the 27-year monitoring period, less than 6 percent of the samples collected from the SW Yancy station were outside the acceptable range (two samples were less than 6.5 and ten samples were greater than 8.5). The last pH excursion occurred in 2000. Similarly, only 3 percent of the samples collected at the SW Brandon station between 1992 and 2005 were outside the acceptable range (one sample was less than 6.5 and three samples were greater than 8.5). The last pH excursion at SW Brandon Street occurred in 1998.

Fecal Coliform Bacteria

Fecal coliform bacteria data for Longfellow Creek were collected at SW Brandon Street and SW Yancy Street monthly from 1996 through 2005 by King County as part of its Stream Monitoring Program. Samples were collected during both storm and non-storm flow conditions, more often during periods with little or no rainfall. Bacteria levels were quite variable, ranging over three orders of magnitude. Levels at SW Brandon Street (upstream) were similar to the levels measured at SW Yancy Street (downstream) (see Table 19). Fecal coliform bacteria levels frequently exceeded the state water quality criteria for primary contact recreation (i.e., a geometric mean of 100 colony-forming units per 100 milliliters [100 cfu/100 mL], with no more than 10 percent exceeding 200 cfu/100 mL [Ecology 2006a]). The annual geometric mean fecal coliform counts at SW Brandon Street always exceeded the 100 cfu/100 mL criterion. In addition, the SW Brandon Street samples exceeded the 200 cfu/100 mL criterion every year, with 43 to 92 percent of the samples exceeding the limit (Table 20).

In all years but 2005, the annual geometric mean fecal coliform counts at SW Yancy Street were well above the 100 cfu/100 mL criterion, and 55 to 92 percent of the samples exceeded the 200 cfu/100 mL criterion. The 200 cfu/100 mL criterion was met only once, at SW Yancy Street in 2005, when only 8 percent of samples exceeded 200 cfu/100 mL (Table 20).

Table 20. Longfellow fecal coliform bacteria data collected by King County, 1996–2005.

		Fecal Coliform Bacteria (cfu/100 mL)			
Year	**Number of Samples**	**Minimum**	**Maximum**	**Geometric Mean**	**Percentage Greater than 200**
Longfellow Creek at SW Brandon Street (J370, upstream station)					
1996	13	56	2,000	210	45
1997	12	38	20,000	320	58
1998	11	61	9,100	980	82
1999	12	53	3,200	380	67
2000	13	130	1,900	730	92
2001	17	63	39,000	860	82
2002	15	68	2,700	360	73
2003	13	28	730	300	85
2004	16	10	760	260	69
2005	14	58	1,700	220	43
Longfellow Creek at SW Yancy Street (C370, downstream station)					
1996	9	9	10,000	440	82
1997	12	28	5,500	460	75
1998	11	73	10,000	1,100	91
1999	9	50	1,800	270	44
2000	16	70	2,100	490	84
2001	17	82	16,000	890	82
2002	18	33	6,200	330	61
2003	13	25	25,000	200	46
2004	11	40	610	150	55
2005	13	35	340	100	8

Data source: King County (undated).
cfu/100 mL = colony-forming units per 100 milliliters

In addition to the King County data, Ecology (2006c) measured fecal coliform bacteria in 13 samples collected between September 2003 and September 2004 in Longfellow Creek upstream of 24th–25th avenues SW (station 09J090). The fecal coliform counts at this upstream location were slightly lower then those reported at SW Brandon and SW Yancy Streets. Eleven of these 13 samples (85 percent) were collected during dry-weather conditions. Measurable rainfall occurred only on October 19, 2003 (0.07 inches) and November 17, 2003 (0.52 inches). However, fecal coliform counts still exceeded both criteria, with a geometric mean of 140 cfu/100 mL and 23 percent of the samples exceeding 200 cfu/100 mL on an annual basis.

Stormwater samples were collected by SPU at one station in Longfellow Creek two or three times each year beginning in 1999. As expected, the stormwater samples generally contained higher levels of fecal coliform bacteria than non-storm flow samples collected by King County and Ecology. The geometric mean for non-storm flow samples ranged from 100 to 1,100 cfu/100 mL, compared with 2,900 to 5,200 cfu/100 mL in the stormwater samples. Furthermore, 100 percent of the stormwater samples exceeded 200 cfu/100 mL on an annual basis.

Potential sources of fecal coliform bacteria in urban watercourses are wildlife and pet wastes, leaking wastewater systems, failing septic systems, wastewater treatment plant effluent, and combined sewer overflow events. Stormwater runoff from urban development can easily wash bacteria from these sources into urban watercourses. The exact source of bacteria in Longfellow Creek is unknown; however, data from other microbial source tracing studies in Seattle urban watercourses (i.e., Piper's Creek and Thornton Creek), have shown the primary source to be pet and wildlife wastes.

Metals

Fourteen priority pollutant metals with recommended water quality criteria for the protection of aquatic life and human health in surface waters were reviewed (see Table 9). Sampling records for Longfellow Creek under storm and non-storm flow conditions are limited. The metals data have a short historical record; samples were collected only 11 times from December 2001 through March 2005. However, metals concentrations reported for Longfellow Creek were low, with only 14 to 52 percent of samples above detection limits. Metals concentrations can be determined as the total metal concentration, as well as the dissolved fraction of the total concentration. Dissolved metals are commonly believed to be more bioavailable than particulate-bound metals.

For the purposes of this report, the King County and Ecology samples are called non-storm flow samples, and SPU samples are called storm flow samples.

King County (2006b) and Ecology (2006c) analyzed dissolved metals in 11 samples collected between December 13, 2001 and March 26, 2005 at two stations in Longfellow Creek (stations 09J090 and C370; Map 11). Metals concentrations during non-storm flow events were very low, and there were no exceedances of the chronic or acute criteria for any metal analyzed. Similarly, dissolved metals concentrations in Longfellow Creek were also low during storm flow events. SPU analyzed eight stormwater samples collected between June 27, 2001 and July 8, 2005 at three stations on Longfellow Creek (stations LF-98B, LF-Graham, and LF-Yancy; Map 11); these samples showed no exceedances of the chronic or acute criteria for any metal analyzed.

Total metals were analyzed for seven sample dates under non-storm flow conditions at station 09J090, C370, and J370 with no exceedances of aquatic life toxicity criteria. Total arsenic results exceeded the human health criterion of 0.018 µg/L 100 percent of the time under both non-storm flow conditions (12 samples) and storm flow conditions (one sample). This drinking water criterion applies to human consumption of water and fish (see Table 9). Therefore, the risk to human health is minimal if people do not drink the water or consume fish from the stream. Although the human health criterion for arsenic is frequently exceeded, the aquatic life chronic and acute toxicity criteria are seldom exceeded. In general, most metals concentrations were slightly higher during storm flow than non-storm flow. A summary of metals sample statistics and time series plots is provided in Appendix B.

Metal pollutants accumulate on impervious surfaces in urban watersheds and are washed off during storms. In addition, some metals are bound to sediments; so as storm flows entrain soil and sediment, metals are more easily transported to watercourses. Sources of metal pollutants include wear and tear of vehicle parts (e.g., brake pads, tires, rust, and engine parts), atmospheric deposition, common building materials (e.g., galvanized flashing and metal downspouts), and roof maintenance activities (e.g., moss control).

Nutrients

Under non-storm flow conditions, King County (undated) and Ecology (undated) analyzed nutrients (i.e., ammonia-N, nitrate+nitrite, total nitrogen, and total phosphorus) in approximately 188 samples collected between April 15, 1998 and December 14, 2005 at three stations (09J090, C370, and J370; Map 11). Ammonia frequently exceeded established criteria under non-storm flow conditions, which is significant because ammonia can be toxic to fish. Total nitrogen and total phosphorus concentrations frequently exceeded established benchmarks under non-storm flow conditions as well; however, these nutrients are not toxic to aquatic organisms.

Because benchmarks represent surface water quality conditions that are minimally influenced by human activity, exceeding a benchmark does not necessarily indicate a violation of the water quality criterion.

Under storm flow conditions, SPU analyzed nutrients (i.e., ammonia, nitrate+nitrite, and total phosphorus) in approximately 13 samples collected between November 9, 1999 and July 8, 2005 at three stations (LF-98B, LF-Graham, and LF-Yancy; Map 11). These data show that the total phosphorus benchmark in Longfellow Creek was frequently exceeded under storm flow conditions. Nutrient data collected from an upstream location and a downstream location under both non-storm and storm flow conditions are summarized in Table 21.

Table 21. Longfellow summary statistics for nutrients.

	Ammonia-N (mg/L)		**Nitrate+nitrite (mg/L)**		**Total Nitrogen (mg/L)**		**Total Phosphorus (mg/L)**	
	Non-Storm [a]	**Storm** [b]	**Non-Storm** [a]	**Storm** [b]	**Non-Storm** [a]	**Storm** [b]	**Non-Storm** [a]	**Storm** [b]
Longfellow Creek Upstream								
No. of samples	83	5	87	5	87	ND	87	4
Minimum	0.01	0.022	0.37	0.55	0.79	ND	0.014	0.16
Maximum	1.8	0.1	2.6	0.8	5.5	ND	0.56	0.21
Median	0.026	0.047	1.2	0.78	1.4	ND	0.05	0.18
Mean	0.067	0.053	1.2	0.7	1.5	ND	0.066	0.18
5th percentile	0.01	0.025	0.78	0.55	1.1	ND	0.034	0.16
95th percentile	0.085	0.092	1.6	0.8	2.1	ND	0.13	0.21
Benchmark [c]	0.43 – 2.1		–		0.34		0.1	
Longfellow Creek Downstream								
No. of samples	89	5	88	5	85	ND	86	4
Minimum	0.01	0.019	0.5	0.33	0.7	ND	0.017	0.23
Maximum	0.5	0.098	2.6	0.86	3.2	ND	0.97	0.67
Median	0.03	0.083	0.97	0.55	1.3	ND	0.066	0.41
Mean	0.04	0.061	1.0	0.56	1.3	ND	0.083	0.43
5th percentile	0.011	0.019	0.55	0.36	0.84	ND	0.043	0.24
95th percentile	0.062	0.096	1.5	0.80	2.0	ND	0.15	0.64
Benchmark [c]	0.43 – 2.1		–		0.34		0.1	

[a] Non-storm samples collected at stations J370 and C370.
[b] Storm samples collected at stations Graham and Yancy.
[c] Ammonia chronic toxicity criteria are pH-dependent and the given range is for a pH of 6.5–8.5. All nutrient criteria and benchmarks are described in more detail in Part 3 of this report.
mg/L = milligrams per liter.
ND= no data collected.

Phosphorus and nitrogen are common pollutants in urban watercourses. Sources include fertilizer applications, increased soil erosion, nutrients from washwater (e.g., car and boat cleaning), failing septic systems, pet wastes, and improper dumping of yard wastes. All of these sources can result in increased nutrient concentrations in stormwater runoff. This is of particular concern for water quality in the larger water bodies such as freshwater lakes and Puget Sound. Elevated nutrient levels can lead to eutrophication, a process in which rapid growth of algae may overcome natural self-purification processes in the water body. The resulting algal blooms degrade water quality as the decomposing algae reduce the dissolved oxygen concentrations in receiving waters. Ultimately, increased nutrient concentrations can reduce the survival opportunities for salmonids, which rely on oxygen-rich waters.

Organic Compounds

The rising limb of a storm refers to the portion of the hydrograph where flow begins to rise due to a storm event.

Organic compounds that cause water quality problems in urban watercourses include pesticides, phthalates, and petroleum-related products such as polycyclic aromatic hydrocarbons (PAHs). The U.S. Geological Survey found low levels of some pesticides in storm flow samples collected from Longfellow Creek during a May 14, 1998 storm (Voss and Embrey 2000). Three storm flow samples collected during the rising limb of the storm contained detectable levels (0.03 to 0.35 µg/L) of several herbicides and their metabolites (2,4-D, acetochlor, dicamba, dichlobenil, dichlorprop, MCPA, mecoprop, pentachlorophenol, prometon, and trichlorpyr), as well as one insecticide (diazinon at 0.046 µg/L), and one insecticide metabolite (4-nitrophenol at 0.05–0.12 µg/L). With the exception of diazinon, concentrations were below reported thresholds of toxic effects on aquatic organisms.

To support an ongoing coho prespawn mortality investigation (discussed in the next section under Fish) conducted by the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey and SPU collected time-weighted composites (i.e., 1-hour composites composed of 15-minute grab samples) from Longfellow Creek between SW Alaska Street and SW Genesee Street during three storms in October–November 2003. A total of 16 stormwater samples were analyzed for semivolatile organic compounds. In addition, one sample was analyzed for pesticides and polychlorinated biphenyls (PCBs). Organic compounds detected during the study are summarized in Table 22.

Bis(2-ethylhexyl) phthalate was detected most frequently (in 100 percent of the samples), followed by pentachlorophenol (88 percent of the samples), phenol (88 percent), benzyl alcohol (75 percent), benzoic acid (62 percent), and PAHs (6 to 50 percent). With the exception of bis(2-ethylhexyl) phthalate, the concentrations of most organic compounds detected in Longfellow Creek were well below available toxicity criteria for aquatic life. Phthalates belong to a class of chemicals known as plasticizers that are used in the production of many polyvinyl chloride (PVC) construction materials and consumer products. Plasticizers have been used for a long time but have recently become an environmental concern because they have been found at elevated concentrations in sediment in urban receiving water bodies. Phthalates are used to make a wide variety of plastic products such as flexible tubing, vinyl flooring, wire insulation, weather-stripping, upholstery, clothing, plastic containers, and plastic wraps.

Table 22. Longfellow organic compounds detected in stormwater samples, October–November 2003.

Chemical	Toxicity Criteria [a] (μg/L)	Detection Frequency (percent)	Min (μg/L)	Max (μg/L)	Mean [b] (μg/L)	Median [b] (μg/L)
Bis(2-ethylhexyl)phthalate [c]	3	100	0.24U	4.61	0.99	0.685
Butylbenzyl phthalate [c]	3	6	0.063U	0.51	0.47	0.5B
Diethyl phthalate [c]	3	12	0.0834U	0.55	0.48	0.5
Di-n-butyl phthalate [c]	3	6	0.0592U	0.51	0.47	0.5
Naphthalene [c]	620	25	0.024U	0.029	0.03	0.025
Phenanthrene [f]	630	38	0.016U	0.051	0.03	0.02
Chrysene [f,g]	630	6	0.019U	0.034	0.02	0.02
Fluoranthene [c,g]	3,980	12	0.018U	0.054	0.05	0.05
Pyrene [f,g]	5.7	50	0.019U	0.046	0.03	0.0205
2-Methylphenol [f,g]	8,400	38	0.049U	0.12	0.07	0.05U
3-Methylphenol [f,g]	8,900	6	0.048U	0.13	0.06	0.05U
4-Methylphenol [f,g]	8,500	31	0.049U	0.18	0.09	0.05U
4-Nitrophenol [f,g]	230	31	0.48U	0.94	0.59	0.5
Benzoic acid [f,g]	112,500	62	0.5U	1.9	0.85	0.77
Benzyl alcohol [f,g]	10,500	75	0.099U	0.805	0.41	0.39
Coprostanol	NA	6	0.88U	2.6	2.39	2.5
Pentachlorophenol [c,e]	7.5[d,e]	88	0.4U	1.1	0.79	1
Phenol[c]	2,560	88	0.099U	2.37	0.52	0.2865

μg/L = micrograms per liter
U = chemical not detected at listed concentration.
[a] Chronic toxicity to aquatic life unless otherwise noted.
[b] Analytical detection limit included in the calculations for undetected values.
[c] U.S. EPA (1986).
[d] Ecology (2003).
[e] Standard is pH-dependent. Value shown is for pH = 7.5.
[f] ECOTOX database (U.S. EPA undated).
[g] Chronic toxicity criterion not available. Value is the criterion for acute toxicity.

Pesticides (which include herbicides, insecticides, and fungicides) are often detected in urban watercourses, sometimes at levels higher than in agricultural areas. These compounds are commonly used around residential, commercial, and industrial buildings, as well as in lawn, garden, and golf course management. These compounds can also reach watercourses through atmospheric deposition, as dustfall or through rainfall. Sources of PAHs include vehicle exhaust, automotive oil leaks, industrial effluent, and petroleum spills that wash into watercourses during storms. Organic compounds can bioaccumulate in fish and reach levels that can cause developmental and reproductive problems in both fish and humans.

Stream-Scale Conditions

Longfellow Creek upstream of the golf course (photo by Bennett)

Longfellow Creek is a relatively low-gradient channel within a wide glacial valley (Map 12). Upstream of the West Seattle golf course the watercourse flows over compacted glacial sediments within the wider valley, while within and below the golf course the watercourse has eroded through the glacial valley floor into glacial, lake, and ice contact deposits. The upstream reaches of Longfellow Creek are characterized by a floodplain 75 to 150 feet wide, in contrast to the downstream reaches where historically the stream has a valley migration zone between 200 and 400 feet in width (Stoker and Perkins 2005). The watercourse has been gradually eroding valley sediments over thousands of years, erosion that started near the mouth and moved upstream, until the recent past when road culverts locked the watercourse into a fairly fixed elevation (Stoker and Perkins 2005). The three tributaries of Longfellow Creek are rather short and steep, delivering water and—historically—sediment from the walls of Delridge Valley.

Watercourses are divided into reaches, reaches are divided into segments, and segments are divided into sections.

Through Delridge Valley the Longfellow Creek channel has three reaches, described separately below (Stoker and Perkins 2005). Stream codes, shown on the watercourse maps, consist of two letters of the watercourse name (LF for Longfellow) and the number of the stream segment, starting with 01 at the mouth and increasing in the upstream direction:

- A glacial upper-valley reach surrounded by dense residential and commercial development (LF08–LF06)
- A middle reach through a ravine eroded into the glacial-age valley bottom (LF05)
- A lower estuary reach that has been filled and piped (LF04–LF02).

Upper Longfellow Creek and Headwaters (LF08–LF06)

Watercourse codes (also shown on the watercourse maps) consist of two letters of the watercourse name (LF for Longfellow) and the number of the stream segment, starting with 01 at the mouth and increasing in the upstream direction.

The headwaters of Longfellow Creek originate from a series of seeps and springs located in the Roxhill bog wetland near SW Cambridge Street and 29th Avenue SW. The Roxhill bog, covering less than one acre, is a single restored, remnant wetland in a formerly complex area of peat bogs and wetlands. At one time, the headwaters contained a low-gradient channel (less than 1 percent) that constantly changed its shape and course by shifting sediment, water, and wetland plants within the channel migration zone. The wetlands, associated peat deposits, and wide floodplain maintained productive conditions in the downstream reaches by facilitating storage of water, sediment and wood; controlling water temperatures; and providing nutrients (Seattle 2005). Today, flow through the wetland and bog complex has been piped under residentially and commercially developed land. The piped headwaters of the watercourse contain six drainage outfalls, including one of the largest subcatchments in the watershed (160 acres).

From the headwaters, Longfellow Creek first becomes an open channel just downstream of SW Thistle Street near Chief Sealth High School, flowing 2,600 feet before entering a long culvert beginning at SW Webster Street (LF07–LF08; representing 12 percent of the main stem channel length). The 1,800-foot culvert (LF06) runs underneath a large shopping center (comprising 9 percent of the main stem length). This open-channel portion and the culvert downstream comprise the reach discussed below (LF06–LF08).

Riparian Habitat

Longfellow Creek emerges into an open channel in a park dominated by a native deciduous and coniferous forest (Map 14). The understory in this segment contains a mixture of native shrubs, invasive Himalayan blackberry, and lawns. The riparian corridor width typically exceeds 100 feet, and coupled with the mature trees in the overstory, the stream has over 75 percent canopy coverage. No buildings or roads are closer to the stream than 100 feet in this segment (Map 15).

Riparian conditions change drastically downstream of SW Elmgrove Street. The riparian plant community is dominated by nonnative species, landscaping, and lawns. Himalayan blackberry is the dominant invasive plant throughout this segment. The riparian corridor width narrows to less than 50 feet in most locations as the stream runs through single-family and multifamily developments. The lack of mature trees and dominance of blackberry and lawns has limited stream canopy cover and shading. For the entire reach, riparian habitat quality is moderate. However, habitat quality is higher in the upstream park segment of the reach and lower in the downstream segments.

The watercourse passes through a culvert in the lowest segment of this reach (LF06, 1,800 feet in length). The culvert passes under a parking lot and through open space adjacent to a residential neighborhood. Riparian vegetation in the open space has not been extensively surveyed, although it appears to consist of sparse deciduous trees and nonnative plants. This segment does not contain many structures within 100 feet of the stream, except for a few houses and other buildings near SW Orchard Street and SW Myrtle Street.

Instream Habitat

Longfellow Creek is restricted to a width of 8 feet within this reach due to filling, encroachment, culverts, and bridges. In the past, the stream was able to migrate across a floodplain of about 100 to 200 feet in width for most of the reach (Stoker and Perkins 2005), where the relatively low watercourse gradient (1 to 3 percent) in the upper portion prompted the stream to form meander bends and gravel bars and to connect with the floodplain during higher flows (Map 12).

Almost all of this reach is actively eroding, and channel erosion in this area provides the largest source of fine sediment to the watercourse (Stoker and Perkins 2005; Map 13). Bed erosion has caused the stream to become entrenched below the surrounding floodplain, with an average bank height of 3.5 feet and a maximum of 9 feet. This entrenchment precludes any connection between the stream and floodplain. Such connections are further prevented by the long expanses of frozen channel where both the streambed and banks are armored by concrete and riprap, which force all flood flows into one narrow floodway, increasing velocities, bank and bed erosion, and sediment transport. The channel contains almost no structure, and with the lack of floodplain connections the stream cannot reduce the energy of high flows by spilling over its bank onto a floodplain.

Stormwater runoff is supplied from ten outfalls to the Longfellow channel along this segment (LF07–LF08; Map 13), in addition to runoff from the upper watershed discharged through the SW Thistle Street culvert (draining a total area of approximately 460 acres, or 27 percent of the total watershed). The culverted portion of upper Longfellow Creek receives runoff from an additional area of 94 acres; so cumulatively the upper watercourse receives runoff from one-third of the watershed.

The stream habitat in upper Longfellow Creek is in poor to moderate condition (Map 16). Under more natural conditions, this reach would be classified as pool-riffle and step-pool channel types (Seattle 2005). Although 18 percent of the open channel length is pool habitat and 39 percent is riffle habitat, this reach has the highest proportion of plane-bed channel in the system (44 percent; Map 14). Channel incision, lack of floodplain connections, and lack of instream structure contribute to this simple channel form. There are areas of step-pool habitat, mostly created by instream improvement projects and a series of rock weirs constructed upstream of the Webster detention pond (near SW Webster Street). The dominant substrates are gravel in the higher-velocity sections (downstream of SW Thistle Street) and sand in the lower-velocity sections (the backwater area upstream of the SW Webster culvert entrance).

Constructed weirs along Longfellow Creek (photo by Bennett)

Because Longfellow Creek is a relatively low-gradient system, it could be used by fish through the upper reach (Washington Trout 2000). However, no trout have been found in this reach of the watercourse (Washington Trout 2000; Lantz et al. 2006). Fish access is restricted by several manmade fish passage barriers located downstream within this reach. These barriers include the series of 4-foot-high rock weirs upstream of the Webster detention pond. The gradient of the 1,800-foot culvert also may function as a fish passage barrier, although the pipe has been not been examined (Map 17).

Middle Longfellow Creek (LF05)

The middle reach of Longfellow Creek is approximately 6,750 feet in length with an average gradient of less than 1 percent. The surrounding valley ranges from 100 to 200 feet in width, and historically the channel was a meandering, braided stream shifting across floodplain wetlands within the valley's channel migration zone (Seattle 2005). These conditions are reflected in historical accounts of the area, which in the late 1800s was avoided by loggers because of the wetness of the watercourse valley and the resulting difficulty in removing logs (Trotter 2002).

Riparian Habitat

The riparian corridor in this reach is characterized by alternating areas of mixed deciduous and coniferous trees, lawns, landscaping, and nonnative vegetation (primarily Himalayan blackberry and reed canarygrass). Coniferous and deciduous forest typically dominates the riparian corridor in open-space pockets, such as those located near SW Willow Street and SW Graham Street (e.g., segment LF05b; Map 14). These pockets of forest also contain native understory plants and tend to have a wider riparian corridor than other parts of the reach, averaging over 100 feet without encroachment from surrounding houses. However, the discontinuous canopy has many breaks and does not provide much shading to the stream. Riparian quality in this middle segment of the reach (LF05b) is of moderate quality, assisted by restoration activities in that area (Map 18).

Outside the open space and park areas (i.e., most of LF05a, LF05c, and LF05d), the riparian vegetation has been converted to lawns and landscaping or has been overtaken by invasive species (e.g., Himalayan blackberry, reed canarygrass, and English ivy). The watercourse tends to run through residential yards, flowing less than 25 feet from buildings and roads. The stream receives no shading from riparian vegetation in such locations, and the overall riparian quality is poor.

Instream Habitat

Under more natural conditions a braided, pool-riffle channel classification would be expected in this reach (Seattle 2005). However, today the watercourse is contained within a single channel averaging approximately 9 feet in width. The lower gradient, increased flood flows, and encroaching properties in the upper half of this reach prompted construction of a flood overflow bypass between SW Juneau Street and Findlay Street in 1989. The frequency and extent of flooding in this area have decreased substantially following construction of the overflow bypass (Hausman 2003).

Erosion of the streambed and banks is the primary source of sand and fine sediments in this reach of the watercourse (Stoker and Perkins 2005). Historically the stream retrieved sediment from the floodplain as it migrated across the valley, storing and picking up sediment (e.g., gravel and sand) from past storage and from slides on the valley walls. The combination of increased high flows, channel confinement, lack of floodplain storage, and limited stream bank forests minimize the watercourse's ability to withstand erosive forces. Sediment and wood from the valley walls and stream banks are rarely recruited to the channel except as highly infrequent deliveries from the young and sparse riparian forest areas. As a result, much of the stream is incising and widening through erosion of the streambed and banks (Map 13).

Many portions of middle Longfellow Creek are becoming increasingly entrenched and separated from the floodplain, particularly where the channel is heavily confined by encroachment from houses, yards, roads, and culverts. The lack of large wood, the increased flood flows, and the confined, entrenched channel leave many segments with thin streambed sediment or none at all, exposing the dense underlying glacial deposits. In many places the stream is held in place by bank armoring (Map 15). High flows are removing gravel from the streambed, except where there are instream structures to capture and store gravel.

However, wider stream segments with meander bends form channel bars that store sediment. In addition, rehabilitation projects constructed within this area, such as those between SW Juneau Street and SW Willow Street, are providing additional sediment storage and creating more diversity in the channel.

Habitat quality varies within this reach. In general, high-quality areas exist where rehabilitation measures were implemented in 2002 through 2004, while low-quality habitat is found in areas where little or no improvement has been made to the channel (Maps 16 and 18). Note that the Longfellow habitat data presented in the maps were collected prior to the Delridge restoration work. Current conditions are quite different than the maps indicate, with improved hydraulic diversity, floodplain connection, and riparian conditions.

The open-channel areas of middle Longfellow Creek have a pool-to-riffle ratio approaching 1-to-1. Pools make up 29 percent of the channel, and riffles cover 35 percent (Map 14). The majority of the pools within the middle portion of the stream were formed by boulders, constructed weirs, and large woody debris structures placed in the stream during restoration efforts. The structures have increased hydraulic diversity by forming pools one to two feet deep, potentially providing good rearing and holding habitat.

Almost one-third of the middle reach is glide habitat (36 percent), mostly found in the unimproved segments. These unimproved segments lack structure and habitat diversity where the channel is encroached, channelized, and entrenched (Map 14; Stoker and Perkins 2005). Eight percent of the reach length is located within culverts, with limited habitat value.

Migratory fish access to this reach is restricted by downstream fish passage barriers (Map 17). Resident rainbow trout were found within middle Longfellow Creek in 1999 (Washington Trout 2000). Anadromous fish have not been documented above the barrier located under the 12th fairway of the golf course. Once the barriers are removed, this segment potentially offers rearing and refuge habitat, particularly in sections that have pools, reestablished riparian wetlands, and floodplain connections.

Lower Longfellow Creek (LF04–LF02)

Upon entering the West Seattle golf course, Longfellow Creek flows north almost 7,000 feet (33 percent of the main stem channel length) to the inlet of the culvert just south of SW Andover Street. About 80 percent of this reach is located within the golf course. In the downstream segments (LF03–LF02), the channel has eroded an inner valley into the larger glacial-age Delridge Valley. The inner valley bottom ranges between 75 and 150 feet in width in the upstream portions of the golf course, before widening to between 200 and 400 feet in the middle area of the golf course (Stoker and Perkins 2005). The lowest portions of this reach (downstream of SW Yancy Street) are tidally influenced.

Riparian Habitat

Riparian habitat varies dramatically in quality between the golf course segment (LF04) and those downstream (LF03–LF02). The golf course contains an intact and extensive riparian corridor, averaging over 100 feet in width. The riparian vegetation in the upper portion of the golf course is dominated by native forest conditions (Map 14). Roughly a mile in length, the riparian corridor is disconnected only twice where fairways cross the stream channel. Although invasive species (primarily Himalayan blackberry) dominate the understory in limited sections, the majority of this riparian stretch consists of a native understory with a mixture of mature deciduous and coniferous canopy. The tree canopy is relatively dense and provides 25 to 75 percent stream cover. Within the golf course there is a high-quality riparian corridor for an urban stream (Map 16).

The lowest segments of the watercourse have poor riparian quality (Map 16). Within the golf course, downstream of the 12th fairway, invasive species (primarily Himalayan blackberry and reed canarygrass) dominate the understory in the inner valley bottom. Downstream of SW Genesee Street the stream corridor has better riparian quality, largely as a result of stream rehabilitation projects. However, much of the area surrounding the riparian corridor is dominated by invasive species, and within the riparian corridor there is only an intermittent canopy, partly because the planted trees are still maturing. Riparian conditions in the lower segments are expected to improve as riparian plantings mature. The corridor width in this reach typically exceeds 50 feet.

Instream Habitat

Stream gradients in this reach range between 1 and 2 percent, prompting a pool-riffle, meandering channel type (Seattle 2005; Map 12). Today, there are abrupt changes in stream elevation at the Works Progress Administration (WPA) dam within the golf course and at the mouth of the golf course tributary. The channel is also confined in this area to widths between 7 and 15 feet, with little ability to meander and interact with its floodplain (Stoker and Perkins 2005).

Erosion activity is moderate to extensive in this reach (Map 13). Stream banks are generally unstable in segments with ongoing incision, and most of the channel is incised and widening from increased flood flows (Stoker and Perkins 2005). The majority of the sediment is supplied to the watercourse by erosion of the bed and banks and by fine sediments washed from roads and yards into storm drains. Incision has disconnected the stream from its floodplain, similar to upstream areas. Bank heights range from 5 to 8 feet above the present channel bed (Stoker and Perkins 2005).

Under more natural conditions lower Longfellow Creek would be expected to contain pools and riffles, but today much of this reach is a simple plane-bed channel. Within the upper golf course (upstream of the 12th fairway culvert) the stream contains primarily riffle habitat (65 percent). Pools are scattered throughout the golf course segment; most pools are associated with wood debris and with backwater areas behind the culverts and the WPA dam. There is a large, deep pool downstream of the 12th fairway culvert, and beaver activity often causes a backwater area to form upstream of SW Genesee Street.

The average active channel width in the golf course is wider than most of the rest of the watercourse, averaging over 18 feet and expanding to over 20 feet in certain locations. Within this area, channel bars and meander bends form, promoting better floodplain connection, lower velocities, more stable substrate, and better aquatic habitat conditions. The stream within the upper area of the golf course contains mostly gravel substrate recruited from the more narrow valley walls in this area and from the Longfellow Creek tributary within the golf course (Stoker and Perkins 2005; Seattle 2005).

Longfellow Creek's highest-quality habitat is found within the West Seattle golf course (Map 16), particularly upstream of the WPA dam located just upstream of the 12th fairway. This in-channel wetland is unique among Seattle watercourses. Over 12 percent of the channel length in this segment is wetland habitat, which was created by the WPA dam placed within the watercourse in the 1930s (Map 14). This backwater wetland ranges from 50 to 150 feet in width and offers some of the highest-quality aquatic and terrestrial habitat within the Longfellow system. Ironically, the dam is a full fish passage barrier, the second-farthest downstream barrier on the watercourse (Map 17). The pools through this wetland segment average between 1 and 2 feet in depth, similar to upstream, although the area contains one pool 8 feet deep.

Instream wetland along Longfellow Creek (photo by Bennett)

Yancy Street restoration project on Longfellow Creek (photo courtesy Seattle Municipal Archives; photo by Toczek)

Downstream of SW Genesee Street (LF02), placement of instream structures such as log weirs, deflector logs, and rootwads has created step-pool and pool-riffle channel types. Pool habitat exceeds the length of riffle and glide habitat, largely because of long pools that have formed in backwater areas behind log weirs (Map 14). The channel incision is most severe in the lowest portions of the stream, with bank heights averaging 6 feet. There is no floodplain connection along the entrenched portions of the channel, downstream of the WPA dam in the golf course. However, the wood placed in the stream as part of rehabilitation efforts in 1999–2001 provides grade controls that are increasing the elevation of the streambed by preventing additional downcutting and by recruiting sediment (Map 18). The sediment in the lowest portions of this reach is primarily gravel and cobble placed in the stream by restoration projects; the golf course wetland captures much of the gravel and reduces the amount moving downstream.

Longfellow Creek discharges to the Duwamish River through a long culvert. Historically, the stream discharged into the larger Duwamish–Elliott Bay estuary system, which was composed of saltwater sloughs, marshes, and mudflats. The flow of Longfellow Creek was diverted into a culvert prior to the 1920s, when the mudflats of Young's Cove at the mouth of the stream were filled to provide additional land for the steel mill (Longfellow Creek Watershed Management Committee 1992). Although adjustments were made to the culvert in both 1967 and 1974, this segment of Longfellow Creek remains covered. As a result, Longfellow Creek flows 3,258 feet through a culvert underneath roads, bridges, and buildings before discharging into the West Waterway of the Duwamish River. Instream and riparian habitat is nonexistent throughout this long piped segment of the watercourse, which provides no beneficial habitat advantages and serves only as a conduit to discharge flow. It is not a barrier to fish passage, however, and provides migratory access for salmon entering and leaving the watercourse.

Anadromous fish use the lower segments of this lower Longfellow Creek reach (Map 17), and it is also used by prickly and staghorn sculpin and three-spine stickleback within the tidal zone of the watercourse (Lantz et al. 2006). No anadromous species have been documented above the barrier located at the culvert outlet under the 12th fairway in the golf course.

Use by Fish and Benthic Invertebrates

Fish Access

Prior to urban development, Longfellow Creek flowed through the wide Delridge Valley floodplain to the intertidal mudflats of the Duwamish estuary. This habitat complexity made Longfellow Creek highly productive for salmon and trout species. Historically, Longfellow Creek contained coho salmon, sea-run cutthroat trout, and steelhead, although steelhead use of the stream probably was low because of the small size of the stream (historical records do not mention chum salmon using the stream; Trotter 2002). Both cutthroat trout and steelhead are now absent from the watercourse.

Today, Longfellow Creek receives the highest numbers of returning coho salmon in Seattle watercourses, with more than 270 spawning adults in some years, indicated by daily or weekly carcass counts (Table 23). By applying a corrective factor for loss of carcasses through decay, predation, or stream flow, it is estimated that actual adult coho use of Longfellow Creek may surpass 400 fish. These coho are a mixture of wild and hatchery fish, ranging from 8 percent hatchery fish in 2004 to 90 percent in 2000 and 2002 (McMillan 2007). The source of hatchery fish in the watercourse could be either fish released as fry (fry were released into the watercourse between 1986 and 1995, and most releases have stopped today), or fish that have strayed en route to their natal hatchery.

Chum salmon also return consistently, and one live adult Chinook salmon was sighted in 2003 (Table 23). Longfellow Creek also contains resident rainbow trout, prickly sculpin, Pacific staghorn sculpin, and three-spine stickleback (Lantz et al. 2006). The latter two species appear to be restricted to the lower portion of the watercourse, which is tidally influenced.

Table 23. Longfellow salmon spawning survey results based on carcass and redd counts.

Year	Chinook		Coho		Sockeye [a]		Chum	
	Carcasses	Redds	Carcasses	Redds	Carcasses	Redds	Carcasses	Redds
1999	0	0	93	16	–	–	0	0
2000	0	0	277	55	–	–	0	0
2001	0	1	274	66	–	–	67	36
2002	0	0	148	27	–	–	21	16
2003	1 [b]	0	32	21	–	–	25	18
2004	0	0	40	43	–	–	5	5
2005	0	0	125	51	–	–	0	0

Data sources: McMillan (2005); SPU unpublished data. Values are averaged between the two data sources.
Survey conducted in the lower reach of Longfellow Creek up to WPA dam within West Seattle golf course.

[a] Sockeye salmon do not use the Longfellow Creek system, because the stream does not fulfill their spawning and rearing habitat requirements.

[b] This was a live sighting. There was no carcass for verification, although the surveyors gave 90% confidence level for their identification.

Currently, only 15 percent of the open-channel length of Longfellow Creek is available to anadromous salmon. Manmade barriers are the primary limitation to salmon use of the remaining open-channel length. Salmon appear able to migrate through the 3,258-foot culvert at the mouth of Longfellow Creek but are blocked by a dam and culvert on the 12th fairway of the West Seattle golf course. Between these two culverts, approximately 1,900 feet of open stream channel is available for spawning and rearing. Fish passage barriers may also limit resident trout distribution; the farthest upstream point at which rainbow trout have been recorded is just downstream of the culvert at 25th Avenue SW (Washington Trout 2000).

Coho and chum spawning is clustered in two areas: between SW Yancy Street and SW Adams Street, and just downstream of the 12th fairway culvert. The stream area near the salmon bone pedestrian bridge (parallel with SW Adams Street) offers the highest-quality accessible spawning habitat, with patches of gravel and adjacent holding pools. The concentration of spawning activity downstream of the 12th fairway culvert does not correspond with high-quality spawning habitat and appears to be associated with the barrier, which prompts fish to spawn in this lower-quality area. Redd concentrations indicate that redd superimposition may be occurring, where digging for new redds dislodges eggs deposited during previous spawning, resulting in mortality.

Longfellow Creek and the fishbone bridge (photo courtesy Seattle Municipal Archives)

Smolt trapping is performed annually on Longfellow Creek to record the quantities of juvenile salmon produced in the watercourse. Trapping conducted over a few days has captured from two to 62 juvenile coho, with wide variability each year (Table 24). These low catches indicate rather low production compared with Thornton Creek and Bear Creek (a suburban tributary of the Sammamish River). The low smolt numbers in Longfellow Creek (averaging less than one coho smolt per day) may reflect poor rearing habitat and lack of pools in the stream, or low spawning success as a result of redd superimposition or coho prespawn mortality. These low catches indicate a rather low production compared with Thornton (averaging eight coho smolts per day), and a much lower production compared to Bear Creek (averaging more than 400 coho smolts per day; Dave Seiler, personal communication 2000). Between 1999 and 2005, the Longfellow Creek coho prespawn mortality rate averaged 71 percent and ranged between 54 and 82 percent (comparable to Thornton Creek and among the highest within Seattle; Table 25). The causes of coho prespawn mortality are still under investigation.

Table 24. Longfellow coho smolt trapping results, 2001–2006.

Year	Total Coho Smolts	Number of Sample Days	Coho per Day
2001	7	14	0.5
2002	2	7	0.3
2003	12	12	1.0
2004	52	24	2.2
2005	62	14	4.4
2006	6	14	0.4

Data source: SPU smolt trapping data.

Table 25. Longfellow coho female prespawn mortality, 1999–2005.

Year	Number of Spawned Females	Number of Unspawned Females	Number of Unknown Spawning Condition	Total Number of Female Carcasses	Total Number of Females in Known Spawning Condition	Prespawn Mortality Percentage
1999	6	7	14	27	13	54
2000	35	100	26	161	135	74
2001	42	69	26	137	111	62
2002	14	62	7	83	76	82
2003	5	7	4	16	12	58
2004	2	3	6	11	5	60
2005	11	34	9	34	45	76
Totals	115	282	92	469	397	71

Data sources: McMillan (2005); SPU unpublished data. Values are averaged between the two data sources.
1999–2002 data source is McMillan (2005). Data for 2003–2005 are from daily surveys conducted by NOAA Fisheries for prespawn mortality studies.

Benthic Invertebrates

The number of individuals collected in an invertebrate sample influences the number of taxa counted because the more individuals collected, the higher probability of detecting a new taxon (Larsen and Herlihy 1998). For an accurate measure of taxa richness, a 400-count sample is preferred.

Longfellow Creek contains four benthic monitoring stations: one in the lower watercourse, two in the middle portion of the watercourse, and one in the upper watercourse. Abundance of invertebrates was adequate to accurately represent the benthic community at all sites in nearly all years monitored (i.e., greater than 400 individuals). The benthic index (B-IBI) scores for Longfellow Creek range between 12 and 18, and the average score for all sites across all years is 15, indicative of very poor habitat and/or water quality conditions (Table 26). These very low benthic index scores reflect poor species diversity, high proportions of pollution-tolerant taxa (i.e., midges, small minnow mayflies, freshwater amphipods, leeches, and nematodes), an absence of intolerant species, a presence of few mayfly-stonefly-caddisfly taxa, few clingers or predators, and very few long-lived taxa (see Appendix C).

Benthic index scores:

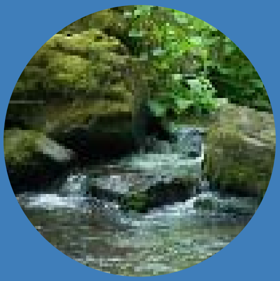
10–16	*very poor*
18–26	*poor*
28–36	*fair*
38–44	*good*
46–50	*excellent*

Table 26. Longfellow average benthic index scores.

Reach	Site Identification	Collection Sites	Years Sampled	Average B-IBI Score	Range
LF02	LF04	Lower Longfellow U/S SW Adams	1999–2002, 2004	16	14–18
LF04/LF05[a]	LF01	U/S of golf course U/S SW Brandon	1996, 1999–2004	14.9	14–18
LF05d	LF03	U/S Restoration-D/S SW Willow	1999–2000, 2002, 2004	14	12–16
LF08[a]	LF02	Upper Longfellow-DS/SW Thistle	1999–2001	13	12–14
			Average for System	14.7	12–18

Data source: SPU B-IBI data 1994–2004.
U/S = upstream; D/S = downstream.
[a] Discontinued sample site.

Furthermore, there are indications that the watercourse has become even more degraded over time; benthic samples collected for 7 years at SW Brandon Street have shown a decline in the number of aquatic worms and an increase in midges. These results and the low benthic index scores indicate that Longfellow Creek's ability to support aquatic life is severely compromised.



Piper’s Creek

Piper's Creek Key Findings

Piper's Creek, shown in Figure 21, originates on a residentially dominated upland plateau with relatively poor conditions before entering Carkeek Park, where conditions improve through the park and downstream to Puget Sound. Factors that promote functioning stream habitat in the Piper's Creek watercourse include the following:

- *Dissolved oxygen and temperature conditions* are good. More than 98 percent of samples collected from the watercourse over the past 18 years met state water quality criteria.
- *The forested riparian corridor* in Carkeek Park, free from encroachment, maintains low water temperatures and provides nutrients and woody debris to the stream.

The following factors tend to degrade water quality and functioning stream habitat in Piper's Creek:

- *Altered hydrology* produced by the heavily developed upland plateau has increased the 2-year storm event runoff by fivefold over forested conditions. These high flows damage stream banks, promote erosion, and degrade instream conditions.
- *Fecal coliform bacteria* levels frequently exceed the state water quality criterion. Annual geometric mean levels exceeded the criterion for extraordinary primary contact recreation (50 colony-forming units per 100 milliliters) in all of the past ten years (480 to 1,200 cfu/100 mL).
- *Concentrations of toxic materials* (metals and ammonia) are moderate. Dissolved lead concentrations exceeded the chronic toxicity criterion once under storm conditions and once under non-storm flow conditions. Seven of 27 stormwater samples (26 percent) exceeded the chronic toxicity criterion for dissolved copper under storm flow conditions, and two samples (7 percent) exceeded the acute toxicity criterion. Fourteen of 14 total arsenic results (100 percent) exceeded the human health criterion under non-storm flow conditions, and three of three results (100 percent) exceeded the human health criterion under storm flow conditions.
- *Concentrations of nutrients* (total nitrogen and total phosphorus) frequently exceed established benchmarks (100 and 14 percent exceedances, respectively, for total nitrogen and total phosphorus under non-storm flow conditions, and 74 percent exceedance of the total phosphorus benchmark under storm flow conditions).
- *Few instream structures, lack of floodplain connections, and high amounts of sand* promote poor instream conditions, with little wood or floodplain area to store sediment or help control flows. Sand covers the streambed in low-velocity sections, reducing biological productivity.
- *Fish passage barriers* at the King County pumping station, and just upstream, restrict anadromous fish to 25 percent of the potential fish-bearing watercourse.
- *Benthic index of biotic integrity (B-IBI) scores* indicate very poor to fair conditions, with scores ranging from 10 to 30. (Higher scores are reported for Venema Creek and upper Piper's Creek.)
- *Coho prespawn mortality* rates are highly variable, ranging from 18 to 100 percent and averaging 56 percent.

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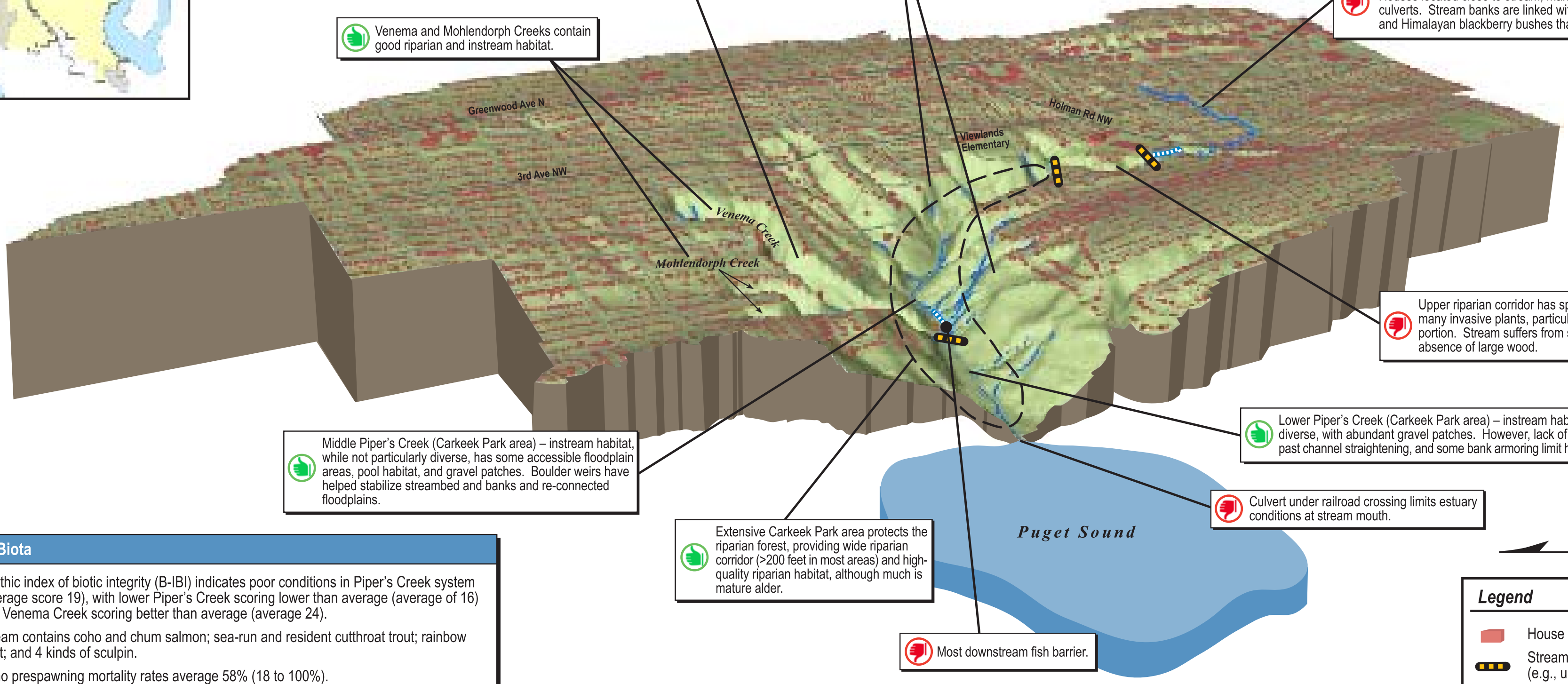
Unique Conditions

- Piper's Creek watershed covers 2.5 mi^2, the third largest in Seattle.
- Stream is unique in having multiple high-gradient tributaries in steep ravines with grades of more than 20%.
- Large portion of stream is located in Carkeek Park.
- Watershed contains a mixture of land uses, dominated by residential.
- Drains to Puget Sound.

Watershed-wide Conditions*

- Buildings, roads, and other impervious surfaces cover 57% of the watershed, substantially increasing stormwater runoff and stream flows that damage stream habitat.
- Stormwater outfalls average 5.8 per stream mile.
- Dissolved oxygen and water temperature levels generally meet criteria.
- Fecal coliform bacteria levels exceed criteria.
- Concentrations of toxic materials (metals and ammonia) are moderate under storm flow conditions. Parameters of concern include dissolved lead, and dissolved copper.
- Concentrations of nutrients (total nitrogen and total phosphorous) frequently exceed established benchmarks.



Upland impervious areas and lack of infiltration have increased stream flows that could destabilize steep ravine walls.

Venema Creek, which cuts through erosion-susceptible sand deposits, is suffering from runoff-related erosion of valley walls and streambed.

Venema and Mohlendorph Creeks contain good riparian and instream habitat.

Upper Piper's Creek – low-quality instream and riparian habitat. Houses located close to stream; many sections conveyed in culverts. Stream banks are linked with lawns, landscaping, and Himalayan blackberry bushes that provide no shading.

Upper riparian corridor has sparse tree canopy and many invasive plants, particularly in the upstream portion. Stream suffers from streambed erosion and absence of large wood.

Middle Piper's Creek (Carkeek Park area) – instream habitat, while not particularly diverse, has some accessible floodplain areas, pool habitat, and gravel patches. Boulder weirs have helped stabilize streambed and banks and re-connected floodplains.

Lower Piper's Creek (Carkeek Park area) – instream habitat is diverse, with abundant gravel patches. However, lack of pools, past channel straightening, and some bank armoring limit habitat.

Extensive Carkeek Park area protects the riparian forest, providing wide riparian corridor (>200 feet in most areas) and high-quality riparian habitat, although much is mature alder.

Culvert under railroad crossing limits estuary conditions at stream mouth.

Most downstream fish barrier.

N

Legend

🟥 House or building
▬ Stream sections (e.g., upper, middle, and lower)
▬ Stream
▬ Culverted stream (>200 feet)
▬ Road

Stream Biota

- Benthic index of biotic integrity (B-IBI) indicates poor conditions in Piper's Creek system (average score 19), with lower Piper's Creek scoring lower than average (average of 16) and Venema Creek scoring better than average (average 24).
- Stream contains coho and chum salmon; sea-run and resident cutthroat trout; rainbow trout; and 4 kinds of sculpin.
- Coho prespawning mortality rates average 58% (18 to 100%).
- Stream contains 10 complete barriers to fish passage and 10 partial barriers, limiting usable anadromous fish habitat to 2,100 feet.

Note: Information here is based on limited data for stream flow and water quality – more data representing both storm and non-storm events are needed.

Figure 21. Current conditions of Piper's Creek

The Piper's Creek Watershed

The Piper's Creek watershed covers 1,604 acres, or 2.5 square miles, in northwest Seattle. It is the third largest watershed in the city, and is just under one-quarter the size of the largest watershed, Thornton Creek. The main stem channel is roughly 2 miles in length, with an additional 3 miles in tributaries, including one major tributary (Venema/Mohlendorph) and 13 minor tributaries.

The watershed has three distinct zones: a gently rolling upland plateau, an area of steep-walled ravines, and a low-gradient valley. The headwaters of Piper's Creek originate on the upland plateau, and the watercourse enters Carkeek Park as it drops down from the plateau through a steep ravine. Once on the low-gradient valley, the watercourse discharges to Puget Sound. The lower portion of the watercourse is tidally influenced, with a delta deposition area. The tributaries of Piper's Creek flow through steep ravines, with gradients exceeding 20 percent.

The underlying geology of the watershed includes upland plateau glacial till that is dense, erosion-resistant, and nearly impermeable to water, as well as advance outwash deposits that are easily eroded by moving water in the ravines of Piper's Creek and its tributaries (Troost et al. 2003, 2005; Stoker and Perkins 2005). These easily eroded sediments, particularly in the steep tributaries, contribute over 50 percent of the sediment in the watercourse (Stoker and Perkins 2005; Barton 2002).

The Piper's Creek watercourse has experienced many erosion problems stemming from watershed development. Erosion control efforts, including bank armoring, grade controls, and tight-lining (i.e., piping) of outfalls, have reduced erosion of the stream banks and valley walls. However, sediment production in the watershed today is about six times greater than predevelopment levels. Venema Creek and other steep tributaries entering Piper's Creek upstream are the largest areas of sediment introduction to the watercourse (Stoker and Perkins 2005).

Gravel is the predominant substrate in the stream, and sand covers the streambed locally in slow-flow areas, particularly within lower and middle Piper's Creek and Venema Creek. Sand dominates the streambed in the upper portions of Piper's Creek, upstream of the twin pipes stormwater outfall. The sand and gravel in the watercourse come from sources in different watershed locations. Gravel is introduced from the gravel-bearing outwash deposits located near the tops of the ravines, while sand is recruited to the stream from outwash deposits in the steep valley walls. In addition, the stream has been filled (with a mixture of silt, sand, gravel, and concrete) in some places both in the lower valley and in local areas in the headwaters.

Historically the Piper's Creek watershed was a heavily forested drainage (Stoker and Perkins 2005). Today, however, nearly 90 percent of the watershed has been developed into residential and commercial areas and street rights-of-way (Map 19 in the map folio accompanying this report). The watershed is dominated by residential land uses (59 percent; Figure 22). Transportation rights-of-way, commercial uses, and industrial development cover a large portion of the watershed as well (31 percent). Most of this development occurred in pulses, one in the 1920s, followed by a larger surge in the 1950s (King County 2005b). Ten percent of the watershed is in parks and open space, including Carkeek Park.

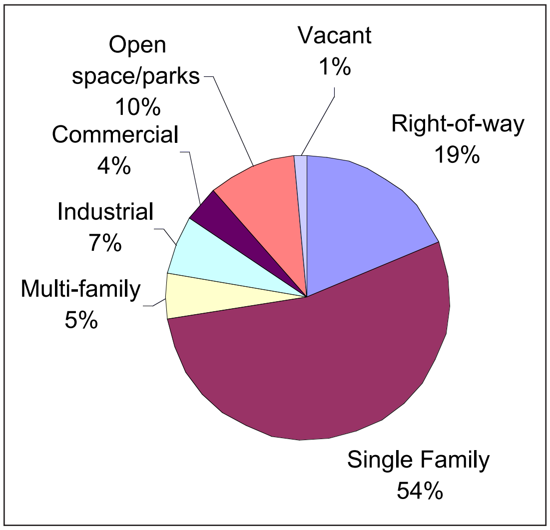


Figure 22. Land uses in the Piper's Creek watershed.

These land uses result in approximately 57 percent coverage of the Piper's Creek watershed with impervious surfaces (e.g., roads, buildings, and parking lots) that limit stormwater infiltration (Alberti et al. 2004). Excluding parks and accounting only for areas served by the formal drainage system, impervious coverage in the watershed totals 66 percent. Most of the impervious coverage is concentrated along Greenwood Avenue North, a major transportation corridor and commercial area.

In areas with formal drainage systems, stormwater runoff enters a pipe or ditch and is quickly carried to a watercourse, causing large amounts of water to be discharged to the watercourse over a short time period.

Watershed-Scale Conditions

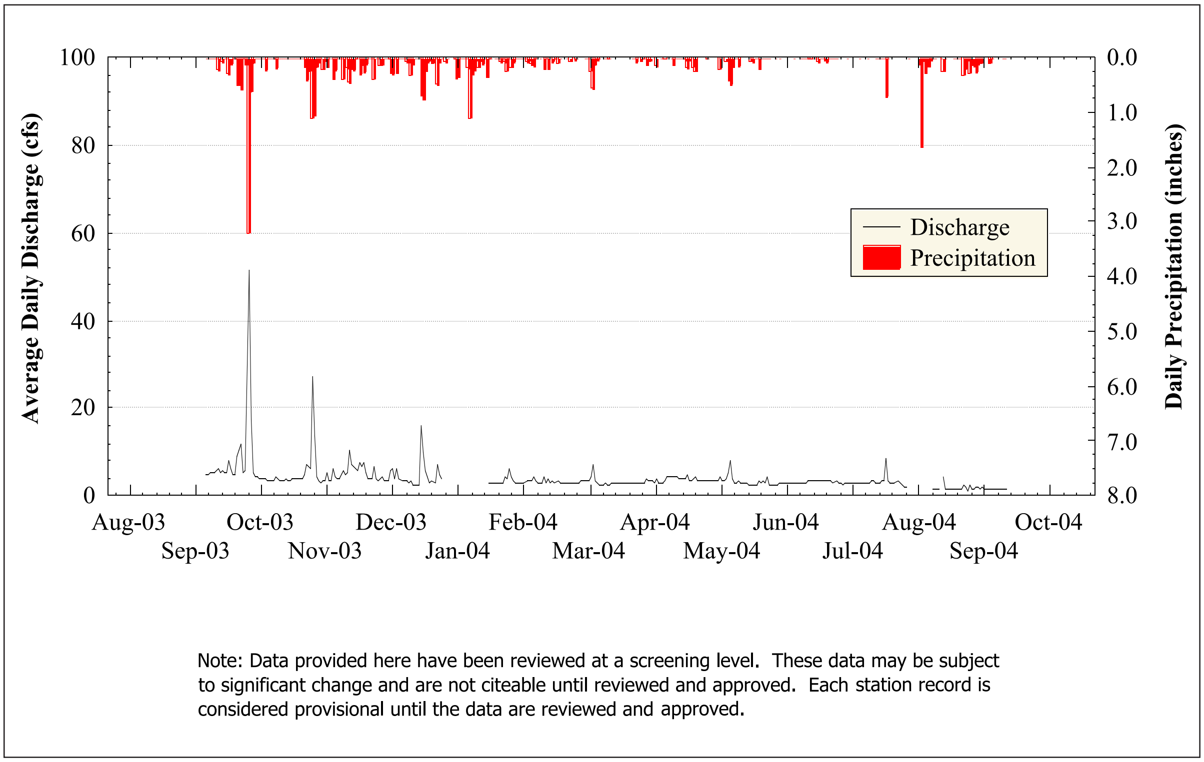
Piper's Creek Hydrology

Piper's Creek and Venema Creek have year-round flow, while Mohlendorph Creek (a tributary of Venema Creek) and some smaller tributaries can go dry in some years. Average flows are 3 to 9 cubic feet per second (cfs) in the main stem of Piper's Creek (4.7 cfs in water year 2004; Figure 23); 0.1 to 1.3 cfs in Mohlendorph Creek; and 0.5 to 3 cfs in Venema Creek (based on SPU data for water year 2004).

A 2-year storm event occurs every 2 years on average, or has a 50% chance of occurring any given year.

The flow patterns seen today in the watercourse are a result of urbanization in the watershed, which has increased high flows in the watercourse and the flashiness of those flows. Hydrologic modeling indicates that the magnitude of 2-year storm event runoff for both Piper's Creek and Venema Creek has increased roughly fivefold compared to predevelopment conditions (Hartley and Greve 2005). Model estimates of storm flows at the mouth of Piper's Creek are 180 cfs for the 2-year event and 400 cfs for the 100-year event.

Twenty-nine storm drains discharge stormwater to Piper's Creek and its tributaries (5.8 outfalls per watercourse mile); however, none are combined sewer overflow outfalls (Map 22). Sixteen storm drains discharge stormwater from the upper plateau to upper Piper's Creek, upstream of the wastewater pumping station culvert (discharging to both main stem Piper's Creek and its tributaries). There are eight outfalls on Venema Creek and Mohlendorph Creek. Two outfalls drain relatively large areas in the watershed: one in the upper reach of Mohlendorph Creek drains an area of 290 acres (18 percent of watershed), and the twin pipes area of upper Piper's Creek drains nearly 575 acres (35 percent of watershed). The areas of the basin that are predicted to contribute the greatest rate and volume of stormwater runoff are located in the upper portions of Piper's Creek and Venema Creek, which drain the upland plateau (Appendix E).



Note: Data provided here have been reviewed at a screening level. These data may be subject to significant change and are not citeable until reviewed and approved. Each station record is considered provisional until the data are reviewed and approved.

Figure 23. Piper's Creek mean daily stream flows recorded near the mouth, 2003–2004.

The overall potential for the watershed to produce large flows quickly is a result of various factors. The twin pipes basin has a higher potential due to the extremely large area it drains (575 acres), although its highly permeable soils help to retain runoff from this area. Other Piper's Creek drainage basins and outfalls have high runoff potential due to low-permeability soils and extensive impervious surface areas. In the central Piper's Creek watershed, Seattle Public Utilities has completed several natural drainage system projects that have decreased runoff and increased onsite retention of stormwater. Similar work is planned in the next few years for an area draining to the headwaters of Venema Creek.

Natural drainage system (NDS) projects replace traditional piped street drainage systems, instead using bioretention swales; stormwater cascades; and wetland ponds to manage stormwater runoff, emphasizing infiltration and decentralized treatment to more closely resemble natural hydrologic functions lost due to urbanization.

Piper's Creek Water Quality

Urban development has affected water quality in the Piper's Creek watershed. Sediment quality data are not currently available. Although clear connections and thresholds are difficult to demonstrate, degraded water quality conditions may affect aquatic organisms in Piper's Creek. Water quality is being investigated as a potential contributor to coho salmon prespawn mortalities reported in urban watercourses in the Puget Sound region since 1999 (discussed later in this chapter). The following discussions summarize existing information on water quality in the Piper's Creek watershed. More detailed tables and summary statistics for all water quality data are presented in Appendix B.

Piper's Creek water quality is generally good with the exception of fecal coliform bacteria levels, which frequently exceed the state water quality criteria. The watercourse also experiences occasional problems with total suspended solids (TSS) and turbidity, particularly during storm flow conditions, and occasionally exceeds the aquatic life criteria for dissolved copper and mercury during storm flow conditions. In 1992, the U.S. EPA issued a programmatic total maximum daily load (TMDL) limit for fecal coliform bacteria in Piper's Creek based on the 1990watershed action plan (Piper's Creek Watershed Management Committee 1990). However, data collected since that time indicate that elevated fecal coliform levels persist in many locations within the basin. In addition, the Department of Ecology included Piper's Creek on the Clean Water Act Section 303(d) list of threatened and impaired water bodies as a water of concern (i.e., category 2) for turbidity in Venema Creek.

Table 27 presents summary statistics for conventional water quality indicators reported in monthly samples collected by King County (2006b) between 1988 and 2005. These samples represent mostly dry-weather, non-storm flow conditions. The results for each indicator are discussed separately in the following subsections.

For the purposes of this report, the King County and Ecology samples are called non-storm flow samples, and SPU samples are called storm flow samples.

Dissolved Oxygen and Temperature

Dissolved oxygen and temperature were measured monthly at three locations on Piper's Creek by King County for the 1988–2005 period of record. At all three locations, dissolved oxygen and temperature followed seasonal patterns, with temperature readings lowest in winter and highest in summer, and dissolved oxygen concentrations highest in winter and lowest in summer. These patterns are typical: as temperature increases, dissolved oxygen concentrations decrease based on changes in the solubility of oxygen.

Piper's Creek has experienced very few exceedances of water quality criteria for watercourses designated as core summer salmon habitat. Exceedences occur primarily during the summer months. Samples are compared to the 2006 state water quality standards (WAC 173-201A) for dissolved oxygen and the 1997 standards for temperature, because the existing data, which are from monthly samples, are not directly comparable to the revised temperature criterion, which is based on the 7-day average of the daily maximum temperatures. From 1996 to 2005, Piper's Creek and Venema Creek never exceeded the water quality criterion for temperature, and only zero to 2 percent of the samples failed to meet the criterion for dissolved oxygen at the three sampling locations. Over the entire 18-year period of record, Piper's Creek upstream of Venema Creek exceeded the temperature criterion in one of 398 samples, and no exceedances occurred in Venema Creek or in Piper's Creek upstream of Venema Creek. Between 1988 and 2005, dissolved oxygen concentrations in Piper's Creek and Venema Creek failed to meet the water quality criterion in only 1 to 2 percent of the samples at the three sampling locations.

In typical urban watersheds, inputs of relatively warm stormwater runoff can cause temperatures in streams to increase above naturally occurring levels. In addition, channel simplification resulting from such actions as levee construction, bank hardening, channel straightening, dredging, and woody debris removal can reduce the hyporheic exchange in streams that helps to promote lower stream temperatures. Hyporheic exchange refers to the mixing of surface water and ground water beneath the active stream channel and riparian zone. Finally, reduced shading in streams due to removal of the riparian canopy can cause stream water temperatures to increase.

Table 27. Piper's Creek summary statistics for conventional water quality parameters, collected by King County, 1998–2005.

	Dissolved Oxygen (mg/L)	Temperature (degrees C)	Fecal Coliform (cfu/100 mL)	pH	TSS (mg/L)	Turbidity (NTU)
Piper's Creek Upstream of Venema Creek (Station KTAH02)						
No. of samples	209	398	412	206	204	203
Minimum	6.6	2.0	1	6.0	0.5	0.2
Maximum	13.1	16.1	37,000	8.4	223	70
Median	10.7	11.4	200	7.9	3.3	1.7
Mean	10.8	10.8	762	7.8	9.7	4.3
5th percentile	9.7	6.0	24	7.1	1.1	0.7
95th percentile	12.2	14.4	3,760	8.2	35.7	15.0
Criteria [a]	9.5	16	50	6.5–8.5	–	–
Venema Creek (Station KTAH03)						
No. of samples	210	211	218	207	205	205
Minimum	6.3	2.0	4	6.1	0.01	0.1
Maximum	13.1	14.5	9,700	8.4	166	73
Median	11.0	10.2	70	7.9	3.0	1.3
Mean	11.1	9.7	258	7.8	8.3	3.2
5th percentile	10.0	5.1	12	7.3	0.9	0.5
95th percentile	12.6	13.3	602	8.2	29	9.8
Criteria [a]	9.5	16	50	6.5–8.5	–	–
Piper's Creek Downstream of Venema Creek (Station KHSZ06)						
No. of samples	254	259	264	251	249	249
Minimum	6.0	1.5	11	6.0	0.5	0.1
Maximum	14.0	16.0	40,000	10.0	425	180
Median	10.9	10.2	250	7.7	3.7	2.0
Mean	10.9	10.0	1,201	7.7	22.4	8.8
5th percentile	9.8	5.0	31	7.0	1.1	0.7
95th percentile	12.7	14.0	5,825	8.2	94.2	37
Criteria [a]	9.5	16	50	6.5–8.5	–	–

[a] Established criteria from WAC 173-201A. See Part 3 of this report for more details.
mg/L = milligrams per liter.
cfu/100 mL = colony-forming units per 100 milliliters.
TSS = total suspended solids.
NTU = nephelometric turbidity units.

Turbidity and Suspended Solids

The Department of Ecology included Piper's Creek as a category 2 water body for turbidity on the 2004 Section 303(d) list of threatened and impaired water bodies, based on samples collected on February 3, 1999 from two stations on Venema Creek. The 2006 state water quality standard for core summer salmon habitat use requires that turbidity levels not exceed 5 nephelometric turbidity units (NTU) over background turbidity when the background level is 50 NTU or less, and not have more than a 10 percent increase in turbidity when the background level is greater than 50 NTU. Summary statistics and time series plots for turbidity and total dissolved solids are provided in Appendix B.

Background turbidity conditions can be difficult to establish in Seattle's urban watercourses. Typically, background conditions are determined from samples collected upstream of a particular input to a watercourse, such as a construction site, storm drain outfall, or municipal or industrial discharge. Background conditions are then compared to samples collected downstream of a specific source input to determine compliance with the turbidity standard. However, because the monitoring stations in Piper's Creek are all located within Carkeek Park rather than upstream and downstream of specific source inputs, these data are not suitable for assessing compliance with the turbidity standard.

The February 3, 1999 samples were collected at two stations on Venema Creek during a 0.53-inch rainfall event. The upstream station (V2) was located just upstream of the confluence with Mohlendorph Creek, and the downstream station (V1) was located just upstream of the confluence with Piper's Creek. Turbidity levels increased by 7.7 NTU between station V2 (38.8 NTU) and station V1 (46.5 NTU). There are no storm drain inputs along this reach of Venema Creek, and the measured turbidity in Mohlendorph Creek on February 3 was only 23.7 NTU. Therefore, the increase in turbidity on this date appears to be related to instream erosion rather than a specific source input to the watercourse.

The historical data from King County (2006b) indicate that particulate levels in Piper's Creek tend to increase as the watercourse passes through Carkeek Park. Mean values of total suspended solids and turbidity are generally higher at the station downstream of Venema Creek (22.4 mg/L and 8.8 NTU, respectively) compared to the upstream station (9.7 mg/L and 4.3 NTU, respectively). However, the increase does not appear to be associated with Venema Creek discharges, because mean values of total suspended solids concentrations and turbidity levels for Venema Creek are generally the same as levels reported at the upstream Piper's Creek station (see Table 27).

The portion of Piper's Creek between the upstream and downstream sampling stations receives a number of inputs, primarily from seeps but also from a few small storm drain outfalls. Because most of the historical samples were collected during non-storm flow conditions (i.e., either during a dry period or during the receding limb of a previous storm), it is not possible to determine whether storm drains or seeps, or both, contribute to the increase in suspended solids in Piper's Creek. Given the relatively steep channel gradient in this portion of the watercourse, increases in particulate concentrations also could be associated with channel erosion rather than source inputs.

The receding limb of a storm refers to the period after the storm has passed and flows in downstream receiving waters are declining relative to the peak rate that occurred after the storm began.

Stormwater samples collected by SPU in Venema Creek between 2000 and 2005 contain higher turbidity levels than the routine King County samples, which mostly represent non-storm flow conditions. The median turbidity measured in stormwater samples between 2000 and 2005 was 34 NTU, compared to 1.3 NTU for the non-storm flow samples. As shown in Table 28, most of the non-storm flow samples (93 percent) contained less than 10 NTU, compared to only 30 percent of the storm samples.

Increases in turbidity and suspended solids downstream typically result from larger storm flows associated with urbanization in the watershed. Larger peak flows tend to erode the streambed and entrain particles more effectively than smaller, less frequent storm flows. In addition, urban stream banks typically erode more easily as riparian vegetation is removed or modified, resulting in increased turbidity and suspended solids downstream, particularly during storms. Finally, turbidity and suspended solids tend to increase downstream in urban streams due to unnaturally high inputs of turbid water resulting from upland construction activities and ground disturbance.

Table 28. Piper's Creek turbidity data summary, 1988–2005.

Turbidity (NTU)	Frequency (percent) King County Monthly Samples	 SPU Storm Samples
<1	14	0
<10	93	29
<50	99	71
<100	100	93

NTU = nephelometric turbidity units.

pH Conditions

Piper's Creek routinely meets the state water quality criterion for pH. Of the more than 650 samples collected from the three Piper's Creek sampling stations by King County between 1988 and 2005, only eight samples (1 percent) were outside the allowable range established in the state criterion (pH 6.5 to 8.5). The most recent excursion occurred on May 26, 2004 near the mouth of Piper's Creek (pH 6.4). All of the other excursions occurred between 1988 and 1999.

Fecal Coliform Bacteria

Since 1998, King County has collected fecal coliform bacteria samples monthly in Piper's Creek. Fecal coliform levels are quite variable, ranging over three orders of magnitude (see Table 27). Bacteria levels in Venema Creek (median value of 70 colony-forming units per 100 milliliters [cfu/100 mL]) were lower than the levels measured in Piper's Creek upstream of Venema (median value of 200 cfu/100 mL) and downstream of Venema (median value of 250 cfu/100 mL). Over the 18-year period of record, approximately 70 percent of the samples collected in Piper's Creek (upstream and downstream of Venema Creek) exceeded 100 cfu/100 mL, compared to only 39 percent in Venema Creek. Under the state water quality standard for extraordinary primary recreation, no more than 10 percent of the samples are permitted to exceed 100 cfu/100 mL.

Recent data for fecal coliform bacteria collected from 1996 through 2005 at three stations (in Venema Creek and in Piper's Creek upstream and downstream of Venema Creek) are summarized in Table 29. Fecal coliform levels frequently exceeded the state water quality criterion for extraordinary primary contact recreation (i.e., a geometric mean of 50 cfu/100 mL, with no more than 10 percent exceeding 100 cfu/100 mL; Ecology 2006a). For example, the annual geometric mean fecal coliform level exceeded the criterion every year in Piper's Creek (both upstream and downstream of Venema Creek) and in 9 of the 10 years at the Venema Creek station. In addition, the 100 cfu/100 mL limit was exceeded in 15 to 94 percent of the samples across all three sites. The annual geometric mean fecal coliform levels in Venema Creek (43 to 210 cfu/100 mL) were generally lower than the levels measured in Piper's Creek (76 to 630 cfu/100 mL).

Piper's Creek (photo by Bennett)

Table 29. Piper's Creek fecal coliform bacteria levels, 1996–2005.

Year	Number of Samples	Fecal Coliform Bacteria (cfu/100 mL) Minimum	Maximum	Geometric Mean	Percent Greater than 100
Piper's Creek Upstream of Venema (KTAH02)					
1996	12	72	4,700	300	83
1997	14	11	15,000	410	79
1998	11	52	5,700	260	73
1999	12	70	37,000	530	83
2000	11	35	2,300	290	82
2001	15	14	1,100	76	27
2002	16	11	840	100	50
2003	14	17	640	130	71
2004	11	23	390	150	73
2005	12	23	420	130	67
Venema Creek (KTAH03)					
1996	13	48	1,000	150	54
1997	14	12	610	60	29
1998	10	20	6,900	120	40
1999	14	31	9,700	210	57
2000	11	22	2,200	120	45
2001	13	19	3,600	61	15
2002	11	30	200	77	36
2003	28	5	360	43	18
2004	12	21	230	52	25
2005	13	10	470	96	46
Piper's Creek Near Mouth (KTAH06)					
1996	16	80	5,100	390	81
1997	18	31	14,000	400	72
1998	19	53	8,000	630	79
1999	16	89	14,000	550	94
2000	17	64	10,000	460	88
2001	22	23	8,000	380	68
2002					
2003	12	54	3,600	220	58
2004	12	41	6,900	350	67
2005	15	25	1,500	190	73

cfu/100 mL = colony-forming units per 100 milliliters.

SPU collects stormwater samples two or three times each year at three stations in the Piper's Creek basin (Piper's UP, Piper's DN, and Venema Creek; see Map 20). Results from stormwater samples collected in 1999 through 2005 are summarized in Table 30. As expected, the SPU stormwater samples generally contain higher levels of fecal coliform bacteria than the mostly non-storm flow samples collected monthly by King County. The annual geometric mean for the King County samples ranged from 43 to 210 cfu/100 mL in Venema Creek and from 76 to 630 cfu/100mL in Piper's Creek, compared to the SPU storm flow results (annual geometric means) of 2,200 cfu/100 mL in Venema Creek and 3,800 to 4,100 cfu/100 mL in Piper's Creek.

Table 30. Piper's Creek and Venema Creek fecal coliform bacteria statistics for stormwater samples, 2000–2005.

Location	Number of Samples	Fecal Coliform Bacteria (cfu/100 mL) Minimum	Maximum	Geometric Mean	Percent Greater Than 100
Venema Creek	9	150	10,300	2,200	100
Piper's Creek above the orchard	12	500	23,000	4,100	100
Piper's Creek below Venema	9	530	25,000	3,800	100

cfu/100 mL = colony-forming units per 100 milliliters.

The Department of Ecology (Olsen 2003) collected samples at 17 sites in Piper's Creek under non-storm flow conditions on July 7, 2003 to identify potential sources of fecal coliform bacteria (see Map 20). All samples were collected within Carkeek Park. Fecal coliform levels ranged from 10 to 1,800 cfu/100 mL. Only seven of the 17 samples were below the 100 cfu/100 mL percentage criterion, and five samples were below 50 cfu/100 mL. The highest levels (1,400 to 1,800 cfu/100 mL) were measured in the 48-inch culvert at the head of the ravine in Carkeek Park (at the upper end of Piper's Creek), and in Piper's Creek just above the twin pipes stormwater outfall (1,200 cfu/100 mL). The 48-inch culvert carries flow from a ten-block area in the upper watershed between NW 95th Street and NW 97th Street. Fecal coliform counts in the twin pipes, which convey the majority of the flow from the upper watershed, were 49 to 64 cfu/100 mL. Fecal coliform levels in the main stem of Piper's Creek below the twin pipes were about one order of magnitude lower than the levels at the head of the watercourse (220 to 320 cfu/100 mL), presumably caused by dilution from the twin pipes. Fecal coliform levels in the small tributaries and seeps that enter Piper's Creek within Carkeek Park were generally low (10 to 140 cfu/100 mL).

Potential sources of fecal coliform bacteria in urban streams are wildlife and pet wastes, leaking wastewater systems, failing septic systems, wastewater treatment plant effluent, and combined sewer overflow events. Stormwater runoff from urban development can easily wash bacteria from these sources into urban streams. Data from microbial source tracing studies in Seattle urban watercourses (i.e., Piper's Creek and Thornton Creek) have shown the primary source to be pet and wildlife wastes.

Piper's Creek (photo by Bennett)

Metals

Fourteen priority pollutant metals with recommended water quality criteria for the protection of aquatic life and human health in surface water were reviewed (see Table 9), with sample results available under non-storm flow and storm flow conditions. The period of record is relatively representative for Piper's Creek downstream of Venema Creek (station KSHZ06; King County 2006b), with good data quality. The quality of the storm flow data is relatively poor. Summary statistics and time series plots for dissolved and total metals are provided in Appendix B.

King County (undated) measured dissolved metals concentrations in Piper's Creek in 21 total samples collected between May 27, 1998 and October 31, 2005 at three stations: KSHZ06, KTHA01, and KTHA03 (Map 20). The results show generally moderate dissolved metals concentrations. One dissolved lead concentration exceeded the chronic toxicity standard in one of 19 non-storm flow samples (5 percent; Table 31); this result is a suspected outlier (an outlier is a value that falls beyond the step spread, as described under Summary Statistics in Part 3). No other dissolved metals exceeded a toxicity standard in the non-storm flow samples.

Table 31. Piper's Creek metals toxicity criteria exceedances between 1998 and 2005.

Flow Condition	Station	Parameter	Sample Date	Result (µg/L)	Acute Criterion Exceeded	Chronic Criterion Exceeded
Nonstorm	KSHZ06	Lead, dissolved	2/12/2001	1.03	–	0.64
Storm	Piper's Dn	Copper, dissolved	2/16/2004	7.2	–	5.6
Storm	Piper's Up	Copper, dissolved	10/3/2002	7.2	–	6
Storm	Piper's Up	Copper, dissolved	11/6/2002	8.8	7.4	5.3
Storm	Piper's Up	Copper, dissolved	12/12/2002	6.3	–	6
Storm	Piper's Up	Copper, dissolved	2/16/2004	8.8	6.8	4.9
Storm	Piper's Up	Mercury, total	2/16/2004	0.12	–	0.012
Storm	Venema	Copper, dissolved	12/12/2002	5.7	–	5.3
Storm	Venema	Copper, dissolved	2/16/2004	5.7	–	4.8
Storm	Venema	Lead, dissolved	2/16/2004	4.2	–	0.82

µg/L = micrograms per liter.

Under storm flow conditions, SPU measured dissolved metals in 27 total stormwater samples collected between August 21, 2001 and July 8, 2005 at three stations: Piper's UP, Piper's DN, and Venema (Map 20). Dissolved lead and copper had some exceedances of toxicity criteria. One of eight stormwater samples (12 percent), a suspected outlier, exceeded the chronic toxicity criterion for dissolved lead (Table 31). Seven of 27 stormwater samples (26 percent) exceeded the chronic toxicity criterion for dissolved copper under storm flow conditions, and two samples (7 percent) also exceeded the acute toxicity criterion (Table 31). All stations sampled recorded at least one exceedance for dissolved copper.

Limited data are available for total selenium and total mercury in Piper's Creek. Total selenium was measured in 21 King County (2006b) samples collected near the mouth (station KSHZ06) between May 27, 1998 and October 31, 2005 under mostly non-storm flow conditions. No selenium exceedances were found. Of the limited mercury data, one stormwater sample collected at the Piper's Creek upstream station on February 16, 2005 exceeded the chronic toxicity criterion for total mercury (Table 31).

Fourteen of fourteen total arsenic results (100 percent) exceeded the human health criterion of 0.018 µg/L under non-storm flow conditions, and three of three results (100 percent) exceeded the human health criterion under storm flow conditions, typical for Seattle urban watercourses. This drinking water criterion applies to human consumption of water and fish (see Table 9). Therefore, the risk to human health is minimal if people do not drink water from the stream or consume fish living in the stream. Although the human health criterion for arsenic is frequently exceeded, the aquatic life chronic and acute toxicity criteria are seldom exceeded.

As noted earlier, exceeding a criterion does not necessarily indicate that the water quality standard has been violated. Often, other polluting conditions must exist for a stream segment to be in violation of water quality standards. For example, if the natural conditions of a water body fail to meet the established water quality criteria, then the natural conditions may be adopted as the water quality criteria for that water body.

Metal pollutants accumulate on impervious surfaces in urban watersheds and are washed off during storms. Some metals are bound to sediments; consequently, as storm flows entrain soil and sediment, metals are more easily transported to streams. Sources of metal pollutants include wear and tear of vehicle parts (e.g., brake pads, tires, rust, and engine parts), atmospheric deposition, common building materials (e.g., galvanized flashing and metal downspouts), and roof maintenance activities (e.g., moss control).

Nutrients

King County (undated) analyzed nutrients (i.e., nitrate+nitrite, total nitrogen, and total phosphorus) in samples collected between April 13, 1998 and December 20, 2005 at four stations (KSHZ06, KTHA01, KTHA02, and KTHA03; Map 20). Nutrient concentrations in Piper's Creek frequently exceeded established benchmarks. Total nitrogen and total phosphorus concentrations under non-storm flow conditions exceeded benchmarks in 100 percent and 14 percent of samples, respectively (74 percent for total phosphorus under storm flow conditions).

Exceedances of the total phosphorus benchmark occurred infrequently in Venema Creek (KTHA03) and in Piper's Creek upstream of the Carkeek treatment plant (KTHA01), but more frequently near the mouth (KSHZ06) and upstream of Venema Creek (KYHA02). However, several of the samples that exceeded the benchmarks are suspected outliers (see Data Analysis in Part 3 for information about outlier values).

Stormwater samples were collected by SPU between January 13, 1999 and July 8, 2005 at three stations in Piper's Creek (Piper's UP, Piper's DN, and Venema; Map 20). Ammonia-N, nitrate+nitrite, and total phosphorus concentrations were reported. Total phosphorus concentrations in stormwater samples frequently exceeded the benchmark, with 75 percent of the samples greater than 0.1 mg/L. A summary of non-storm flow and storm flow nutrient data are shown in Table 32.

Phosphorus and nitrogen are common pollutants in urban streams. Sources include fertilizer applications, increased soil erosion, nutrients from washwater (e.g., car and boat cleaning), failing septic systems, pet wastes, and improper dumping of yard wastes. All of these sources can result in increased nutrient concentrations in stormwater runoff. This is of particular concern for water quality in the larger water bodies such as freshwater lakes and Puget Sound. Elevated nutrient levels can lead to eutrophication, a process in which rapid growth of algae may overcome natural self-purification processes in the water body. The resulting algal blooms degrade water quality as the decomposing algae reduce the dissolved oxygen concentrations in receiving waters. Ultimately, increased nutrient concentrations can reduce survival opportunities for salmonids, which rely on oxygen-rich waters.

Table 32. Piper's Creek summary statistics for nutrients.

	Ammonia-N (mg/L)		Nitrate+nitrite (mg/L)		Total Nitrogen (mg/L)		Total Phosphorus (mg/L)	
	Non-Storm [a]	Storm [b]	Non-Storm [a]	Storm [b]	Non-Storm [a]	Storm [b]	Non-Storm [a]	Storm [b]
Piper's Creek Upstream of Venema Creek								
No. of samples	55	17	84	16	78	ND	84	16
Minimum	0.01	0.01	0.55	0.32	1.2	ND	0.045	0.0034
Maximum	0.27	1.0	2.1	1.4	2.6	ND	0.23	0.57
Median	0.013	0.13	1.5	0.87	1.7	ND	0.075	0.19
Mean	0.034	0.23	1.5	0.85	1.7	ND	0.081	0.22
5th percentile	0.01	0.026	0.97	0.33	1.4	ND	0.054	0.039
95th percentile	0.15	0.64	1.9	1.4	2.2	ND	0.13	0.56
Benchmark [c]	0.43 – 2.1		–		0.34		0.1	
Venema Creek								
No. of samples	51	17	85	16	86	ND	87	15
Minimum	0.01	0.01	0.63	0.035	1.1	ND	0.044	0.054
Maximum	0.044	0.14	2.1	1.4	2.2	ND	0.2	0.99
Median	0.01	0.025	1.4	0.99	1.6	ND	0.073	0.13
Mean	0.014	0.046	1.4	0.93	1.6	ND	0.073	0.25
5th percentile	0.01	0.01	0.89	0.45	1.3	ND	0.052	0.056
95th percentile	0.03	0.14	1.8	1.3	2.0	ND	0.095	0.75
Benchmark [c]	0.43 – 2.1		–		0.34		0.1	
Piper's Creek Downstream of Venema Creek								
No. of samples	85	17	89	16	86	ND	83	16
Minimum	0.01	0.01	0.5	0.42	1.1	ND	0.046	0.06
Maximum	0.11	0.44	2.1	1.5	2.8	ND	0.44	0.86
Median	0.013	0.088	1.5	0.97	1.7	ND	0.076	0.18
Mean	0.023	0.15	1.5	0.94	1.7	ND	0.09	0.26
5th percentile	0.01	0.012	0.61	0.43	1.2	ND	0.049	0.072
95th percentile	0.063	0.43	2.10	1.5	2.2	ND	0.18	0.71
Benchmark [c]	0.43 – 2.1		–		0.34		0.1	

[a] Non-storm samples collected at stations KTAH02, KTAH03, and KTAH06.
[b] Storm samples collected at stations Pipers Up, Venema, and Pipers Dn.
[c] Ammonia chronic toxicity criteria are pH-dependent, and the given range is for a pH of 6.5–8.5. All nutrient criteria and benchmarks are described in more detail in Part 3 of this report.
mg/L = milligrams per liter.
ND= no data collected.

Stream-Scale Conditions

Piper's Creek is mostly a steep, narrow watercourse but has a relatively broad, low-gradient valley in its lower watershed. The main channel and its tributaries have been gradually cutting steep ravines into the upland plateau for the past 10,000 years. As the channels gradually cut farther into the plateau through soft, glacially deposited sediments (mostly advance outwash sands), surface erosion and landslides have widened the steep ravine walls. The Piper's Creek watercourse today is heavily influenced by erosion of the channel and ravine walls, and that process was probably at work even prior to urban development, given the geology of the watershed.

The Piper's Creek ravine extends over a mile into the plateau and has a fairly flat gradient. Venema Creek and Mohlendorph Creek, which are major tributaries on the north side of the plateau, are shorter and steeper. Piper's Creek has several other tributaries that are very short and extremely steep. Some of these tributaries originate from ground water seepage in landslide scars high on the ravine walls, while others drain surface runoff from the plateau.

Piper's Creek is divided into five reaches for this discussion. Watercourse codes, shown on the watercourse maps, consist of two letters of the watercourse name (PI for Piper's) and the number of the stream segment, starting with 01 at the mouth and increasing in the upstream direction:

Watercourses are divided into reaches, reaches are divided into segments, and segments are divided into sections.

- Piper's Creek Plateau (PI05)
- Upper Piper's Creek (PI04), upstream of the twin pipes stormwater outfall (NW 105th Street)
- Middle Piper's Creek (PI03–PI02), between the twin pipes and the wastewater pumping station
- Lower Piper's Creek (PI01), between the pumping station and the mouth
- Tributaries of Piper's Creek, focusing on Venema Creek and Mohlendorph Creek.

Piper's Creek Plateau (PI05)

Historically, this reach flowed through a forested wetland plateau with numerous wetlands and peat deposits. The low-gradient channel connected to a broad floodplain, both of which stored water, sediment, and wood and delivered water slowly to lower reaches of the stream (Seattle 2005). The plateau reach regulated stream flows, water temperature, sediment, and nutrient availability. Today this reach functions to collect and convey runoff to lower reaches of Piper's Creek. Former plateau channels and wetlands have been replaced by storm drains and ditches (Stoker and Perkins 2005) and are now covered by fill and impervious surfaces.

The Piper's Creek channel emerges in the Greenwood neighborhood, on the gently rolling upland plateau (Map 21). The channel in the upper reach extends over 3,000 feet in length (38 percent of the total main stem channel length), ending in a culvert under NW 100th Place.

Riparian Habitat

The Piper's Creek plateau reach has a fragmented riparian corridor of rather low quality where the watercourse is not in culverts and flows along roads and between houses and businesses. Encroachment is severe along this reach, and most structures are closer than 20 feet to the watercourse (Map 24). The riparian corridor is composed of lawns, landscaping, and invasive Himalayan blackberry (Map 23). The riparian corridor supplies no shading or wood debris to the stream throughout this reach.

Instream Habitat

Much of Piper's Creek upstream of NW 100th Place flows through culverts (for 52 percent of the channel length), with the active channel width averaging 6.7 feet (where the watercourse is not in a culvert). With the high amount of residential and commercial encroachment on the watercourse, nearly 30 percent of the open-channel segments are armored on either one or both banks (Map 24). The channel also has been straightened and realigned. Most of its floodplain connections have been lost, and the channel contains little or no structure.

The plateau reach has poor-quality instream habitat. The typical channel type for the 2 to 4 percent gradient is a forced pool/riffle morphology where enough large wood is present. However, this reach is dominated by a plane-bed channel due to the absence of large wood debris (Seattle 2005). Of the 680 feet of open channel surveyed in this reach, 61 percent is riffle, 26 percent is glide, and only 12 percent is pool (Map 23). The only slow-water (pool) habitat within this reach is a shallow pond that has been dug on private property and is maintained by a 3-foot-high dam at its downstream end. Of the 3,000 feet of channel, 1,725 feet has sufficient channel width and flow to be typed as potentially fish-bearing (probably for resident species). Fish are not present and have not been documented above the fish barrier at NW 103rd Street.

Upper Piper's Creek (PI04)

Piper's Creek in upper Carkeek Park (photo by Bennett)

Instream and riparian conditions improve as the watercourse enters Carkeek Park, at the NW 100th Place culvert outlet. This reach is 1,630 feet in length from NW 100th Place to the twin pipes stormwater outfall (18 percent of the total main stem length).

Riparian Habitat

Riparian habitat is rather spotty throughout the upper Piper's Creek reach. The overstory is dominated by a deciduous forest that provides a sparse canopy. The canopy shades between 25 and 75 percent of the stream, depending on location. The understory contains nonnative plants, particularly Himalayan blackberry, concentrated at the upstream end of the reach.

In general, riparian conditions tend to be worse near the upstream end of this reach, improving as the watercourse moves farther into the ravine and park. The riparian corridor width follows a similar trend, averaging 25 to 75 feet at the upstream end of the reach where the watercourse is adjacent to houses. The corridor width increases to over 100 feet downstream. There are limited areas of encroachment within the lower portion of the reach, particularly at pedestrian bridges near the twin pipes outfall. The conditions within this reach cumulatively indicate moderate riparian habitat quality, although downstream segments of the reach have better conditions than those upstream.

Instream Habitat

The upper Piper's Creek reach has two distinct watercourse segments for instream habitat: the upper segment from NW 100th Street to a former logging railroad embankment known as Camel's Hump, and the lower segment from Camel's Hump to the twin pipes outfall.

The upper segment currently functions as a depositional area where the 85-foot culvert under the railroad embankment has prevented channel incision and causes water to accumulate immediately upstream (Map 22). Sediment deposition upstream of this culvert has actually reduced the stream gradient in the reach and created a sinuous, low-gradient channel (2.5 percent gradient). This segment of upper Piper's Creek is mostly sand-bedded, with connection to a depositional floodplain and wetlands (Stoker and Perkins 2005). Sediment from valley-wall landslides mostly is stored on the floodplain, although a small percentage is likely transported downstream.

Downstream of Camel's Hump, the gradient increases to almost 4 percent. This lower segment of the reach appears to receive somewhat lower flows than other parts of the watercourse. Most of the channel in this segment is stable, except for an area of channel degradation (incision) downstream of the Camel's Hump culvert (Map 22). Where channel degradation has occurred, the channel is entrenched and confined between terraces that are remnants of former floodplains. The terrace heights in this reach average less than 3 feet, except for the watercourse segment immediately downstream of Camel's Hump, which has terrace heights of 3 to 6 feet.

Streams with active floodplains generally have terrace heights below 2 feet. In Piper's Creek, most terraces are 2 to 4 feet high in the tributaries and 4 to 5 feet high in the lower main stem, although they can reach 9 feet.

The lowest segment in this reach is supplied by sediment from sandy valley-wall landslides delivered by steep tributaries near the downstream end of the reach. Given its moderate gradient of 2 to 4 percent (Map 21), historically this reach has both stored and transported sediment to the lower reaches of the stream. Downstream transport of wood was probably always minor due to the small size of the channels. Although large woody debris once provided stability for the step tributaries, logging has since removed sources of this structure.

The habitat in upper Piper's Creek is of medium quality (Map 25). The streambed, dominated by sand and continuous riffle, lacks habitat diversity (Map 23). Given the 2 to 4 percent gradient, the channel should provide a forced pool-riffle channel type, but there is no structure to force the formation of pool habitat (Seattle 2005).

This watercourse segment supports resident cutthroat trout; several juvenile trout were documented in 1999 upstream of the confluence with the first steep tributary (Washington Trout 2000). This segment is unlikely to support anadromous fish, because the base stream flow here is reduced by almost half the volume upstream of the twin pipes outfall (Washington Trout 2000; Stoker and Perkins 2005).

Middle Piper's Creek (PI03–PI02)

Twin pipes outfall along Piper's Creek (photo by Bennett)

The middle reach of Piper's Creek extends downstream 2,870 feet from the twin pipes outfall in an open channel (33 percent of the main stem channel length) before being conveyed via a 342-foot culvert around the wastewater pumping station. In this area, the valley bottom widens along the downstream portions of the watercourse, where the channel is relatively unconfined, with a moderate gradient of 2 to 4 percent (Map 21). Historically, the channel meandered somewhat and connected laterally to the floodplain, including wetlands at the bottom of the valley walls. These connections to the floodplain are important for dissipating energy from high stream flows.

Riparian Habitat

Riparian habitat quality is high throughout this reach. The stream is surrounded by a mostly deciduous forest with some conifers, and a native understory with an occasional Himalayan blackberry shrub. The deciduous forest provides the stream with about 50 percent canopy coverage. The riparian corridor is capable of supplying some wood, particularly small pieces, to Piper's Creek.

Carkeek Park has protected the channel from encroachment (Map 24). The riparian corridor is generally over 100 feet in width, although in some locations it exceeds 300 feet in width due to the boundaries of Carkeek Park. There is some encroachment by trails near the north end of 8th Avenue NW and immediately across the ravine, although even in those locations riparian vegetation extends beyond 50 feet from the stream.

Instream Habitat

Upper and middle Piper's Creek combined supply 34 percent of the watercourse's sediment load. Ecologically, this reach should temporarily store wood and sediment (primarily gravel), and transport these materials to the lower watercourse. While segments in the middle reach (PI03 and PI02) historically were similar, the watercourse within the lower segment (PI02) has been placed in a culvert. This piped segment offers little habitat (Map 25).

Currently, 29 percent of the Piper's Creek watershed drains to middle Piper's Creek through the twin pipes outfall, nearly doubling the average active channel width of this reach to about 12 feet (compared with about 6 feet upstream). Despite this alteration, the channel in the upper segment (PI03) is in relatively stable condition. Fourteen valley-spanning boulder weirs, constructed in 1973, have largely succeeded in stabilizing approximately three-quarters of the length of the channel (Map 22). The weirs function as grade controls that have prevented the channel from further incision, allowed sediment to deposit, and rebuilt the streambed elevation to reconnect the stream and floodplain. The substrate is mostly gravel with small patches of sand (Stoker and Perkins 2005). Typically there is channel incision immediately downstream of the weirs, and depositional (restabilized) areas immediately upstream of the weirs with floodplain connections. Likewise, channel incision and bank armoring limit floodplain connections in the lower half of the reach, with terrace heights of 4 to 9 feet surrounding the stream (Stoker and Perkins 2005). The upper segment (PI03) contains high-quality habitat, mostly on the basis of floodplain connection, riparian protection, and substrate quality (Map 25).

The condition that detracts from higher-quality habitat in this segment is the lack of instream habitat diversity. While the channel is expected to have a forced pool-riffle channel type, instead the stream has a plane-bed channel type dominated by riffles (through 88 percent of the reach length; Stoker and Perkins 2005; Seattle 2005). The pool- to-riffle ratio is 1-to-14, and pools make up only about 6 percent of the reach length. Although the weirs provide some structure, there is little other instream structure to store sediment and create pools (Stoker and Perkins 2005). Small wood jams were reported in this area during habitat surveys performed in 2000, although these small jams probably were highly mobile and may have been blown out in subsequent storm events. Despite the lack of instream structure, however, this reach has relatively high-quality habitat compared to other parts of Piper's Creek, and compared to other Seattle watercourses.

Both anadromous and resident fish use this reach, although only a few adult coho make it upstream of the 342-foot culvert that carries the watercourse around the wastewater pumping station (PI02). This culvert is considered a full barrier to fish movement upstream (Map 26). In addition, other barriers are located upstream of the treatment plant culvert in segment PI03, mostly boulder weirs that create jumps in the bed elevation.

Lower Piper's Creek (PI01)

Downstream of the wastewater pumping station culvert, Piper's Creek flows westward 2,160 feet (25 percent of the main stem channel length) before entering Puget Sound. The surrounding valley continues to widen and flatten. At one time this reach probably was a meandering channel with associated wetlands, beaver ponds, side channels, and sloughs within a wide floodplain valley (Stoker and Perkins 2005; Seattle 2005).

Piper's Creek (photo by Bennett)

Riparian Habitat

The deciduous forest, with the occasional conifer, continues from middle Piper's Creek into this lower reach. The trees create a mature, dense canopy that provides the stream with almost full shading. The area also contains a native understory. The riparian corridor, while having high-quality habitat, is somewhat affected by lawns and trails on the north side of the stream, downstream of the pumping station. In these locations, a single band of trees borders the stream, while on the south side the riparian corridor extends for over 800 feet. This limits the ability of the riparian corridor to contribute to the stream, and most wood and other structures in the stream throughout this reach have been added through restoration projects (Map 27).

Instream Habitat

Historically the channel migrated across a valley more than 60 feet in width, compared with an average active width of 16 feet today (Stoker and Perkins 2005). The channel is currently confined to the base of the south valley wall due both to past realignment and straightening, and to the addition of fill material in the valley. To reduce channel erosion, bank armoring was added to the lower channel (through 26 percent of the length of the reach). The lower channel is mostly constructed and entrenched.

The habitat in lower Piper's Creek is considered of high quality because of its diversity (having the deepest pools in the system) and its abundance of gravel substrates (Maps 23 and 25). Park lawns encroach within 20 feet on the north side of the channel, although the entire reach is fully shaded by mature deciduous vegetation on the south bank. The 1 to 2 percent gradient in this reach (Map 21) is low enough to maintain a pool-riffle channel type, although the habitat is dominated by riffle habitat (70 percent). The pool-to-riffle ratio is 1-to-4.7, lower than the expected 1-to-1 ratio, with pools making up about 15 percent of the reach length. The pool deficiency is partially caused by past channel straightening, which has reduced the gradient and eliminated the pools that would normally occur at stream bends (Stoker and Perkins 2005). Most of the pools are associated with constructed wood weirs, although a few have been formed by debris jams.

Log deflectors along lower Piper's Creek (photo by Bennett)

The majority of the habitat structures in this reach are constructed. Log weirs and bank protection structures were installed from 1998 to 2000 to reduce channel erosion and create pools for fish. While the installed structures have increased the habitat diversity, the engineered result presents a trade-off between functions. The channel now is both armored and entrenched, preventing it from widening to accommodate increased stream flows and from reestablishing connection with the floodplain (Stoker and Perkins 2005). Moreover, the bank armoring and log weirs require ongoing maintenance, because the narrow channel (averaging 15 feet, and rarely exceeding 20 feet) is subject to the scouring velocities of high-flow events.

This reach provides spawning and rearing habitat for salmonids. Almost all of the available gravel area in the reach (about 35 percent of the reach, or 800 feet of the total length) is used by spawning chum and coho salmon in the fall (McMillan 2007). The pools in this area are used by spawning adults for holding and by juveniles for rearing (Washington Trout 2000; McMillan 2007).

Sand is the dominant substrate at the mouth of Piper's Creek, and the watercourse is responsible for introducing that sediment into Puget Sound. As with Fauntleroy Creek, sand supplied to the marine waters becomes incorporated into the marine ecosystem, feeding nearby beaches. This sediment is critical to the creation and maintenance of marine shoreline habitats, similar to the role that sediment plays in creating stream habitat. However, the railway embankment and associated culverts running between the watercourse and Puget Sound effectively separate these two ecological systems. The altered connections between the watercourse and the sound likely affect the ability of the watercourse to move sediment into the marine area to nourish the beach, estuary, and near-shore eelgrass beds near the mouth of Piper's Creek. The altered connections also confine the estuarine area and limit the quality of that habitat as a nursery for salmonids, flat fishes, and other marine species.

Piper's Creek Tributaries

Piper's Creek has 14 tributaries, of which the largest is Venema Creek, with its major tributary, Mohlendorph Creek. The Venema and Mohlendorph headwaters, located in steep upper ravines, are fed by ground water seeps and stormwater runoff from the upper plateau. Channel gradients are steep, averaging 11 percent in upper Venema Creek and 17 percent in upper Mohlendorph Creek (Stoker and Perkins 2005; Map 21). Mohlendorph Creek flows 2,525 feet from its upper extent to the junction with Venema Creek. Venema Creek runs about 2,100 feet from its headwaters to the Mohlendorph confluence. Below the Venema–Mohlendorph junction, Venema Creek flows another 550 feet before discharging into the lower Piper's Creek reach (PI01), just downstream of the wastewater pumping station culvert. The lower reaches of these tributaries decrease in gradient to a range of 3 to 5 percent (Stoker and Perkins 2005).

Riparian Habitat

Venema Creek and Mohlendorph Creek both contain high-quality riparian habitat. The riparian corridors, exceeding 100 feet in width, are composed of deciduous trees, as well as coniferous trees to a lesser extent. The mature trees create a dense canopy that provides a large amount of shading to these two tributaries. The understory consists of native shrubs and groundcover. The roads and trails create breaks in the riparian corridor near the confluence with Piper's Creek. The upper segments of the two tributaries also are affected by the encroachment of surrounding houses.

The other Piper's Creek tributaries tend to have wider, dense riparian forests without encroachment by nearby structures. However, upstream conditions tend to degrade where the tributaries come closer to developed properties on the plateau above the stream ravine.

Instream Habitat

Based on stream gradients, coupled with narrow valley walls in the upper ravines, both Venema Creek and Mohlendorph Creek are expected to exhibit a forced pool-riffle channel type in their lower segments (with gradients below 4 percent), and, in the upper segments, step-pools (where gradients are 4 to 8 percent) or cascades (where gradients are above 8 percent). The presence of instream wood debris is critical to the formation of steps and pools in the channel (Seattle 2005).

Despite similar flow increases, the channel erosion in Venema Creek is unlike the erosion process in Mohlendorph Creek and upper Piper's Creek. The difference in erosion among these parts of the watercourse is attributed to both geology and instream grade controls (Stoker and Perkins 2005). The sandy canyon walls in upper Venema Creek are continuing to retreat in response to runoff-related channel incision and bank failure. Erosion is progressing slower downstream where soils are less erodible and natural large woody debris jams in middle Venema Creek protect the channel from incision by trapping sediment (Stoker and Perkins 2005).

Lower Mohlendorph Creek is aggrading and widening in response to upstream erosion, particularly in its east fork. However, Mohlendorph Creek has fewer erosion problems than either Venema Creek or the steep tributaries of upper Piper's Creek, because of its smaller size and erosion-resistant geology, particularly the glacial till substrate of its uppermost forks. Overall, Venema Creek above Mohlendorph Creek contributes about 42 percent of the Piper's Creek sediment supply, and Mohlendorph Creek contributes only about 10 percent (Barton 2002; Stoker and Perkins 2005).

In general, Venema Creek and Mohlendorph Creek provide moderate instream habitat quality within a forested riparian corridor that protects the channels from encroachment (Map 25). Both channels have cobble and gravel substrate in their steeper segments, and the Venema Creek streambed has more sand in the lower-gradient segments. Past logging has not left enough instream structure to maintain the pool-riffle morphology in segments of 2 to 4 percent gradient or to maintain the step-pool morphology in segments of 4 to 8 percent gradient (Map 21) to the extent necessary to dissipate high-flow energy, control the stream gradient, and provide diverse habitat. Both channels alternate between long stretches of riffle habitat and short stretches of step-pool habitat. An exception is in Venema Creek, just upstream of the confluence with Mohlendorph Creek, which contains two large, valley-spanning logjams. There is a large depositional area upstream of the logjams, where the channel meanders across a narrow floodplain with large gravel bars and some side channels.

The lowest section of Venema Creek has a lower gradient (3 percent) and is a largely constructed channel dominated by armored banks (through 75 percent of the reach length). The lowest section is dominated by riffle habitat (through 85 percent of the reach length) with several step-pools (through 16 percent of the reach length) forced by constructed weirs (Map 23). Gravel areas are often dominated by intermixed sands. The armoring and weirs have largely succeeded in stabilizing the channel from incising and eroding banks; however, as in lower Piper's Creek, this has implications for the stream's ability to function. The channel is unable to widen and reconnect with its floodplain to accommodate the increased runoff, and the control structures require ongoing maintenance in response to the erosive action of high flows.

Piper's Creek (photo by Bennett)

Both Venema Creek and Mohlendorph Creek support salmonids, and both have resident adult and juvenile cutthroat trout documented in upper segments of the channel (Washington Trout 2000). Juvenile trout were found up to the confluence of the east and west forks in Mohlendorph Creek. Adult cutthroat were recorded 2,300 feet upstream of the mouth of Venema Creek. Salmon spawning probably is limited more by channel size and flow than by fish passage barriers. A few coho and chum salmon spawn in the lower reaches of Venema Creek during most years, but they spawn in the lower reaches of Mohlendorph Creek only during higher-flow years (McMillan 2005).

The remaining 13 Piper's Creek tributaries have not been intensively surveyed or rated for their habitat quality. These tributaries are too steep to be fish-bearing, ranging from 8 to 20 percent in channel gradient, except for short sections immediately upstream of their mouths (Map 21). All of the steep tributaries in the upper Piper's Creek watershed, with the exception of Becker's Pond tributary with its valley-spanning dam, lack effective structures to provide grade control and dissipate energy from the increased storm runoff. Channel downcutting through easily eroded sand has oversteepened the banks and valley walls, increasing channel erosion and landslides. The steep tributaries of Piper's Creek were formerly a major source of sediment (mostly sand), but this has been greatly reduced by piping stormwater outfalls all the way to the valley bottom. However, erosion rates remain high in many of the steep tributaries, because ground water seepage still causes landslides and channel erosion.

Use by Fish and Benthic Invertebrates

Fish Access

Historically, coho salmon and both resident and sea-run cutthroat trout inhabited Piper's Creek (Trotter 2002). There is no historical record of chum salmon using Piper's Creek (Trotter 2002). Since 1927, no salmon were seen spawning in Piper's Creek until 1987, when adult chum salmon were seen in the stream, presumably originating from hatchery releases in previous years. Today the fish community in Piper's Creek includes resident and sea-run cutthroat trout, rainbow trout, chum and coho salmon, and four species of sculpin (Pfeifer 1984; Thomas 1992; Washington Trout 2000; Lantz et al. 2006).

Today, adult coho and chum salmon use the watercourse for spawning. Based on carcass counts from 1999 through 2006, use of Piper's Creek by adult coho ranges between five and 122 fish annually (Table 33). Carcass counts represent a minimum level of use; the actual spawning numbers are higher (McMillan 2007). These coho are a mixture of wild and hatchery salmon, which either were released as fry or strayed during their return to their natal hatcheries. There was a long absence of coho from Piper's Creek, from 1927 to 1987, and the origin of the wild portion of the coho returns could represent either strays from other nearby watercourses or the repercussions of juvenile coho releases between 1980 and 1983 (Trotter 2002).

Table 33. Piper's Creek salmon spawning survey results based on carcass and redd counts.

	Chinook [a]		Coho		Sockeye [b]		Chum	
Year	Carcasses	Redds	Carcasses	Redds	Carcasses	Redds	Carcasses	Redds
1999	–	–	15	0	–	–	16	8
2000	–	–	28	36	–	–	16	18
2001	–	–	122	45	–	–	142	91
2002	–	–	37	12	–	–	398	85
2003	–	–	5	6	–	–	202	102
2004	–	–	9	14	–	–	87	38
2005	–	–	45	19	–	–	113	60

[a] Chinook do not use Piper's Creek, as the stream is too small to allow for spawning activities.
[b] Sockeye salmon are not expected to use the stream, as they need a lake environment for rearing.
Sources: McMillan (2005); SPU unpublished data. Values in table are averaged between the two data sources.

Adult chum salmon numbers ranged between 16 and 398 fish per year (Table 33). Chum were not in the watercourse historically, probably because of the small size of the watercourse and the relatively large size of chum salmon. However, community and school groups release thousands of juvenile hatchery chum salmon into Venema Creek each spring. Over 35,000 chum fry have been released in recent years.

Spawning use of the Piper's Creek watershed is limited by both natural and manmade features. Many of the smaller tributaries, as well as the upper reaches of the main stem and larger tributaries, are naturally too steep and narrow to provide appropriate habitat for salmon (e.g., above the twin pipes outfall, and the upper segments of Venema and Mohlendorph). Smaller resident and migratory trout may be able to use these upstream areas because they can navigate smaller streams and steeper stream gradients.

Manmade fish passage barriers have limited fish access in Piper's Creek. Resident trout are found throughout Piper's Creek and Venema Creek (Washington Trout 2000; McMillan 2007; Lantz et al. 2006). The culvert at NW 103rd Street (Camel's Hump) appears to be a barrier to resident fishes in upper Piper's Creek. Barriers may also limit the mobility of resident trout within the watercourse. Upstream migration of anadromous salmon is blocked at the culvert and the adjacent bypass pipe next to the wastewater pumping station. An occasional adult coho makes it upstream of these structures, although only 400 feet of watercourse habitat is available before the next barrier is encountered (McMillan 2007). In total, fish passage barriers probably reduce potential resident fish habitat by about 35 percent and reduce potential anadromous fish habitat by 65 percent.

Piper's Creek has not been monitored for smolt out-migration, unlike Longfellow Creek, Thornton Creek, and Fauntleroy Creek. Even without this information, there are concerns that redd superimposition and coho prespawn mortality may affect juvenile salmon production in the watercourse. Salmon redds have been distributed fairly evenly over the entire length of lower Piper's Creek (Map 26). Adult chum salmon arrive approximately one month after the coho arrive and tend to use exactly the same spawning locations. The amount of spawning habitat, number of adult salmon, and small amount of habitat accessible may contribute to redd superimposition, where digging for new redds dislodges eggs deposited during previous spawning, resulting in mortality. Because chum salmon are more abundant than coho in Piper's Creek, redd superimposition has a greater potential of reducing coho production in Piper's Creek than in Seattle's other fish-bearing urban watercourses.

Coho prespawn mortality, a condition in which adult salmon die after they enter the stream but before they are able to spawn, averages about 58 percent in Piper's Creek, an intermediate value compared to other monitored Seattle watercourses. Piper's Creek also exhibits the most variable prespawn mortality rate in Seattle watercourses, ranging from 18 to 100 percent (Table 34). Chum salmon are also affected, although their mortality rate is only 2 to 4 percent (McMillan 2007). The causes of prespawn mortality are still under investigation.

Table 34. Piper's Creek coho female prespawn mortality.

Year	Number of Spawned Females	Number of Unspawned Females	Number of Unknown Spawning Condition	Total Number of Female Carcasses	Total Number of Females of Known Spawning Condition	PSM (%)
1999	0	4	0	4	4	100
2000	14	3	1	18	17	18
2001	13	32	25	70	45	71
2002	4	6	8	18	10	60
2003	1	0	0	1	1	–
2004	2	1	1	4	3	–
2005	1	3	11	15	4	75
Totals	35	49	46	130	84	58

Sources: McMillan (2005); SPU unpublished data. Values in table are averaged between the two data sources.
PSM = prespawn mortality.

Benthic Invertebrates

Benthic index scores:

10–16	*very poor*
18–26	*poor*
28–36	*fair*
38–44	*good*
46–50	*excellent*

Benthic index (B-IBI) data have been collected at seven sites in the Piper's Creek watershed since 1996. Overall, index scores for the system range from 10 to 30 (i.e., very poor to fair), and scores vary significantly among different parts of Piper's Creek and its major tributaries (Table 35). Lower Piper's Creek had the lowest average score (14.8, very poor). No intolerant individuals were found, and the percentage of dominant taxa was quite high (68 to 96 percent of each sample was dominated by three taxa or fewer), indicating low species diversity (see Appendix C). For example, most of the sample in lower Piper's Creek in 2003 was composed of black fly larva and midges, both pollution-tolerant species.

Upper Piper's Creek was sampled both downstream and upstream of the twin pipes stormwater outfall and exhibited a benthic index range of 10 to 26 and an average score of 18.5. The site upstream of the twin pipes (sampled once for a score of 26) had higher species diversity, with more predatory species, mayflies, stoneflies, and caddisflies than all other downstream sites, indicating better habitat conditions. The site downstream of the twin pipes had an average score of 16 over 3 years, representing a macroinvertebrate community that is severely degraded. This community appears to be influenced by high stream flows and degraded water quality from the twin pipes outfall.

Table 35. Piper's Creek average benthic index scores.

Reach	Site ID	Collection Sites	Years Sampled	Average B-IBI Score	Range
PI01[a]	PI05	Piper's main stem near mouth	1999–2001	12.7	10–16
PI01[a]	PI04	Piper's main stem U/S of K-weirs	1999–2000	12	12
PI01	PI01	D/S Piper's/Venema confluence	1996, 1998–2001, 2003, 2005	18	12–24
			Average for lower Piper's	15.5	10–24
PI03	PI03	Upper Piper's D/S of twin pipes	1999–2001, 2003, 2005	17	10–22
PI04	PI02	Upper Piper's U/S of twin pipes	1999–2001, 2003, 2005	25	24–26
			Average for upper Piper's	19.7	10–26
PI01.VE01	PV01	Venema D/S Carkeek Park Rd	1996, 1998–2001, 2003, 2005	24.4	22–30
PI01.VE02	PV02	Venema near Mohlendorph	1998, 2005	23	22–24
			Average for Venema	24	22–30
			Average for System	19	10–30

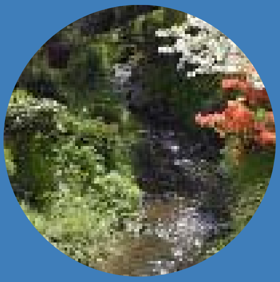
[a] Discontinued sample sites. U/S = upstream, D/S = downstream.
Most samples had low counts; samples were included if they contained >335 individuals.
Source: SPU benthic index of biotic integrity data 1994–2004.

The number of individuals collected in an invertebrate sample influences the number of taxa counted because the more individuals collected, the higher probability of detecting a new taxon. To accurately measure taxa richness, a 400-count sample is preferred.

Venema Creek had an average benthic index score of 24 (in a range of 22 to 30), comparable to conditions above the twin pipes stormwater outfall and significantly higher than the scores in lower Piper's Creek and downstream of the twin pipes. The scores for Venema Creek represent higher overall numbers of stoneflies and clingers, and greater species diversity, than those found on the main stem of Piper's Creek. However, abundance was typically low in the samples. The samples also contained more degradation-tolerant midges and a degradation-tolerant stonefly (the common forest fly, *Zapada cinctipes*).

The benthic community in the Piper's Creek watershed overall is dominated by species that tolerate degraded conditions. Venema Creek and upper Piper's Creek above the twin pipes outfall scored significantly higher than the remainder of the watercourse, although none of the benthic sampling sites in the watershed attained average index scores above the poor category. Reduced riparian and instream habitat complexity, degraded water quality conditions, and high flows likely contribute to the low benthic index scores.

In addition, the steep gradients of its many tributaries and its easily eroded sediments make Piper's Creek especially prone to deposition of fine sediments that reduce the productivity of the benthic community in the watercourse. Due to the high frequency of landslides and bank erosion, the benthic community may not have sufficient time to recover its numbers before another disturbance occurs. As with other watercourses in Seattle, while instream conditions in Piper's Creek may have improved in recent years and may be capable of supporting additional benthic species, there are concerns about the ability of other (desirable) invertebrate species to migrate to and recolonize Piper's Creek, given the general lack of healthy benthic communities in and around Seattle-area watercourses.



Taylor Creek

Taylor Creek Key Findings

Similar to Fauntleroy Creek and Piper's Creek, Taylor Creek contains high-quality areas within protected park lands, with lower-quality habitat in residential areas (Figure 24). Several characteristics in the Taylor Creek watercourse are critical to its relatively good physical and biological conditions:

- *Flows are moderated* by the west fork wetland, which stores water during storm events and controls its release to downstream areas.
- *Erosion-resistant sediments* characterize the streambed through Lakeridge Park, providing the foundation for relatively stable channel conditions compared with other Seattle watercourses that contain erosion-prone substrates.
- *Good floodplain connections, instream structure, and riparian forest* in Lakeridge Park help to accommodate increased flows and local landslides, store sediment, stabilize stream banks, and create instream diversity.

Taylor Creek also has areas where its ability to function are seriously impaired:

- *Altered hydrology* induced by upland plateau development has increased the 2-year storm event runoff fivefold over predevelopment conditions, despite the flow control benefits provided by the west fork wetland. High and flashy flows cause streambed and bank erosion, along with flooding, within the lowest portions of the watercourse.
- *Fish passage barriers* near Rainier Avenue South prevent migratory salmon from using about 93 percent of the potential habitat within the watercourse, including high-quality habitat within Lakeridge Park.
- *Floodplain connections and riparian forest* are lacking downstream of Lakeridge Park. These conditions prevent the stream from forming diverse habitat or accommodating high-flow events, which often result in flooding on adjacent residential properties during storm events.
- *Benthic index of biotic integrity (B-IBI) scores* indicate poor conditions (averaging 19 and ranging from 10 to 22), despite good habitat conditions within Lakeridge Park.
- *Low benthic index scores* suggest that water quality, physical habitat, or instream flows may be contributing to degraded benthic communities, despite relatively good riparian and instream habitat conditions.

No water quality data are available for this watercourse.

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Unique Conditions

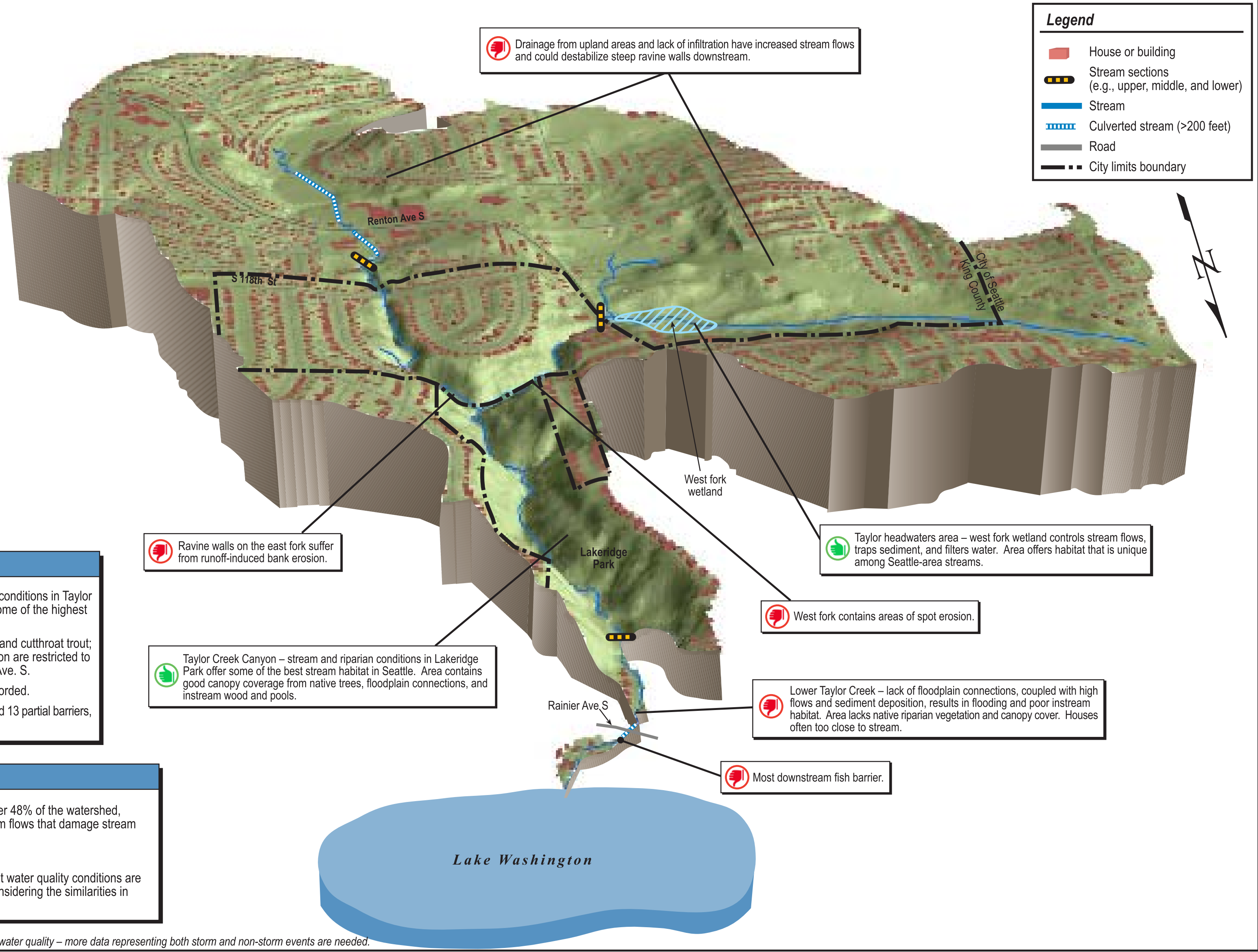
- Relatively small watershed (1 mi^2).
- Two major branches, with 1 small tributary.
- Large portion is contained within Lakeridge Park.
- Mostly residential land uses.
- Drains to Lake Washington.

Stream Biota

- Benthic index of biotic integrity (B-IBI) indicates poor conditions in Taylor Creek (average score 19), even though it contains some of the highest quality habitat in Seattle.
- Stream contains coho and sockeye salmon; rainbow and cutthroat trout; threespine stickleback; and 3 kinds of sculpin. Salmon are restricted to a very small area of stream, downstream of Rainier Ave. S.
- Coho prespawning mortality rates have not been recorded.
- Stream contains 7 complete barriers to fish passage and 13 partial barriers, limiting usable anadromous fish habitat to 600 feet.

Watershed Conditions*

- Buildings, roads, and other impervious surfaces cover 48% of the watershed, substantially increasing stormwater runoff and stream flows that damage stream habitat.
- Stormwater outfalls average 6.7 per stream mile.
- No water quality information available. It is likely that water quality conditions are similar to those of Fauntleroy and Piper's creeks, considering the similarities in watershed land uses.



Drainage from upland areas and lack of infiltration have increased stream flows and could destabilize steep ravine walls downstream.

Ravine walls on the east fork suffer from runoff-induced bank erosion.

Taylor headwaters area – west fork wetland controls stream flows, traps sediment, and filters water. Area offers habitat that is unique among Seattle-area streams.

West fork contains areas of spot erosion.

Taylor Creek Canyon – stream and riparian conditions in Lakeridge Park offer some of the best stream habitat in Seattle. Area contains good canopy coverage from native trees, floodplain connections, and instream wood and pools.

Lower Taylor Creek – lack of floodplain connections, coupled with high flows and sediment deposition, results in flooding and poor instream habitat. Area lacks native riparian vegetation and canopy cover. Houses often too close to stream.

Most downstream fish barrier.

*Note:Information here is based on limited data for stream flow and water quality – more data representing both storm and non-storm events are needed.

Figure 24. Current conditions of Taylor Creek

The Taylor Creek Watershed

Taylor Creek (photo by Bennett)

Taylor Creek is located in the southeastern corner of Seattle and originates in the Skyway area of unincorporated King County. The watershed is relatively small, covering an area of 627 acres, or 1 square mile. The watercourse is approximately 2.7 miles in length, with 3,800 feet (0.7 miles) in the main stem and over 10,400 feet (2 miles) in tributaries divided almost equally between two forks.

Similar to Fauntleroy Creek and Piper's Creek, the Taylor Creek watershed has three distinct zones: a rolling upland plateau, a steep forested ravine located within a park, and a relatively flat lower plain. The west and east forks of Taylor Creek originate on the upland plateau, then increase in gradient as they flow to their junction in Lakeridge Park (which contains most of Dead Horse Canyon). The main stem of Taylor Creek runs through Lakeridge Park before emerging into a low-gradient residential area and discharging to Lake Washington. Below Rainier Avenue South, the watercourse crosses the former Lake Washington lake bed (which was under water before the lake level was lowered with construction of the Lake Washington Ship Canal) and terminates at a small delta at the current lake edge.

The underlying geology of the Taylor Creek watershed is dominated by dense, erosion-resistant soils, which are important in controlling the condition of the stream (Stoker and Perkins 2005). The upland plateau is underlain by silt, clay, sand, and gravel mixtures with low permeability and low infiltration capacity, which can cause rapid surface water runoff and erosion where surface soils have been removed (Troost et al. 2003). However, these sediments and a portion of the deposits within the stream ravine tend to be hard and dense, and therefore fairly resistant to erosive forces. The stream ravine also contains some valley wall deposits that are susceptible to landslides, which are an important source of sand and gravel deposited as alluvium in the stream channel (Stoker and Perkins 2005).

During the late 1800s and early 1900s, the forested watershed of Taylor Creek was a key location of timber harvest, supporting a lumber mill near the stream mouth during that time. A small community developed near the mill to house the workers and loggers (Trotter 2002). Development near the stream mouth continued during the 1940s and expanded into other areas of the watershed, particularly those areas draining to the east fork of the stream. Areas draining to the west fork developed primarily between 1940 and 1970, although some areas are still being developed today. These development patterns have been dominated by residential land uses (greater than 50 percent; Figure 25, Map 28). Nonresidential land in the basin consists mostly of park or vacant lands (21 percent), or transportation and utility uses (18 percent roads, parking, and rights-of-way). Only a small area of the watershed contains commercial and industrial land uses (8 percent). Nearly three-fourths of the watercourse channel length is located within vacant land, park land, or preserved lands.

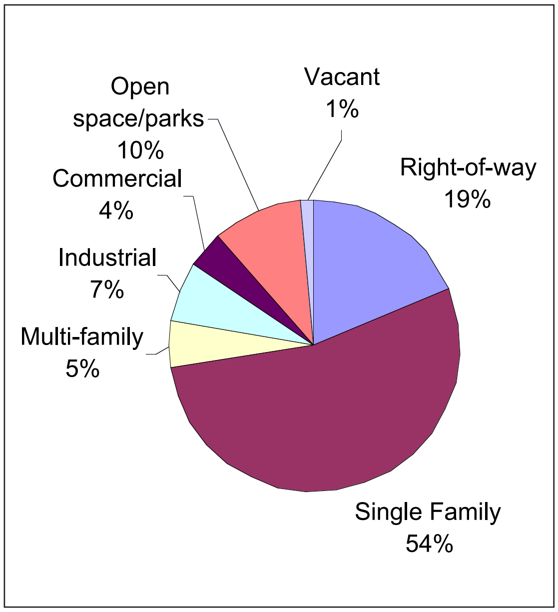


Figure 25. Land uses in the Taylor Creek watershed.

Based on the land use composition in the watershed, it is estimated that 48 percent of the Taylor Creek watershed is covered by concrete, asphalt, and other impervious surfaces. These impervious surfaces limit stormwater infiltration and typically result in larger amounts of surface water runoff to the watercourse or the formal storm drainage system. Within the areas drained by the formal drainage system in the Taylor Creek watershed, there is 58 percent coverage by impervious surfaces. The east fork of the watercourse contains the highest amount of impervious surfaces (66 percent).

In areas with formal drainage systems, stormwater runoff enters a pipe or ditch and is quickly carried to a watercourse, causing large amounts of water to be discharged to the watercourse over a short time period.

Watershed-Scale Conditions

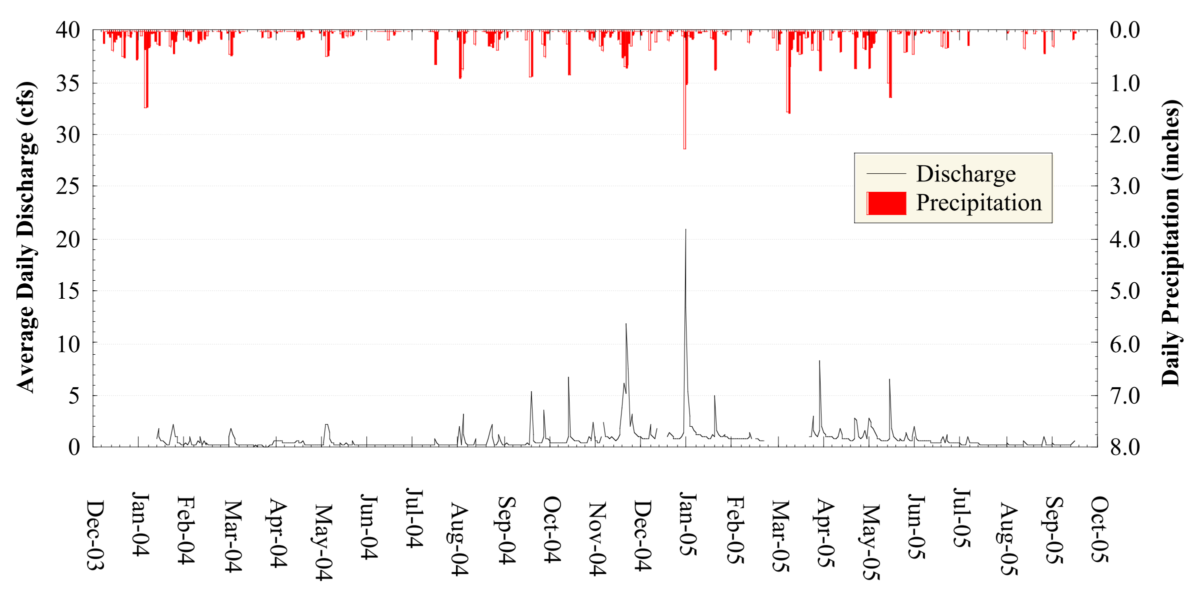
Taylor Creek Hydrology

A 2-year storm event occurs every 2 years on average, or has a 50% chance of occurring any given year.

Taylor Creek, which flows year-round, has a limited period of record for flow data, from February 8, 2004 to December 8, 2005 (Figure 26). The mean daily flow over the period of record was 0.65 cubic feet per second (cfs), measured at the gauge near the mouth of Taylor Creek. The peak flow over this period was 104.8 cfs (15-minute peak flow), 17.86 cfs (mean daily peak flow); the 7-day low flow was 0.1 cfs. Model-based peak discharge estimates for the mouth of Taylor Creek range from roughly 100 cfs for the 2-year storm event, to 130 cfs for the 25-year storm event, to over 200 cfs for the 100-year storm event. (The King County Runoff Time Series [KCRTS] hydrologic model was used with low confidence in results due to the lack of flow data [King County 1998; Hartley and Greve 2005].)

Urban development in the Taylor Creek watershed has altered the timing and quantity of stormwater runoff; modeling results indicate that the magnitude of the 2-year storm event runoff has increased approximately fivefold compared to predevelopment conditions (Hartley and Greve 2005).

Taylor Creek receives stormwater from 21 storm drains (6.7 outfalls per watercourse mile). Stormwater runoff predictions show that the upland plateau area of the watershed, which delivers water to the east and west forks of Taylor Creek, has the highest potential to contribute large storm flows to the watercourse quickly (Map 31 in the map folio accompanying this report). The west fork wetland receives water from eight subcatchments, two of which are relatively large (60 to 90 acres). The east fork receives water from ten outfalls, two of which drain subcatchments exceeding 30 acres. No combined sewer overflow outfalls discharge to the watercourse.



Note: Data provided here have been reviewed at a screening level. These data may be subject to significant change and are not citeable until reviewed and approved. Each station record is considered provisional until the data are reviewed and approved.

Figure 26. Taylor Creek mean daily stream flow from February 2004 to December 2005, measured near the mouth.

The low permeability of the deposits underlying the upland plateau, coupled with the large size of the plateau subcatchments (averaging collectively over 20 acres) compared to those in the lower watershed (with an average size of 5 acres), are expected to produce greater stormwater runoff than areas lower in the watershed. However, because the subcatchment sizes overall are relatively small compared to other Seattle watersheds, flows are expected to exhibit significant increases only at the confluence of the east and west forks. Downstream channel conditions suggest that increases in stream flows from west fork watershed development are mitigated, at least in part, by the west fork wetland located just upstream of Renton Avenue South (Stoker and Perkins 2005). Future development is expected within this watershed, and development impacts are projected to increase stormwater runoff peak flows by about 14 percent (King County 1998).

Taylor Creek Water Quality

Water and sediment quality in Taylor Creek have not been characterized. However, given the urbanized conditions in the watershed, Taylor Creek water quality is expected to be comparable to conditions in other urban watercourses in Seattle. The Taylor Creek watershed is similar to Piper's Creek, with a largely developed upper portion and a protected natural stream channel at the downstream end of the system. Therefore, Taylor Creek water quality conditions are expected to be most similar to those in Piper's Creek, rather than Longfellow Creek or Thornton Creek. Based on this assumption, water quality conditions in the watercourse are expected to be fairly good, with the exception of fecal coliform bacteria levels. Because of the dense urban development in the upper watershed, the watercourse likely has elevated levels of fecal coliform bacteria, particularly during storm flow conditions. Overall, there is insufficient information to identify water or sediment quality problems.

Stream-Scale Conditions

The topography of the Taylor Creek watershed is dominated by ravines that extend over a mile into the upland plateau. The stream has been gradually cutting into the plateau ever since the last glacier retreated 10,000 years ago. Prior to human disturbance, erosion rates were probably somewhat high as the stream cut into glacially deposited sediments and landslides widened the steep ravine walls. However, today the gravel supply is somewhat moderated by the erosion-resistant glacial deposits in the watershed (Stoker and Perkins 2005). These erosion-resistant deposits, which are highly consolidated and contain very little sand, are responsible for the relative stability in the Taylor Creek watercourse, contrasting greatly with conditions found in the Piper's Creek and Fauntleroy Creek watersheds.

Today, the upper east fork valley and middle walls of the main canyon are primary sources of sand and gravel. Landslides provide the largest amount of sediment to the watercourse, with other sediments introduced through erosion of the streambed (Perkins GeoSciences 2007). The main canyon represents the steepest portions of the channel (between 4 and 8 percent gradient), while the upper portions of the east and west forks and the main stem near the mouth have lower gradients, below 4 percent (Map 30).

Watercourses are divided into reaches, reaches are divided into segments, and segments are divided into sections.

For this discussion, the watercourse is divided into four reaches, with varying gradient, channel conditions, and habitat. Watercourse codes, shown on the watercourse maps, consist of two letters of the watercourse name (TA for Taylor) and the number of the stream segment, starting with 01 at the mouth and increasing in the upstream direction:

- East fork of Taylor Creek (TA05.EF03–TA05.EF01)
- West fork of Taylor Creek (TA05.WF03–TA05.WF01)
- Taylor Creek Canyon (TA05–TA03)
- Lower Taylor Creek (TA02–TA01).

East Fork of Taylor Creek (TA05.EF03–TA05.EF01)

The headwaters of the east fork of Taylor Creek are located on an upland plateau in Skyway Park (in unincorporated King County). The east fork flows for 4,350 feet, or 31 percent of the total watercourse length, before converging with the west fork in Lakeridge Park. Historically this relatively flat area contained a series of forested wetlands that stored and filtered water before controlling its release downstream. These conditions regulated the flow, temperature, and nutrients delivered to downstream areas (Seattle 2005). Today, wetlands on the upper plateau have been replaced by fill that is drained by a mostly piped watercourse section, and the open stream channel suffers from channel erosion and a lack of structure.

While the east fork upstream of Lakeridge Park has not been well surveyed, a 1999 stream typing survey reported potentially good habitat in the valley, extending to South 116th Street (Washington Trout 2000). Houses are sited along the top edges of ravines and do not physically encroach on the ravine (Map 33). The forested riparian corridor provides canopy cover and brushy undergrowth, although much of the understory is dominated by nonnative species such as Himalayan blackberry and English ivy (Map 32).

Seattle Public Utilities (SPU) detailed habitat data on the east fork begin in the lower 500 feet of the east fork in Lakeridge Park, ending at the confluence with the west fork (TA05.EF01). That 500-foot segment is the focus of this discussion.

Riparian Habitat

The riparian corridor in the lower 500 feet of the Taylor Creek east fork has formed around the steep ravine surrounding the channel. The riparian community is dominated by a mixture of deciduous and coniferous forest that provides moderately dense canopy cover to the stream. Much of the understory is dominated by nonnative plants, particularly Himalayan blackberry and English ivy. Residential development is located on the plateau above the steep ravine, at least 100 feet from the stream. However, even with the lack of encroachment, the overall riparian quality is moderate (Maps 32 and 34).

Instream Habitat

Historically, this segment of the east fork of Taylor Creek provided steps and pools where wood debris and boulders trapped and stored sediment and created diverse stream habitat. Today this segment is a combination of plane-bed and step-pool channel types with gradients exceeding 8 percent. The valley narrows in this segment where the channel is moderately confined by the rising canyon walls (Map 30).

A culvert, 147 feet in length, divides this segment into two sections. The watercourse just above the culvert inlet is wide, having been disturbed by dredging of the gravel deposits. Above the culvert, the stream gradient increases to form step-pool and then cascade channel types (Map 31). The average active channel width ranges between 11 and 13 feet, with small, pocket floodplains used during high-flow events. The area shows some previous channel erosion, which appears to have been alleviated by placement of logs and concrete slabs as bed stabilization measures. The valley walls in this section and upstream are sources of stream sediment (i.e., sand and gravel), although no major landslides have been reported since the 1980s. Upstream of the surveyed segment, the channel appears to be entrenched, with a plane-bed channel type and eroding banks.

High flows have created a bypass channel that conveys backwater and storm flows around the culvert. Downstream of the culvert, the channel has been disturbed substantially by the effects of the culvert bypass channel, a stormwater outfall, a former wastewater line that runs down the streambed, and erosion of streambed and banks caused by the culvert discharge (Stoker and Perkins 2005). These influences have caused the channel to incise, prompting severe bank erosion that delivers mostly silt and sand to the stream. Due to channel incision, the stream does not maintain connections with the surrounding floodplain. Overall, the east fork is probably the largest source of sediment input to Taylor Creek, originating from landslides and erosion of the streambed and banks (Stoker and Perkins 2005).

The overall habitat quality of the surveyed 500-foot segment of the east fork reach is moderate (Map 34). Although the stream suffers from incision and erosion, there are beneficial characteristics of the instream habitat, encroachment level, and riparian quality. The open channel contains 70 percent riffle and 30 percent pool habitats, with the pool-to-riffle ratio approaching 1-to-2 (a 1-to-1 ratio is ideal; Map 32).

West Fork of Taylor Creek (TA05.WF03–TA05.WF01)

Taylor Creek (photo by Bennett)

The west fork of Taylor Creek is 4,670 feet in length, or 0.9 miles, from the headwaters to the confluence with the east fork, constituting 30 percent of the total watercourse length. The west fork also has one branched tributary that is 1,370 feet in length. The spring-fed headwaters of the west fork originate in Seattle but pass into unincorporated King County before flowing back inside the city limits. The west fork is similar to the east fork in originating on the upland plateau, where historically it was contained in forested wetlands that detained and controlled stream flows, water temperatures, and nutrients. In contrast to the east fork, the west fork has retained a large wetland area upstream of where the channel increases in gradient and enters Lakeridge Park.

Riparian Habitat

The west fork is dominated by a forested and shrub wetland of about 12 acres located at the junction of the west fork with its tributary, just upstream of Renton Avenue South. The wetland is surrounded by deciduous and coniferous trees that contribute woody debris to the wetland and the stream channel (Kidder 2003). The wetland and stream are well-shaded by the tree canopy, although pockets of Himalayan blackberry dominate the understory along Renton Avenue South (Maps 32 and 34). Encroachment by roads, buildings, and other structures is relatively low in the wetland area, where most of the structures are located more than 100 feet from the stream (Map 33). Planned development on the wetland's tributary could affect the hydrology and habitat quality of the west fork wetland.

Within Dead Horse Canyon, downstream of Renton Avenue South, the riparian conditions are mixed. The upstream portion of this segment, immediately downstream of Renton Avenue South, is dominated by nonnative species and landscaping; however, the mixed, mostly deciduous canopy provides some cover and contributes woody debris to the stream. The riparian habitat in this section is considered of moderate quality. Residences line the stream ravine, typically at least 75 feet from the stream (Map 33).

Closer to the junction with the east fork, the west fork riparian corridor improves in habitat quality. The corridor contains deciduous and coniferous forest and a mostly native understory (Map 32). The mixed tree canopy provides full stream cover and contributes woody debris to the stream channel. Houses and roads are located at least 100 feet from the stream through this segment, and in some sections the riparian forest extends more than 200 feet before reaching residential neighborhoods.

Instream Habitat

The 4,670 feet of the Taylor Creek west fork channel contains the only sand-bedded section in Taylor Creek and represents the largest remaining headwater wetland in the five major Seattle watersheds (Seattle 2005; Stoker and Perkins 2005). The west fork wetland plays an important role in regulating downstream flow and sediment transport by providing detention and storage of high flows and sediments (Stoker and Perkins 2005). The wetland also provides high-quality habitat, and the channel in this area is stable and unentrenched (i.e., banks are less than one foot high), with good connection to the floodplain (Stoker and Perkins 2005).

Downstream of Renton Avenue South, flow from the west fork enters Dead Horse Canyon where the gradient increases, promoting a step-pool channel (TA05.WF02–TA05.WF01). Due to the high gradient ranging from 3 to 8 percent, this segment acts as a transport reach for sediment (Stoker and Perkins 2005; Seattle 2005). Boulders, large woody debris, and wood jams at the upstream and downstream portions of this segment provide pools (13 percent) interspersed with riffle habitat (87 percent), providing instream complexity and stabilizing the channel (Map 32). The channel also maintains connections with a narrow floodplain (Stoker and Perkins 2005). As a result, the instream habitat quality in this watercourse segment is ranked high (Map 34).

The middle portion of the west fork canyon, however, contains little structure and exhibits a mostly plane-bed channel type. Bank erosion and landslides appear to contribute small amounts of silt, sand, and gravel to the stream through this middle portion (Stoker and Perkins 2005). Throughout this segment, the channel has only slightly incised into the canyon floor, indicating that resistant geologic deposits, sufficient bed controls in the form of boulders and logs, and floodplain connections are combining to withstand high stream flow effects. The stream flow control provided by the west fork wetland also contributes to the stability of the west fork canyon (Stoker and Perkins 2005).

Taylor Creek Canyon (TA05–TA03)

After the west and east forks meet, the water of Taylor Creek flows 2,350 feet or 0.44 miles (23 percent of the total channel length) through Dead Horse Canyon. The channel gradient ranges from 3 to 7 percent, and the watercourse is naturally confined by a narrow valley, particularly in the middle segment.

Riparian Habitat

Lakeridge Park protects the stream from encroachment in this reach, resulting in high-quality riparian habitat. The riparian area is predominantly a mixture of deciduous and coniferous canopy with native understory vegetation (Map 32). In many places, the riparian area extends more than 200 feet from the stream before reaching houses and streets, although the downstream segments of this reach contain some bank armoring (Map 33). The riparian forest provides intermittent cover for the stream, as well as woody debris to be used for forming instream habitat. No invasive plants were reported along the stream through this segment.

Collectively, these conditions provide high-quality riparian habitat along this reach of Taylor Creek, which is among the highest-quality riparian areas found within all Seattle watercourses.

Instream Habitat

The channel gradient prompts forced pool-riffle and step-pool channel types, with instream wood and plane-bed channels where these elements are absent (Map 30; Seattle 2005). The channel shows high stability with little streambed or bank erosion (Map 31). The active channel ranges between 15 and 8 feet in width, with sufficient space to form in-channel gravel bars (Stoker and Perkins, 2005). The majority of this reach contains boulders, large log steps, and logjams that provide the expected pool-riffle and step-pool structure and grade control.

Some segments of the canyon reach exhibit minor problems; for example, the upper canyon segment contains fewer wood steps and thus has rare spots of exposed glacial substrate, some unstable banks, and sections of simple riffle habitat. The middle segment of the canyon reach, which is more naturally confined than other segments, experiences increased erosion of the valley walls and stream banks. The lower segment suffers from past incision, although the addition of large woody debris in 2002 is acting to build the streambed by trapping sediment. Based on the instream structure and floodplain connections, this reach of Taylor Creek could probably accommodate increased runoff anticipated with future development, without significant increases in channel erosion (Stoker and Perkins 2005).

Dead Horse Canyon has the highest-quality habitat in Taylor Creek; it is among the highest-quality habitat in major Seattle watercourses (Map 34). Pools are relatively abundant, created by the large woody debris and boulder steps, some from restoration projects (Maps 32 and 36). Pools make up about 16 percent of the linear stream length, with a median residual depth of 0.75 feet and a 1-to-5 pool-to-riffle ratio. The pools, although mostly small step pools, are of high quality, offering cover and complexity. The woody debris also creates a number of side pools within the system, adding to instream diversity, although additional instream structure would further improve the habitat.

Lower Taylor Creek (TA02–TA01)

The lowest reach of Taylor Creek begins along the eastern edge of Lakeridge Park, downstream of Holyoke Way South, and emerges in a residential neighborhood on the shore of Lake Washington. The gradient decreases in this reach from 4 percent to 2 percent as the watercourse emerges from Dead Horse Canyon into a wide valley and across the former lake bed of Lake Washington. Conditions differ radically upstream and downstream of the 68th Avenue South road crossing.

Riparian Habitat

Riparian conditions change dramatically downstream of Lakeridge Park. The forested riparian conditions within the park continue through the upper segment of this reach (TA02), but the understory is overrun by nonnative plants, particularly Himalayan blackberry. Blackberry tends to be concentrated near culverts and at road crossings, as well as areas with intermittent canopy cover. In this segment, roads, culverts, and associated bank armoring encroach into the riparian corridor, although no houses are located within 100 feet of the stream. Due to the invasive plants present and areas of low canopy coverage, the riparian habitat is considered low quality (Map 34).

Downstream of the 68th Avenue South road crossing, riparian conditions are similarly of low quality. Here the riparian corridor contains an intermittent tree canopy and an understory consisting of a mixture of lawn and landscape shrubs. Numerous houses and roads encroach upon the stream through this segment, leaving as little as 15 feet between the stream bank and adjacent houses in some locations. In addition, the watercourse runs underneath houses in culverts in some places.

Instream Habitat

Gradient and valley conditions should shape a slightly meandering, forced pool-riffle channel in this reach (Seattle 2005). The upper segment of lower Taylor Creek (TA02) is characterized by a sediment fan, created at some point in the past when large landslides from the valley walls deposited debris at the downstream end of the canyon. Through time, the watercourse has worked to cut through these deposits, although construction of roads adjacent to the stream and across it has interfered with its function in this area.

Taylor Creek near 68th Street (photo by Bennett)

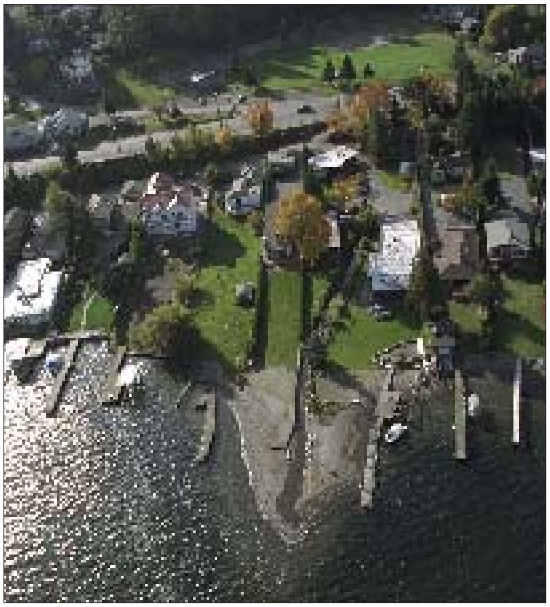
The Holyoke Way South road crossing was built on landslide deposits in 1919. Originally the culvert under the road embankment was undersized, causing sediments to deposit upstream of the culvert. This upstream deposition starved the stream of sediment downstream of the Holyoke culvert, causing the stream to incise. Another culvert under 68th Avenue South created similar sediment problems, although the upstream Holyoke Way culvert did not allow much sediment to reach this downstream culvert from upstream areas. Both culverts were replaced with larger culverts in 1999, and the section of the watercourse between them was augmented with log weirs and rootwads to promote sediment storage and elevate the streambed.

The upper watercourse segment (TA02) has been dynamic since the two culverts were replaced. Above Holyoke Way South, where sediment had been deposited since 1919, the channel and stream banks began to erode, transporting sediment downstream. Erosion continued for several years until existing boulders and added large wood debris created stability in this watercourse section. The streambed has coarsened, containing large gravel and small cobbles. The enhancement efforts in this reach have created moderate instream habitat quality (Map 34). Formerly a plane-bed channel, the enhanced area now contains riffles (84 percent) and pools (16 percent), with a pool-to-riffle ratio of 1-to-5 (Map 32). Downstream, a wide, braided channel has formed between the culverts, occupying the entire narrow floodplain (17 feet in width).

Encroachment on riparian area along Taylor Creek (photo by Bennett)

Below the 68th Avenue South crossing, stream conditions change dramatically (TA01). The surrounding land is relatively flat in this reach, and historically the stream had a meandering pattern and pool-riffle morphology (Seattle 2005). However, today this area is substantially altered by residential development as the watercourse runs through private yards close to buildings (Map 33). The channel is mostly armored (80 percent) and contains numerous bridge crossings (mostly driveways), with about one-third of the watercourse running through culverts. The channel has also been realigned and straightened. Collectively, these changes have resulted in an extremely narrow stream. The average active channel width has been reduced to 5 or 6 feet, compared with 15 to 18 feet in upstream reaches. Undersized driveway culverts and bridges in the upper portion of this reach, coupled with the narrow channel, promote flooding in adjacent areas.

Downstream of the Rainier Avenue South culvert, the channel drains through the historical stream delta that was covered by Lake Washington prior to construction of the ship canal (Trotter 2002; Stoker and Perkins 2005). Lowering of the lake level and subsequent development prompted bank armoring, channelization, and stream realignment, which have removed historical habitats from the stream and have placed the stream channel 2 to 5 feet below the ground surface in some areas. This segment of the watercourse is also prone to flooding due to the narrow channel and the depositional nature of the area. The deposition of stream sediment has recreated the Taylor Creek delta in Lake Washington at the mouth of the watercourse, which is an important habitat type for fish rearing in the lake (e.g., Chinook salmon; Tabor et al. 2006). Overall, this area has very low instream habitat quality (Maps 32 and 34).



Taylor Creek outflow in Lake Washington (photo courtesy Seattle Municipal Archives)

Use by Fish and Benthic Invertebrates

Fish Access

Historically, Taylor Creek probably had resident and adfluvial (lake migratory) cutthroat trout, as well as coho and kokanee salmon (Trotter 2002). Anadromous and adfluvial fish probably did not access the stream in the early part of the twentieth century due to the presence of a sawmill at the mouth of Taylor Creek and a dam that diverted about half the flow to supply the mill boilers (Trotter 2002). Today, the watercourse contains coho and sockeye salmon, rainbow and cutthroat trout, three-spine stickleback, and prickly, torrent, and coast-range sculpin (Lantz et al. 2006).

The most abundant salmon using Taylor Creek for spawning is sockeye. On average, about 19 adults use the watercourse each year, although adult returns range from zero to 32 sockeye per year, based on carcass counts from 1999 through 2005 (Table 36). Coho adults use the watercourse for spawning in lower numbers, with very few fish recorded each year. Other adult salmon do not use Taylor Creek, because it is too small for Chinook, and chum and pink salmon are not typically found within Lake Washington tributaries. However, juvenile Chinook have been documented a short distance upstream of the mouth, in the delta area and along the adjacent lakeshore. Only three juvenile Chinook salmon have been observed in the watercourse, and these were limited to the area of the channel that was under the backwater influence of Lake Washington.

Table 36. Taylor spawning survey results based on carcass and redd counts.

Year	Chinook [a]		Coho		Sockeye		Chum [a]	
	Carcasses	Redds	Carcasses	Redds	Carcasses	Redds	Carcasses	Redds
1999	–	–	0	0	0	0	–	–
2000	–	–	0	0	28	6	–	–
2001	–	–	2	5	25	2	–	–
2002	–	–	4	1	32	2	–	–
2003	–	–	1	1	7	0	–	–
2004	–	–	0	0	32	4	–	–
2005	–	–	0	0	6	3	–	–

[a] Chinook and chum salmon do not use Taylor Creek as the stream is too small to allow for spawning activities, although juvenile Chinook might use the delta area. Chum salmon are very rare in the Lake Washington basin.

Sources: McMillan (2005); SPU unpublished data. Values in table are averaged between the two data sources.

Sockeye and coho salmon are able to access only the 580-foot segment of Taylor Creek downstream of Rainier Avenue South (representing only 16 percent of potentially suitable habitat in the watercourse; Washington Trout 2000; Map 35). Few coho redds are found each year, mostly concentrated within 250 to 300 feet upstream of the mouth in an area that offers some gravel and shallow pools. Sockeye salmon appear to spawn mostly along the lakeshore at the mouth of the watercourse, although adult sockeye have been observed 250 feet upstream (McMillan 2007).

Like salmon, adfluvial trout are limited to habitat downstream of Rainer Avenue South. Resident cutthroat trout have been observed in Taylor Creek as far upstream as the fish passage barrier at Renton Avenue South on the west fork (Lantz et al. 2006). Currently, resident trout appear to be the only fish able to use the high-quality habitat within Lakeridge Park. However, the barriers at Rainier Avenue South are planned for removal in the next few years.

Smolt trapping is not conducted on Taylor Creek, and the productivity of the watercourse has not been studied. Few coho return to the watercourse, on average, with no coho adults in the watercourse since 2003, limiting any assessment of coho prespawn mortality. Prespawn mortality may be occurring in sockeye, although most of the adult sockeye in Taylor Creek have been males (85 of 92 carcasses were males), limiting the ability to determine spawning condition (McMillan 2007).

Low benthic index (B-IBI) scores in Taylor Creek indicate that watercourse productivity could limit the success of any adult salmon using the watercourse (see Appendix C). However, compared to the other urban watercourses in Seattle, Taylor Creek contains abundant instream structure, which has formed pools throughout the park reaches. Pools are generally small and range from 0.5 to 1.3 feet in depth, but they could support rearing by small juvenile salmon and trout. Severe bank erosion in the upper watershed deposits fine sediments into the stream, which could also affect stream productivity.

Benthic Invertebrates

The number of individuals collected in an invertebrate sample influences the number of taxa counted because the more individuals collected, the higher probability of detecting a new taxon. To accurately measure taxa richness, a 400-count sample is preferred.

Benthic invertebrates were sampled at three sites in Taylor Creek, all within Lakeridge Park (Map 29). The upstream site near the pedestrian bridge (TA05) was discontinued in 2001 after 2 years. The site upstream of Holyoke Avenue South (TA01) in Dead Horse Canyon was sampled seven times between 1994 and 2004. The site between Holyoke Avenue and 68th Avenue South (TA03), chosen to show any change resulting from a stream restoration project undertaken by SPU in 1999, was sampled four times from 1999 to 2004. At each of the lower sites, in two of the years sampled, the total abundance of macroinvertebrates did not meet the threshold of 400 individuals needed to accurately describe the benthic community with a high level of confidence.

All three sites have benthic index scores in the poor range (Table 37). However, the average score for the system (18.9) is significantly higher than the averages for Thornton Creek, Longfellow Creek, and lower Piper's Creek. The three sites in Taylor Creek scored similarly despite important habitat differences among the sites. The two lower sites have been disturbed recently following culvert replacements and installation of log weirs in 1999, while the upper site is the least disturbed, with existing pool habitat and a connection to the floodplain.

Benthic index scores:

10–16	*very poor*
18–26	*poor*
28–36	*fair*
38–44	*good*
46–50	*excellent*

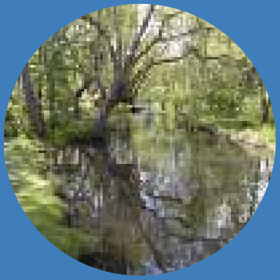
Table 37. Taylor average benthic index scores.

Reach	Site ID	Collection Sites	Number Years Sampled	Average B-IBI Score	Range
TA02	TA03	Between Holyoke & 68th	1999–2001, 2004	21	20–22
TA02/03	TA01	U/S Holyoke Avenue S	1994–1996, 1998–2002, 2004	17.6	10–22
TA05	TA02	Pedestrian bridge in park	1999–2000	20	18–22
			Average	18.9	10–22

U/S = Upstream.
Source: SPU benthic index of biotic integrity data 1994–2004.

The benthic macroinvertebrate community in Taylor Creek suffers from low species diversity, few predators, and a high proportion of degradation-tolerant species, resulting in poor benthic index scores. The degradation-tolerant species found included worms, freshwater amphipods, prong gill mayflies, small minnow mayflies, and *Hydropsyche* caddisflies. The moderately tolerant common forest fly was also found in Taylor Creek.

The low benthic index scores, for a sampling site within some of the best stream habitat found in Seattle watercourses, suggest that stream habitat is not as good as it appears, at least for supporting diverse benthic communities. It is not known whether factors such as poor water quality, poor habitat, erosive instream flows—or a combination of factors—are the major contributors to degraded benthic invertebrate communities. However, given the habitat conditions within Dead Horse Canyon, it appears that water quality or high flows may exert a larger influence on instream invertebrates. This segment of the watercourse also has good connection to the floodplain and instream structure, both of which should help to dissipate the energy of high flows, perhaps pointing to water quality as a larger cause of the low benthic index scores.



Thornton Creek

Thornton Creek Key Findings

As shown in Figure 27, Thornton Creek alterations and watershed development have led to relatively poor stream conditions, with few beneficial conditions that promote functioning stream habitat in the system:

- *Habitat restoration projects* have produced consistently higher instream and riparian habitat quality in several areas, by providing adequate channel structure to form hydraulic and instream complexity and promoting native riparian vegetation.
- *The north branch wetland and stream complex* downstream of the Jackson Park golf course has a wide floodplain with little encroachment and some of the best instream and riparian habitat in the watercourse.
- *Concentrations of toxic materials* (metals and ammonia) are relatively low under non-storm flow conditions, although 100 percent of 23 samples exceeded the human health criterion for total arsenic under non-storm flow conditions.

Thornton Creek has numerous problematic conditions:

- *Altered hydrology*, with high and flashy flows, has degraded instream habitat through bank and streambed erosion. Two-year storm event flows have increased three to four times over forested watershed conditions due to the presence of impervious surfaces and soils with low permeability.
- *Conventional water quality indicators* exceed water quality criteria. Fecal coliform bacteria exceeded the criterion for primary contact recreation (100 colony-forming units per 100 milliliters) in all of the last ten years (100–1,100 cfu/100 mL). Water temperatures and dissolved oxygen levels are problematic in summer months. From 1988 to 2005, temperatures and dissolved oxygen concentrations did not meet the state water quality criteria in 8 percent and 20 percent of samples, respectively.
- *Concentrations of nutrients* under non-storm flow conditions frequently exceed established benchmarks (100 percent exceedance for total nitrogen and 18 percent exceedance for total phosphorus).
- *Detectable levels of some pesticides* (including organochlorine pesticides) have been found in stormwater and sediment samples, although most concentrations were below reported toxic effect levels for aquatic organisms (pesticides were not analyzed for other watercourses).
- *Lack of floodplain connections and restricted channel width* impair the stream's ability to accommodate increased flows, leading to channel incision and degraded instream habitat.
- *Coarse sediment, instream wood, and riparian forest* are minimal. Erosion of the streambed and unarmored banks, coupled with the lack of wood to store sediment, has caused the channel to fill with fine sand and silt.
- *Adjacent lawns and nonnative landscaping* provide no shading, natural nutrients, or woody debris to the stream.
- *Fish passage barriers* on the watercourse branches limit anadromous fish to 30 percent of the watercourse length.
- *Benthic index of biotic integrity (B-IBI) scores* are poor, ranging between 10 and 20.
- *Coho prespawn mortality* rates are high, averaging 79 percent.

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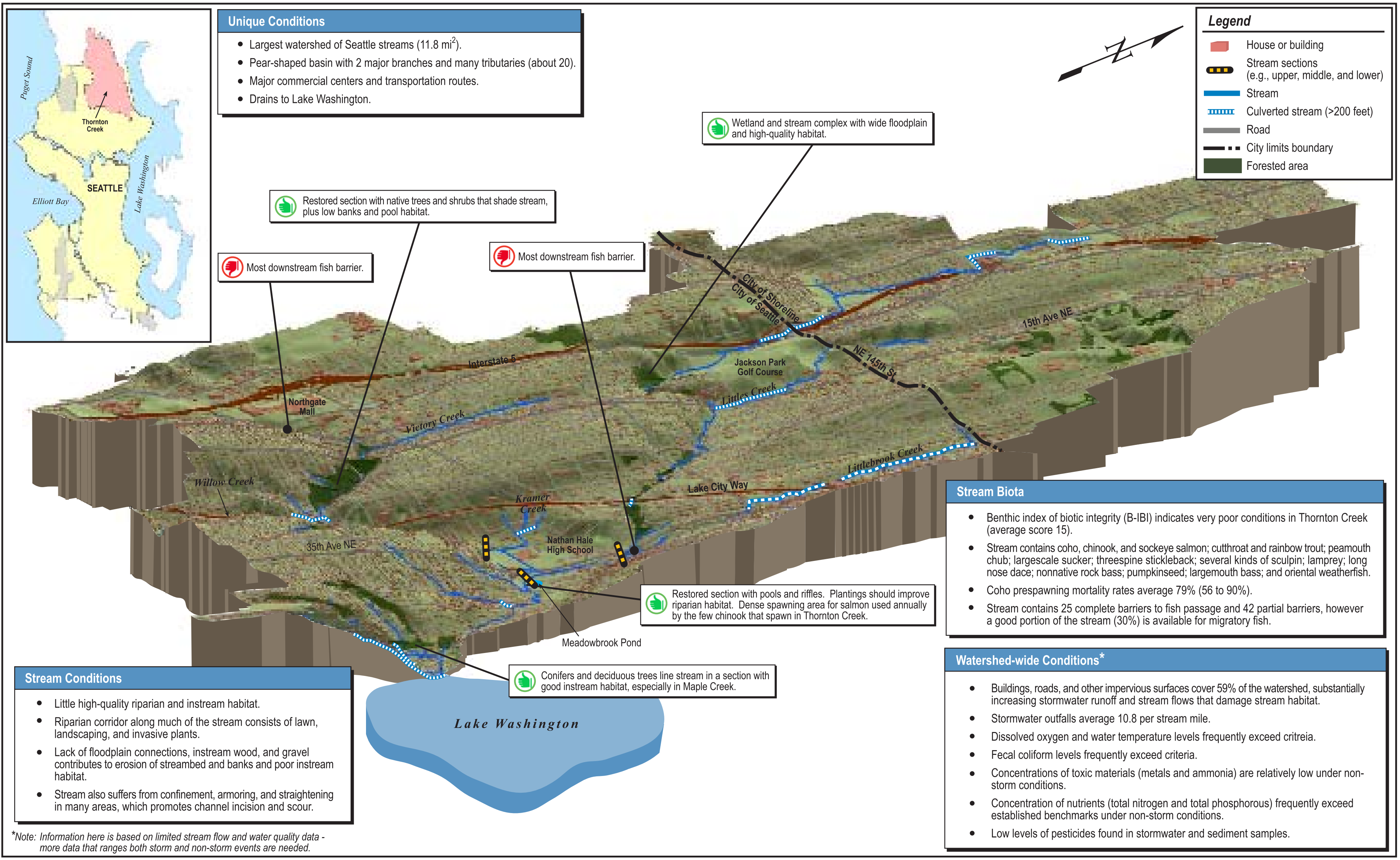


Legend

- House or building
- Stream sections (e.g., upper, middle, and lower)
- Stream
- Culverted stream (>200 feet)
- Road
- City limits boundary
- Forested area

Unique Conditions

- Largest watershed of Seattle streams (11.8 mi^2).
- Pear-shaped basin with 2 major branches and many tributaries (about 20).
- Major commercial centers and transportation routes.
- Drains to Lake Washington.

Restored section with native trees and shrubs that shade stream, plus low banks and pool habitat.

Most downstream fish barrier.

Most downstream fish barrier.

Wetland and stream complex with wide floodplain and high-quality habitat.

Restored section with pools and riffles. Plantings should improve riparian habitat. Dense spawning area for salmon used annually by the few chinook that spawn in Thornton Creek.

Conifers and deciduous trees line stream in a section with good instream habitat, especially in Maple Creek.

Stream Conditions

- Little high-quality riparian and instream habitat.
- Riparian corridor along much of the stream consists of lawn, landscaping, and invasive plants.
- Lack of floodplain connections, instream wood, and gravel contributes to erosion of streambed and banks and poor instream habitat.
- Stream also suffers from confinement, armoring, and straightening in many areas, which promotes channel incision and scour.

Stream Biota

- Benthic index of biotic integrity (B-IBI) indicates very poor conditions in Thornton Creek (average score 15).
- Stream contains coho, chinook, and sockeye salmon; cutthroat and rainbow trout; peamouth chub; largescale sucker; threespine stickleback; several kinds of sculpin; lamprey; long nose dace; nonnative rock bass; pumpkinseed; largemouth bass; and oriental weatherfish.
- Coho prespawning mortality rates average 79% (56 to 90%).
- Stream contains 25 complete barriers to fish passage and 42 partial barriers, however a good portion of the stream (30%) is available for migratory fish.

Watershed-wide Conditions*

- Buildings, roads, and other impervious surfaces cover 59% of the watershed, substantially increasing stormwater runoff and stream flows that damage stream habitat.
- Stormwater outfalls average 10.8 per stream mile.
- Dissolved oxygen and water temperature levels frequently exceed critreia.
- Fecal coliform levels frequently exceed criteria.
- Concentrations of toxic materials (metals and ammonia) are relatively low under non-storm conditions.
- Concentration of nutrients (total nitrogen and total phosphorous) frequently exceed established benchmarks under non-storm conditions.
- Low levels of pesticides found in stormwater and sediment samples.

*Note: *Information here is based on limited stream flow and water quality data - more data that ranges both storm and non-storm events are needed.*

Figure 27. Current conditions of Thornton Creek

The Thornton Creek Watershed

Mouth of Thornton Creek (photo by Bennett)

The Thornton Creek watershed is the largest drainage basin within Seattle, draining 7,120 acres, or 11.1 square miles. The watercourse headwaters are located in northeast Seattle and the City of Shoreline, flowing generally south and east before discharging to Lake Washington. The drainage system is the longest within Seattle, with nearly 20 miles of watercourse length contained in two main branches, the main stem, and 20 tributaries. Thornton Creek is substantially different from the other major watercourses, having a pear-shaped watershed reflecting its two substantial branches and their numerous tributaries (ten tributaries in the south branch, four in the north branch, and six in the main stem).

The north branch of Thornton Creek originates at the Ronald bog in the City of Shoreline and flows 5 miles southeast through Seattle's Jackson Park golf course and the Lake City Way commercial area. This branch drains 7 square miles, 60 percent of the watershed.

The south branch, also known as Maple Leaf Creek, drains a watershed of 3.8 square miles, 33 percent of the watershed. The south branch originally began in wetlands in the Northgate–North Seattle Community College–Interstate-5 area, but the headwaters were extensively filled during development of the area. Consequently, the south branch now begins near Park 6, just east of the Northgate shopping center, and flows 2.3 miles before joining the north branch.

The north and south branches converge just upstream of Meadowbrook pond near 35th Avenue NE and NE 107th Street. The main stem of Thornton Creek drains a small portion of the watershed (0.8 square miles, or 7 percent), and flows southeast approximately 1.4 miles before emptying into Lake Washington at Matthews Beach.

The underlying geology of the Thornton Creek watershed is heavily influenced by the Vashon glacier that once covered Puget Sound (Troost et al. 2005). Similar to other Seattle watersheds, the upland portions of the basin draining to Thornton Creek are dominated by Vashon till deposits, which are erosion-resistant, nearly impermeable to water, and typically are associated with rapid surface water runoff. Deposits underlying the stream corridor are variable, consisting of both unconsolidated sand and gravel deposits that are permeable to and easily eroded by flowing water, and dense combinations of sand, gravel, and silt that restrict infiltration and are slow to erode.

Areas of lake and wetland deposits that are nearly impermeable also occur within the watershed. Many areas adjacent to Thornton Creek have been filled to provide for buildings, infrastructure, and landscaped grounds (Stoker and Perkins 2005). These areas include the Interstate 5 corridor, arterial roads such as Lake City Way, large commercial developments such as Northgate on the south branch, residential areas, parking lots, and playfields such as Nathan Hale on the south branch and the Matthews Beach area at the watercourse mouth.

The Thornton Creek watershed is the most extensively developed of Seattle's five major watercourse basins. Historically the stream was heavily forested, until substantial logging began in 1882 (Trotter 2002). Urban growth coupled with railroad expansion improved the transport of lumber, and by 1910 most of the timber had been logged from the Thornton watershed (Trotter 2002). The subsequent development of the watershed occurred primarily between the 1920s and 1950s. By 1950, 80 percent of property parcels were developed, and development continued through the 1980s (King County 2005b). Today, 53 percent of the land use in Thornton Creek watershed is residential, 26 percent is dedicated to roads and rights-of-way, and 8 percent is commercial and industrial (Figure 28; Map 37 in the map folio accompanying this report). Only 9 percent of the watershed area is park land or vacant land (Alberti et al. 2004).

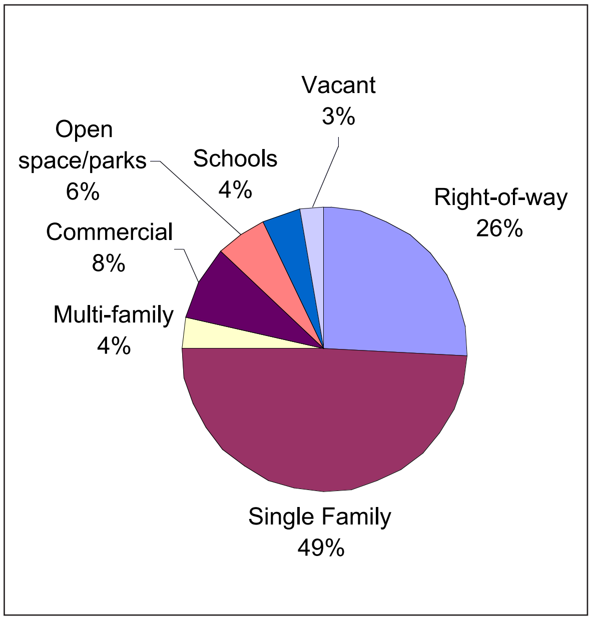


Figure 28. Land uses in the Thornton Creek watershed.

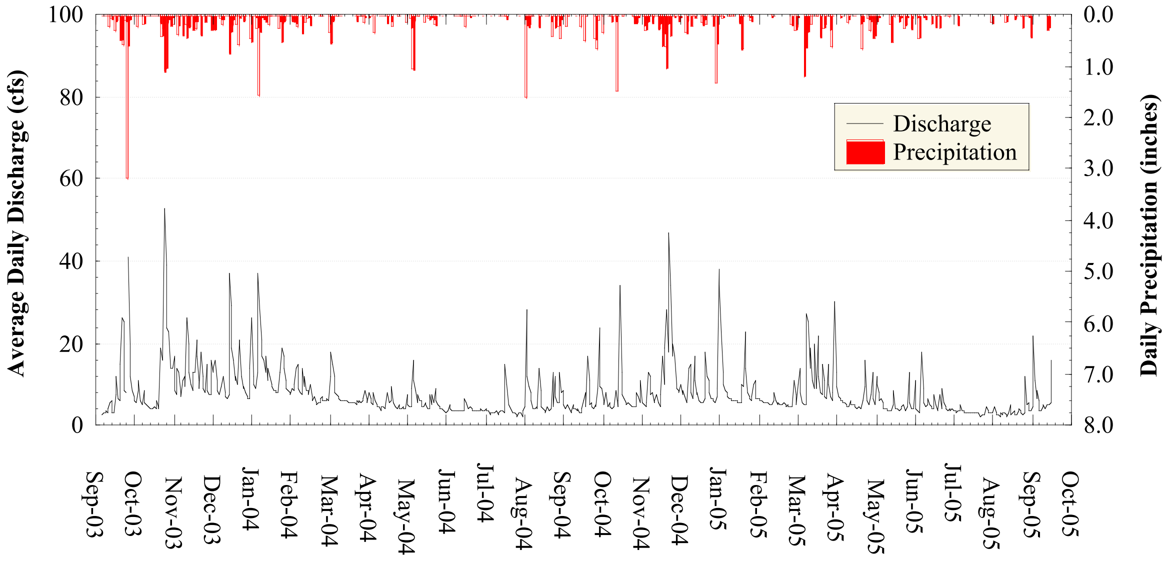
Fifty-nine percent of the Thornton Creek watershed is covered by impervious surfaces such as roads, buildings, and parking lots, which restrict infiltration of stormwater and increase the rate and volume of stormwater runoff. Sixty-two percent of the area served by formal stormwater drainage systems is covered by impervious surfaces. The south branch of the watercourse contains the highest amount of impervious coverage (65 percent), which is associated with the large commercial area at Northgate. Willow Creek, a tributary of the south branch, and the Thornton Creek main stem have the lowest degree of impervious coverage (50 percent and 54 percent, respectively).

In areas with formal drainage systems, stormwater runoff enters a pipe or ditch and is quickly carried to a watercourse, causing large amounts of water to be discharged to the watercourse over a short time period.

Watershed-Scale Conditions

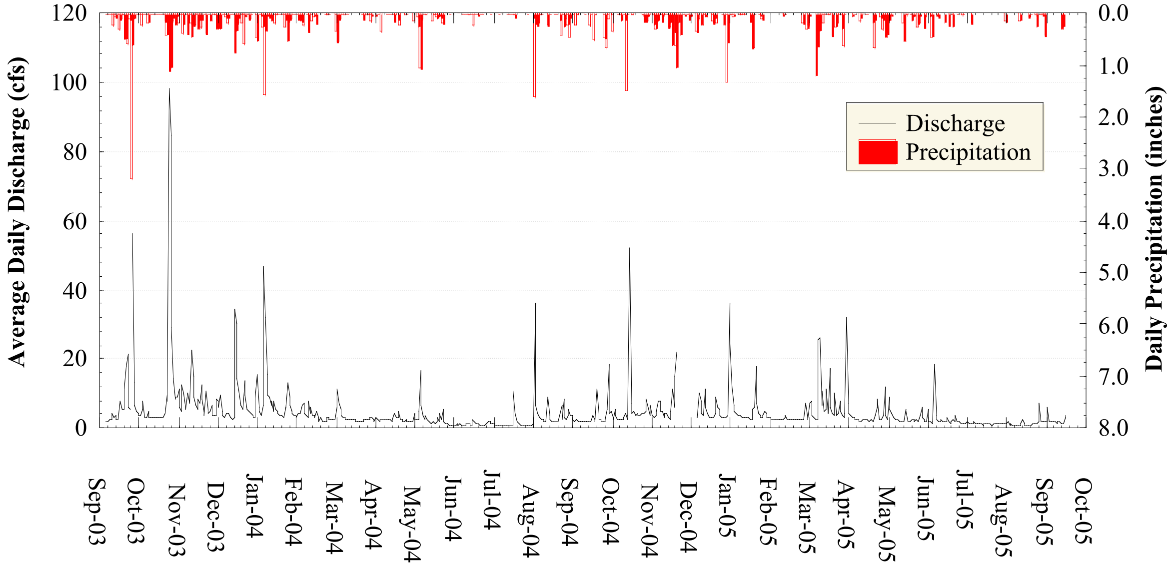
Thornton Creek Hydrology

Thornton Creek flows throughout the year, with mean annual flows of 13.0 and 12.1 cubic feet per second (cfs) for water years 2004 and 2005, respectively (measured at the mouth). The peak flows recorded for water years 2004 and 2005 were 539 cfs and 129.5 cfs, respectively (based on 15-minute data), and the 7-day low flows were 3.9 and 3.6 cfs, respectively (Figure 29; U.S. Geological Survey [USGS] gauge data). The north branch may illustrate stream flows more accurately, as a high-flow bypass at Meadowbrook Pond can dampen storm flow peaks at the mouth of Thornton Creek. The north branch of Thornton Creek had mean annual flows of 5.2 and 4.1 cfs for water years 2004 and 2005, respectively, with peak flows of 204.5 and 106.6 cfs, respectively (based on 15-minute data; Figure 30; USGS gauge data).



Note: Data provided here have been reviewed at a screening level. These data may be subject to significant change and are not citeable until reviewed and approved. Each station record is considered provisional until the data are reviewed and approved.

Figure 29. Thornton mean daily stream flows measured near the mouth.



Note: Data provided here have been reviewed at a screening level. These data may be subject to significant change and are not citeable until reviewed and approved. Each station record is considered provisional until the data are reviewed and approved.

Figure 30. Thornton mean daily stream flows measured on the north branch.

About 84 percent of the total watershed area has a formal stormwater drainage system, and 216 storm drains deliver stormwater runoff to the watercourse (10.8 outfalls per watercourse mile). The outfalls drain 216 subcatchments (i.e., areas draining to a single storm drain outlet) that range in size from 0.12 acres to 494 acres. No combined sewer overflow outfalls drain to Thornton Creek.

A 2-year storm event occurs every 2 years on average, or has a 50% chance of occurring any given year.

Based on the extent of impervious surfaces and graded lawns, hydrologic models indicate that the magnitude of the 2-year storm event runoff measured at the mouths of the north and south branches has increased by approximately three- to four-fold compared to predevelopment conditions (Hartley and Greve 2005). The upper portions of the watershed, particularly the south branch and Littlebrook Creek, are estimated to deliver large amounts of stormwater to the watercourse quickly (Map 40). These areas are underlain by low-permeability soils, have relatively high coverage of impervious surfaces, and have large subcatchment areas.

In addition, the watercourse can experience drastic increases in stream flows over short distances where tributaries and outfalls draining large areas discharge to the watercourse. One such location is along Littlebrook Creek, about 3,000 feet upstream of the confluence with the north branch, where a stormwater outlet draining nearly 30 percent of the Littlebrook Creek subbasin is located (off NE 125th Street, east of Lake City Way NE).

At the mouth of Thornton Creek, modeling estimates of the magnitude of the 2-year storm event runoff show no increase from predevelopment levels. In fact, it may be slightly reduced (Hartley and Greve 2005), due to a bypass structure on the main stem of the watercourse that diverts up to 350 cfs directly into Lake Washington via the Meadowbrook stormwater management system. The bypass appears to be effective in reducing peak flows in the main stem, as Thornton Creek does not demonstrate a flow regime typical of a highly urbanized basin at its mouth. A natural drainage system project at Pinehurst, draining to Kramer Creek on the south branch, has been installed to control stormwater runoff and increase onsite detention for approximately 50 acres.

Thornton Creek Water Quality

Thornton Creek, the largest watercourse in Seattle, has received the most attention from public resource agencies. King County collects monthly water samples at a monitoring station near the mouth (0434), and the U.S. Geological Survey has frequently included Thornton Creek in regional studies of water and sediment quality in urban streams (MacCoy and Black 1998; Bortleson and Davis 1997; Voss et. al. 1999). Overall, the urban development and altered hydrologic regime within the watershed have dramatically affected the water and sediment quality of Thornton Creek.

Although clear connections and thresholds are difficult to demonstrate, degraded water and sediment quality conditions are presumed to affect aquatic organisms in Thornton Creek. Water quality is currently being investigated as a potential contributor to the coho salmon prespawn mortalities reported in urban watercourses in the Puget Sound basin since 1999 (Reed et al. 2003). The following subsections summarize existing information on water and sediment quality in the Thornton Creek watershed. More detailed tables and summary statistics for all water quality data are presented in Appendix B.

In 2004, the Department of Ecology included Thornton Creek on the list of threatened and impaired water bodies under Clean Water Act Section 303(d), classifying the watercourse as a category 5 water body, requiring total maximum daily load (TMDL) limits based on demonstrated exceedances of state water quality standards for temperature, dissolved oxygen, and fecal coliform bacteria (Ecology 2004). In addition, Ecology has identified Thornton Creek as a water of concern (i.e., category 2) for both pH and mercury. Summary statistics for conventional water quality indicators based on monthly samples collected by King County (2006b) between 1974 and 2005 are presented in Table 38, and the results for each indicator are discussed separately in the following subsections.

Table 38. Thornton summary statistics for conventional water quality parameters sampled monthly near the mouth by King County, 1975–2005.

	Dissolved Oxygen (mg/L)	Temperature (degrees C)	Fecal Coliform (cfu/100 mL)	pH	TSS (mg/L)	Turbidity (NTU)
No. of samples	394	450	451	399	401	402
Minimum	6.9	1.6	14	6.4	0.6	0.1
Maximum	14.7	23.2	31,000	11.2	180	66
Median	10.5	11.3	690	7.5	5.7	3.2
Mean	10.5	11.1	1,507	7.5	15.0	6.3
5th percentile	8.8	5.4	115	6.9	2.0	1.2
95th percentile	12.6	16.2	5,500	7.9	56	22.9
Criteria [a]	9.5	16	50	6.5–8.5	–	–

[a] Established criteria from WAC 173-201A. See Part 3 of this report for more details.
mg/L = milligrams per liter.
cfu/100 mL = colony-forming units per 100 milliliters.
TSS = total suspended solids.
NTU = nephelometric turbidity units.

Dissolved Oxygen and Temperature

Dissolved oxygen and temperature display seasonal trends in long-term observations for the 1974–2005 period of record in Thornton Creek near the mouth. Dissolved oxygen and temperature often do not meet the state water quality criteria for Class AA streams and core summer salmon habitat in the summer months, although they typically meet those criteria during other times of the year. Samples are compared to the 2006 state water quality standards (WAC 173-201A) for dissolved oxygen and the 1997 standards for temperature, because the existing data, which are from monthly samples, are not directly comparable to the recently revised temperature criterion, which is based on the 7-day average of the daily maximum temperatures.

Temperature and dissolved oxygen are closely related; both are important for fish to maintain healthy metabolic rates (Welch and Lindell 2000). Between 1996 and 2005, temperature and dissolved oxygen did not meet the state criteria in 9 percent and 21 percent, respectively, of the samples collected from Thornton Creek. Similarly, over the 28-year period of record, temperature and dissolved oxygen failed to meet the state water quality criteria in 8 percent and 20 percent of samples, respectively.

In 2002, Seattle Public Utilities (SPU) began monitoring select locations along Thornton Creek to evaluate temporal patterns in water temperature (Map 38). Temperature readings are collected and recorded at 30-minute intervals at the following six stations:

- North branch upstream of Jackson Park golf course
- North branch downstream of Jackson Park golf course
- Main stem above Meadowbrook pond
- Main stem below Meadowbrook pond
- South branch at NE 105th Street and Eighth Avenue NE
- South branch at NE 100th Street and Ravenna Avenue.

These data can be compared to the Ecology (2006a) temperature criterion, which is based on the 7-day average of the daily maximum temperature. The temperature criterion for Thornton Creek (16ºC) is based on protection for use as core summer salmon habitat.

The data indicate that below Jackson Park, Thornton Creek consistently exceeds the temperature criterion during the summer months. As shown in Figures 31 and 32, water temperatures increase significantly downstream of the Jackson Park golf course and again below Meadowbrook pond. Temperatures upstream of the Jackson Park golf course in 2003 and 2004 exceeded the 7-day average on zero and 8 days, respectively. However, the number of exceedances increased to 81 and 87 days, respectively, at the station below Jackson Park; 83 and 91 days, respectively, above Meadowbrook pond; and 100 and 103 days, respectively, below Meadowbrook pond.

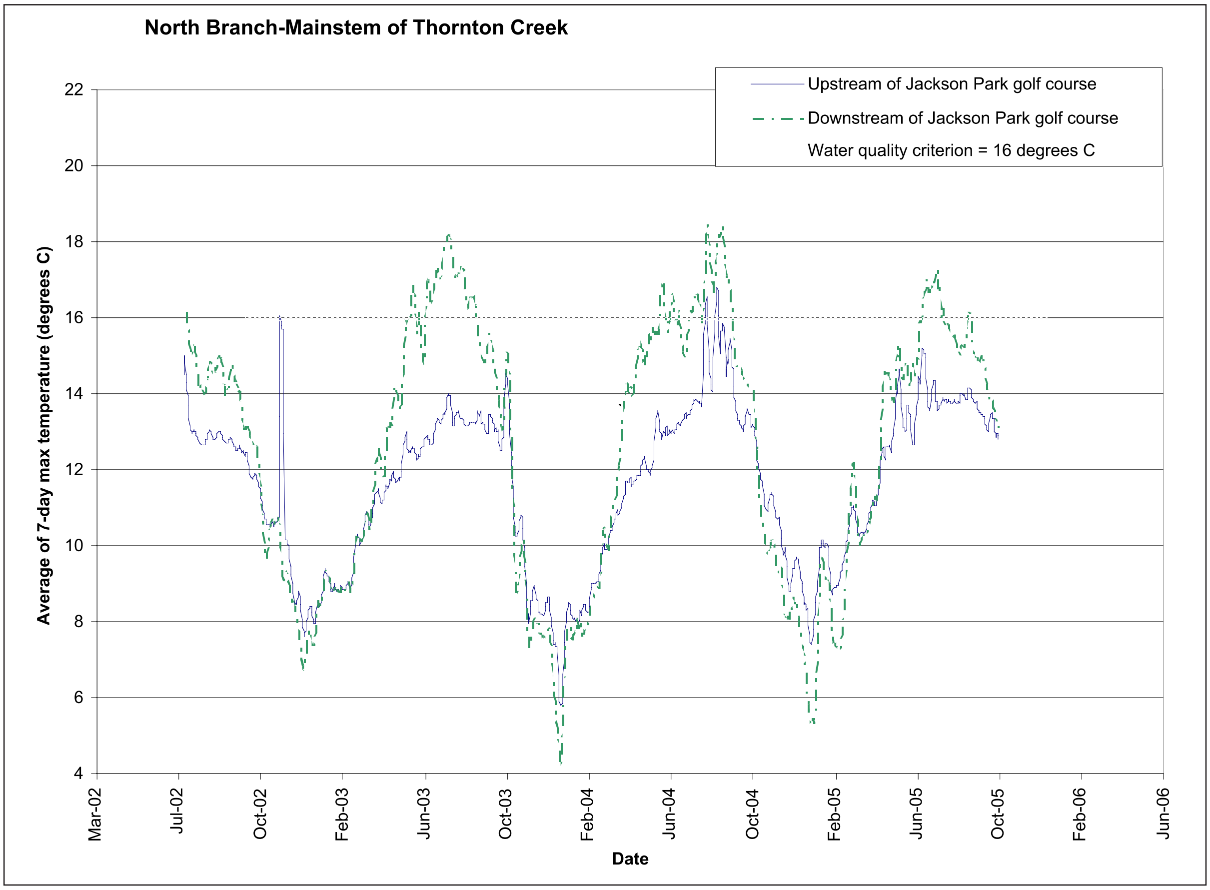


Figure 31. Thornton water temperature measured at the Jackson Park golf course, 2002–2005.

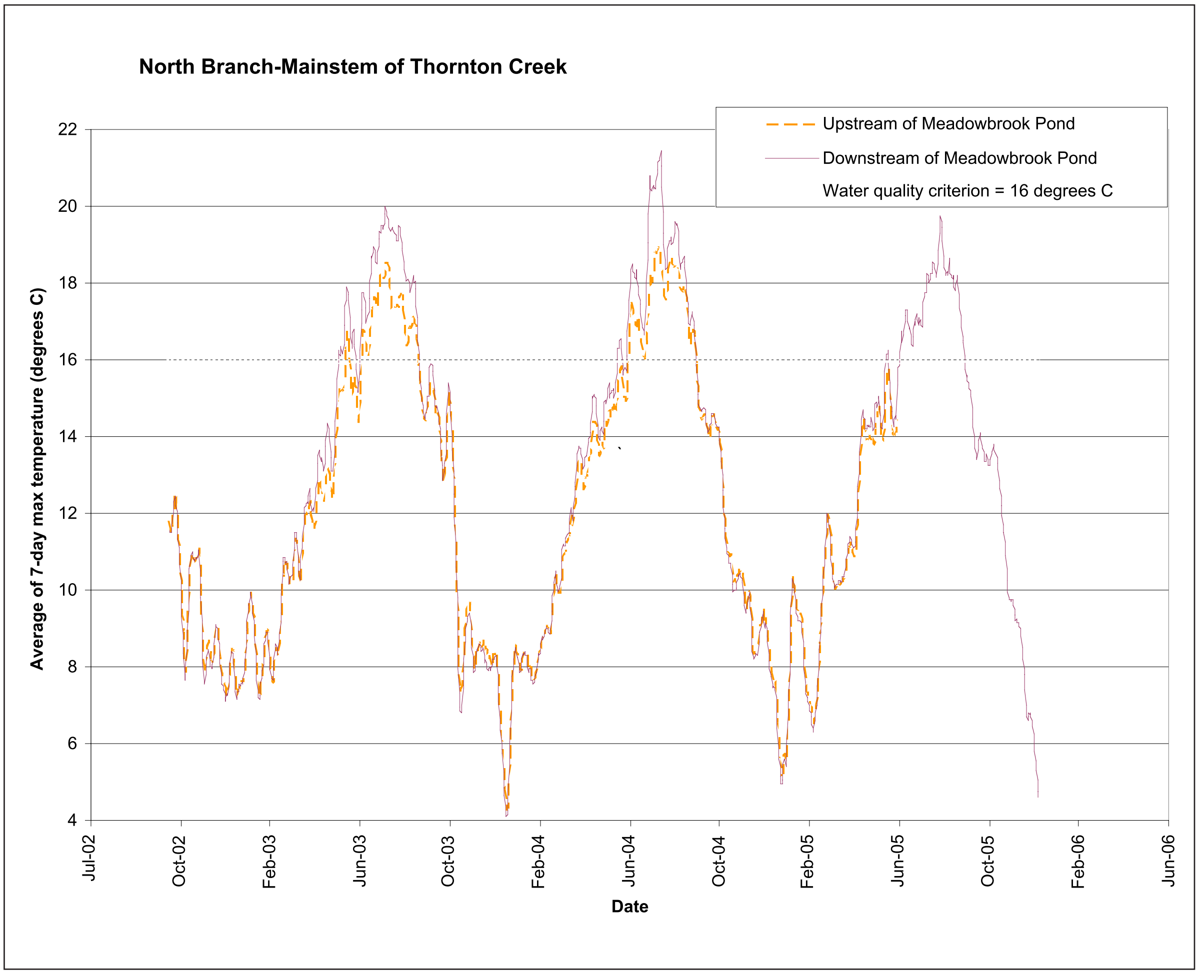


Figure 32. Thornton water temperatures measured at Meadowbrook pond, 2002–2005.

Similar to the north branch and main stem, water temperature data for the south branch of Thornton Creek regularly exceed the 7-day average criterion during the summer months. In 2003–2005, the number of days exceeding the criterion ranged from 66 to 95 days at the NE 105th Street/Eighth Avenue NE station and from 67 to 72 days at the NE 100th Street/Ravenna Avenue site (not including 2004, when data were missing).

In typical urban watersheds, inputs of relatively warm stormwater runoff can cause temperatures in streams to increase above naturally occurring levels. In addition, channel simplification (resulting from such actions as levee construction, bank hardening, channel straightening, dredging, and woody debris removal) can reduce the hyporheic exchange that helps to promote lower stream temperatures. Hyporheic exchange refers to the mixing of surface water and ground water beneath the active stream channel and riparian zone. Finally, reduced shading in streams due to removal of the riparian canopy can cause stream water temperatures to increase.

Turbidity and Suspended Solids

Summary statistics for total suspended solids and turbidity near the mouth of Thornton Creek for the entire period of record are summarized in Table 38. Particulate levels in the watercourse are generally low. For example, turbidity ranges from 0.1 to 66 nephelometric turbidity units (NTU), although most of the samples contain less than 10 NTU. Similarly, total suspended solids concentrations range from less than 1 to 180 mg/L, but most samples contain less than 10 mg/L. Higher particulate levels are expected to occur during storm events. The historical data set represents routine samples collected once each month and does not necessarily provide a good representation of storm flow conditions.

Background turbidity conditions can be difficult to establish in Seattle's urban watercourses. Typically, background conditions are determined from samples collected upstream of a particular source input to a watercourse, such as a construction site, storm drain outfall, or municipal or industrial discharge. Background samples are then compared to samples collected downstream of a specific source input to determine compliance with the turbidity standard. However, because the monitoring stations in Thornton Creek are not located upstream and downstream of specific source inputs, these data are not suitable for assessing compliance with the turbidity standard.

Increases in turbidity and suspended solids downstream typically result from larger storm flows associated with urbanization in the watershed. Larger peak flows tend to erode the streambed and entrain particles more effectively than smaller, less frequent storm flows. In addition, urban stream banks typically erode more easily as riparian vegetation is removed or modified, resulting in increased turbidity and suspended solids downstream, particularly during storms. Finally, turbidity and suspended solids tend to increase downstream in urban streams due to unnaturally high inputs of turbid water resulting from urban upland construction activities and ground disturbance.

pH Conditions

Of the 399 field pH measurements recorded by King County (2006b) during the period of record, only four samples (less than 1 percent) were outside the state water quality criterion of 6.5 to 8.5. Two measurements were below the allowable range, and two measurements were above that range. The last excursion of the pH criterion was in February 2002.

Fecal Coliform Bacteria

Fecal coliform bacteria data collected near the mouth of Thornton Creek for the 1974–2005 period of record (King County 2006b) are quite variable, ranging over three orders of magnitude. As shown in Table 39, over the past ten years fecal coliform bacteria levels in Thornton Creek frequently have exceeded state water quality criteria for extraordinary primary contact recreation (i.e., a geometric mean of 50 colony-forming units per 100 milliliters [cfu/100 mL], with no more than 10 percent of samples exceeding 100 cfu/100 mL; Ecology 2006a). The annual geometric mean fecal coliform counts (ranging from 480 to 1,200 cfu/100 mL) were well above the 50 cfu/100 mL criterion every year, and 93 to 100 percent of the annual samples exceeded the 100 cfu/100 mL limit over the ten-year period.

Table 39. Thornton fecal coliform bacteria summary for samples collected by King County near the mouth at Matthews Beach, 1996–2005.

Year	Number of Samples	Fecal Coliform Bacteria (cfu/100 mL)			Percent Greater than 100
		Minimum	Maximum	Geometric Mean	
1996	14	150	5,100	800	100
1997	16	240	7,700	1,100	100
1998	17	130	9,000	1,200	100
1999	35	68	10,000	850	94
2000	34	28	31,000	800	94
2001	32	190	9,000	860	100
2002	12	170	3,000	610	100
2003	13	150	1,900	550	100
2004	14	130	5,000	820	100
2005	15	91	2,300	480	93

cfu/100 mL = colony-forming units per 100 milliliters

Ecology (2006d) measured similar fecal coliform levels in the south branch of Thornton Creek at NE 107th Street (station 08M070) in 11 samples collected between October 2003 and September 2004. During this period, fecal coliform bacteria levels ranged from 80 to 5,900 cfu/100 mL, with 73 percent of the samples exceeding the criterion of 100 cfu/100 mL.

Six of the 11 Ecology samples (55 percent) were collected during dry-weather conditions (based on data from the University of Washington rooftop station). Two of the remaining five sampling events had 0.1 inches of rainfall or less. Significant rainfall occurred only on three of the sampling dates. The largest fecal coliform bacteria count (5,900 cfu/100 mL) was reported from the October 20, 2003 sample, when 2.7 inches of rainfall occurred.

King County (2001a) also measured elevated fecal coliform levels in Thornton Creek during a microbial source tracing survey conducted in April–May 2001 to evaluate whether leaking wastewater pipes could be affecting water quality in the watercourse. Samples were collected during non-storm flow conditions from 13 stations located throughout the Thornton Creek watershed. Fecal coliform levels ranged from 150 to 1,500 cfu/100 mL. Both the geometric mean for all samples (515 cfu/100 mL) and the percentage of samples above 100 cfu/100 mL (23 percent) exceeded the state criterion for extraordinary primary contact recreation. The highest levels were measured in Victory Creek at NE 108th Street (1,500 cfu/100 mL), at Meadowbrook pond (1,500 cfu/100 mL), and in Thornton Creek at NE 105th Street (1,100 cfu/100 mL).

Results from the microbial source tracing study show that 88 percent of the isolates tested were successfully matched to library strains associated with animal sources (i.e., bird, dog, cat, rodent, opossum, squirrel, raccoon, rabbit, muskrat, and beaver/otter). The remaining 12 percent could not be matched to a known source. Of these, 3 percent were correlated to human sources. Because of the low correlation to human sources, King County (2001a) concluded that municipal wastewater was not a significant contributor to the fecal coliform bacteria levels found in Thornton Creek.

Potential sources of fecal coliform bacteria in urban streams are wildlife and pet wastes, leaking wastewater systems, failing septic systems, wastewater treatment plant effluent, and combined sewer overflow events. Stormwater runoff from urban development can easily wash bacteria from these sources into urban streams.

Metals

Fourteen priority pollutant metals with recommended water quality criteria for the protection of aquatic life and human health in surface waters were reviewed (see Table 9). Sample results for Thornton Creek are available only for non-storm flow conditions; however, the period of record is fairly representative, with good data quality. Appendix B contains a summary of metals sample statistics and time series plots.

For the purposes of this report, the King County and Ecology samples are called non-storm flow samples, and SPU samples are called storm flow samples.

Thornton Creek is on the 2004 Department of Ecology Clean Water Act Section 303(d) list of threatened and impaired water bodies as a category 2 water body (i.e., a water of concern) for mercury, based on exceedances of the chronic toxicity criterion for aquatic life. Ecology assigned a category 2 listing because the measured concentrations were below the laboratory reporting limit.

Other than mercury, metals concentrations in Thornton Creek are relatively low. King County (2006b) and Ecology (2006d) analyzed dissolved metals in 36 samples collected between May 27, 1998 and October 31, 2005 at two stations, 0434 and 08M070 (Map 38). Two of 36 samples (6 percent) exceeded the chronic toxicity criterion for dissolved lead under non-storm flow conditions. Dissolved lead exceedances of the chronic toxicity criterion were reported near the mouth of Thornton Creek (1.12 µg/L, exceeding the standard of 0.69 µg/L), and on the south branch of Thornton Creek at NE 107th Street (0.834 µg/L, exceeding the standard of 0.79 µg/L). However, these sample results are outliers (falling beyond the step spread, as described under Summary Statistics in Part 3), and additional data are needed to determine whether the samples are representative of actual water quality conditions. None of the dissolved metals samples exceeded the acute toxicity criterion.

Total metals were measured in 14 samples collected between May 27, 1998 and September 13, 2004 by King County (2006b) at station 0434, and by Ecology (2006d) at station 08M070. One of 14 samples (7 percent), a suspected outlier, exceeded the chronic toxicity criterion for total mercury under non-storm flow conditions, and none exceeded the acute toxicity criterion. Specifically, the total mercury chronic criterion of 0.012 µg/L was exceeded at station 08M070 with a sample result of 0.016 µg/L in February 2004.

All 23 samples (100 percent) exceeded the human health criterion of 0.018 µg/L for total arsenic under non-storm flow conditions, typical for Seattle urban watercourses. This drinking water criterion applies to human consumption of water and fish (see Table 9). Therefore, the risk to human health is minimal if people do not drink water from the stream or consume fish living in the stream. Although the human health criterion for arsenic is frequently exceeded, the aquatic life chronic and acute toxicity criteria are seldom exceeded.

Metal pollutants accumulate on impervious surfaces in urban watersheds and are washed off during storms. In addition, some metals are bound to sediments; so as storm flows entrain soil and sediment, metals are more easily transported to streams. Sources of metal pollutants include wear and tear of vehicle parts (e.g., brake pads, tires, rust, and engine parts), atmospheric deposition, common building materials (e.g., galvanized flashing and metal downspouts), and roof maintenance activities (e.g., moss control).

Nutrients

Nutrients were analyzed (including ammonia-N, nitrate-nitrite, total nitrogen and total phosphorus) in 148 samples collected between April 1998 and December 2005, by King County (2006b) at station 0434 and by Ecology (2006d) at station 08M070 under non-storm flow conditions (Map 38). Because Thornton Creek is not currently monitored by SPU, no storm data are available. Summary statistics for King County nutrient data are provided in Table 40.

Table 40. Thornton summary statistics for nutrients near the mouth.

	Ammonia-N (mg/L)		**Nitrate+nitrite (mg/L)**		**Total Nitrogen (mg/L)**		**Total Phosphorus (mg/L)**	
	Non-Storm [a]	**Storm** [b]	**Non-Storm** [a]	**Storm** [b]	**Non-Storm** [a]	**Storm** [b]	**Non-Storm** [a]	**Storm** [b]
Thornton Creek (station 0434)								
No. of samples	110	ND	109	ND	109	ND	124	ND
Minimum	0.01	ND	0.37	ND	0.96	ND	0.032	ND
Maximum	0.24	ND	1.6	ND	2.4	ND	0.22	ND
Median	0.032	ND	1.1	ND	1.4	ND	0.07	ND
Mean	0.037	ND	1.1	ND	1.4	ND	0.079	ND
5th percentile	0.013	ND	0.48	ND	1.1	ND	0.039	ND
95th percentile	0.068	ND	1.4	ND	1.7	ND	0.16	ND
Benchmark [c]	0.43 – 2.1		–		0.34		0.1	

[a] Non-storm samples collected at stations J370 and C370.
[b] Storm samples collected at stations Graham and Yancy.
[c] Ammonia chronic toxicity criteria are pH-dependent, and the given range is for a pH of 6.5–8.5. All nutrient criteria and benchmarks are described in more detail in Part 3 of this report.
mg/L = milligrams per liter.
ND = no data collected.

Nutrient concentrations in Thornton Creek frequently exceeded established benchmarks under non-storm flow conditions. The total nitrogen benchmark (0.34 mg/L, see Table 8) was exceeded in 100 percent of samples, and the total phosphorus benchmark (0.1 mg/L, see Table 8) was exceeded in 18 percent of samples. However, several of the nutrient samples that exceeded the benchmarks are suspected outliers, because the concentrations were greater than 1.5 times the interquartile range.

Because benchmarks represent surface water quality conditions that are minimally influenced by human activity, exceeding a benchmark does not necessarily indicate a violation of the water quality standard.

Phosphorus and nitrogen are common pollutants in urban streams. Sources include fertilizer applications, increased soil erosion, nutrients from washwater (e.g., car and boat cleaning), failing septic systems, pet wastes, and improper dumping of yard wastes. All of these sources can result in increased nutrient concentrations in stormwater runoff. This is of particular concern for the larger water bodies such as freshwater lakes and Puget Sound. Elevated nutrient levels can lead to eutrophication, a process in which rapid growth of algae may overcome natural self-purification processes in the water body. The resulting algal blooms degrade water quality as the decomposing algae reduce the dissolved oxygen concentrations in receiving waters. Ultimately, increased nutrient concentrations can reduce survival opportunities for salmonids, which rely on oxygen-rich waters.

Organic Compounds

The U.S. Geological Survey has found low levels of some pesticides in stormwater, sediment, and fish tissue collected from Thornton Creek (Voss and Embrey 2000). Of the five major watercourses evaluated in this report, only Thornton Creek has sufficient sediment data available to support conclusions about sediment quality.

Water quality sampling in Seattle (photo by Bennett)

Stormwater samples collected from the north branch, south branch, and mouth of Thornton Creek contained detectable levels (0.013 to 0.16 µg/L) of several herbicides and their metabolites (2,4-D, 2,6-dichlorbenzamide, atrazine, dichlobenil, MCPA [4-chloro-2-methyl phenoxy acetic acid], mecoprop, pentachlorophenol, prometon, simazine, tebuthiuron, and trichlorpyr), two insecticides (0.003 to 0.154 µg/L), and insecticide metabolites (carbaryl, diazinon, and 4-nitrophenol). With the exception of diazinon, concentrations were below reported toxic effect levels for aquatic organisms. In 2003, the U.S. EPA canceled diazinon product registrations and restricted the sale of this pesticide to existing stocks. As a result, diazinon concentrations in Thornton Creek are expected to begin declining as existing stocks are depleted.

Several organochlorine pesticides (i.e., dieldrin, chlordane, DDD, DDE, and DDT) ranging in concentration from 1.2 to 8.1 µg/kg were also found in streambed sediments near the mouth of Thornton Creek (MacCoy and Black 1998). Washington state has not established standards for freshwater sediment; for the purposes of this analysis, Thornton Creek sediment data are evaluated based on comparisons to the sediment quality criteria and guidelines outlined in Part 3 of this report.

Thornton Creek sediment quality results are compared to available sediment quality guidelines in Table 41. Only bis(2-ethylhexyl)phthalate (estimated at 990 µg/kg) exceeded the Ecology proposed freshwater quality value of 640 µg/kg. Phthalates belong to a class of chemicals known as plasticizers that are used in the manufacture of many polyvinyl chloride (PVC) construction materials and consumer products. They are used to make a wide variety of plastic products such as flexible tubing, vinyl flooring, wire insulation, weather-stripping, upholstery, clothing, plastic containers, and plastic wraps. Phthalates have been used for a long time but have recently become an environmental concern because they have been found at elevated concentrations in sediment of urban receiving water bodies.

High molecular weight polycyclic aromatic hydrocarbons (HPAH) and pesticides concentrations exceeded the lower-effects levels established by other jurisdictions, and DDE (6.9 µg/kg) exceeded the NOAA upper-effects threshold of 6.75 µg/kg, indicating a strong potential for adverse biological effects in Thornton Creek. Further evaluation should be conducted after Ecology develops freshwater sediment management standards for the state of Washington.

Pesticides (which include herbicides, insecticides, and fungicides) are often detected in urban streams, sometimes at levels higher than in agricultural areas. These compounds are commonly used around residential, commercial, and industrial buildings, as well as in garden, lawn, and golf course management. These chemicals can also reach streams through atmospheric deposition (as dustfall or through rainfall). Sources of PAHs include vehicle exhaust, automotive oil leaks, industrial effluent, and petroleum spills that wash into streams during storms.

Stream-Scale Conditions

Thornton Creek, which originates on a rolling, glacially contoured upland plateau, has been eroding through sediment deposits formed by the retreating Vashon glacier over thousands of years to create the Thornton Creek valley. The north branch of the watercourse is characterized by a relatively low-gradient channel (slightly greater than 1 percent), which is fed by mostly low-gradient tributaries. In some reaches, the north branch is naturally confined by narrow valley walls. The alternating pattern of confined and unconfined reaches, which promotes the exchange of surface and subsurface waters, is a primary source of hydraulic diversity and habitat complexity in the north branch (Seattle 2005).

The south branch of the watercourse, with a gradient of 1 to 2 percent (Map 39), differs from the north branch primarily in two ways. First, the south branch is slightly steeper than the north branch, descending from the same upland elevation in approximately half the distance. Second, the south branch has several short, high-gradient tributaries (up to 8 percent). These steep tributaries provide most of the hydraulic diversity and habitat complexity in the south branch, because the confluences present areas of abrupt change (from high to low gradient) that store sediment and wood (Seattle 2005). Historically, these tributaries were a major source of sediment and wood debris to the south branch.

The lower reaches of both Thornton Creek branches and the entire main stem are located on an alluvial floodplain, which is mostly unconfined (Stoker and Perkins 2005). The main stem is a low-gradient channel (0.2 to 0.6 percent). Historically, the stream had a meandering course, probably splitting into multiple channels and connecting laterally to the relatively wide floodplain and floodplain wetlands on the valley bottom (Seattle 2005; Stoker and Perkins 2005). The channel migration zone was wider here than in the more confined upstream reaches, expanding to at least a width of 450 feet at the historical mouth and delta area (Stoker and Perkins 2005).

Table 41. Thornton organic compounds detected in sediment samples compared to available freshwater sediment guidelines.

Chemical	Thornton Creek Sediment Sample	Consensus-Based Guideline [a]		Ecology Sediment Quality Values [b]	Ontario [c]		NOAA [d]		
	(µg/kg)	TEC (µg/kg)	PEC (µg/kg)	FSQV (µg/kg)	LOEL (µg/kg)	SEL (mg/kg OC)	TEL (µg/kg)	PEL (µg/kg)	UET (µg/kg)
LPAH									
Acenaphthene	19E	NA	NA	3,500	NA	NA	NA	NA	290[e]
Acenaphthylene	39E	NA	NA	1,900	NA	NA	NA	NA	160[e]
Anthracene	71	57.2	845	2,100	220	370	NA	NA	260[e]
Fluorene	39E	77.4	536	3,600	190	160	NA	NA	300[e]
Phenanthrene	200	204	1,170	5,700	560	950	41.9	515	800[f]
HPAH									
Benzo(a)anthracene	220	108	1,050	5,000	320	1,480	NA	NA	NA
Benzo(a)pyrene	310	150	1,450	7,000	370	1,440	31.9	782	700[f]
Benzo(b)fluoranthene	260	NA	NA	NA	NA	NA	NA	NA	NA
Benzo(k)fluoranthene	230	NA	NA	NA	240	1,340	NA	NA	13,400[g]
Benzo(b+k)fluoranthene	490	NA	NA	11,000	NA	NA	NA	NA	13,400[g]
Benzo(g,h,i)perylene	170	NA	NA	1,200	170	320	NA	NA	300[e]
Chrysene	270	166	1,290	7,400	340	460	57.1	862	800[f]
Dibenz(a,h)anthracene	93	33	NA	230	60	130	NA	NA	100[e]
Indeno(1,2,3-c,d)pyrene	300E	NA	NA	730	200	320	NA	NA	330[e]
Fluoranthene	470	423	2,230	11,000	750	1,020	111	2,355	1,500[e]
Pyrene	240	195	1,520	9,600	490	850	53	875	1,000[f]
Phthalates									
Bis(2-ethylhexyl)phthalate	990E	NA	NA	640	NA	NA	NA	NA	750[e]
Butylbenzylphthalate	110	NA	NA	NA	NA	NA	NA	NA	NA
Dimethylphthalate	10E	NA	NA	NA	NA	NA	NA	NA	NA
Pesticides									
4,4’-DDD	4.6	4.88	28	NA	8	6	3.54	8.51	60[f]
4,4’DDE	6.9	3.16	31.3	NA	5	19	1.42	6.75	50[f]
4,4’-DDT	8.1	4.16	62.9	NA	7	12	NA	NA	<50[f]
Dieldrin	1.3	1.9	61.8	NA	2	91	2.85	6.67	300[f]
cis-Chlordane	1.6	3.24	17.6	NA	7	6	4.5	8.9	30[f]
trans-Chlordane	1.2	3.24	17.6	NA	7	6	4.5	8.9	30[f]
Trans-Nonachlor	1.7	NA	NA	NA	NA	NA	NA	NA	NA
Others									
Carbazole	63	NA	NA	NA	NA	NA	NA	NA	NA
1,6-Dimethylnaphthalene	15E	NA	NA	NA	NA	NA	NA	NA	NA
1-Methyl-9H-fluorene	35E	NA	NA	NA	NA	NA	NA	NA	NA
1-Methylphenanthrene	31E	NA	NA	NA	NA	NA	NA	NA	NA
1-Methylpyrene	71	NA	NA	NA	NA	NA	NA	NA	NA
2,6-Dimethylnaphthalene	15E	NA	NA	NA	NA	NA	NA	NA	NA
2-Methylanthracene	50E	NA	NA	NA	NA	NA	NA	NA	NA
Acridine	54	NA	NA	NA	NA	NA	NA	NA	NA
9,10-Anthraquinone	89	NA	NA	NA	NA	NA	NA	NA	NA

µg/kg = micrograms per kilogram.
NA = Not available.
[a] MacDonald et. al. (2000).
[b] Cubbage et al. (1997).
[c] Persaud et. al. (1993).
[d] NOAA (1999).
[e] Microtox bioassay.
[f] Infaunal community impacts.
[g] Bivalve.

FSQV Freshwater sediment quality value.
TEC: Threshold effect concentration.
PEC: Probable effect concentration.
LOEL: Lowest observed effect level.
SEL: Severe effect level.
ERL: Effects range-low (concentrations at which biological effects would be rarely observed).
ERM: Effects range-median.

TEL: Threshold effect level or concentration below which adverse effects are expected to occur only rarely. Geometric mean of the 15th percentile concentration of the toxic effects data set and the median of the no-effect data set.
PEL: Probable effects level, the level above which adverse effects are frequently expected. Geometric mean of the 50th percentile of impacted, toxic samples and the 85th percentile of the non-impacted samples.
UET: Upper effects concentration derived as the lowest adverse effects threshold (AET) on 1% TOC basis from a compilation of endpoints analogous to the marine AET endpoints.
LPAH: Low molecular weight polycyclic aromatic hydrocarbons.
HPAH: High molecular weight polycyclic aromatic hydrocarbons.

The mouth of Thornton Creek, as it exists today after the water level in Lake Washington was lowered, is restricted in width by concrete lining and heavy bank armoring. Historically, the main stem was very productive biologically because of upstream inputs (wood, sediment, and nutrients) in combination with an extensive floodplain/wetland complex (Seattle 2005).

For the discussion that follows, Thornton Creek is divided into the south branch, the north branch, and the main stem. These major parts of the system are further divided into reaches, starting at the headwaters and moving downstream toward the confluence. The major tributaries of each reach are also discussed.

Watercourses are divided into reaches, reaches are divided into segments, and segments are divided into sections.

South Branch of Thornton Creek

The south branch of Thornton Creek, also known as Maple Leaf Creek, begins near Park 6 at the culvert outlet just east of the Northgate shopping complex. The south branch flows in an easterly direction for 2.3 miles, 11 percent of the total basin channel length, to its confluence with the north branch just east of 35th Avenue NE. Ten tributaries, including Victory Creek, Willow Creek, and Kramer Creek, also join the south branch channel, contributing to its flow toward Lake Washington.

The south branch has three reaches, based on gradient and natural channel confinement. Watercourse codes, shown on the watercourse maps, consist of two letters of the watercourse name (TS for Thornton south branch) and the number of the stream segment, starting with 01 at the mouth and increasing in the upstream direction:

- The upper south branch plateau, an upland area upstream of Fifth Avenue NE (TS08–TS06)
- The south branch canyon, downstream of Fifth Avenue NE (TS05–TS02)
- The south branch alluvial fan, downstream of 30th Avenue NE (TS01).

Upper South Branch Plateau (TS08–TS06)

The headwaters of the south branch of Thornton Creek originate in wetland deposits on a gently rolling upland plateau of glacial till in the vicinity of the Northgate retail area, North Seattle Community College, and the Interstate 5 corridor (Troost et al. 2005; Seattle 2005). Historically, wetlands and cranberry bogs occupied this area, hydrologically supplied by surface and subsurface water that moved through the area without a well-defined stream channel. With urbanization the plateau headwaters have been largely piped and filled to provide suitable areas for development. Today, the south branch emerges from a long culvert just east of the south parking lot of the Northgate mall.

Upper South Branch Canyon (TS05)

The south branch emerges from a culvert at Fifth Avenue NE and flows 2,570 feet (22 percent of the total south branch length) to the Victory Creek confluence. The channel flows between hills through a small canyon that is about 10 feet deep, with a valley bottom width between 40 and 100 feet (Stoker and Perkins 2005). Through this reach, the watercourse is contained in culverts for about 275 feet (11 percent of reach TS05), with about 2,300 feet in an open channel. The channel meanders through a park (Park 6) and residential neighborhoods.

Riparian Habitat

This reach of the Thornton south branch is mostly confined within an inner valley canyon that was formed by surface water cutting into the glacial deposits of the original wider valley. The riparian corridor is often less than 50 feet wide, with houses and roads located within 100 feet of the stream, and some limited bank armoring in places at the downstream end of this reach. The park areas contain a predominantly deciduous canopy with a nonnative understory, while the downstream residential segments are dominated by lawns and relatively sparse nonnative landscaping. There is little wood that can be contributed to the stream from the riparian corridor.

Residential encroachment on Thornton Creek riparian area (photo by Bennett)

Portions of this reach are undergoing an extensive riparian enhancement program intended to remove invasive species and reestablish native vegetation. Currently, the riparian corridor in this reach is of moderate quality (Map 43).

Instream Habitat

The active channel width in this canyon reach ranges between 5 and 10 feet and averages about 8 or 9 feet. The channel is incised along the entire reach, although bank erosion is beginning to widen the channel, which is increasing its capacity to carry storm flows (Stoker and Perkins 2005). Encroachment, particularly bank armoring in the upper canyon, has contributed to increasing channel incision and has separated the stream from its floodplain.

Habitat in this reach is rather low in quality, based on conditions observed during the 2000 habitat survey (Map 43). Logs were added to the channel in Park 6 in 2005 (Map 45) and the associated habitat quality has been improving, with some segments now containing higher-quality areas. The channel has an average gradient of 1 to 2 percent, which is typically suited to forming a pool-riffle channel type. The habitat consists of pool areas (42 percent) and riffle areas (29 percent), although in 2000 there was a high percentage of glide habitat (21 percent; Map 41). Pools in this reach have been formed by four culverts and by the instream structure pieces (wood and boulders) that were added to the channel. The farthest upstream segment of this reach is the highest in quality, where the stream flows through a low-gradient forested park area (Park 6), which provides active floodplain connections, shade, and some channel structure.

Prior to the rehabilitation projects, the stream in this reach was actively incising in response to high flows, particularly in the downstream residential areas where the stream is confined by infrastructure, yards, and bank armoring (Maps 40 and 42). One of the primary objectives of the 2005 rehabilitation projects was to provide instream structure to prevent further channel incision and begin the process of building the streambed with instream sediment storage. Although silt dominated this reach prior to rehabilitation, sand and gravel now comprise the majority of the substrate. The pools created by the added structures tend to trap fine sediments, helping to keep the gravel in downstream riffles relatively free of fine sediment (Stoker and Perkins 2005).

Rainbow and cutthroat trout have been documented in this reach up to the culvert under Fifth Avenue NE (Washington Trout 2000). These are probably resident trout; no adfluvial cutthroat trout from Lake Washington have been documented upstream of a full barrier located downstream at NE 107th Street and 25th Avenue NE (McMillan 2005).

South Branch Canyon (TS04–TS02)

The middle reach of the south branch extends from the Victory Creek confluence to 30th Avenue NE (Ravenna NE becomes 30th Avenue NE at the south branch). This reach is contained within an 8,000-foot canyon (constituting 66 percent of the length of the south branch) that ranges from 30 to 100 feet deep and from 40 to 100 feet wide (Stoker and Perkins 2005).

Between Lake City Way and Ravenna NE (TS02), the canyon widens and the channel gradient begins to drop from just over 2 percent to 1.5 percent. As the south branch channel descends from the upland plateau, the gradient of the channel increases and the canyon walls confine the lateral movement of the stream (Map 39). About 7,600 feet (95 percent) of this reach is open channel. Willow Creek and five other smaller tributaries join the south branch in this reach.

Riparian Habitat

Conditions in this reach of the south branch vary between the upper segment, which flows predominantly through park land (Park 2), and the lower segment, which courses through residential areas. The park area (TS04) is dominated by native deciduous and coniferous forest with a predominantly native composition of understory vegetation (Map 41). The riparian corridor ranges between 20 and 50 feet through this upper segment, but can exceed 50 feet in some locations. The trees provide a good amount of stream cover within this segment as well. While the uppermost section of this segment (TS04b) is of moderate quality due to lawn and landscaping along one bank, the lower section (TS04a) is of high riparian quality and has the best riparian habitat found along Thornton Creek.

The downstream segments of this reach are more moderate in habitat quality. The riparian corridor is dominated by landscaping and lawns, and contains many nonnative plants such as Himalayan blackberry and English ivy, and to a lesser extent, Japanese knotweed and reed canarygrass. There is little riparian canopy cover, averaging less than 25 percent. Houses and roads encroach within 100 feet of the stream, sometimes as close as 20 feet, and bank armoring increases in downstream areas (Map 42).

Instream Habitat

The upper and lower segments of this reach differ in their instream habitat conditions. The upper segment (between 15th Avenue NE and 18th Avenue NE) contains sections of connected floodplain that allow the stream to meander and shift locations (TS04). In this area the stream is depositing sediment in the channel, often in gravel bars at meander bends, and the channel is widening in response to increased runoff (Stoker and Perkins 2005). The stream channel varies between 5 and 20 feet in width, averaging 13 feet. The wider stream sections, such as the section upstream of 15th Avenue NE, also have low bank heights, promoting connection between the stream and floodplain. These connections allow flood flows to spread, slowing the water velocity and reducing bank and streambed erosion. While the upper segment has some encroachment into the stream corridor, encroachment is more severe in the lower segments (TS03–TS02).

Bank stabilization along Thornton Creek (photo courtesy Seattle Municipal Archives; photo by Toczek)

In the lower segments (TS03–TS02), the channel is mostly constructed, armored (53 percent), and confined (Map 42), with stream width ranging between 5 and 15 feet and bank heights of 3 to 6 feet. In response to higher flows, the lower segment of TS03-02 has eroded its bed and banks and is incised (Map 40). Incision, limited instream structure (consisting of wood, channel bars, and meander bends), and high flow velocities have left this segment with a relatively thin layer of unstable substrate (Stoker and Perkins 2005).

However, the lowest segment in this reach (TS02) has a few areas with intact stream–floodplain connections. For example, there is a meander bend between NE 105th Place and NE 107th Street, which is wide enough to have established a channel bar. The active channel width expands to about 15 feet at this location, and the stream banks are less than 2 feet in height. This is the location of a proposed community project (the Maple Leaf reach project) planned to extend the widened section of the stream channel, add wood, and create a 450-foot floodplain bench to dissipate the energy from storm flows.

Instream habitat quality is high within the upper segment of this reach and moderate in the lower segments (Map 43). While the gradient of the system promotes a pool-riffle channel type, this reach is dominated by riffle habitat (64 percent; Seattle 2005). Pools comprise approximately 17 percent of the channel length, and glides occupy another 16 percent (Map 41). Pools are more frequent in the upper segment, particularly in sections of the stream surrounded by undeveloped park land (TS04). The pools, which range in depth from 1 to 4 feet, are formed by either large woody debris (on public land) or constructed weirs (on private land). Almost 30 percent of the overall pool habitat is of relatively high quality, with good hydraulic diversity and both instream and overwater cover. The downstream segments (TS03–TS02) lack both instream structure and floodplain connections, which causes channel incision, removes streambed substrates, and contributes to habitat simplification in response to high flows.

Adult Chinook salmon, coho salmon, and adfluvial cutthroat trout (from Lake Washington) all have been recorded upstream of Lake City Way. There is a full barrier located at NE 107th Street and 25th Avenue NE, just downstream of the confluence with Victory Creek, which represents the upstream extent of migratory fish use (i.e., by salmon and adfluvial cutthroat trout).

South Branch Alluvial Fan (TS01)

The farthest downstream reach of the Thornton south branch (TS01) extends 1,500 feet eastward from the confluence with Kramer Creek to the confluence with the north branch, constituting 12 percent of the south branch channel length. This reach has a low channel gradient of 1 percent.

Riparian Habitat

Thornton Creek flowing adjacent to playfields (photo courtesy Seattle Municipal Archives; photo by Starstead)

Historically, this reach was probably a depositional area with a broad valley and forested, riparian wetlands. Much of this riparian corridor today is based on fill, brought in to prepare land for development within the stream valley. There is little riparian forest along this reach as vegetation has been replaced by parking lots, playfields, and high school buildings. There is little to no understory vegetation except where invasive Japanese knotweed and Himalayan blackberry grow along the banks of the stream. Lombardi poplars planted along the south side of the lower reach provide some canopy cover, although their spacing is intermittent. The riparian corridor averages less than 20 feet and is of extremely low quality.

Instream Habitat

Historically, the reduced gradient and presence of alluvial soils probably produced a meandering, split flow, or even a braided channel, with a floodplain and channel migration zone from 50 to several hundred feet wide (Stoker and Perkins 2005). The floodplain stored sediment and wood, and promoted the formation of floodplain wetlands (Seattle 2005). Kramer Creek, the only tributary in this reach, could have promoted diversity within the watercourse. Today, however, this reach has been extensively filled and graded, and the stream has been straightened to accommodate buildings, bridges, parking lots, roads, and playfields. Instead of channel migration widths approaching 30 to 50 feet, the channel has an average width of approximately 8 feet. The stream is completely disconnected from its surrounding floodplain by bank armoring, culverts, and fill (Map 42).

This reach of the south branch is incised and no longer functions as a depositional zone (Map 40). Sediment deposition occurs around culverts but is often dredged to protect encroaching infrastructure. The streambed is dominated by larger gravel with some cobble, and silt dominates the substrate in the few slow-water areas.

The habitat composition in this reach is dominated by fast-water riffle (59 percent), although slow-water pools make up 20 percent of the available habitat (Map 41). The reach has six pools ranging in depth from 1 foot to almost 4 feet, formed by failed bank armor that has fallen into the stream. The failed bank armor and culverts provide the only instream structure for the entire reach. The farthest downstream portion of the south branch is a 150-foot concrete-lined trough of low habitat quality (Map 43).

This reach is accessible to anadromous fish and is used by Chinook, sockeye, and coho salmon and adfluvial cutthroat trout (White 1999).

South Branch Tributaries

The flow in the south branch of Thornton Creek is supplemented by three larger tributaries and three smaller ones. The confluence locations where tributaries join the south branch historically were highly productive, dynamic areas within the watercourse (Seattle 2005). In a natural condition, a sediment fan forms at the junction of tributaries and main stem streams because of the decreasing gradient and width of the main stem valley. The sediment fan promotes the interchange of surface and subsurface water, providing a complex mixture of water temperatures, upwelling and downwelling zones, and nutrient introduction. The steep tributary valleys also contribute woody debris to the watercourse. Today, however, increased high flows in the Thornton Creek watercourse often erode tributary junction sediment deposits, and the majority of these junctions are armored and culverted (Seattle 2005), further reducing the productivity of tributary junction habitats. Riparian and instream conditions in the three larger tributaries—Victory Creek, Willow Creek, and Kramer Creek—are briefly summarized in the subsections below.

Of the three major south branch tributaries, Kramer Creek and Willow Creek were found to contain juvenile cutthroat trout in their lowest sections. Kramer Creek was also found to contain juvenile coho, although in substantially fewer numbers. No fish were found in Victory Creek, which has a steep gradient at the confluence (Lantz et al. 2006).

Victory Creek

The farthest upstream tributary, Victory Creek, originates on an upland plateau in what was once a wetland, joining the Thornton south branch just south of NE Northgate Way. Today the basin of Victory Creek is almost entirely developed, except for a few pocket parks located along the stream channel. Victory Creek flows mostly in a simple armored channel through residential properties and under roads, with stream gradients of 1 to 3 percent. Ten outfalls enter the tributary. Combined, they drain the majority of the Victory Creek basin.

Erosion and channel downcutting in the lower section of Victory Creek illustrate how altered hydrologic conditions are actively degrading the stream channel (Map 40). Houses and yards encroach along the length of this tributary, with lawns and landscaping occupying most of the riparian corridor, except in the lowest section which is dominated by invasive plant species (Maps 41 and 43).

Willow Creek

Restoration work along Willow Creek (south branch of Thornton Creek; photo courtesy Seattle Municipal Archives; photo by Toczek)

Willow Creek enters the Thornton south branch just downstream of Lake City Way. The watershed conditions in this tributary are similar to those in Victory Creek. The Willow Creek headwaters originate in a low-lying valley portion of the watershed that historically was wetland habitat. The flow of Willow Creek then passes through residential neighborhoods and along Lake City Way before discharging into the south branch. Where the watercourse borders Lake City Way, the valley has been filled, the channel straightened, and the banks armored. Much of this section flows within culverts that control the stream gradient, resulting in only slight downcutting. Willow Creek drains a smaller area and receives flow from fewer outfalls than Victory Creek. Riparian areas are dominated by invasive plant species, lawns, and landscaping; riparian trees and canopy cover are lacking in most of the watercourse sections.

Kramer Creek

Kramer Creek and the other tributaries of the south branch have not been thoroughly surveyed. These tributaries are steep (4 to 8 percent gradient) compared to the rest of the channel within the south branch basin, draining down the valley walls. Historically these small tributaries were sources of sediment through landslide generation and overall hillslope erosion, and they also formed important tributary junction habitat. Many of these tributaries are heavily culverted or piped and therefore are no longer able to contribute sediment to the system.

Kramer Creek, the largest of the small tributaries, discharges into the depositional zone of the lower reach of the Thornton Creek south branch. Kramer Creek drains a rather steep watershed consisting of about 90 acres. The lowest section of Kramer Creek (TS01.KR01) flows within the low-gradient valley bottom and alluvial fan downstream of the north and south branch canyons. Completely channelized along the street edge in front of residential properties, the tributary often floods during storm events. Lawns are the only bank vegetation for most of Kramer Creek.

North Branch of Thornton Creek

Watercourse codes (also shown on the watercourse maps) consist of two letters of the watercourse name (TS for Thornton south branch) and the number of the stream segment, starting with 01 at the mouth and increasing in the upstream direction.

The north branch originates at the Ronald bog in the City of Shoreline and is 5 miles in length, constituting 25 percent of the total Thornton Creek channel length. The north branch flows in a southwesterly direction from Shoreline, under Interstate 5, and through the Jackson Park golf course, the Lake City Way commercial area, and residential neighborhoods before joining the south branch near Nathan Hale High School. The north branch has two major tributaries, Littles Creek and Littlebrook Creek, and two small tributaries.

The north branch of Thornton Creek is divided into four reaches based on gradient and valley confinement:

- The north branch headwaters (TN05–TN04), located upstream of Interstate 5 in the City of Shoreline
- The north branch within the Jackson Park golf course (TN03)
- The north branch ravine and alluvial fan (TN02–TN01), which includes the confluence with the south branch
- The north branch tributaries, Littles Creek and Littlebrook Creek (TN03.LI04–TN03.LI01).

North Branch Headwaters (TN05–TN04)

The headwaters reach of the Thornton Creek north branch is approximately 10,200 feet in length, 39 percent of the total length of the north branch, with about half (5,240 feet) contained within culverts. It extends from the Ronald bog in the City of Shoreline to the outlet of the culvert under Interstate 5, which borders the Jackson Park golf course in Seattle. Stream survey activities north of the twin ponds were curtailed where the channel extends beyond city limits, although some habitat data were collected.

Riparian Habitat

Similar to the south branch, the north branch originates on a rolling upland plateau with wetlands and forested swales (Troost et al. 2005).

Instream Habitat

Prior to development, the 75- to 200-foot-wide upland plateau contained a meandering stream in a split flow and sometimes braided channel, laterally connected to wetland areas and forested swales (Troost et al. 2005; Seattle 2005, Stoker and Perkins 2005). Most of the wetlands and swales have been filled, although some remnants exist. The Ronald bog and the twin ponds are both former peat deposits within the City of Shoreline, currently functioning as in-line detention ponds. Remnant wetlands areas are located just downstream of the twin ponds at Peverly Pond.

The instream habitat throughout this headwaters reach is of poor quality (Map 43). Historically, the upper channel had room to form channel bars and meander bends, and build a floodplain (Stoker and Perkins 2005). Filling, culverts, and bank armoring now confine most of the channel to a width between 5 and 20 feet; the active channel width averages 8 feet. Much of the channel is armored or is entrenched 3 to 6 feet below remnants of the former floodplain, except within the twin ponds. Floodplain connection is limited along most of the channel.

The channel is dominated by riffle and glide habitat for at least 41 percent of the open channel length. Pool habitat makes up about 18 percent of the open channel length, and most of this is located within the twin ponds (Map 41). The majority of sediment in this reach comes from erosion of the banks and channel bed, along with fine sediments that wash from the roads and yards (Stoker and Perkins 2005).

This headwaters reach of the north branch is not used by migratory fish, because downstream barriers prevent passage. Washington Trout (2000) found adult and juvenile rainbow trout upstream of NE 155th Street in the City of Shoreline, in the vicinity of a trout pond.

North Branch Golf Course (TN03)

This reach of the north branch is just over a mile in length (5,566 feet, for 22 percent of the north branch channel length). It begins just upstream of the Jackson Park golf course and extends to the confluence with Littles Creek.

Riparian Habitat

Within the golf course, riparian conditions are dramatically different from conditions downstream of the golf course. Within and upstream of the golf course in this segment (TN03c), nonnative plants, turf, and landscaping make up the primary vegetation in the riparian zone. Himalayan blackberry is the primary invasive plant, which dominates the stream bank, particularly along the segment parallel to Interstate 5 upstream of the golf course. The riparian zone provides no canopy or shading over the stream. Although there are few structures within 100 feet of the stream through this segment, there is little vegetation other than lawn and golf course landscaping. The riparian habitat quality is poor in this segment.

Downstream of the golf course (TN03b), riparian conditions improve with a mixed deciduous and coniferous forest, shading the stream and riparian wetlands. Although pockets of invasive plant species exist here, the majority of the valley bottom is dominated by native wetland and riparian plant species. The riparian corridor averages over 50 feet in width, except where there are road crossings. The riparian forest continues downstream of 10th Avenue NE with a mixed deciduous and coniferous forest, although nonnative plants become more dominant in the understory. The steep surrounding ravine and park prevent any encroachment by houses within 100 feet of the stream. Riparian habitat through this segment is of moderate quality.

The lowest segment of this reach (TN03a), near the junction with Littles Creek, is of poor riparian quality. The watercourse enters a multifamily residential development, where lawns surrounding the stream and substantial amounts of bank armoring exist.

Instream Habitat

Through the golf course reach, the Thornton north branch has a low gradient of near 1 percent (Map 39). Historically, the valley bottom and channel migration zone were 100 to 350 feet wide with sand and gravel substrates left behind by the glacier (Stoker and Perkins 2005). However, the stream valley has been modified by grading, fill, and excavation in most of this reach, particularly in the upstream segment parallel to Interstate 5, where the stream has been straightened and confined. The stream valley here is about 40 feet in width, and the stream has incised into the valley 3 to 4 feet. Within the golf course, the channel is wider and has some sinuosity, although the banks are hardened by riprap and the stream cannot migrate.

In the upstream segment, the channel is mostly eroding and degrading or has been locked into place through bank armoring (Map 40). Gravel and sand are the dominant sediment types in the channel, although there is little structure in the stream through the golf course to trap and store sediment. The wider stream widths in the golf course, however, allow the stream to increase in size in response to high flows, moderating erosion of the streambed and entrenchment of the channel (Stoker and Perkins 2005). Armored banks near the golf course fairways restrict connections between the stream and floodplain; as a result, high flows are contained within the active channel, which is 30 feet in width (Map 42). For the most part, the stream in this upstream segment is not heavily encroached upon compared to other areas of Thornton Creek, although roads and armoring affect this segment of the north branch.

Riffles and glides dominate the stream through the golf course and immediately upstream (Map 41). With little instream structure to prompt pool formation, the stream has rather simple habitat in this area. Instream habitat quality is considered poor (Map 43).

Downstream of the golf course the north branch changes dramatically, entering a wetland and park segment before the junction with Littles Creek. In this segment, the stream connects freely with its floodplain and has a width in excess of 30 feet, prompting wetlands and diverse habitat. Valley walls confine the stream in this segment.

In contrast to the upstream segment of this reach, the highest-quality instream habitat in Thornton Creek is found just downstream of the Jackson Park golf course, before the watercourse passes underneath 10th Avenue NE (TN03b). In this lower segment, the stream flows through unconfined open space with active connections to the floodplain. This is the only segment of restabilized channel in the entire Thornton Creek watercourse; the channel is not downcutting, widening, or aggrading, is not entrenched, and is connected to the floodplain. This segment has pockets of forested riparian wetlands that are hydrologically connected to the channel.

The conditions in this segment indicate how upstream areas may have functioned prior to development of the golf course and surrounding watershed. This area formerly contained a mill and mill pond but the stream was restored after timber harvesting ceased in the area. The current condition demonstrates that historically degraded areas can be restored to good-quality habitat if the stream is given sufficient room (Stoker and Perkins 2005).

Higher-quality conditions continue downstream into the narrow valley, where park designation has restricted encroachment next to the north branch. Instream conditions begin to degrade approaching the confluence with Littles Creek, as armoring and residential properties line the stream (Maps 41, 42, and 43).

Habitat restoration along north branch of Thornton Creek (photo courtesy Seattle Municipal Archives; photo by Toczek)

A series of barriers obstruct anadromous salmon and adfluvial trout access to habitat through this reach. Resident cutthroat trout are found as far upstream as the golf course, and the warmer waters of the golf course ponds and adjacent stream contain pumpkinseed sunfish. Some of the highest densities of juvenile cutthroat trout found within the north branch occur within this reach (Lantz et al. 2006).

North Branch Ravine and Deposition Zone (TN02–TN01)

The north branch of Thornton Creek continues in a ravine after the junction with Littles Creek. The ravine and deposition zone of the north branch extend about 1.8 miles, or 9,541 feet, constituting 38 percent of the Thornton north branch channel length.

Riparian Habitat

The riparian vegetation through this reach of the north branch is dominated by lawns and landscaping, although pockets of deciduous and coniferous forest exist (Map 41). Nonnative plants also dominate areas along the riparian corridor, including Himalayan blackberry, English ivy, and Japanese knotweed. The riparian corridor is generally less than 50 feet wide, and in some places houses and other residential structures encroach within 20 feet. The surrounding land uses are primarily single-family and multifamily homes, and the riparian corridor is heavily fragmented with an intermittent canopy. The riparian corridor also contains few trees or other vegetation to provide woody debris to the stream. The riparian habitat quality within this reach is either poor or moderate (Map 43).

Instream Habitat

The north branch ravine (TN02), about 200 feet wide, runs for about 8,000 feet at gradients between 2 and 4 percent (Map 39). The channel through the ravine is confined by encroachment of 9 to 11 feet. About 1,500 feet before the north branch meets the south branch, the ravine opens into a sediment depositional area caused by the wide valley and decreased gradient, less than 2 percent. The stream in this lowest segment is straightened, armored, and constrained into a channel width between 8 and 10 feet.

The channel is mostly eroding and degrading in this segment as a result of the unnatural confinement (Map 40). This segment contains a high degree of bank armoring (54 percent), which restricts connections between the stream and floodplain, limits bar formation, and prevents channel migration (Map 42). Historically, this area contained a channel migration zone between 50 and 150 feet wide (Stoker and Perkins 2005). High flows, coupled with a high degree of bank armoring, have caused bed erosion. Throughout this reach the stream has incised 3 to 6 feet within the ravine and 5 to 8 feet in the deposition zone below the surrounding floodplain. There is little woody debris or other natural structure in the stream to store sediment and scour pools, although a few constructed weirs control the gradient of the stream.

Restoration site along north branch of Thornton Creek (photo courtesy Seattle Municipal Archives; photo by Toczek)

In this reach the north branch channel is relatively homogenous and devoid of instream structure. Although small sections within the reach display diverse local conditions, the stream in general is dominated by riffle habitat and plane-bed channel characteristics (Map 41). A few areas provide some diversity, such as a wide section of the stream between 20th and 22nd avenues NE, which has allowed meander bends and instream gravel bars to form (Stoker and Perkins 2005). A small right bank landslide just upstream of 20th Avenue NE also provides some diversity by supplying gravel to the channel. The instream habitat within this section varies, ranking as either poor or moderate (Map 43).

Portions of this reach are accessible to migratory fish, particularly Chinook, coho, and cutthroat (Map 44). Resident cutthroat trout are found throughout this reach, along with coast-range sculpin, although sculpin occur only in low numbers (Lantz et al. 2006).

Littles Creek and Littlebrook Creek

The north branch of Thornton Creek has fewer tributaries than the south branch; the two primary tributaries are Littles Creek and Littlebrook Creek. The lower segments of these tributaries have been surveyed for instream and riparian conditions).

Littles Creek is similar in channel gradient to the north branch (1 to 2 percent) with a pool-riffle structure. The upper segment of Littles Creek (TN03.LI04) is located within an open-space area in the City of Shoreline. Within Seattle, the middle segments (TN03.LI03 and TN03.LI02) carry flow through mixed land uses including multifamily residential neighborhoods and the Jackson Park golf course. The lowest segment in the Littles Creek tributary system, with a length greater than 1,600 feet, is confined in culverts (TN03.LI01; see Figure 27). Littles Creek is ranked as having poor instream quality, although the riparian quality varies between poor and moderate. (Map 43).

Littlebrook Creek is a steeper tributary, with channel gradients reaching 4 percent (Map 39). The upper two-thirds of this tributary are mostly confined in culverts. The lower 3,000 feet of the watercourse is primarily open channel. The lower tributary channel is confined by valley walls and encroached upon by residential development and infrastructure. Historically the tributary would have been classified as a forced pool-riffle morphology, but today the stream habitat is dominated by riffle (61 percent) with few pools (9 percent). Although much of the open-channel watercourse has a deciduous canopy, the understory is dominated by invasive plant species. The instream and riparian habitat quality is ranked as low (Map 43).

The lowest portions of Littlebrook Creek were found in a recent survey to contain juvenile cutthroat trout. No fish were found in Littles Creek; barriers are present downstream of the confluence of Littles Creek with the north branch (Map 44; Lantz et al. 2006).

Thornton Creek Main Stem

The main stem of Thornton Creek extends 1.4 miles, or 7,336 feet, from the confluence of the north and south branches downstream to Lake Washington. The main stem passes through predominantly residential areas before entering Lake Washington at Matthews Beach. The main stem channel has a lower gradient than the rest of the system, at primarily less than 1 percent, and is a depositional area for sediments transported from upstream.

The Thornton Creek main stem is used by Chinook, coho, and sockeye salmon; cutthroat trout; three-spine stickleback; rock bass; pumpkinseed sunfish; juvenile sunfish; coast-range sculpin; prickly sculpin; and lamprey (Lantz et al. 2006).

The main stem of Thornton Creek is divided into three reaches:

- The reach adjacent to Meadowbrook pond (TM04)
- The middle main stem (TM03)
- The lower main stem (TM02–TM01), including the stream mouth.

Meadowbrook Pond (TM04)

Meadowbrook Pond (photo by Bennett)

This reach extends from the confluence of the Thornton north and south branches to 39th Avenue NE and flows adjacent to Meadowbrook pond, a detention pond with an associated high-flow bypass structure installed between 1996 and 1998. This reach makes up about 15 percent of the total length of the main stem (1,077 feet). Historically, this area was a confluence zone with high habitat values characterized by gravel deposition, channel migration, and multiple stream channels (Barton and Booth 2002; Perkins 2003; Stoker and Perkins 2005; Seattle 2005). The location of the confluence probably shifted as the channel moved through time. Peat soils near the surface indicate former wetlands in the area (Barton and Booth 2002; Perkins 2003).

Meadowbrook pond and its high-flow bypass structure were constructed just downstream of the confluence of the branches to detain water and trap sediment. This project was intended to improve downstream water quality, reduce downstream flooding, and reduce sediment accumulation at Matthews Beach (Perkins 2003). When stream flows reach 240 cubic feet per second (cfs), typical of a 6-month storm event, flows are diverted from the stream into the pond. Above a 25-year storm, flow is also diverted into a 72-inch bypass pipe leading to Lake Washington. The pipe is supplemented, when necessary, by a high-flow diversion structure that also ties into the 72-inch pipe. The high-flow bypass reduces the predevelopment 2-year flood volume downstream of Meadowbrook pond by approximately one-third, greatly changing the Thornton main stem hydrology compared to the north and south branches (Hartley and Greve 2005).

Riparian Habitat

The riparian zone is very narrow at the upstream end of this reach, with residential structures as close as 10 feet from the stream. Adjacent to Meadowbrook pond, the riparian corridor expands in width, although the vegetation is dominated by lawns and landscaping. The stream through this reach lacks canopy cover. The riparian habitat is moderate, as native plantings from restoration projects are taking hold (Map 43).

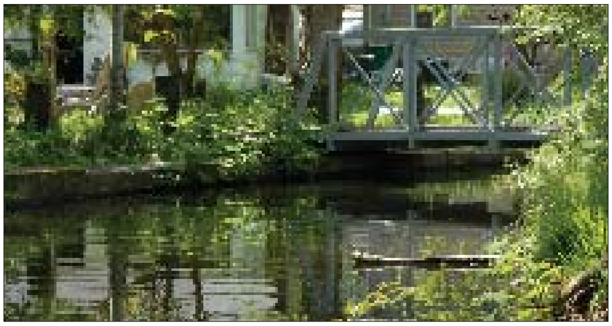
Instream Habitat

The watercourse through the Meadowbrook reach has been affected by extensive grading and filling, and the channel has been straightened and confined to one narrow part of the former channel migration zone (Stoker and Perkins 2005). The majority of the reach is armored as well (Map 42). Despite these alterations to the channel, this reach is rated among the highest-quality habitat in the system, offering riffles with loose gravel and adjacent pool habitat (Map 43). The reach has a high proportion of pools (44 percent), some of the deepest pools in the watercourse, and gravel as the dominant streambed substrate. The average active width of the channel exceeds 12 feet, although the channel upstream of the bypass intake is widening and exceeds 20 feet in areas with active floodplain connection.

This reach is easily accessible to anadromous salmon as well as resident and adfluvial trout. The stream through this reach is heavily used by salmonids for spawning, particularly upstream of the high-flow bypass intake, and contains the highest density of Chinook redds within Thornton Creek (Map 44).

Middle Main Stem of Thornton Creek (TM03)

This reach extends from 39th Avenue NE to the end of the NE 45th Street bridge, for 45 percent of the total length of the main stem, or 3,314 feet. Historically the stream meandered with multiple channels and wetlands across the broad alluvial floodplain in the area (Barton and Booth 2002). Floodplain connections are now limited along almost the entire reach because of encroachment, bank armoring, and channelization (Map 42; Stoker and Perkins 2005).



A residence along Thornton Creek (photo by Bennett)

Riparian Habitat

The riparian corridor in the middle reach of the Thornton Creek main stem is mostly dominated by lawns and landscaping (Map 41). There are some sections of native understory that improve the quality of the riparian corridor. The stream weaves between houses through this reach, maintaining a narrow corridor between the stream and adjacent structures, often less than 20 feet. Riparian habitat quality is ranked as moderate, mostly owing to the continuous, thin band of trees in the narrow riparian corridor.

Instream Habitat

A steady supply of coarse-grained sediment is lacking in this reach, as well as those downstream, which exhibit similar thin streambed substrates seen in the majority of Thornton Creek (Stoker and Perkins 2005). Landslides do not supply a significant amount of sediment to the main stem; most of the sediment in the channel comes from erosion of the bed and banks (Barton and Booth 2002; Stoker and Perkins 2005). Sediment production below Meadowbrook pond has been reduced under current conditions to about one-third of the predevelopment production rate (Barton and Booth 2002). The primary cause of this reduction in sediment load is probably not the current dredging of Meadowbrook pond, because a wetland at the predevelopment location of the pond most likely acted as a natural sediment trap (Barton and Booth 2002). Instead, bank armoring, streambed grade controls, and lack of stream access to floodplain gravel have reduced Thornton Creek's opportunities for natural adjustment and bank erosion, significantly reducing coarse sediment sources (Barton and Booth 2002; Stoker and Perkins 2005). As a result, this reach exhibits channel degradation (Map 40). Encroachment and bank armoring in much of this reach also limit the stream's ability to adjust to flows and recruit bank sediment (Map 42).

This reach has moderate instream habitat quality (Map 43). Although the stream is encroached upon and contains armored banks, the reach has a pool-riffle channel type. The channel averages between 9 and 11 feet in width and 3 to 4 feet in depth (Stoker and Perkins 2005). About half of the instream habitat is riffle, with pools of moderate size and frequency but little instream cover (Map 41). The channel bed consists mostly of sandy gravel, with sections of exposed clay.

As with the Meadowbrook pond reach, this reach is freely accessible to anadromous salmon and adfluvial and resident trout, and is used by salmon and trout species for spawning and rearing.

Lower Main Stem of Thornton Creek (TM02–TM01)

The lowest reach of Thornton Creek extends 2,799 feet, for 38 percent of the main stem length, from 45th Avenue NE to the stream delta in Lake Washington. The upper segment (TM02) contains an area of valley confinement between 45th and 46th avenues NE, which is unique within the main stem of the watercourse (Stoker and Perkins 2005). The lowest segment of the main stem (TM01) extends from Maple Creek to the delta.

Riparian Habitat

Riparian conditions vary between poor and moderate quality in this reach. The upper section (TM02b) is dominated by invasive plants including Himalayan blackberry and Japanese knotweed (Map 41). Residential buildings are closer than 20 feet to the stream in some places. Some trees provide a limited canopy, although riparian habitat quality in this upper section is poor.

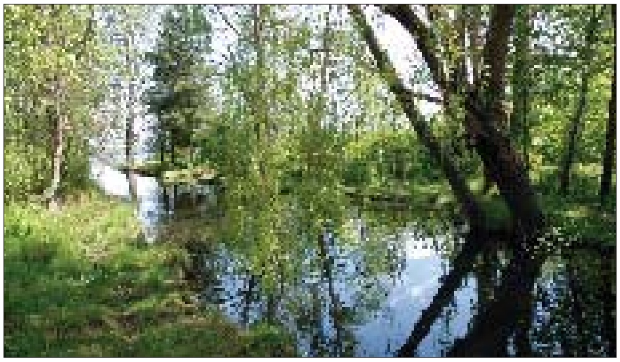
The watercourse enters a park with a narrow valley in the middle section (TM02a). Within the park, the riparian community has a native coniferous and deciduous forest with moderate riparian quality (Map 43). The riparian corridor contains a mostly deciduous canopy that provides stream cover.

Lawns and landscaping are the dominant riparian vegetation along the lowest segment of this reach (TM01). Houses are located less than 20 feet from the stream banks, and bank armoring is present along most of the segment. Riparian conditions in the lower segments are moderate, primarily because of deciduous cover along the lowest segment of the watercourse, within Matthews Beach Park.

Instream Habitat

Instream habitat quality is moderate in the upper segment of the reach (TM02b), with mostly riffles and glides, but improves to high quality as the watercourse enters the park near NE 95th Street (TM02a; Map 41). The short section of stream located in these park lands has a small channel migration zone, which is very limited within the main stem watercourse (Stoker and Perkins 2005). An eroding bank of gravelly deposits on the left bank within the park provides a good source of gravel. The channel is still somewhat incised in the park area, because the stream lacks sufficient access to floodplain sediment, and also lacks instream structure to trap and accumulate sediment. A number of culverts within this reach also affect instream habitat.

The lowest segment of the main stem (TM01) was the original Thornton Creek delta. Historically, the backwater influence from Lake Washington extended about 1,500 feet upstream of the present watercourse mouth (almost up to NE 95th Street), prior to the lowering of the lake level in 1917 (Stoker and Perkins 2005). Historically, there was a broad, unconfined streambed with a large, complex floodplain and a delta area at least 450 feet wide (Seattle 2005; Stoker and Perkins 2005).



Lower Thornton Creek, near the outlet to Lake Washington (photo by Bennett)

This reach has been highly modified by the addition of grade controls (e.g., a former rail line, roads, and culverts) and a concrete channel in the upper sections of the present delta (Map 40). The lower delta was straightened and confined by bank armoring and has lost its sediment supply (Stoker and Perkins 2005). The stream has incised through the original delta, and the armored channel prevents the channel from shifting or splitting to form productive delta conditions (Stoker and Perkins 2005).

The lower segment of Thornton Creek is dominated by glide habitat (76 percent) and is of low instream habitat quality (Map 43). Historically, this area of Thornton Creek was highly productive for both stream and lake fish species, offering diverse habitat in a low-gradient valley influenced by lake water levels (Seattle 2005).

Maple Creek

Maple Creek is a steep, multibranching tributary entering the lower main stem of Thornton Creek. Historically it provided sources of wood, sediment, and nutrients and was a productive area due to the abrupt gradient change (Map 39). The ecological advantages of the confluence area have been mostly lost, because the channel has been lined in concrete at the lower end. In contrast, the headwaters of Maple Creek are forested and relatively pristine.

Use by Fish and Benthic Invertebrates

Fish Access

Historically, Thornton Creek was probably used by coho, Chinook, and kokanee (non-anadromous sockeye) salmon, and both migratory and resident cutthroat and steelhead/rainbow trout (Trotter 2002). Currently, resident and adfluvial cutthroat and rainbow trout, as well as anadromous Chinook, coho, and sockeye salmon, all spawn in Thornton Creek. There have also been single sightings of steelhead and chum salmon in Thornton Creek (McMillan 2007).

Native nonsalmonid species that use Thornton Creek include peamouth chub, large-scale sucker, three-spine stickleback, prickly sculpin, coast-range sculpin, lamprey, and long-nose dace (Lantz et al. 2006). Nonnative fish species that have been introduced to Thornton Creek, either intentionally or unintentionally, include rock bass, pumpkinseed, large-mouth bass, and oriental weatherfish (Lantz et al. 2006).

Coho salmon are the most numerous salmonids using Thornton Creek. Based on carcass counts from 1999 through 2005, an average of about 33 adult coho spawn in Thornton Creek each year, with returns varying widely (Table 42). Adult coho using the watercourse over that period were a combination of wild and hatchery fish, with the hatchery influence ranging between 15 and 91 percent.

Table 42. Thornton salmon spawning survey results based on carcass and redd counts.

	Chinook		Coho		Sockeye		Chum	
Year	Carcasses	Redds	Carcasses	Redds	Carcasses	Redds	Carcasses	Redds
1999	2	3	7	2	0	0	0	0
2000	2	6	94	32	9	17	0	0
2001	4	4	70	32	18	13	1	0
2002	3	0	17	11	11	2	0	0
2003	3	3	5	6	3	0	0	0
2004	6	6	7	19	7	3	0	0
2005	6	0	29	15	1	1	0	0

Source: McMillan (2005); SPU unpublished data. Values in table are averaged between the two data sources.

Sockeye returns to Thornton Creek average seven fish per year and range from zero to 18 fish per year. Hatchery sockeye are released into the Cedar River, (which enters the southern end of Lake Washington) as fry, which are too small to be marked; hence hatchery and wild sockeye cannot be visually distinguished.

Adult Chinook use of Thornton Creek is low, ranging from two to six fish annually. Chinook adults using the watercourse have been evenly divided between wild and hatchery fish.

Hatchery fish in the watercourse could be either fish that have strayed while en route to their natal hatchery, or fish released into the watercourse as fry. Numerous releases of various salmon and trout species occurred between 1937 and 1999 as part of Washington Department of Wildlife programs, as well as Salmon in the Classroom and other local community programs. It is likely that some small releases of salmon still occur today.

Migratory cutthroat trout are the most abundant salmonid using Thornton Creek, with an average annual adult count of over 200 live fish on the spawning grounds. These trout are likely all wild fish, since cutthroat trout are no longer stocked in Thornton Creek.

Approximately 12 miles of Thornton Creek is potentially fish-bearing, including both branches and the lower segments of the Littles, Littlebrook, Willow, and Maple tributaries (Washington Trout 2000). Manmade barriers at NE 107th Street and 12th Avenue NE on the south branch and at NE 115th Street and 35th Avenue NE on the north branch restrict salmon migration to 67 percent of potential upstream habitat. Cutthroat trout can proceed slightly farther upstream than salmon, but their distribution is restricted by barriers at the confluence of Victory Creek on the south branch and at NE 125th Street on the north branch.

Spawning activity tends to be concentrated in slightly different areas, depending on the species. Chinook redds from 2000 to 2005 have been concentrated in two locations. Approximately half of the Chinook redds have been found in the stream adjacent to Meadowbrook pond. A smaller concentration of Chinook redds has been located immediately downstream of the fish barrier in the north branch (at NE 115th Street and 35th Avenue NE). Coho and sockeye salmon tend to spawn in the Meadowbrook pond area and near the Maple Creek confluence. Cutthroat trout use most of the accessible habitat in the main stem and the north and south branches, except immediately upstream of the mouth of Thornton Creek, at culverts, and in confined residential sections.

Spawning activity in Thornton Creek is typically concentrated in areas with gravel substrates near pools that can provide holding areas for adults. Spawning areas are typically high in hydraulic diversity, including areas associated with tributary confluences, gravel bars in stream meander bends, and transitions from confined to unconfined sections of stream channel. Exchange between well-oxygenated surface water and cooler subsurface water is higher in these areas, producing zones of upwelling and downwelling that spawning salmon prefer. Spawning densities appear to be greater in the north branch than in the south branch or the main stem, probably because of the salmon barrier that restricts use of the north branch to the lowest segments.

Smolt trapping is conducted annually in Thornton Creek to count the numbers of juvenile salmon produced in the watercourse. The catches in Thornton Creek generally are rather low, particularly compared with Bear Creek, a suburban tributary of the nearby Sammamish River. Thornton Creek smolt catches, however, are much higher than those in Longfellow Creek.

Smolt trapping occurs over a few days, and the number of fish caught annually varies widely in Thornton Creek (Table 43). Cutthroat trout are the most numerous smolts caught, averaging just over 200 fish annually, with a range of six to 405 fish captured over the 7-year survey period. The annual average coho captures are about 37 fish per year, with the annual catches also ranging widely from year to year. Chinook smolt captures are generally just a few fish each year, although over 300 Chinook smolts were captured in the trap in 2004. These captures are probably the result of a release of Chinook smolts into Thornton Creek rather than a result of 2003 redds in the watercourse.

Table 43. Thornton salmon smolt trapping results, 2000–2006.

Year	Total Coho Smolts	Total Cutthroat Smolts	Total Chinook Smolts	Number of Sample Days	Coho per Day	Cutthroat per Day
2000	5	6	0	5	1.0	1.2
2001	37	637	0	8	4.6	79.6
2002	89	120	2	9	9.9	13.3
2003	98	405	2	12	8.2	33.8
2004	14	210	309	25	0.6	8.4
2005	9	32	1	11	0.8	2.9
2006	11	61	0	15	0.7	4.1

Source: SPU Smolt Trapping Data 2000–2006.

The low smolt numbers in Thornton Creek could be a reflection of poor rearing habitat and lack of pools in the stream. It is likely that some juvenile fish are washed out of the watercourse by high flows during storm events earlier in the year. Low spawning success could also be an issue for coho salmon due to coho prespawn mortality. Thornton Creek had the highest average coho prespawn mortality rate (79 percent) among Seattle's salmon-bearing watercourses from 1999 through 2005 (Table 44). Despite these conditions, Thornton Creek still produces higher numbers of coho smolts than other Seattle watercourses, including watercourses with more returning coho adults, such as Longfellow Creek. The cause of coho prespawn mortality is not known, but a combination of water quality, sediment quality, and other environmental factors is under investigation. No underlying biological causes (such as infection, disease, or parasites) have been identified.

Table 44. Thornton coho female prespawn mortality.

Year	Number of Spawned Females	Number of Unspawned Females	Number of Unknown Spawning Condition	Total Number of Female Carcasses	Total Number of Females of Known Spawning Condition	PSM (%)
1999	2	0	0	2	2	–
2000	4	29	11	44	32	90
2001	2	9	19	30	11	82
2002	1	4	2	7	5	80
2003	0	2	0	2	2	–
2004	0	1	2	3	1	–
2005	4	5	5	14	9	56
Totals	13	50	39	102	63	79

PSM = prespawn mortality.
Sources: McMillan (2005); SPU unpublished data. Values in table are averaged between the two data sources.

Benthic Invertebrates

SPU has collected benthic macroinvertebrate data every other year since 1996 in Thornton Creek. Seven currently active sampling sites are located near the confluences of major branches and tributaries, on the main stem, and upstream and downstream of major stream improvement sites. Additional sampling of benthic invertebrates at three sites on smaller tributaries (Willows Creek and Littles Creek) has been discontinued.

Benthic index scores:

10–16	*very poor*
18–26	*poor*
28–36	*fair*
38–44	*good*
46–50	*excellent*

Thornton Creek benthic index (B-IBI) scores are very poor, averaging 15 for the entire system and ranging from 10 to 20 for 44 samples collected from 1994 through 2005 (Table 45). Abundance was sufficient (exceeding 400 individuals) for a high level of confidence that the samples accurately represent the overall benthic community (see Appendix C).

The number of individuals collected in an invertebrate sample influences the number of taxa counted because the more individuals collected, the higher probability of detecting a new taxon. To accurately measure taxa richness, a 400-count sample is preferred.

Table 45. Thornton average benthic index scores.

Reach	Site ID	Collection Sites	Years Sampled	Average B-IBI Score	Range
Main Stem TM04	TM01	U/S Meadowbrook Pond	1999–2001, 2003, 2005	14.4	12–16
TM04	TM02	D/S Meadowbrook Pond	1996, 1998, 1999–2001, 2003, 2005	13.4	10–16
			Average for Main Stem	13.8	10–16
South Branch TS05b	TS03	Park 6	1999–2001, 2003, 2005	16	14–18
TS03	TS02	U/S Lake City Way	1998–1999, 2001, 2003, 2005	13	10–16
TS01	TS01	Nathan Hale	1994–1996, 2000	12	10–16
		Average for South Branch		14	10–18
North Branch TN03c	TN02	U/S Golf Course (I-5)	1998–2001, 2003, 2005	15	10–20
TN03b	TN01	D/S Golf Course (10th Ave NE)	1999–2001, 2003, 2005	18.7	14–20
			Average for North Branch	16.9	10–20
Tributaries TN01.LI04	TL01	Littles Ck (NB) Paramount Pk[a]	1998–2000	19	18–20
TS02.WI01	TW01	Willow Creek (SB) @ 91st St[a]	1998	–	12
TS02.WI01	TW02/ TW03	Willow Creek tributary (SB)[a]	1999–2001, 2003, 2005	13	12-14
			Average for System	15	10–20

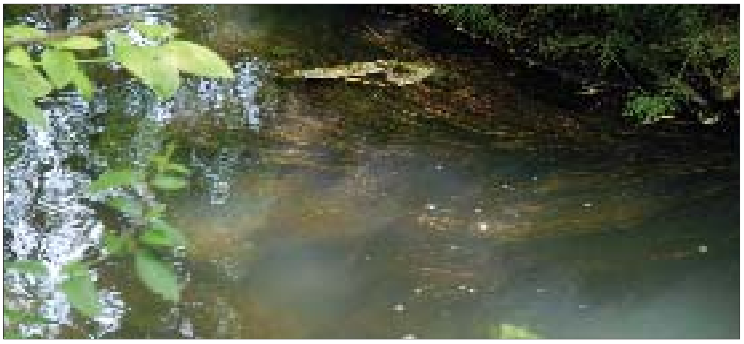
[a] Discontinued sample site. U/S = Upstream. D/S = Downstream. SB = South Branch. NB = North Branch. I-5 = Interstate 5.
Source: SPU benthic index of biotic integrity data 1994–2004.

Thornton Creek (photo by Bennett)

All the sampling sites had benthic invertebrates indicative of degraded conditions, including many aquatic worms (*Oligochaeta*) and midge larva (*Chironomidae*). The numbers of mayfly, stonefly, and caddisfly taxa, indicators of good water quality, were minimal. The dominance percentage was rather high (70 to 80 percent), indicating that the system is degraded compared to 40–50 percent dominance typical in a more natural system. The diversity of the benthic community is low in Thornton Creek, with most species tolerant of degraded conditions. Poor water quality conditions, high stream flows, and lower-quality riparian and instream habitat probably contribute to the low benthic index scores. The lack of coarse sediment may also reduce the productivity of the benthic community in the watercourse.

Although none of the benthic index scores at any sites ranked higher than poor, there were notable differences within the Thornton Creek watercourse. On average, the north branch had higher scores (16.9) than the south branch (14) or the main stem (13.8). The scores were highest at the wetland downstream of the Jackson Park golf course (18.7) and for Littles Creek (19). In the north branch, macroinvertebrates indicative of poor conditions were not as common as in the other branches, and the numbers of two common net-spinner caddisflies (*Hydropsyche* spp. and *Parapsyche almota*) increased over the past 3 years, suggesting a possible improvement in stream conditions. Both Jackson Park and Littles Creek had higher-quality instream habitat and riparian areas.

Park 6 on the south branch also had higher scores (16) than the rest of the south branch. In addition to benthic invertebrates frequently found in Thornton Creek overall, the south branch sites had freshwater amphipods (*Crangonyx*), planarians (*Turbellaria*), and leeches (*Hirudinea*), also indicative of degraded conditions.



Thornton Creek (photo by Bennett)

Small Watercourses

Key Findings for Small Watercourses

The small watercourses within Seattle include but are not limited to Mapes, Seola Beach, Puget, Yesler, Fairmount, Madrona, Frink, Washington Park, Wolfe, Blue Ridge, Ravenna, and Schmitz creeks and Licton Springs (Figure 33). These and many other unnamed urban watercourses do not support populations of anadromous salmonids. These watercourses are surrounded by urban and residential development, although the density of land use varies. A brief description of each watercourse location follows.

- Mapes Creek is located in the southeastern area of Seattle, draining to Lake Washington.
- Seola Beach Creek is located at the southwestern boundary of Seattle, draining to Puget Sound.
- Puget Creek is located on the eastern side of West Seattle, draining to the Duwamish River.
- Yesler Creek is located in the central portion of Seattle near the neighborhoods of Maple Leaf, Laurelhurst, and the University Village. The watercourse discharges to Lake Washington in Union Bay.
- Fairmount Creek is located in the northeastern area of West Seattle, draining to Elliott Bay.
- Madrona Creek is located in the Madrona neighborhood, draining to Lake Washington.
- Frink Creek is located along the shore of Lake Washington, just north of the Interstate 90 bridge.
- Washington Park/Arboretum Creek is located in the Washington Park Arboretum, draining to Lake Washington on the southern side of Union Bay.
- Wolfe Creek is located in the Magnolia neighborhood and historically flowed into Salmon Bay. It is now connected to the wastewater drainage system is conveyed to the West Point treatment plant. This watercourse contains a heron rookery.
- Blue Ridge Creek is a series of watercourses that drain the area just north of Shilshole Bay, discharging into Puget Sound.
- Ravenna Creek is located in the Maple Leaf and Ravenna neighborhoods, draining to Lake Washington through University Slough in Union Bay.
- Schmitz Creek is located in the northwestern area of West Seattle, draining to Puget Sound in a culvert off Alki Beach.
- Licton Springs is a set of springs located in the Greenwood neighborhood, just east of the headwaters of Thornton Creek.

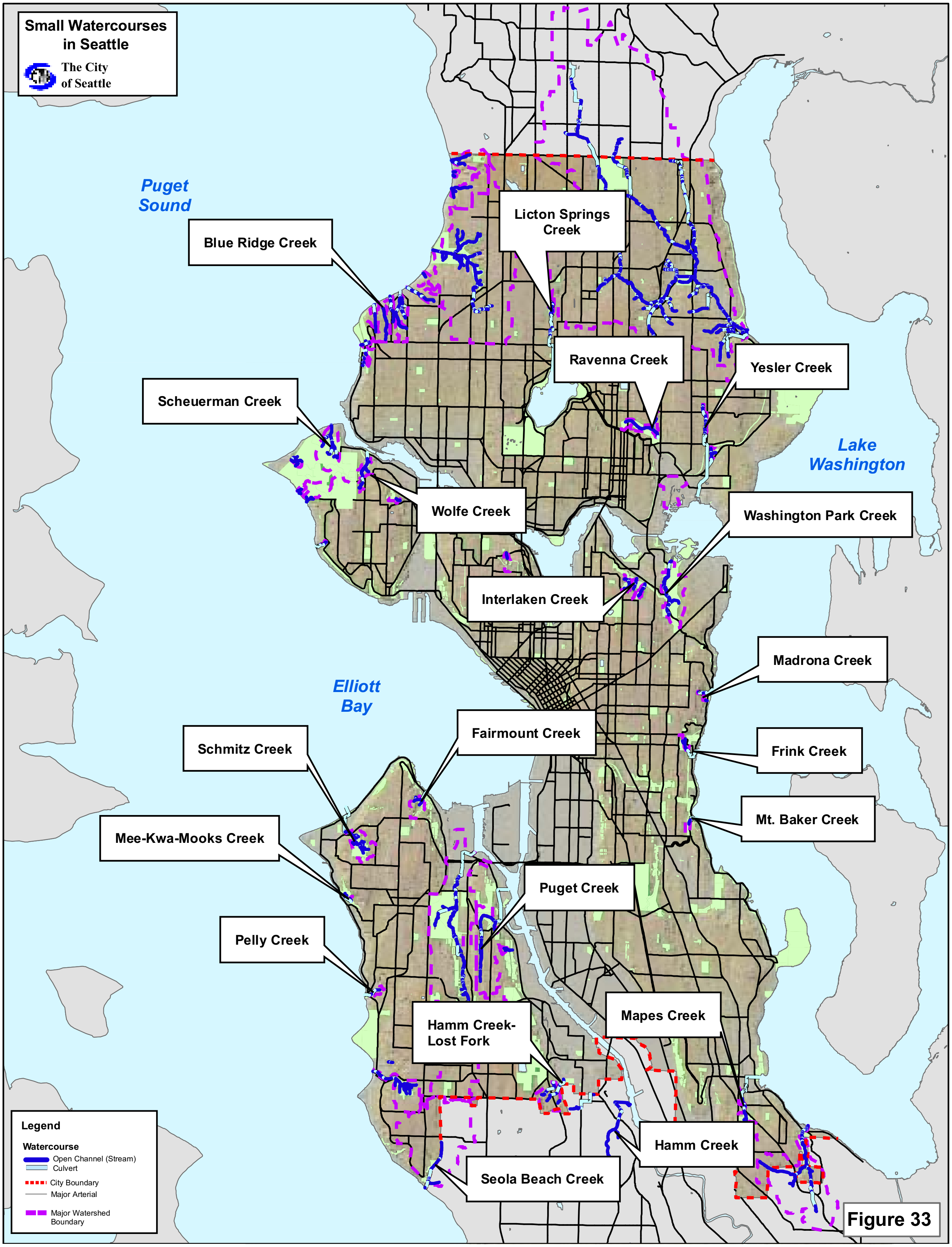


Figure 33. Small watercourses in Seattle.

Watershed and Stream Conditions

These smaller urban watercourses have not been intensely studied for their hydrology, water and sediment quality, physical habitat, and use by biological communities. However, the limited information available for these systems indicates that their conditions are similar to the larger Seattle watercourses, based on similarities in land uses and urban impacts.

It is likely that most of the smaller watercourses experience degraded water quality, altered hydrology, floodplain disconnection, loss of connectivity between upstream and downstream areas due to passage barriers, loss of riparian vegetation, lack of channel complexity, abundance of fine sediments, and absence of coarse sediments. Culverts and channel armoring are also common in these smaller watercourses.

Use by Fish and Benthic Invertebrates

Fish Access

These small watercourses do not support anadromous salmon (unless they are stocked in the watercourses), although some contain trout and other fish species. The mouths of some of the watercourses, particularly those draining to Lake Washington, are used in a limited fashion by juvenile salmon such as Chinook migrating through Lake Washington (Tabor et al. 2004, Tabor et al. 2006). Culverts have been installed at the mouths of many of Seattle's small watercourses, which could restrict fish access to most of these smaller systems. Table 46 lists the fish species found during recent surveys in the smaller watercourses of Seattle.

Table 46. Fish species found in small Seattle watercourses during 2005 surveys.

	Species								
Stream	**Coho**	**Cut-throat**	**Rainbow Trout**	**Stickle-back**	**Small-mouth Bass**	**Pumpkin Seed**	**Brown Bullhead**	**Goldfish**	**Koi**
Arboretum				✓	✓	✓	✓	✓	✓
Hamm Creek – Lost Fork	✓[a]			✓					
Lower Discovery Park				✓					
Mapes				✓					
Ravenna			✓						

[a] Presence due to release of hatchery fish into stream.

Benthic Invertebrates

Mapes Creek, located in the southeastern part of the city and draining into Lake Washington, includes a benthic invertebrate sampling site with 2 years of data. The benthic index (B-IBI) scores for these 2 years were 22 (poor) and 32 (fair) (see Appendix C). The sampling site is surprisingly rich in biota for a small watercourse in such a densely populated area of the city. This may be attributed to the fact that the sampling site has larger substrate than is usually available in Seattle watercourses, creating a more diverse habitat. Mapes Creek also has the greatest number of taxa reported in Seattle watercourses, with 43 taxa represented in the benthic sample collected in 2004. There was an abundance of planaria, scuds, and black flies, but also three kinds of riffle beetles (*Cleptelmis addenda*, *Lara*, and *Optioservus*) and a finger-net caddisfly (*Wormaldia*) that was not found in any other watercourse in Seattle. In addition, there were many clinger taxa, midges (some unique to this site), and more predators than found at many other locations, indicating good habitat conditions.

Puget Creek is located on the eastern side of West Seattle and drains to the Duwamish River. Benthic samples were collected in Puget Creek annually from 1994 through 1999. The benthic index scores were relatively consistent from year to year (14 to 16), indicating very poor conditions. In 1999, the Puget Creek sample received its lowest score, 12, although the abundance (369 individuals) was not sufficient to meet the minimum threshold (i.e., greater than 400 individuals).

The number of individuals collected in an invertebrate sample influences the number of taxa counted because the more individuals collected, the higher probability of detecting a new taxon. To accurately measure taxa richness, a 400-count sample is preferred.

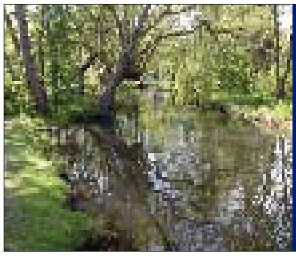
Washington Park/Arboretum Creek, draining to Union Bay in Lake Washington, was sampled once for benthic invertebrates. Although the quantity of invertebrates collected in the sample was relatively high for an urban system (4,750), the lack of diversity of the invertebrates collected indicate very poor stream conditions (benthic index score of 12).

Ravenna Creek is located near the University of Washington and drains to Union Bay in Lake Washington. Benthic samples were collected in Ravenna Creek annually between 1998 and 2001. The benthic index scores averaged 16, with a range from 14 to 18. While these results show an improvement in conditions over time from very poor to poor, the scores are of limited value because low numbers of invertebrates were collected (i.e., 126 to 377 individuals) and the abundance was not sufficient to meet the minimum threshold (i.e., greater than 400 individuals).

Schmitz Creek in West Seattle, which drains to Puget Sound from Alki Beach, has a 9-year record of benthic data. Overall benthic index scores have ranged from 14 to 30 (very poor to fair.) This small watercourse, like Fauntleroy Creek, is not exposed to the high range of flows seen in some of the larger watercourses. Like Fauntleroy, benthic abundance was low in all sampled years at this site, making the benthic index scores of limited value. The minimum threshold of 400 individuals was not collected in any year. The greater percentage of predators, low percentage of tolerant taxa, and decent dominance percentage (33 percent) in Schmitz Creek (all indicators of good habitat conditions) may be attributed to its small drainage area. On the negative side, the watercourse has a low abundance of macroinvertebrates, and the mayfly–stonefly–caddisfly taxa numbers are also disproportionately low.

Benthic index scores:

10–16	*very poor*
18–26	*poor*
28–36	*fair*
38–44	*good*
46–50	*excellent*



State of the Waters 2007

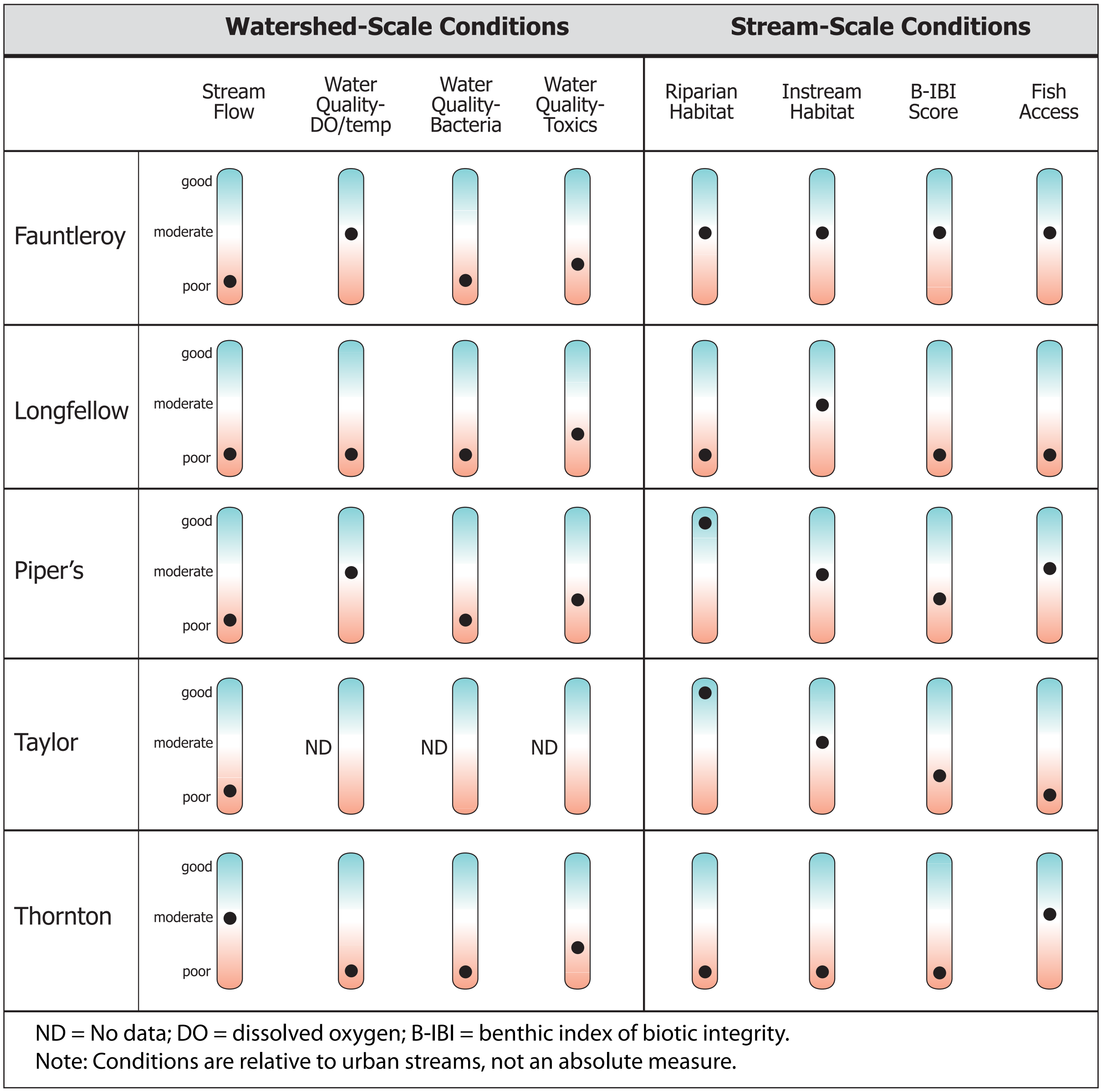
Part 5 Watercourse Summary & Conclusions

Piper's Creek (photo by Bennett)

Conditions in Seattle's urban watercourses vary substantially, with similarities and differences among the features that are functioning and those that are not. This chapter compares hydrology, water quality, riparian and instream habitat, and biological conditions among the five major watercourses of Seattle.

Understanding ecological challenges, particularly those challenges unique to specific watercourses, is important for implementing effective improvements. Truly improving stream conditions relies on addressing the scale of the problem and implementing actions in the right combination and sequence. For example, high and flashy stream flows are generated by land uses throughout the watershed and are a major influence on instream habitat. If a watercourse has high and flashy flows and lacks floodplain connections, then simply adding woody debris to the stream may not generate pools or trap sediment and may actually exacerbate flooding problems. Instead, hydrology and floodplain connections must be addressed before the effectiveness of instream work can be maximized.

Figure 34 provides a visual summary of watercourse conditions in Fauntleroy, Longfellow, Taylor, Thornton, and Piper's creeks. Conditions are categorized as good, moderate, or poor based on primary indicators, which are discussed further below. The intent of this summary is not to compare the watercourses to one another, but rather to provide information on the existing challenges for ecological health in Seattle watercourses. This information should help to inform planning for improvement actions in terms of their scale, sequencing, and appropriateness. The chapter closes with a summary of conclusions drawn from this study of Seattle watercourses.



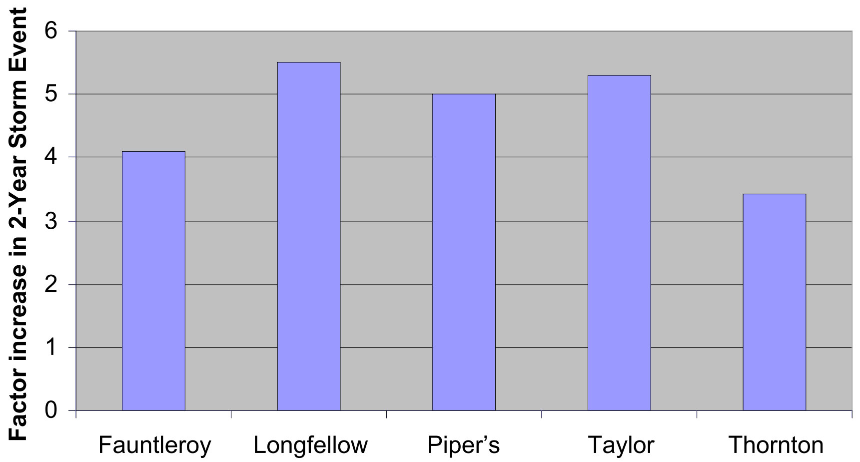
ND = No data; DO = dissolved oxygen; B-IBI = benthic index of biotic integrity.
Note: Conditions are relative to urban streams, not an absolute measure.

Figure 34. Summary of watershed-scale and stream-scale conditions within Seattle's five major watercourses.

Stream Flow Summary

Existing stream flow data, as well as hydrologic modeling, was used to estimate flow differences between forested watershed conditions and current watershed conditions in Seattle. The estimated increase in 2-year storm flow rates above those expected under forested conditions is compared among the five major urban watercourses in Seattle, illustrated in Figure 35.

As Figure 35 shows, Thornton Creek has the smallest increase in the size of 2-year storm flow, illustrated as the average of the north and south branches of the watercourse. (The mouth of Thornton Creek is not used in this comparison, because a bypass at Meadowbrook pond removes peak storm flows from the watercourse and therefore provides an inaccurate picture of flows in the watercourse.)



Notes:

The factor increase is the increase in the 2-year storm event between the forested and current condition. For example, a factor of 2 means that the stream flow during the 2-year storm event has doubled under current conditions compared to forested conditions.

Thornton Creek has a bypass located at Meadowbrook pond that substantially reduces stream flow at the mouth during the 2-year event due to the capacity of the bypass. As a result, an average of the factor increase at the junction of the north and south branches was used, as they are immediately upstream of the bypass and more accurately reflect hydrology changes within the stream system.

Figure 35. Increase in 2-year storm flow rates (forested conditions relative to current conditions) for each major watercourse in Seattle, modeled near the mouth.

Longfellow Creek and Taylor Creek show high increases in the 2-year storm flow compared to forested conditions in those watersheds. The long, narrow shape of the Longfellow watershed and its large areas of impervious surface deliver water quickly to the watercourse during storms. Taylor Creek has a smaller watershed, and the Taylor Creek hydrology is probably not as extreme as that of Longfellow Creek, because the hydrology modeling tends to bias results in smaller watersheds. The increase in Piper’s Creek is similar to the increases in the Longfellow and Taylor watersheds. Fauntleroy Creek is the only watercourse, other than Thornton Creek, in which the 2-year storm flow increased less than a factor of 5 compared to forested conditions.

For the most part, stream flow problems are generated by upland development in the watershed, which reduces infiltration and directs stormwater into drainage pipes for direct delivery to the watercourse. For Fauntleroy Creek, Piper’s Creek, and Taylor Creek, stormwater runoff is generated mostly from the plateau areas above the stream ravines or at the upstream limits of the watercourses. In Longfellow Creek and Thornton Creek, with larger watersheds and more moderate topography, stormwater runoff is generated throughout their watersheds and is delivered to the streams and their tributaries in many locations.

High and flashy stormwater runoff does not operate alone in how it influences stream habitat. The floodplain of a stream helps to contain and moderate high instream flows. In areas where a stream is constrained to an undersized channel or lacks floodplain connections, even moderate increases in stream flow can damage habitat and cause flooding on surrounding lands. For example, Thornton Creek, which is estimated to have the lowest increase in stream flow during the 2-year storm event, is also among the most constrained and consequently contains some of the poorest habitat quality among Seattle watercourses.

While the flow rating presented in this report for each Seattle watercourse is based on the factor increase in the 2-year storm event flow compared to natural forested conditions, available hydrology data are somewhat sparse. *A Science Framework for Ecological Health in Seattle's Streams* identifies hydrology metrics to use in long-term status and trend monitoring (Seattle Public Utilities and Stillwater Sciences 2007), which are better suited to comparisons than the analysis presented here. These ratings should be updated as additional hydrology information becomes available.

Water Quality Summary

Longfellow Creek (photo by Bennett)

Water and sediment quality conditions in Seattle urban watercourses have been evaluated by comparing existing chemistry data to available guidelines or standards, such as the Washington state water quality standards, federal criteria, relevant benchmarks, and the available sediment quality criteria. These guidelines and standards represent indicator levels that are protective of aquatic organisms or human health. The comparisons are summarized in Table 47. In addition, the Washington Department of Ecology has recently completed an assessment of water quality in Washington water bodies (Ecology 2005), which identifies impaired water bodies as required under Section 303(d) of the Clean Water Act. The 303(d) listings for Seattle watercourses are summarized in Table 48. A summary of these comparisons is provided in the following subsections.

As noted previously, much of the water quality data presented in this report was collected and compiled several years before the date of publication of this document. Appendix G provides this detailed—but outdated—compilation of water quality data analyses. The main body of this report presents a summary of that information with appropriate updates to changes in applicable regulatory standards. Readers interested in more detailed water quality data and analyses can find them in Appendix G.

Dissolved Oxygen and Temperature

With the exception of Longfellow Creek and Thornton Creek, dissolved oxygen and temperature levels in Seattle urban watercourses are generally good; less than 2 percent of the samples analyzed exceeded state water quality criteria. Dissolved oxygen and temperature typically exhibit a seasonal trend of higher temperatures and lower dissolved oxygen concentrations in the warm summer months. Figures 36, 37, and 38 illustrate this trend, using the long-term dissolved oxygen and temperature data from the three Seattle watercourses with the longest periods of record (Piper's, Longfellow, and Thornton).

Table 47. Summary of water quality conditions in Seattle watercourses.

	Fauntleroy Creek	Longfellow Creek	Piper's Creek	Taylor Creek	Thornton Creek
Aquatic Life Indicators					
Temperature and dissolved oxygen	░	■	░	░	■
pH	░	▓	░	░	▓
Turbidity and total suspended solids	░	░	▓	░	░
Nutrients	ND	■	■	ND	■
Toxic Pollutants					
Ammonia	░	░	░	░	░
Metals	░	░	▓	ND	▓
Organic compounds	ND	▓	ND	ND	▓
Public Health Indicators					
Fecal coliform bacteria	■	■	■	■	■
Metals	■	■	■	ND	■
Organic compounds	ND	ND	ND	ND	ND
Indicators in Sediment					
Metals	ND	ND	ND	ND	ND
Organic compounds	ND	ND	ND	ND	▓

■	Poor water quality, frequent exceedances of state water quality standards, federal recommended criteria, or benchmarks.
▓	Potential water quality problem (e.g., 303d Category 2 listing; occasional exceedance of state water quality standard)
░	Adequate water quality based on existing data.
ND	Insufficient data available to evaluate.

Table 48. Summary of Clean Water Act Section 303(d) listings of impaired and threatened watercourses in Seattle.

	Category 2 (Threatened)	Category 5 (Impaired)
Fauntleroy Creek	–	Fecal coliform bacteria
Longfellow Creek	Dissolved oxygen, temperature, pH	Fecal coliform bacteria, dissolved oxygen
Piper's Creek	Turbidity (Venema Creek)	Fecal coliform bacteria [a]
Thornton Creek	pH, mercury	Fecal coliform bacteria, temperature, dissolved oxygen

Source: Ecology 303(d) list query tool: http://www.ecy.wa.gov/PROGRAMS/wq/303d/2002/2002-index.html.

[a] Classified as category 4A for a water body with an approved TMDL. In 1992, EPA issued a programmatic total maximum daily load (TMDL) for fecal coliform bacteria in Piper's Creek based on the 1991 Watershed Action Plan.

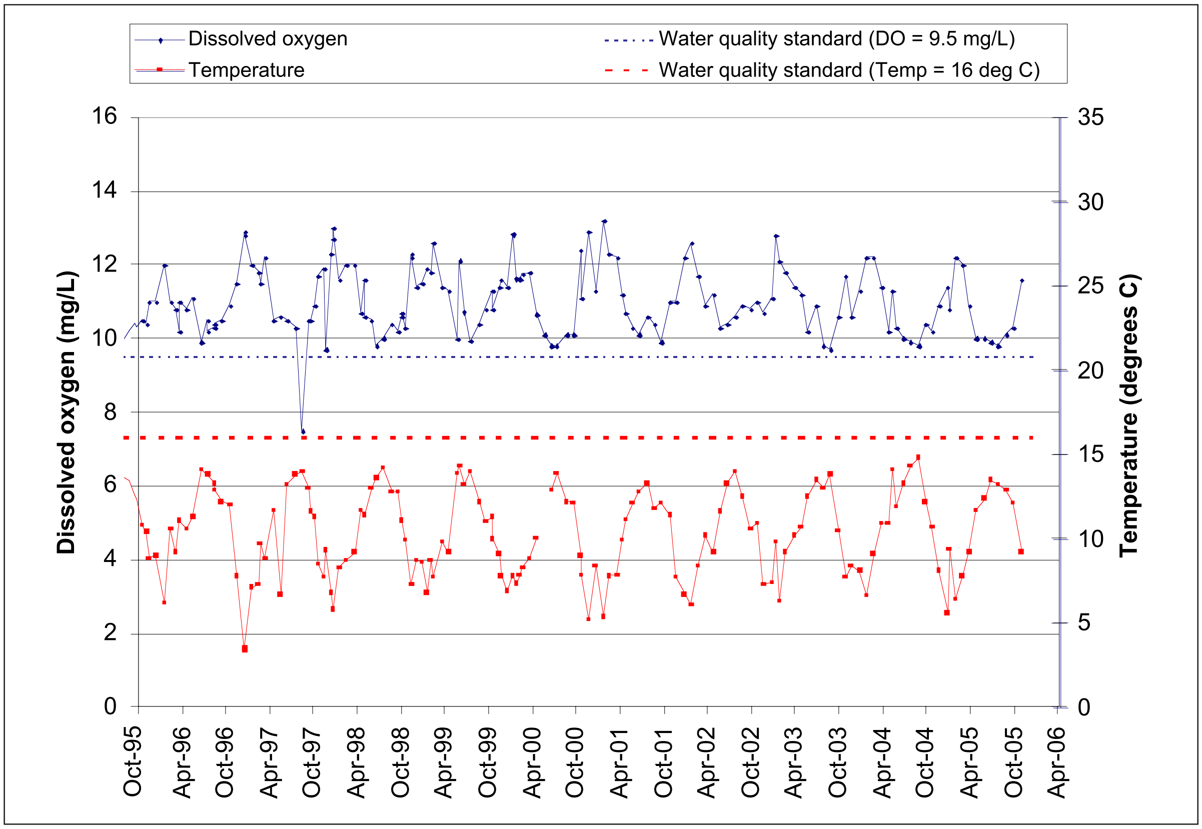


Figure 36. Piper's Creek dissolved oxygen & temperature levels measured near the mouth.

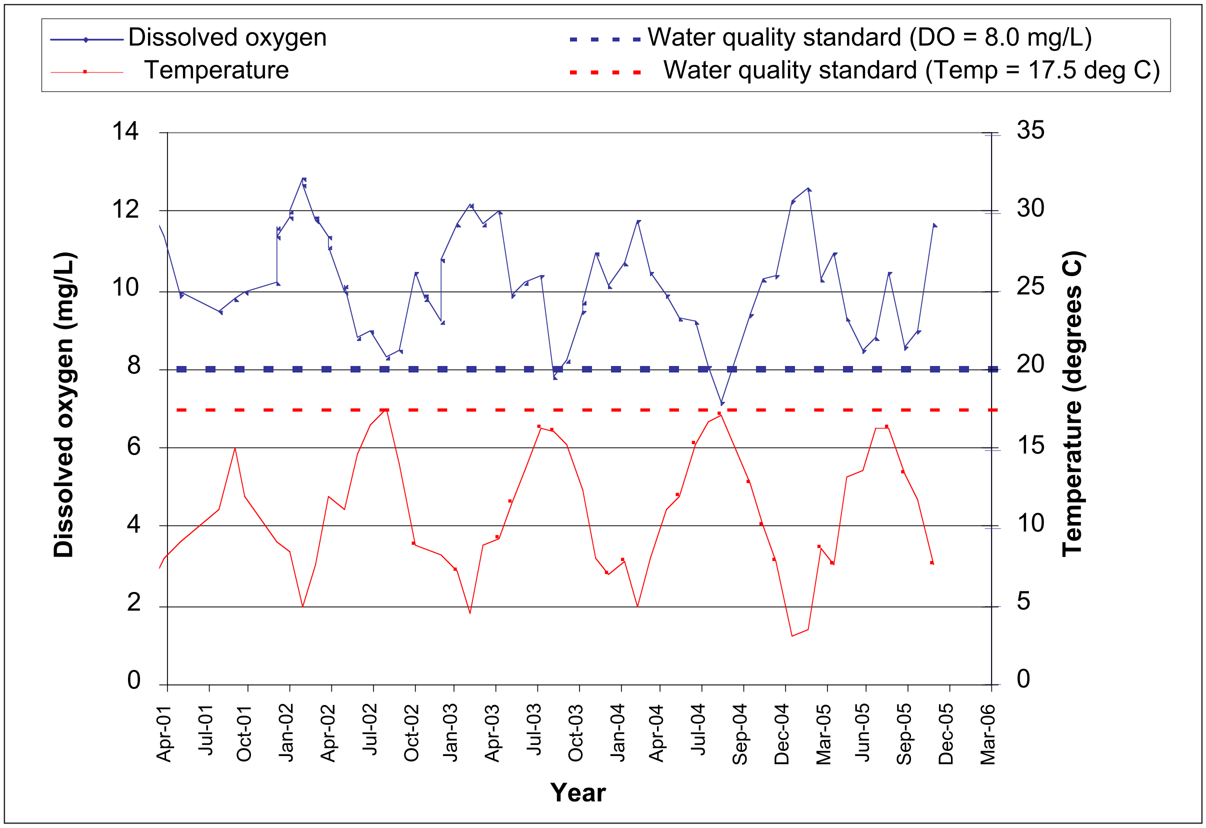


Figure 37. Longfellow Creek dissolved oxygen & temperature levels measured at SW Yancy Street.

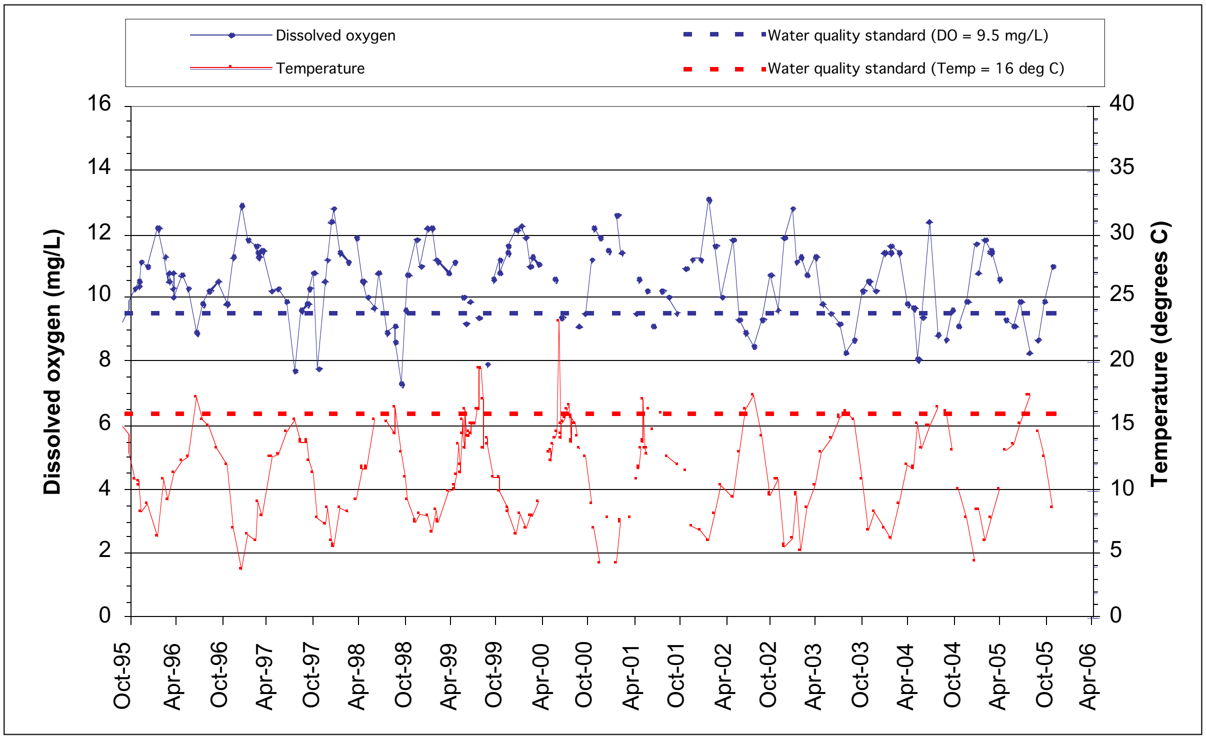


Figure 38. Thornton Creek dissolved oxygen & temperature levels measured near the mouth.

Both Longfellow Creek and Thornton Creek frequently do not meet state water quality criteria for temperature (17.5ºC and 16ºC, respectively) and dissolved oxygen (8 milligrams per liter [mg/L] and 9 mg/L, respectively) during the summer months. Temperature and dissolved oxygen excursions in these two watercourses may be related to the lack of riparian vegetation throughout most of their lengths. Longfellow Creek and Thornton Creek pass through private properties where their riparian zones are largely unprotected. However, other urban watercourses in Seattle, particularly Piper's Creek, Fauntleroy Creek, and Taylor Creek, have retained a large degree of the riparian corridor, because the lower ends of these watercourses typically pass through narrow, steep ravines that are largely undeveloped.

Turbidity and Suspended Solids

As shown in Table 49, particulate levels in Seattle urban watercourses, as measured by turbidity and total suspended solids concentrations, are relatively low compared to stormwater runoff samples collected from four urban catchments in Seattle. Median turbidity levels measured in Seattle watercourses ranged from 1.3 to 5.2 nephelometric turbidity units (NTU), and median total suspended solids concentrations ranged from 2.1 to 5.7 mg/L, compared to 33 NTU and 51 mg/L in urban stormwater. This difference is probably related to the timing of sampling events in the urban watercourses. The stream data generally come from routine monthly grab samples and do not reflect storm flow conditions when solids transport in the watercourses would be higher. Additional analysis of rainfall conditions during the stream sampling events is needed to separate the historical data set into storm flow and non-storm flow samples, for better comparison to the urban stormwater samples.

For the purposes of this report, the King County and Ecology samples are called non-storm flow samples, and SPU samples are called storm flow samples.

Table 49. Particulate levels measured in Seattle watercourses.[a]

	Turbidity (NTU)			Total suspended solids (mg/L)		
	n	Range	Median	n	Range	Median
Longfellow Creek at SW Brandon St	170	0.5–93	2.5	139	0.5–203	2.1
Longfellow Creek at SW Yancy St	221	0.5–160	3.8	182	0.3–463	3.5
Piper's Creek upstream of Venema	203	0.2–70	1.7	204	0.5–223	3.3
Venema Creek	205	0.1–73	1.3	205	0.01–166	3.0
Piper's Creek near mouth	249	0.1–180	2.0	249	0.5–425	3.7
Thornton Creek near mouth	402	0.1–66	3.2	401	0.6–180	5.7
Fauntleroy Creek near mouth	15	1.5–19	5.2	15	3–33	10
Urban stormwater runoff[b]	68	8–86	33	68	10–201	51

[a] Routine monthly samples collected by King County (undated) and Ecology (undated).

[b] Stormwater samples collected 2003–2005 from four urban catchments in Seattle (Taylor and Seattle Public Utilities 2005, Tacoma and SPU unpublished).

NTU = nephelometric turbidity units.

mg/L = milligrams per liter.

For those watercourses where data are available (i.e., Longfellow Creek and Piper's Creek), particulate levels are significantly higher during storm flow conditions than during non-storm conditions. For example, median turbidity levels ranged from 40 to 85 NTU in storm flow samples, compared to 1.3 to 3.8 NTU in non-storm samples. Likewise, median total suspended solids concentrations ranged from 45 to 135 mg/L in storm flow samples, compared to 3.0 to 3.7 mg/L in non-storm flow samples. These storm flow particulate levels are more consistent with the available data for urban stormwater runoff in Seattle.

pH Conditions

The pH levels in most Seattle watercourses are well within the range established by the state water quality standards (6.5 to 8.5 pH units). Only Thornton Creek and Longfellow Creek have exhibited pH levels outside the acceptable range, although these excursions have been infrequent. Over the 27-year period of record, less than 1 percent of the samples collected in Thornton Creek were outside the acceptable pH range, with the most recent excursion occurring in 2002 (pH 6.4). Similarly, only 3 to 6 percent of the samples collected in Longfellow Creek between 1992 and 2005 (at SW Brandon Street and SW Yancy Street) failed to meet the state standard. The latest pH excursions occurred in 2000 at the Yancy station (pH 8.7), and in 1998 at the Brandon station (pH 6.2). The Department of Ecology included both watercourses on the Clean Water Act Section 303(d) list of threatened and impaired water bodies under category 2 (a water body of concern) for pH.

Fecal Coliform Bacteria

All of Seattle's major watercourses frequently exceed Washington state water quality standards for fecal coliform bacteria. Fecal coliform levels vary over a wide range (from 5 to 39,000 colony-forming units per 100 milliliters [cfu/100 mL]) but show no distinct historical trends over the 18- to 32-year periods of record.

For those watercourses where both storm flow and non-storm flow data are available (Longfellow Creek and Piper's Creek), fecal coliform levels are consistently higher during storm flow conditions compared to routine monthly samples that represent mostly non-storm flow conditions (the geometric means for storm flow samples range from 2,200 to 5,200 cfu/100 mL, compared to 80 to 1,100 cfu/100 mL in non-storm flow samples). Summary data for all stations monitored are provided in Table 50.

Table 50. Fecal coliform bacteria levels measured in Seattle watercourses.

		Fecal Coliform Bacteria (cfu/100 mL)		
Location	**Years of Record**	**Minimum**	**Maximum**	**Annual Geometric Mean [a]**
Longfellow Creek at SW Brandon St	27	10	39,000	43–92
Longfellow Creek at SW Yancy St	27	9	25,000	100–1,100
Piper's Creek upstream of Venema	18	11	37,000	76–530
Venema Creek	18	5	9,700	15–57
Piper's Creek near mouth	18	23	14,000	190–630
Thornton Creek near mouth	32	28	31,000	480–1,200
Fauntleroy Creek near mouth	1	23	390	87

Sources: King County (undated) and Ecology (undated).

[a] Annual geometric means calculated for the period 1996–2005.

cfu/100 mL = colony-forming units per 100 milliliters.

Metals

Available data indicate that metals concentrations in Seattle watercourses are generally low. Although the human health criterion for arsenic is frequently exceeded, the aquatic life chronic and acute toxicity criteria are seldom exceeded.

Four of the 14 priority pollutant metals have been identified as potential metals of concern in Seattle's urban watercourses:

- Dissolved copper (7 percent of samples exceeded the acute toxicity water quality criterion, and 26 percent of samples exceeded the chronic toxicity criterion, in Piper's Creek)
- Dissolved lead (4 percent of samples exceeded the chronic toxicity criterion in Piper's Creek, and 6 percent of samples exceeded the chronic toxicity criterion in Thornton Creek)
- Almost all total arsenic samples exceeded the human health criterion for all four watercourses with available data (Fauntleroy Creek, Longfellow Creek, Piper's Creek, and Thornton Creek)
- Total mercury had 13 percent of samples exceeding the chronic toxicity criterion in Fauntleroy Creek, and 7 percent exceedance in Thornton Creek. One of one sample in Piper's Creek also exceeded the criterion.

Thornton Creek is on the 303(d) list of threatened and impaired water bodies for mercury, in category 2 (a water body of concern).

In general, meaningful comparisons of metals concentrations among Seattle watercourses are limited by several variable factors, including the highly flow-dependent nature of the results, the inconsistent period of record for the data sets, the high number of undetected results, and the sampling frequency. The low number of data points is particularly problematic.

Within those limitations, a series of box and whisker plots is presented below to provide comparisons for the four potential metals of concern: dissolved copper, dissolved lead, total arsenic, and total mercury. Each box and whisker plot (see Part 3 for explanation of plots) combines all sample results for all stations in each watershed.

- The general trend in metals water quality data is reflected in Figure 39; that is, based on dissolved copper results during non-storm flow conditions, Fauntleroy Creek and Longfellow Creek tend to have better water quality than Piper's Creek and Thornton Creek. The large spread for Longfellow Creek is attributed to the difference in the two stations. Station C370, which had a median dissolved copper concentration of 4.5 micrograms per liter (µg/L), is located downstream of station 0 9J090, which had a median dissolved copper concentration of 1.2 µg/L.

- For the watercourses with storm flow data available, (Longfellow Creek and Piper's Creek; Figure 40), the dissolved copper concentrations are higher under storm flow conditions than under non-storm flow conditions.

- The general trend in metals water quality data continues to be reflected in Figure 41; that is, based on dissolved lead results during non-storm flow conditions, Fauntleroy Creek and Longfellow Creek tend to have better water quality than Piper's Creek and Thornton Creek. Dissolved lead concentrations are significantly higher under storm flow conditions than under non-storm flow conditions, exhibiting patterns similar to those shown in Figure 40.

- Total arsenic concentrations during non-storm flow conditions exceeded the human health criterion of 0.018 µg/L in all watercourses (Figure 42). Total arsenic data are available under storm flow conditions for Piper's Creek. There is no significant difference between non-storm and storm flow conditions.

- Total mercury concentrations under non-storm flow conditions show the opposite trend compared to other metals, with Fauntleroy Creek having higher concentrations compared to Longfellow and Thornton creeks (Figure 43).

- Dissolved zinc (Figure 44) further illustrates the general water quality trend among sampling stations. Dissolved zinc tends to be a good indicator, because it is usually found in concentrations well above the reporting detection limit and is very mobile.

Nutrients

Total nitrogen and total phosphorus levels measured in Seattle watercourses frequently exceed available water quality benchmarks for nutrients, particularly during storm flow conditions. For example, total nitrogen concentrations exceeded the level established by U.S. EPA (2000) for streams that are minimally affected by human activities (i.e., 0.34 mg/L) in 100 percent of the stream samples.

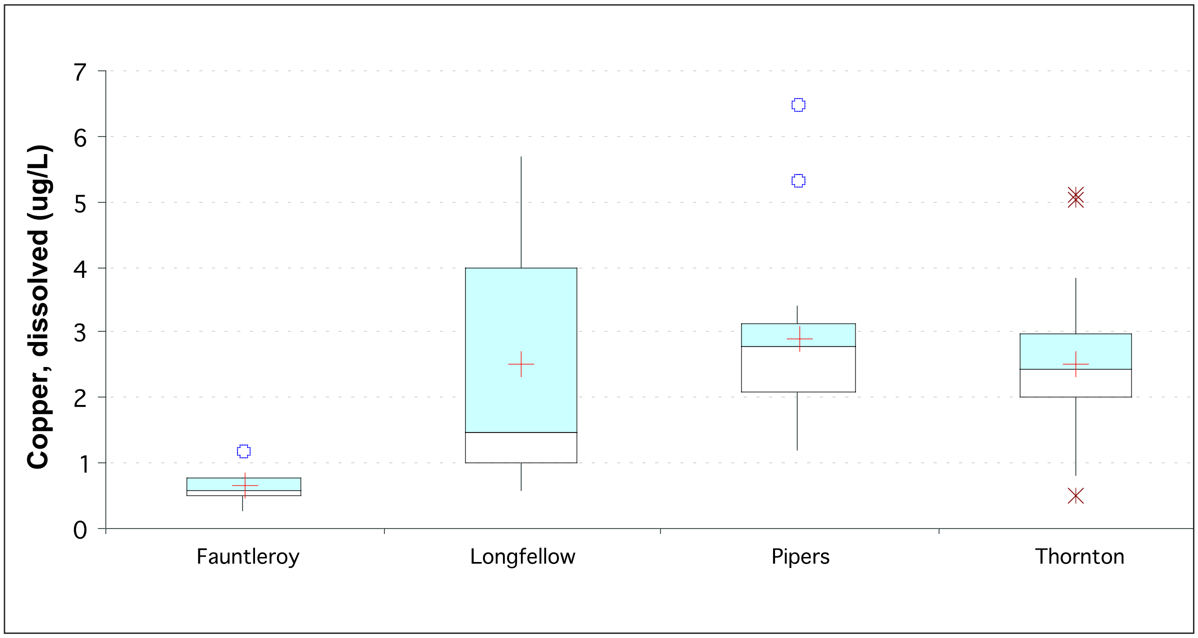


Figure 39. Comparison of dissolved copper concentrations in Seattle watercourses during non-storm flow conditions.

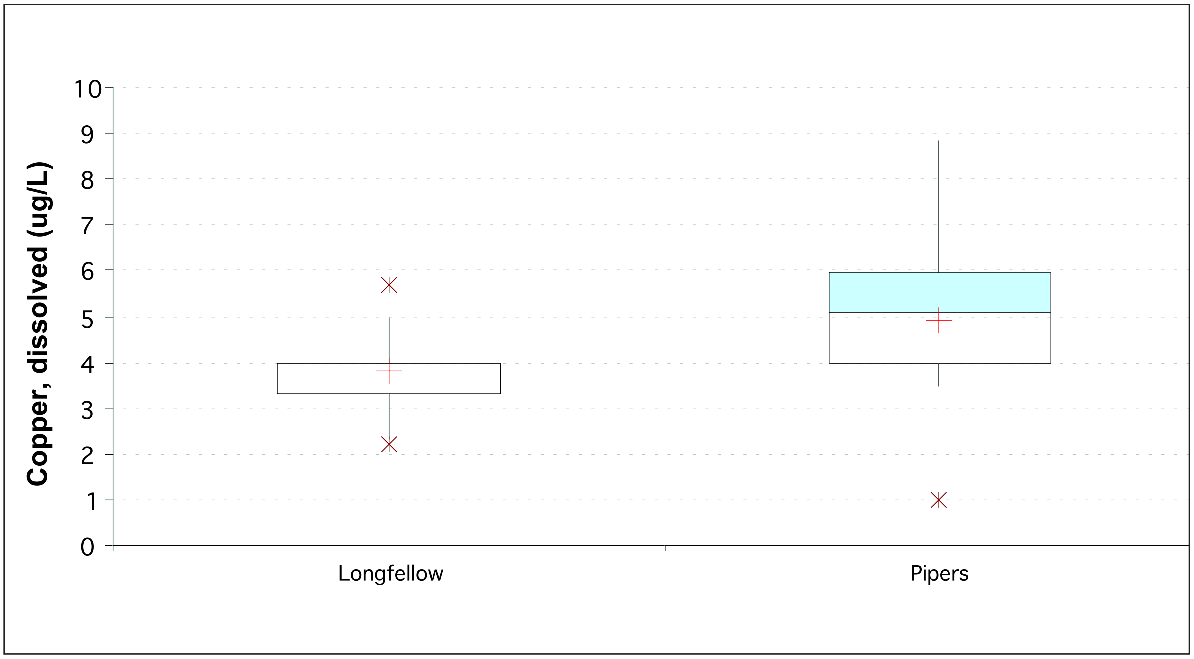


Figure 40. Comparison of dissolved copper concentrations in Seattle watercourses during storm flow conditions.

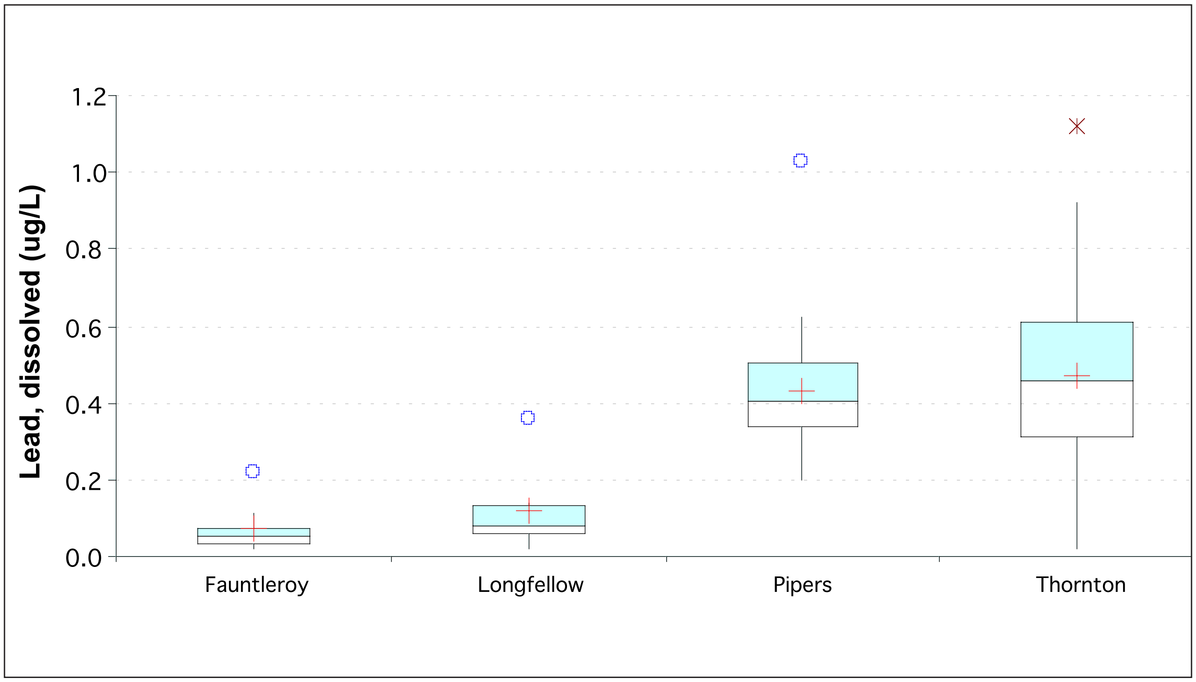


Figure 41. Comparison of dissolved lead concentrations in Seattle watercourses during non-storm flow conditions.

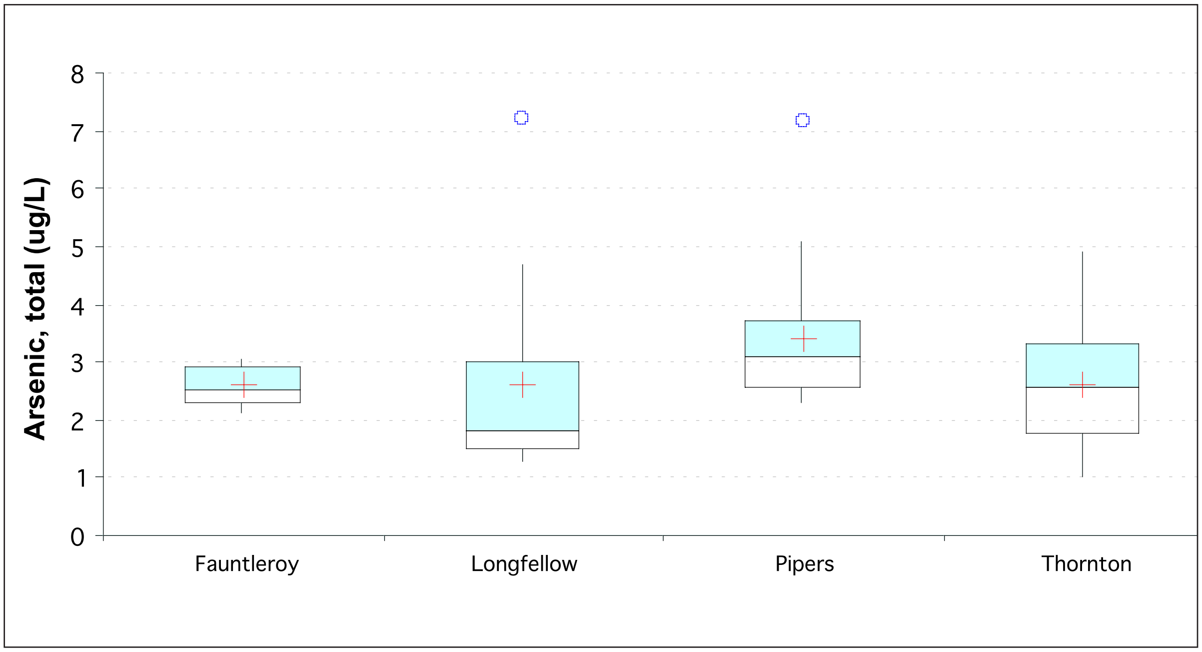


Figure 42. Comparison of total arsenic concentrations in Seattle watercourses during non-storm flow conditions.

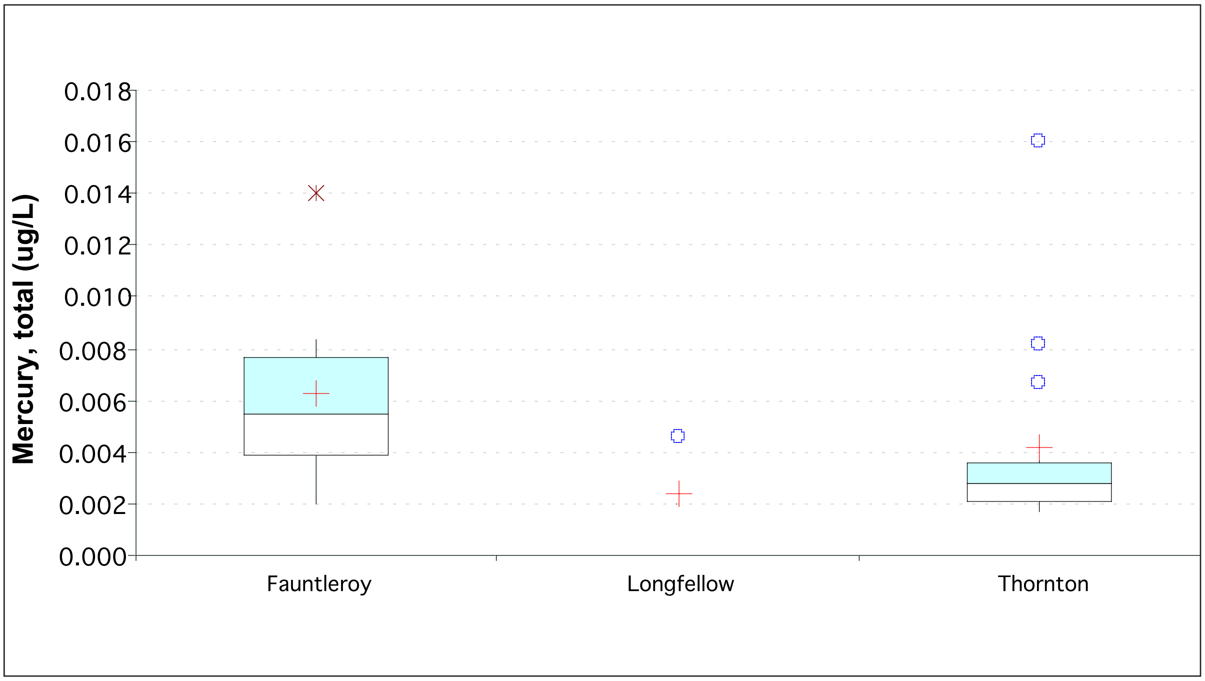


Figure 43. Comparison of total mercury concentrations in Seattle watercourses during non-storm flow conditions.

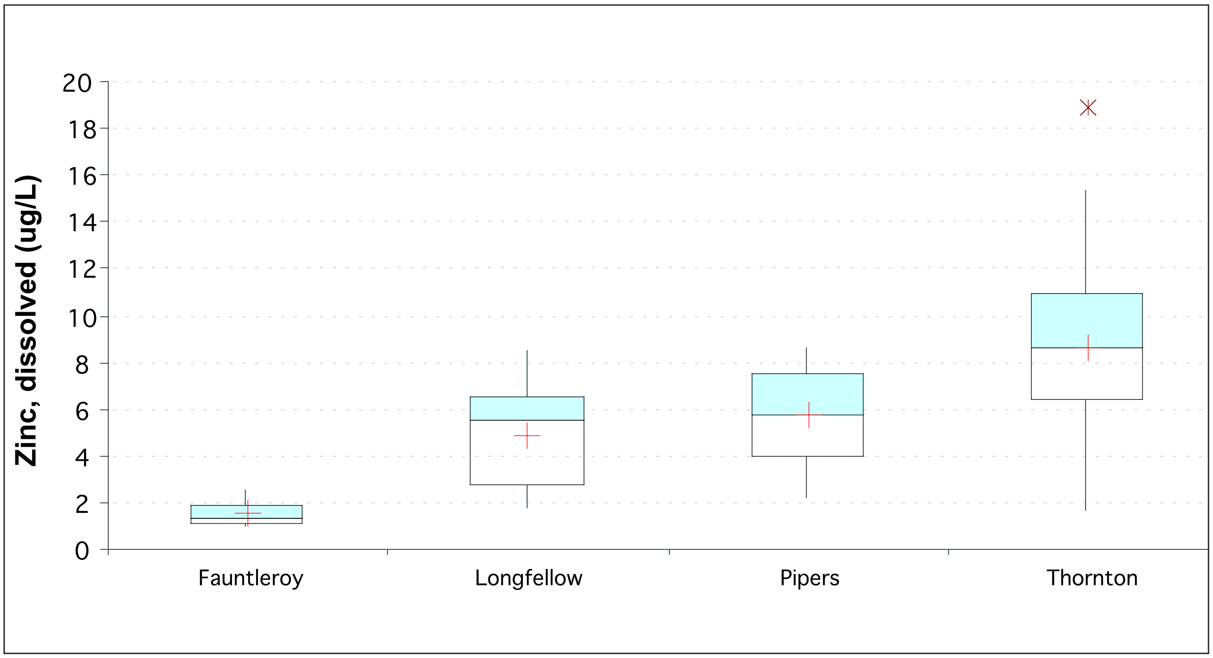


Figure 44. Comparison of dissolved zinc concentrations in Seattle watercourses during non-storm flow conditions.

Similarly, 12 percent of the stream samples exceeded the benchmark for total phosphorus used in this analysis (i.e., 0.1 mg/L), which is based on a goal established by U.S. EPA (1976) to prevent nuisance plant growth in streams that do not discharge directly to lakes or reservoirs. If the lower limit for total phosphorus established by U.S. EPA in 2000 (i.e., 0.0195 mg/L for streams that are minimally affected by human activities) were used as a benchmark in this analysis, the majority of samples collected from Seattle's urban watercourses would exceed the goal. However, ammonia-nitrogen levels were consistently below toxic levels in all Seattle urban watercourses.

In general, comparing nutrient concentrations among watercourses is limited by the inconsistent period of record for the data sets, the high number of undetected results, and the sampling frequency. Based on these limited data, Figures 45 through 49 provide comparisons of all detected nutrient results for the five major watercourses, combining all sample results for all stations, in the form of box and whisker plots.

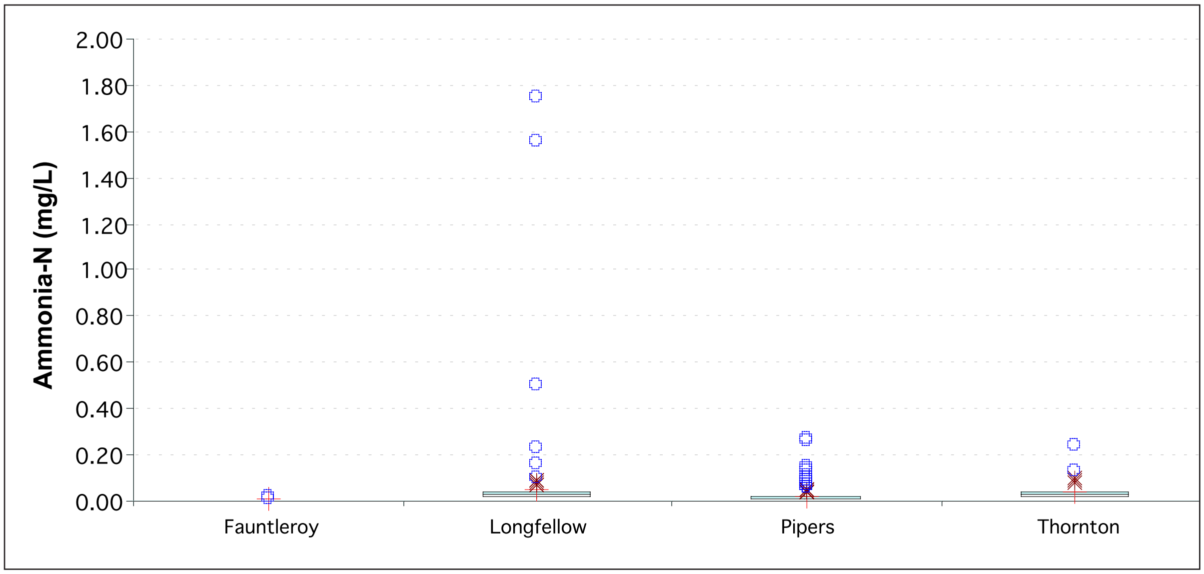


Figure 45. Comparison of ammonia concentrations in Seattle watercourses during non-storm flow conditions.

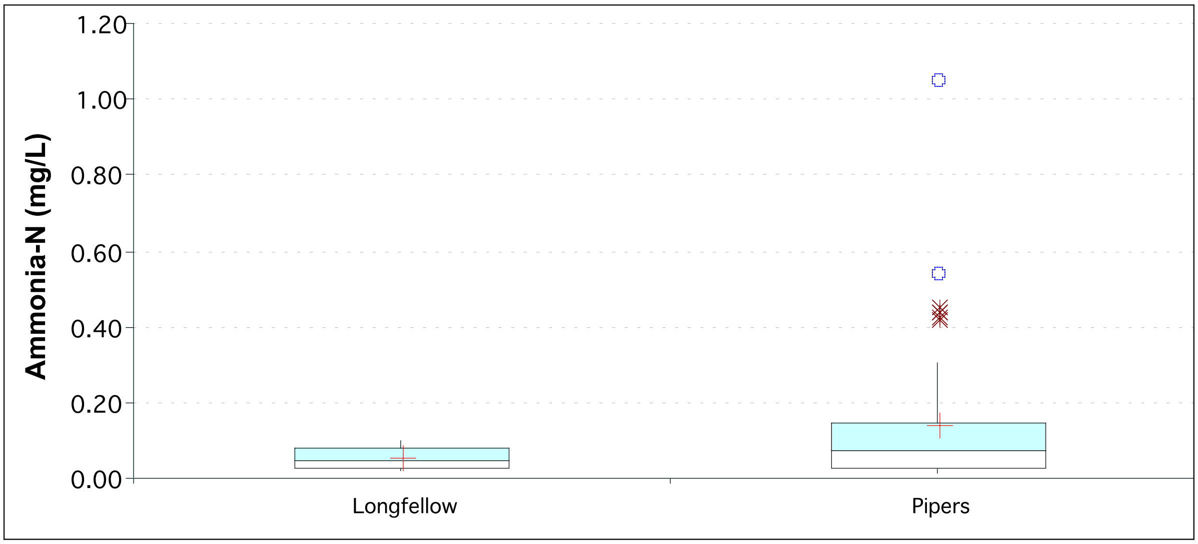


Figure 46. Comparison of ammonia concentrations in Seattle watercourses during storm flow conditions.

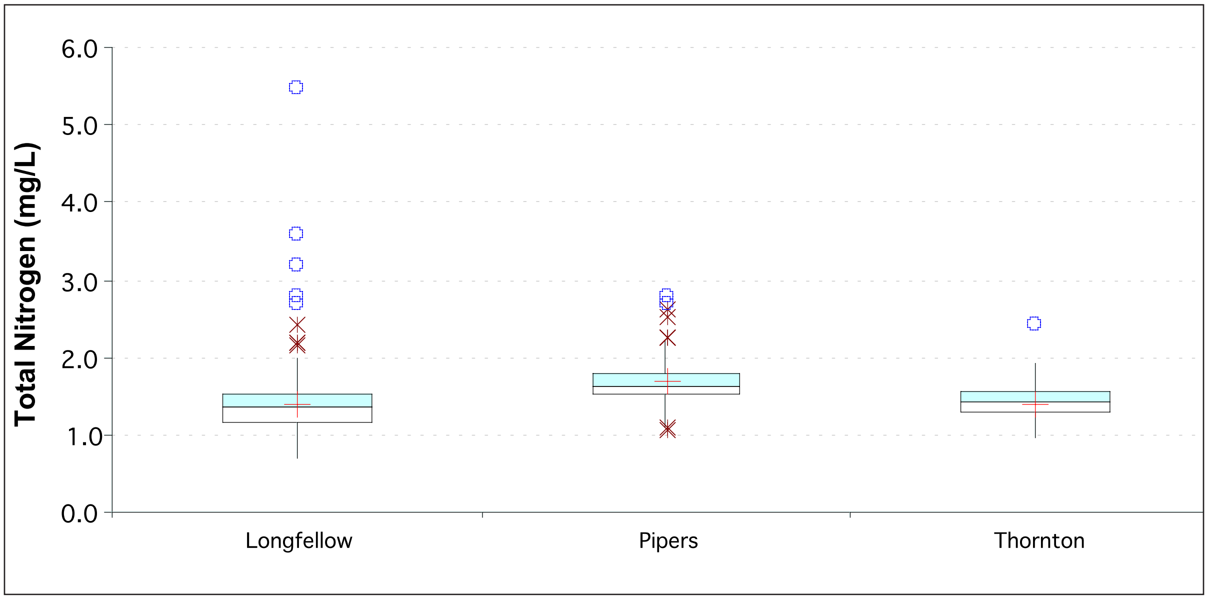


Figure 47. Comparison of total nitrogen concentrations in Seattle watercourses during non-storm flow conditions.

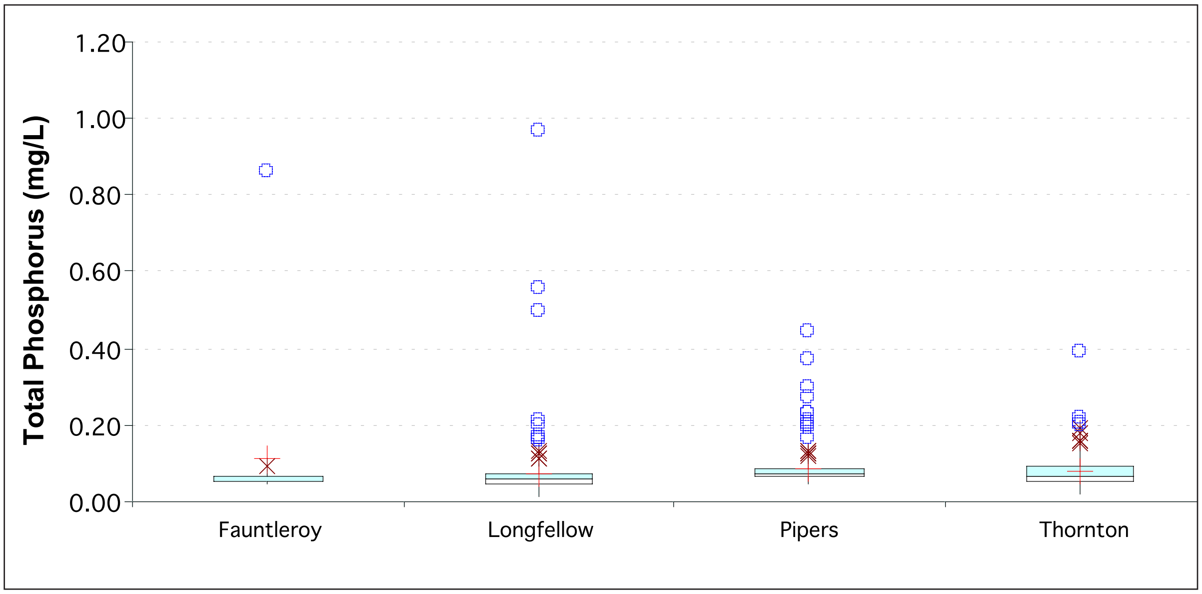


Figure 48. Comparison of total phosphorus concentrations in Seattle watercourses during non-storm flow conditions.

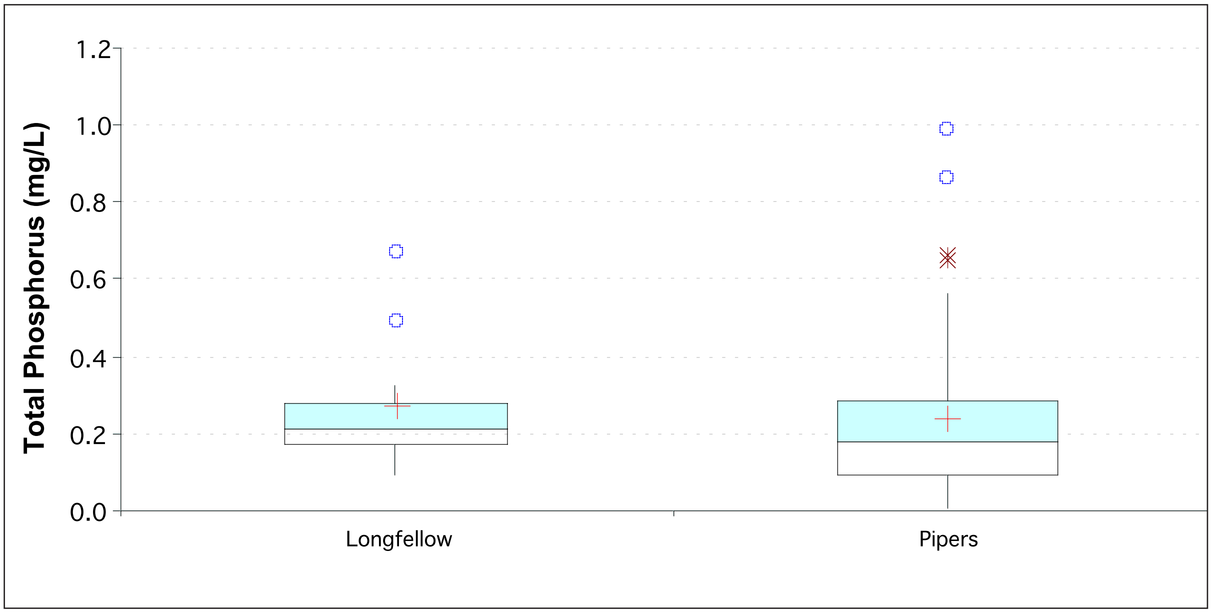


Figure 49. Comparison of total phosphorus concentrations in Seattle watercourses during storm flow conditions.

Organic Compounds

Information on organic compounds in Seattle watercourses is very limited. The U.S. Geological Survey found low levels (0.013 to 0.16 mg/L) of some pesticides (2,4-D, 2,6-dichlorobenzmide, atrazine, dichlobenil, MCPA, mecoprop, pentachlorophenol, prometon, simazine, tebuthiuron, trichlorpyr, carbaryl, diazinon, and 4-nitrophenol) in a stormwater sample collected in 1998 from Thornton Creek (Voss and Embrey 2000). Low levels (0.03 to 0.35 mg/L) of 2,4-D, acetochlor, dicamba, dichlobenil, dichlorprop, MCPA, mecoprop, pentachlorophenol, prometon, trichlorpyr, and diazinon were also found in a stormwater sample collected from Longfellow Creek in 1998 (Voss and Embrey 2000).

However, with the exception of diazinon, these concentrations were below reported toxic effect levels for aquatic organisms. The U.S. EPA canceled diazinon product registrations and restricted the sale of this pesticide to existing stock. As a result, diazinon concentrations should begin to decline as existing stocks are depleted.

Low levels (0.9 to 9.1 µg/kg) of several organochlorine pesticides (dieldrin, chlordane, DDD, DDE, DDT, and methoxychlor) have also been found in streambed sediment collected near the mouth of Thornton Creek (MacCoy and Black 1998). Freshwater sediment standards have not been established in Washington state, but these concentrations of DDD and DDE exceed the threshold effect level set by the interim Canadian sediment quality guidelines, and the DDD concentration also exceeds the probable effects level.

Habitat Summary

Riparian Habitat

The extent of high-quality, moderate-quality, and low-quality riparian habitat was examined for the five major Seattle watercourses (Figure 50). Piper's Creek and Taylor Creek have a high percentage of high-quality riparian habitat, with over 60 percent of those watercourses bordered by mature forest. They also lack large areas of low-quality riparian habitat. Fauntleroy Creek has a fairly even distribution of high-quality, medium-quality, and low-quality riparian habitat. Longfellow Creek and Thornton Creek are dominated by low-quality riparian corridors, with little high-quality riparian habitat.

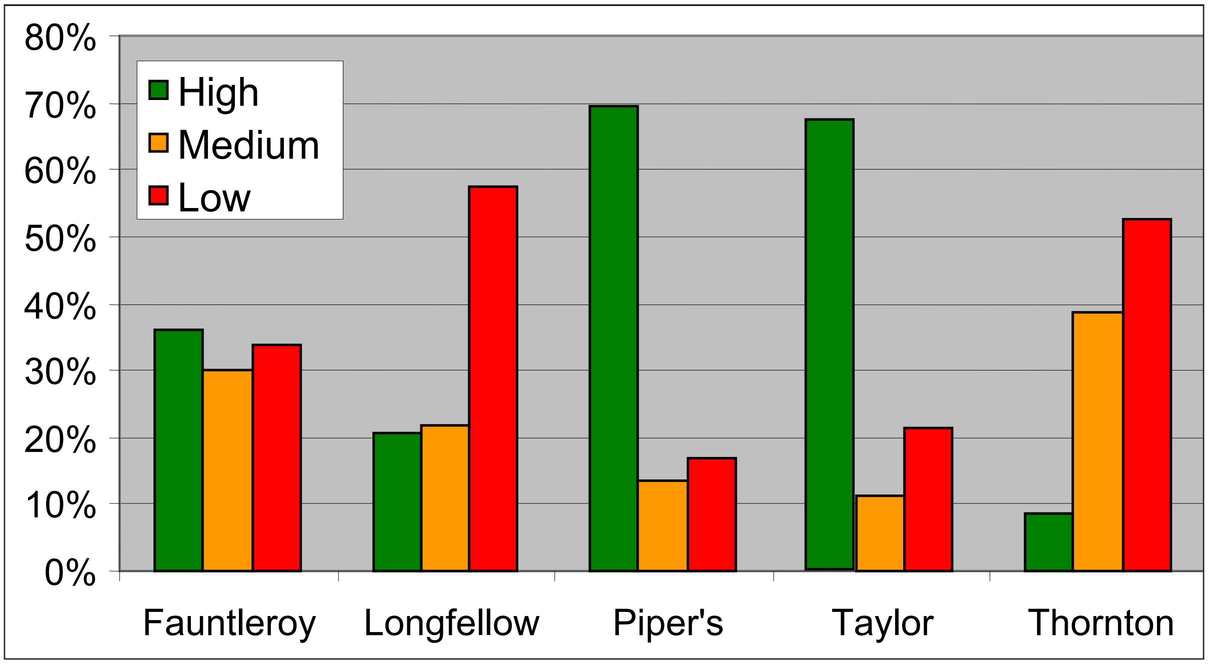


Figure 50. Percentages of high-, moderate-, and low-quality riparian habitat in each major Seattle watercourse.

High-quality riparian habitat is generally characterized by mature, mixed coniferous and deciduous forest that exists in a wide band around the stream, providing shade, woody debris, and natural nutrients to the stream, as well as offering bank stability and stormwater runoff filtration. High-quality areas within Seattle tend to be found in parks, in particular, the large park lands in Carkeek Park (Piper's Creek), Lakeridge Park (Taylor Creek), and Fauntleroy Park (Fauntleroy Creek). The park land use allows riparian corridors to be wide, exceeding 200 feet in some locations, and stewardship of park lands helps to control invasive plant species and support native trees and shrubs.

Low-quality areas are dominated by invasive plants such as Himalayan blackberry and English ivy, lawns, and ornamental landscaping. Often roadways, houses, and other buildings are located close to a stream, sometimes within 10 feet, restricting the width and growth of a native forest. As a result, riparian areas are highly fragmented, if they exist at all, and cannot supply the stream with consistent shading, nutrients, bank stability, or filtration.

Low-quality riparian habitat tends to dominate in residential and commercial areas. For example, Longfellow Creek and Thornton Creek are mostly bordered by residential land uses, which has led to encroachment along those streams and conversion of riparian forests to other uses (e.g., lawns, roads, and buildings). Similarly, low-quality riparian areas along the other three major watercourses in Seattle—Taylor Creek, Piper's Creek, and Fauntleroy Creek—are found along residential stream sections, outside the park areas. The pattern of land use and habitat conditions within all watercourses illustrate that land uses adjacent to urban streams significantly affect the quality of riparian habitat.

Watershed topography has played an important role in urban development patterns, determining the extent of stream encroachment and resulting impacts on habitat quality. Steep ravines have limited development in certain riparian areas along Piper's Creek, Taylor Creek, and Fauntleroy Creek. Less steep areas in those watersheds also exist, near the confluence of Taylor Creek with Lake Washington, at the confluence of Fauntleroy Creek with Puget Sound, and in the headwater plateaus of Piper's Creek and Taylor Creek. These flat areas tend to have urban encroachment and poor habitat conditions similar to most areas of Thornton Creek and Longfellow Creek. Delridge Valley, containing Longfellow Creek, is relatively flat compared to the channels of Piper's Creek, Taylor Creek, and Fauntleroy Creek, facilitating development along the Longfellow corridor. The only high-quality habitat within Delridge Valley is located on public land, within the West Seattle golf course.

Instream Habitat

The quality of instream habitat and riparian habitat follow slightly different distribution patterns in the five major urban watercourses (Figure 51).

- Piper's Creek and Taylor Creek have high amounts of both low- and high-quality instream habitat.
- Fauntleroy Creek and Longfellow Creek have relatively equal amounts of low-, medium-, and high-quality habitat.
- Thornton Creek is dominated by high amounts of low-quality habitat.

Instream habitat in Piper's Creek and Taylor Creek mostly falls into the high-plus-low quality pattern, with little medium-quality habitat. This pattern is attributed to the park lands, where riparian habitat quality is high and encroachment into the stream floodplains is limited. Poor habitat conditions in these two watercourses are found outside the park lands.

The Fauntleroy and Longfellow systems tend to have more even balances of habitat in each of the three quality categories. Again, higher-quality habitat is typical in public areas. Thornton Creek has a large percentage of low-quality instream habitat (greater than 50 percent), with little high-quality instream habitat.

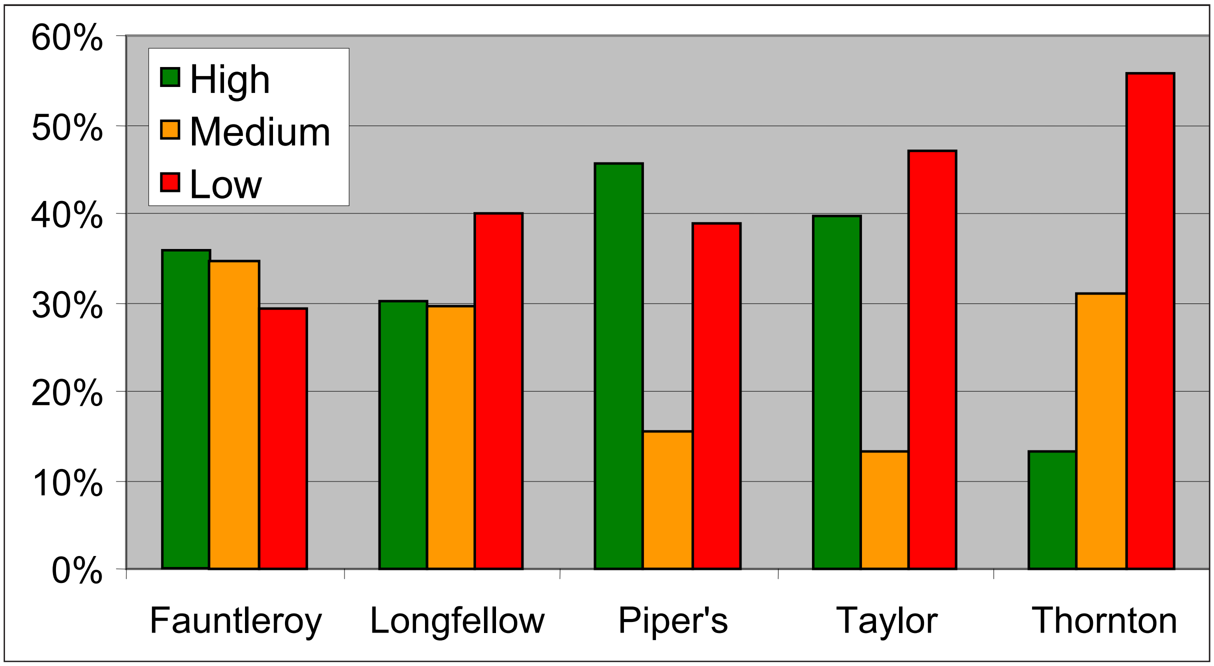


Figure 51. Percentages of high-, moderate-, and low-quality instream habitat in each major Seattle watercourse.

High-quality instream habitat areas are more complex, containing instream wood, boulders, channel meanders, and floodplain connections that allow pools and instream wetlands to form. Low-quality instream habitat areas are rather homogeneous, with plane-bed channels, bank armoring, and fine sediments. However, even in higher-quality habitat areas in the major Seattle watercourses, the lack of woody debris, floodplain connections, and coarse sediment is problematic.

As with riparian conditions, instream features appear related to adjacent land uses. Taylor Creek, Piper's Creek, and Fauntleroy Creek received the highest instream habitat scores (Appendix F). The majority of these watercourses flow through undeveloped park land or open space. This correlation between adjacent park land and good instream habitat is evident at the reach scale as well. For example, in Longfellow Creek the only reach with a good-quality ranking, LF04, is located within the West Seattle golf course; the remainder of the reach rankings in the Longfellow system range from poor to moderate (see Map 16 in the map folio accompanying this report). Likewise, in Piper's Creek the majority of the main stem length, located within Carkeek Park (PI03 through PI01), ranks as having good habitat quality (see Map 25). Watercourse reaches rated in poor condition for instream habitat are located consistently in areas with significant amounts of culvert, encroachment, and bank armoring. In general, the types of land use surrounding a watercourse are directly reflected by instream habitat quality.

Instream habitat quality is a reflection of multiple factors, including stream flow as well as riparian habitat. High and flashy flows and degraded riparian habitat conditions both lead to degraded instream habitat, and their effects are measurable from the point of impact continuing into downstream areas. The root causes of instream habitat problems include hydrology and lack of floodplain connections. Because the floodplain of a stream helps to contain and moderate high flows, in areas where a stream is constrained to an undersized channel or lacks floodplain connections, even moderate increases in stream flow can damage riparian and instream habitat.

Biological Communities Summary

Use by Benthic Invertebrates

Figure 52 shows the average benthic index (B-IBI) scores calculated for each major Seattle watercourse, based on all of the samples available (see Appendix C). Fauntleroy Creek has the highest average score, ranking as fair (31). However, only two samples had adequate numbers of invertebrates to count in calculating an average. The low sample size means that the standard deviation is about 7 points. Piper's Creek and Taylor Creek have poor index scores (19.4 and 18.9, respectively). Longfellow and Thornton benthic index scores rank as very poor (14.6 and 15.0, respectively).

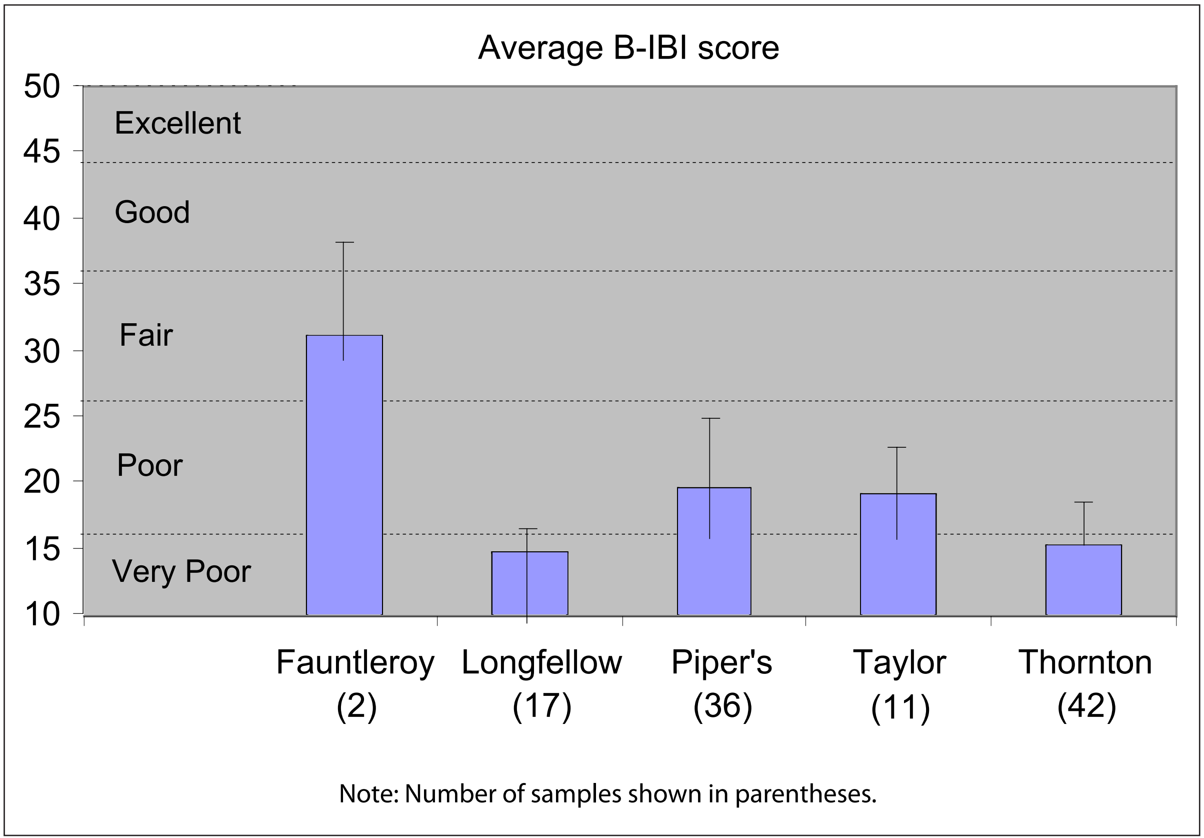
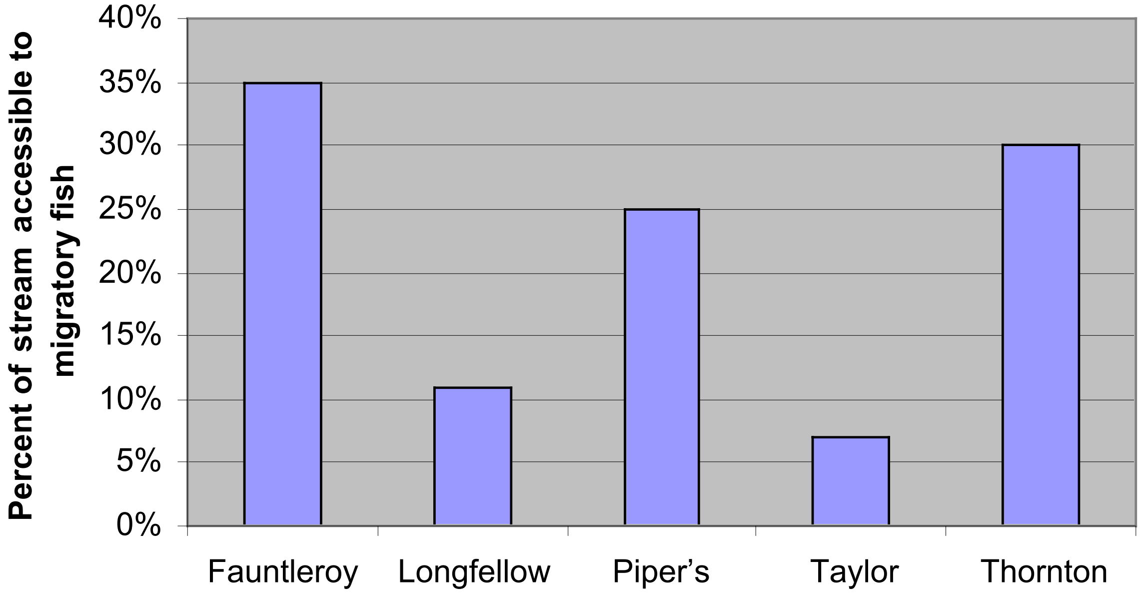


Figure 52. Average benthic index score for each major Seattle watercourse.

The benthic index scores roughly seem to follow the riparian and instream habitat quality rankings, with Longfellow and Thornton exhibiting the poorest habitat and lowest scores among the major urban watercourses. However, even the highest benthic index scores are low on the overall B-IBI scale. Piper's Creek and Taylor Creek rank as only poor, even with a large percentage of good physical habitat. Both stream flow and water quality play large roles in shaping benthic communities, and the combination of hydrologic, water quality, and physical factors could be limiting benthic communities in Seattle watercourses.

Fish Access

Seattle watercourses contain salmonids and other fish species, making accessible habitat important for supporting ongoing fish populations. The percentage of accessible habitat for migratory fish in each major Seattle watercourse was estimated based on the amount of stream currently accessible compared to the extent of stream expected to support anadromous fish (i.e., a Type F stream; see WAC 222-16-031 for fish-bearing stream classifications). Figure 53 illustrates the percentage of each watercourse that is accessible to migratory salmonids at present. Based upon this analysis, Fauntleroy Creek and Thornton Creek are the most accessible, while Taylor Creek and Longfellow Creek are the least accessible.



Note: Fish-bearing stream types are defined in WAC 222-16-031.

Figure 53. Percentage of each major Seattle watercourse accessible to migratory fish, based on accessible Type F stream area.

In summary:

- Taylor Creek offers the smallest amount of accessible stream habitat. Taylor Creek has a manmade barrier about 460 feet upstream of the mouth that blocks anadromous fish passage into Lakeridge Park.
- Roughly 1,300 feet of Fauntleroy Creek can be used by anadromous fish. While calculations show that 35 percent of the watercourse is accessible, Williams et al. (1975) show a cascade located around 45th Avenue SW, which may have represented the historical upstream extent of anadromous fish presence.
- In Longfellow Creek, about 10 percent of the watercourse is accessible after fish pass through a 3,200-foot culvert at the mouth of Longfellow Creek.

- Thornton Creek offers 22,620 feet of stream habitat; 40 percent of the main stem and north and south branches is accessible. Even so, Thornton Creek provides the greatest watercourse length available for salmon and trout.

Overall, with tributaries included, only 30 percent of the length of Seattle's five major watercourses is accessible to salmonids. Across all five major watercourses, about 21 stream miles can support fish, but only 7 miles of stream (34 percent) is accessible to migratory species. This is extremely problematic in Taylor Creek and Longfellow Creek, where the highest-quality habitat is located upstream of fish passage barriers (i.e., Rainier Avenue South and the WPA dam).

Conclusions

The following sections provide a concise summary of overall hydrologic, water quality, habitat, and biological conditions in Seattle watercourses. This summary is based on existing knowledge and available data. This chapter closes with comments on existing data availability and data gaps, as well as thoughts on future directions for Seattle watercourses.

Flow

Stream flow conditions appear to be flashy with high peak flows, resulting from urban development in the watersheds and associated expansion of impervious surface areas. These factors, coupled with encroachment into streamside areas, contribute greatly to poor instream habitat and poor biological communities. However, additional flow data are needed to provide a more accurate picture of hydrologic conditions and to track them through time.

Water Quality

Based on limited sampling conducted mostly during non-storm flow conditions, most chemical parameters that have been measured in Seattle stream samples to date generally meet state water quality criteria for the protection of aquatic life. However, three key water quality indicators do not meet state criteria: dissolved oxygen, temperature, and fecal coliform bacteria. A summary of major conclusions regarding water quality in Seattle watercourses is provided below.

Dissolved Oxygen and Temperature

Dissolved oxygen and water temperature exhibit a distinct seasonal pattern, with temperature generally higher in the summer season and lower in the winter season. Because the solubility of dissolved oxygen is inversely related to temperature, dissolved oxygen exhibits higher concentrations during the winter months, when temperatures are lower.

Dissolved oxygen and temperature in Longfellow Creek and Thornton Creek frequently fail to meet state water quality criteria in the summer months. This pattern is probably related to the loss of vegetative cover resulting from intensive urban development throughout the riparian corridors of these watercourses.

Piper's Creek and Fauntleroy Creek, which flow through steep, largely undeveloped ravines, have retained their riparian corridors to a large extent and exhibit only occasional exceedances of state water quality criteria for temperature and dissolved oxygen. Although water quality has not been monitored in Taylor Creek, it is expected to follow the same general trend seen in Piper's Creek and Fauntleroy Creek, because it has a fairly intact riparian corridor for most of its length (see Map 32).

Fecal Coliform Bacteria

Fecal coliform bacteria levels are high and frequently exceed the state water quality criteria in all of the urban watercourses that have been tested to date (i.e., Thornton, Piper's, Longfellow, and Fauntleroy). Bacteria levels are typically higher in storm flow samples than in non-storm flow samples due to the impact of urban stormwater runoff.

Metals

Metals concentrations in Seattle watercourses generally meet state water quality criteria, based on limited sampling performed mostly during non-storm flow conditions. Like fecal coliform bacteria, the concentrations of most metals are typically higher in storm flow samples than in non-storm flow samples. An exception is zinc, which had concentrations measured in non-storm samples comparable to those measured in storm flow samples.

Nutrients

No state water quality criteria have been established for nutrients. However, total nitrogen and total phosphorus concentrations in Longfellow Creek, Piper's Creek, and Thornton Creek frequently exceed established U.S. EPA criteria. Exceedances in Longfellow Creek and Piper's Creek generally occur more frequently during storm flow conditions. Thornton Creek experiences occasional exceedances of the nutrient benchmarks under non-storm flow conditions; no data are available for storm flow conditions.

Habitat Conditions

Riparian habitat conditions in Seattle range from good (for an urban area) to poor, and instream habitat appears to mimic these conditions. There appears to be a high correlation between the land use adjacent to a stream and the quality of instream habitat and riparian conditions. Stream bank armoring and encroachment into riparian areas by roads and buildings are correlated with degraded habitat conditions in all of the watercourses, but particularly along Thornton Creek, which has the highest amount of private property bordering the watercourse. Piper's Creek, Taylor Creek, and Fauntleroy Creek, which flow through large park areas, have better habitat conditions than the other Seattle watercourses.

While the proximate causes of instream habitat degradation are evident where stream banks and channels have been altered to accommodate urban development, the root causes of instream habitat problems include altered hydrology and lack of floodplain connections. The Seattle 2004 Comprehensive Drainage Plan identifies limiting factors for urban watercourse environments and ranks them in order of severity (Appendix A), for the purpose, in part, of informing Seattle's future planning for habitat improvements needed in its most degraded urban watercourses.

Biological Communities

Fish Access

Fish passage barriers currently block migratory fish access to more than about one-third of the potential fish habitat in Seattle watercourses. Some of the inaccessible habitat is of the highest quality, particularly in Longfellow Creek and Taylor Creek.

Benthic Invertebrates

Benthic index scores illustrate that riparian or instream habitat of high quality does not ensure a healthy benthic community. Even the best physical habitat conditions in Seattle watercourses are not correlated with a benthic index (B-IBI) rating above fair (see Appendix C). Flow patterns, chemical conditions, and physical habitat all affect benthic organisms, and these factors collectively influence the aquatic invertebrates inhabiting Seattle watercourses.

Monitoring and Data Analysis Needs

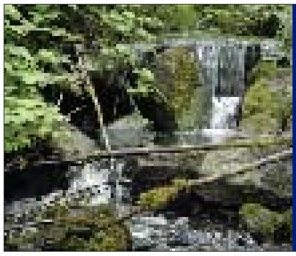
Accurately characterizing Seattle stream conditions is hindered by the limited data available, particularly for water quality and flow conditions. Implementing a monitoring program to track status and trends for flow, water quality, and habitat, including storm and non-storm event sampling, is important for understanding watercourses, the condition of their watersheds, and the results of Seattle's collective efforts to improve stream conditions.

Future Directions

This State of the Waters report describes the current hydrologic, chemical, physical, and biological conditions in the stream portions of watercourses within the City of Seattle. These conditions define overall watershed health and the ability of the city's watersheds to perform critical functions and services, such as filtering water, moderating floods, and capturing sediment, to benefit both human and environmental health.

With these baseline conditions identified, stream improvement efforts can be continued in those areas where further work is needed, and efforts can be refocused in those areas where new problems have come to light, considering the scale and sequencing of actions. It is hoped that the State of the Waters report will help to make everyone aware of the conditions in Seattle's surface water bodies and our role in protecting their health. Through that awareness, we can work to improve conditions for fish, wildlife, people, and the legacy we leave for future generations.

Longfellow Creek with bridge (photo by Bennett)



State of the Waters 2007

Part 6 References & Glossary

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Glossary of Terms

303(d) list A state inventory of impaired water bodies, created according to the federal Clean Water Act, Section 303(d).

acute conditions Changes in an organism's physical, chemical, or biological environment involving a stimulus severe enough to rapidly induce a response, resulting in injury or death to the organism after short-term exposure.

acute exposure value The threshold value below which there should be no unacceptable effects on freshwater aquatic organisms and their uses, if the one-hour average concentration does not exceed that value more than once every 3 years on average. Also known as the criterion maximum concentration (CMC).

adfluvial Adult salmon and trout living in lakes are generally adfluvial; that is, they use the lake to grow, mature, and forage but use tributaries draining to the lake for spawning and early rearing habitat.

aggradation The geologic process by which stream beds or floodplains are raised in elevation or built up through the deposition of sediment eroded and transported from upstream.

algae Small aquatic plants, containing chlorophyll, that occur as single cells, colonies, or filaments and float in the water or attach to larger plants, rocks, and other substrates. Individuals are usually visible only with a microscope. Excessive numbers can make the water appear cloudy and colored, creating a nuisance when conditions are suitable for prolific growth.

algal bloom Proliferation of living algae on the surface of a lake, stream, or pond; often stimulated by phosphate over-enrichment. Algal blooms reduce the oxygen available to other aquatic organisms.

ammonia (NH_3) A nitrogen-containing substance that may indicate the presense of recently decomposed organic material.

anadromous fish species Fishes that are born and reared in fresh water, migrate to the ocean to grow to maturity, and return to fresh water to reproduce (e.g., salmon and steelhead).

antidegradation policy Rules or guidelines required of each state by federal regulations implementing the Clean Water Act, requiring that existing water quality be maintained.

aquatic flora and fauna, aquatic biota All forms of plants (flora) and animals (fauna) found living in or rooted in water.

background concentration The pollutant level that would exist at a site in the absence of pollutant sources in the ndeighborhood of the site, or a naturally occurring pollutant concentration in a stream prior to watershed development.

backwater Water upstream of an obstruction that is deeper than it would normally be without the obstruction.

base flow The portion of stream flow that is not attributable to storm runoff and is supported by ground water seepage into a channel.

baseline condition The state of a system, process, or activity before the occurrence of actions or events that may result in changes; used as the starting point for comparative analysis.

basin The area of land drained by a river and its tributaries, draining water, organic matter, dissolved nutrients, and sediments into a lake or watercourse (see *drainage basin*, *watershed*).

benchmark As the term is used in this report, benchmarks represent interim water quality criteria that are useful for comparison to existing or past conditions found in Seattle surface water bodies. Benchmarks identified in this report are based on U.S. EPA water quality criteria but do not reflect adopted water quality standards. Because these benchmarks represent surface water quality conditions that are minimally influenced by human activity, exceeding a benchmark does not necessarily indicate a violation of the water quality standard.

beneficial uses Those uses of water identified in state water quality standards that must be achieved and maintained as required under the federal Clean Water Act. The terms "beneficial use" and "designated use" are often used interchangeably.

benthic invertebrates Aquatic, bottom-dwelling organisms in streams and lakes, including small invertebrate insects, crustaceans, mollusks, and worms.

best management practices (BMPs) Accepted methods for controlling diffuse pollution; generally, the structural devices, maintenance procedures, managerial practices, prohibitions of practices, and schedules of activities that are used singly or in combination to prevent or reduce the release of pollutants and other adverse impacts on receiving water bodies.

bioaccumulation The process by which substances that are very slowly metabolized or excreted increase in concentration in living organisms, resulting in the accumulation of chemical compounds in their body tissues.

biochemical oxygen demand (BOD) The rate of oxygen consumption by organisms during the decomposition of organic matter. Like chemical oxygen demand, biochemical oxygen demand is an indicator of water pollution.

biota All living organisms (plants and animals) within a specified area.

biotic index A numerical rating scheme using various aquatic organisms to determine their degree of tolerance to differing water conditions.

blue-green algae A group of algae having a blue pigment in addition to the green chlorophyll. A stench is often associated with the decomposition of dense blooms of blue-green algae in fertile lakes.

box and whisker plot A graphical display of a statistical summary of a data set, showing the lowest value, highest value, median value, size of the first and third quartiles, and outliers. (As explained under Summary Statistics in Part 3, an outlier is a value that falls beyond the step spread.)

buffer A defined edge or margin around a protected area that is governed by regulatory controls prohibiting activities that are incompatible with the objectives of the protective regulations.

bypass A channel or conveyance constructed to divert water around a stormwater facility.

catchment Surface drainage area associated with pavement drainage design.

censored data Concentrations of toxic pollutants in receiving waters are sometimes below the analytical laboratory's ability to detect them. These data are classified as censored and require special consideration.

channel A natural stream that conveys water; a natural or artificial watercourse with definite bed and banks to confine and conduct flowing water; or a ditch excavated for the flow of water.

channel erosion The widening, deepening, and headward cutting of small channels and waterways caused by hydraulic forces during moderate to large floods.

channel incision Increases in stream channel depth and width, commonly caused by frequent high and flashy flows.

chemical oxygen demand (COD) The rate of oxygen depleted by the chemical (nonbiological) oxidation of organic and inorganic compounds in water. Like biochemical oxygen demand, chemical oxygen demand is an indicator of water pollution.

chronic conditions Changes in an organism's physical, chemical, or biological environment involving a stimulus of extended duration, resulting in injury or death to the organism as a result of repeated or constant exposure over an extended period of time.

chronic exposure value The threshold value below which there should be no unacceptable effects on freshwater aquatic organisms and their uses, if the 4-day average concentration does not exceed that value more than once every 3 years on average. Also known as the criterion continuous concentration (CCC).

Clean Water Act (CWA) The basic federal water pollution control law in the United States (Federal Water Pollution Control Act, codified at 33 U.S.C. §§1251–1387). Provisions of the statute include technology-based effluent standards for point sources of pollution, a state-administered control program for nonpoint pollution sources, a construction grant program to build or upgrade municipal wastewater treatment plants, a regulatory system for spills of oil and other hazardous wastes, and a wetlands preservation program.

clearing The removal and disposal of unwanted natural material from the ground surface, such as trees, brush, and down timber, using manual, mechanical, or chemical methods.

collector A drainage conveyance pipe that receives flow from catch basins, inlets, and other concentrated sources and connects to interceptors or main (trunk) conveyance pipes.

combined sewer Drainage system pipes that carry both sanitary wastewater (i.e., wastewater from buildings) and stormwater runoff to a wastewater treatment plant.

combined sewer overflow (CSO) A combination of untreated wastewater and stormwater that can flow into a waterway when a combined sewer system reaches its capacity.

conveyance A structure or mechanism for transporting water from one point to another, including pipes, ditches, and channels.

conveyance system The drainage facilities, both natural and constructed, that collect, contain, and provide for the flow of surface water and stormwater from the highest points on the land down to a receiving water. The natural elements of a conveyance system may include swales and small drainage courses, streams, rivers, lakes, and wetlands. Constructed elements of a conveyance system may include gutters, ditches, pipes, channels, and most retention and detention facilities.

critical habitat The area of land, water, and air space required for normal needs and survival of a plant or animal species; under the federal Endangered Species Act, specific geographical areas that are essential to the conservation of listed species may be designated as critical habitat.

culvert A pipe or concrete box structure that drains open channels, swales, or ditches beneath a roadway or embankment, typically with no catch basins or manholes along its length.

designated uses Those uses of water identified in state water quality standards that must be achieved and maintained as required under the federal Clean Water Act. The terms “beneficial use” and “designated use” are often used interchangeably.

detection limit The smallest concentration of a constituent that can be measured with a stated level of confidence. (In practice, detection limits can be determined by different methods in different laboratories.)

detention facility An aboveground or below-grade facility, such as a pond or tank, that temporarily stores stormwater runoff and subsequently releases it at a slower rate than the rate at which it is collected by the drainage facility system. Detention is used to control the peak discharge rate and provide gravity settling of pollutants.

discharge Runoff leaving an area via overland flow or built conveyance systems, typically described as a volume of fluid passing a point per unit of time, such as cubic feet per second (cfs), cubic meters per second, gallons per minute, gallons per day, or millions of gallons per day.

dissolved oxygen The amount of oxygen dissolved in water and available for aquatic life, measured in milligrams per liter. Certain amounts of dissolved oxygen are essential to aquatic animal and plant life, as well as bacterial decomposition of organic matter.

disturbed habitat A habitat in which naturally occurring ecological processes and species interactions have been significantly disrupted by the direct or indirect results of human presence and activity.

ditch A long, narrow excavation dug in the earth for drainage.

drainage basin The tributary area through which drainage water is collected, regulated, transported, and discharged to receiving waters (see *watershed*).

ecological health In surface water systems, environmental conditions exhibiting the ecological functions and features necessary to support diverse, native, self-sustaining aquatic and riparian communities. Ecologically healthy urban streams have the habitat necessary to support benthic invertebrates and native fish, including salmon and trout during all life stages.

effluent Liquid wastes generally from wastewater treatment, septic systems, or industrial sources that are released to a surface water body.

emergent plants Aquatic plants that are rooted in the bottom sediment but project above the water surface, such as cattails and bulrushes. These wetland plants often have high habitat value for wildlife and waterfowl and can aid in pollutant uptake.

encroachment For this report, encroachment refers to the act of building a structure or removing vegetation (in whole or in part) within the riparian corridor surrounding a stream.

Endangered Species Act (ESA) A federal law adopted in 1973 intended to protect species of plants and animals that are of "aesthetic, ecological, educational, historical, recreational, and scientific value." The U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service share authority to designate endangered species, determine critical habitat, and develop recovery plans for species listed as threatened or endangered.

entrenchment Downward erosion of the streambed typically leading to confinement by the channel banks and separation from the floodplain.

environmentally critical areas (ECAs) Landslide-prone areas, liquefaction-prone areas, flood-prone areas, riparian corridors, wetlands, steep slopes, fish and wildlife habitat conservation areas, abandoned landfills, and other areas as defined and regulated under the Seattle critical area regulations.

erosion The detachment and movement of soil or rock fragments by water, wind, ice, or gravity.

erosion and sedimentation control Any temporary or permanent measures taken to reduce erosion, control siltation and sedimentation, and ensure that sediment-laden water does not leave a site.

estuary An area where fresh water meets salt water at the lower end of a river, or where the tide meets the river current (e.g., bays, mouths of rivers and streams, salt marshes, and lagoons). Estuaries serve as nurseries and as spawning and feeding grounds for many marine organisms, and provide shelter and food for birds and wildlife.

eutrophication The addition of nutrients, especially nitrogen and phosphorus, to a body of water, resulting in high organic production rates that may overcome natural self-purification processes. Frequently resulting from pollutant sources on adjacent lands, eutrophication produces undesirable effects including algal blooms, seasonally low oxygen levels, and reduced survival opportunities for fish and invertebrates.

evapotranspiration The collective term for the movement of water from soil and vegetation to the atmosphere by evaporation of water from the soil and transpiration of water by plants.

fecal coliform bacteria Microscopic organisms associated with animal feces, commonly measured in water quality samples as an indirect indicator of the presence of other disease-causing bacteria. Used as a primary parameter and standard of water quality; reported in number of organisms or colony-forming units per 100 milliliters of water.

filling Placement of earthen material to increase the surface elevation at a site using artificial means, usually making the ground especially vulnerable to erosion.

flashy (stream flow) A high rate and volume of flow in a watercourse, typical in a developed watershed with impervious surfaces from which stormwater runoff drains all at once. By contrast, in undeveloped watersheds, infiltration and vegetation retard runoff and attenuate peak watercourse flows.

flood control Methods or facilities for reducing flood flows and the extent of flooding. Methods may include the use of structural facilities such as dikes, river embankments, channels, or dams.

flood frequency When expressed as a percentage, the frequency with which the flood of interest may be expected to occur at a site in any given year. Frequency analysis defines the *n*-year flood as the flood that is expected to be equaled or exceeded on the average of once every *n* years.

floodplain Any normally dry land area that is susceptible to inundation by water from any natural source, usually low land adjacent to a river, stream, watercourse, ocean, or lake.

flow control Efforts to reduce or mitigate surface and stormwater runoff flow rates and volumes. See also *flow control facility*.

flow control facility A stormwater drainage facility designed to mitigate the impacts of increased surface and stormwater runoff flow rates and/or volumes. Flow control facilities are designed either 1) to hold water for a considerable length of time and then release it by evaporation, plant transpiration, or infiltration into the ground, or 2) to hold runoff for a short period of time, releasing it to the conveyance system at a controlled rate.

forested conditions Land conditions generally characterized by woody vegetation at least 6 meters in height, with vegetation communities that represent a significant amount of tree cover consisting of species that offer wildlife habitat and other values.

fry The stage in the life of a fish between hatching of the egg and absorption of the yolk sac.

geographic information system (GIS) A computer database system that can input, store, manipulate, analyze, and display geographically referenced data in map formats.

geometric mean A calculated mean or average value that is appropriate for data sets containing a few values that are very high relative to the other values, or skewed. To reduce the bias introduced by these very high numbers, the natural logarithms of the data are averaged, and the anti-log of this average is the geometric mean. The geometric mean is used to compare fecal coliform bacteria levels to water quality standards.

ground water Water occurring in a saturated zone or stratum beneath the ground surface or a surface water body. Ground water recharge is inflow to a ground water reservoir.

habitat The specific area or environment in which a particular type of plant or animal lives. An organism depends upon its habitat for all of the basic requirements for life.

hardness A measure of the concentration of dissolved calcium carbonate in water; hard water has high concentrations.

headwaters A watercourse forming the source of another larger watercourse.

heavy metals Metals of high specific gravity, present in municipal and industrial wastes, that pose long-term environmental hazards. Such metals include cadmium, chromium, cobalt, copper, lead, mercury, nickel, and zinc.

herbicide A substance intended to control or destroy any vegetation.

hydrograph A plot that shows changes in flow, discharge, or water depth over time at a specified point in a stream, indicating trends such as declining base flows and increasing storm flow peaks associated with urbanization in the watershed.

hydrologic cycle The circuit of water movement from the atmosphere to the earth and returning to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration.

hydrology The science of the behavior of water in the atmosphere, on the surface of the earth, and in the soil and underlying rocks; its occurrence, distribution, circulation, physical and chemical properties, and reaction with the environment.

hyporheic zone A region beneath and lateral to a streambed, where there is mixing of shallow ground water and surface water. The hyporheic zone plays several important ecological roles in a river, because it is an ecotone (ie., a transitional area between two adjacent ecological communities). The interactions between the surface water and ground water make the hyporheic zone an area of great biological and chemical activity.

impaired waters Water bodies not fully supporting their beneficial uses, as defined under the federal Clean Water Act, Section 303(d).

impervious surface A hard surface area that either prevents or retards the entry of water into the soil mantle (as occurs under natural conditions, prior to development), from which water runs off at an increased rate of flow or in increased volumes. Common impervious surfaces include rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled or macadam surfaces.

indicator An observed or calculated characteristic that shows the presence of a condition or trend. Water quality indicators are selected chemical and physical parameters and indices that can be used to characterize overall conditions in the receiving water and also provide benchmarks for assessing the success of watershed management efforts.

infiltration The downward movement of water from the ground surface into the subsoil.

inlet A connection between the ground surface and a drain or sewer for the admission of surface and stormwater runoff.

integrated drainage plan (IDP) An areawide drainage plan created through a partnership between SPU and private or public developers, usually in conjunction with a major development project, to co-locate drainage facilities that meet the developer's requirements while furthering the city's drainage goals.

intermittent flow A watercourse that flows only in direct response to precipitation, receives little or no water from springs and no long-continued supply from melting snow or other sources, and is dry for a large part of the year, ordinarily more than 3 months.

invasive species Opportunistic, nonnative species of inferior biological value that tend to out-compete more desirable forms and become dominant.

invertebrates Animals lacking internal skeletons. Some require magnification to be seen well, while others such as worms, insects, and crayfish are relatively large (called macroinvertebrates). Benthic invertebrates (living in streambed sediments) are collected as samples to be identified and counted. More varied invertebrate communities generally indicate healthier streams.

kokanee Non-anadromous sockeye salmon.

lake An area permanently inundated by water in excess of 2 meters deep and greater than 20 acres in area as measured at the ordinary high water marks.

land-disturbing activity Any activity that results in a movement of earth or a change in the existing soil cover or topography, such as clearing, grading, filling, and excavation.

landslide Episodic downslope movement of a mass of soil or rock that includes rockfalls, slumps, mudflows, and earthflows.

limiting nutrient The nutrient that is in lowest supply relative to the demand. The limiting nutrient will be exhausted first by algae, which require many nutrients and light to grow. Inputs of the limiting nutrient result in increased algal production, but as soon as the limiting nutrient is exhausted, growth stops. Phytoplankton growth in waters of temperate lowland areas is generally phosphorus-limited.

listed species A plant or animal species officially designated as threatened or endangered under the federal Endangered Species Act.

macroinvertebrates Animals that lack internal skeletons and are large enough to see with the naked eye, such as worms, insects, and crayfish. Benthic macroinvertebrates (living in streambed sediments) are collected as samples to be identified and counted. More varied invertebrate communities generally indicate healthier streams.

method detection limit (MDL) The lowest concentration at which an analyte can be detected in a sample that does not cause matrix interferences (typically determined using spiked reagent water). "Detected" in this context means that a sample that contains the analyte detected at the MDL can be distinguished from a blank with 99 percent certainty. The MDL is a laboratory-specific number, dependent on (among other things) the instrumentation used by a particular laboratory and the skill of the operator. This number may change with time.

mg/L (milligrams per liter) and µg/L (micrograms per liter) Units of measure used in describing the amount of a substance in a given volume of water, as in 5 milligrams of oxygen per liter of water.

mitigation Generally, measures to reduce adverse impacts on the environment.

monitoring Systematic measurement and data collection by various methods for the purposes of understanding natural systems, evaluating the impacts of disturbances and alterations, and assessing the performance of mitigation measures.

natural conditions Surface water quality that was present before any human-caused pollution. When estimating natural conditions in the headwaters of a disturbed watershed, it may be necessary to use the less disturbed conditions of a neighboring or similar watershed as a reference condition.

natural drainage system Engineered street drainage that uses open, vegetated swales; deep, healthy soils; stormwater cascades; and small wetland ponds to manage stormwater runoff. In place of traditional pipe systems that quickly convey stormwater away, natural drainage systems emphasize infiltration and decentralized treatment to more closely resemble natural hydrologic functions lost due to urbanization.

nitrate, nitrite (NO_3, NO_2) Two types of nitrogen compounds that are nutrients, or forms of nitrogen that algae may depend upon for growth.

nonpoint source pollution (of water) Pollution that enters a water body from diffuse origins in the watershed and does not have discernible, confined, or discrete points of origin.

nutrient An organic or inorganic chemical essential for growth and reproduction of organisms. In surface water bodies, nutrients affecting water quality include total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, nitrite-nitrogen, and ammonia-nitrogen, measured in milligrams per liter of water.

ordinary high water mark The line on the shore established by the fluctuations of water level and indicated by physical characteristics such as a clearly visible, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, or the presence of litter and debris.

outfall Generally, the point of discharge from a storm drain. Outfalls may discharge to surface waters or ground water.

outlet Generally, the point of water discharge from a watercourse, river, lake, tidewater, or storm drain.

PAHs (polycyclic aromatic hydrocarbons) A class of organic compounds, some of which are persistent and cancer-causing, that are ubiquitous in the environment. PAHs are commonly formed by the combustion of fossil fuels and by forest fires, often reaching the environment through atmospheric fallout, highway runoff, and oil discharge.

parameter One of a set of variable, measurable properties whose values determine the characteristics of a system such as a water body. See *water quality parameter*.

partially separated sewers Independent drainage pipe systems that collect and keep stormwater runoff separate from sanitary sewage (wastewater), except that rooftop drainage is directed to the sanitary sewer, while street runoff goes to the storm drainage system.

PCBs (polychlorinated biphenyls) A group of manmade organic chemicals comprising 209 closely related compounds (congeners) made up of carbon, hydrogen, and chlorine. If released to the environment, PCBs persist for long periods of time and can concentrate in food chains.

peak discharge The maximum instantaneous rate of flow during a storm (usually in reference to a specific design storm event).

permeable soils Soil materials having a sufficiently rapid infiltration rate so as to greatly reduce or eliminate surface and stormwater runoff.

pesticide A general term describing any substance, usually chemical, used to destroy or control undesirable organisms (pests). Pesticides include herbicides, insecticides, fungicides, algacides, and other substances.

pH A measure of the alkalinity or acidity of a substance on a scale of 0 to 14, determined by measuring the concentration of hydrogen ions in the substance. A pH value of 7.0 indicates neutral water. A 6.5 reading is slightly acidic.

phosphorus One of the elements essential as a nutrient for the growth of organisms. In western Washington surface water bodies, it is usually the algal nutrient in shortest supply; hence adding more phosphorus causes more algal growth. Various measures of phosphorus in water samples are made, including total phosphorus and the dissolved portion of phosphorus.

photosynthesis The process by which living plant cells produce simple sugars and starches from carbon dioxide and water, with the aid of chlorophyll and the presence of light.

phytoplankton Microscopic algae and microbes that float freely in open water of lakes and oceans.

point source pollution (of water) Pollutants released into the environment from a discernible, confined, and discrete conveyance, such as a pipe or wastewater outfall.

pollutant A substance introduced into the environment that has adverse effects on organisms, including death, chronic poisoning, impaired reproduction, cancer, or other effects.

pollution (of water) The human-induced alteration of the chemical, physical, biological, or radiological integrity of water.

prespawn mortality Premature death, before spawning, of adult spawning-stage fish, commonly preceded by symptoms such as spasms, gaping, fin splaying, and loss of equilibrium. Prespawn mortality has been observed following storm events in urban watersheds and also can be caused by disease, stranding, or high water temperatures.

Puget Sound basin Puget Sound south of Admiralty Inlet (including Hood Canal and Saratoga Passage); the waters north to the Canadian border, including portions of the Strait of Georgia; the Strait of Juan de Fuca south of the Canadian border; and all the lands draining into these waters, as mapped in water resource inventory areas (WRIAs) 1 through 19, set forth in Washington Administrative Code (WAC) 173-500-040.

receiving waters Bodies of water or surface water systems, such as a lake or stream, to which surface runoff is discharged via a point source of stormwater or via sheet flow.

recharge The addition of water to the zone of saturation (i.e., an aquifer).

recruitment of woody debris The movement of fallen wood into a stream or wetland over time through the action of wind, water, or other means. The potential for recruitment of woody debris influences the long-term habitat structure within an aquatic system.

redd A salmonid fish nest, where eggs are buried in protected gravels for incubation and hatching.

reporting detection limit (RDL) The minimum concentration of an analyte required to be measured and allowed to be reported without qualification as an estimated quantity for samples without substantial interferences, also known as the practical quantification limit. The RDL is generally based on a value 3 to 5 times that of the method detection limit (MDL), considering the amount of sample typically analyzed and the final extract volume of that method. The RDL must be greater than the MDL. The differentiation between MDLs and RDLs is of most concern when analyzing for organic compounds of concern where the MDLs tend to be closer to the RDLs, by contrast with inorganic compounds where the differences between MDLs and RDLs are much greater.

resident A salmonid life history type in which all life stages—spawning, rearing, growth, and maturation—occur in small headwater streams, often upstream of impassable physical barriers.

retention The process of collecting and holding surface and stormwater runoff with no surface outflow.

riffle A fast-flowing section of a stream where shallow water races over stones and gravel; a riffle is smaller than a rapid and shallower than a chute. Riffle habitat usually supports a wider variety of bottom-dwelling organisms than other types of stream habitat.

riparian Pertaining to the bank of a water body. Riparian habitat is associated with stream and lake margins, typically characterized by dense vegetation supporting a variety of waterfowl, songbirds, amphibians, and small mammals.

riprap A facing layer or protective mound of rocks used to line channels, to prevent bank erosion caused by hydraulic forces of surface flow and stormwater runoff.

runoff Water originating from rainfall and other precipitation that flows to drainage facilities, rivers, watercourses, springs, ponds, lakes, wetlands, and shallow ground water.

salmonid A member of the fish family Salmonidae, including Chinook, coho, chum, sockeye, and pink salmon; cutthroat, brook, brown, rainbow, and steelhead trout; Dolly Varden; kokanee; and char species.

scour Erosion of channel banks due to excessive velocity of the flow of surface and stormwater runoff.

sediment Particulate organic or inorganic matter and fragmented material that originates from weathering and erosion of rocks and is transported by, suspended in, or deposited by water, settling to the bottom of surface water bodies. Certain contaminants tend to collect on and adhere to sediment particles.

sedimentation The deposition or formation of sediment.

sediment management standards State regulatory standards pertaining to the quality of sediment, found in WAC 173-204.

separated sewers Independent drainage pipe systems that collect and keep stormwater runoff separate from sanitary sewage (wastewater).

sheet flow Runoff that flows over the ground surface as a thin, even layer, not concentrated in a channel.

slope The degree of deviation of a surface from the horizontal, measured as a numerical ratio, percentage, or in degrees. Expressed as a ratio, the first number is the horizontal distance (the run) and the second is the vertical distance (the rise), e.g., 2:1. A 2:1 slope is a 50 percent slope. Expressed in degrees, the slope is the angle from the horizontal plane, so that a 90 degree slope is vertical, and a 45 degree slope is 1:1, i.e., a 100 percent slope. Sloping terrain with a gradient of 40 percent or more and an elevation change of at least 10 feet is generally regarded as a steep slope.

smolt A juvenile anadromous salmonid that has matured sufficiently to embarking upon its seaward migration.

storm drain Generally, a conveyance or system of conveyances that carries stormwater, surface water, and other drainage (but not sanitary wastewater or industrial wastes) toward points of discharge (sometimes called a storm sewer).

storm event Technical term for a specific precipitation occurrence; for example, the 5-year, 24-hour storm event, the 25-year, 24-hour storm event, or the 100-year, 24-hour storm event.

stormwater Generally, precipitation and surface runoff and drainage.

stormwater drainage system Constructed and natural features that function together to collect, convey, channel, hold, inhibit, retain, detain, infiltrate, divert, treat, or filter stormwater.

stormwater facility Generally, a constructed component of a stormwater drainage system designed to perform particular functions (e.g., pipe, swale, ditch, culvert, detention or retention pond, constructed wetland, infiltration device, catch basin, oil/water separator, or biofiltration swale).

stormwater runoff Stormwater that directly leaves an area in surface drainage.

stream A natural watercourse in which surface waters flow sufficiently to produce a defined channel or bed. In the State of the Waters report, streams are divided into reaches, reaches are divided into segments, and segments are divided into sections.

stream gauge data Quantitative stream flow information derived from measurements using gauges, current meters, weirs, or other measuring instruments.

subcatchment An area of land draining to a single storm drain outfall on a watercourse.

substrate The nonliving material forming the bed of a stream, lake, or ocean, with particles described in terms of size as boulders, cobbles, gravel, sand, silt, or clay.

swale A natural depression or shallow drainage conveyance with gentle side slopes, generally with flow depths less than one foot, used to temporarily store, route, or filter runoff.

topography Configuration of the land surface and degree of elevation change, including characteristics such as plains, hills, mountains, steepness of slopes, and other physiographic features.

total maximum daily load (TMDL) Under Section 303(d) of the federal Clean Water Act, water quality standards must be used to identify threatened and impaired water bodies. Category 2 (threatened) water bodies are those that occasionally exceed water quality standards, while category 5 (impaired) water bodies are those that frequently exceed standards. Impaired water bodies are required to be evaluated to identify the pollutants and sources responsible for the water quality problems. Total maximum daily load (TMDL) limits are then established and allocated to specific pollutant sources in order to reduce pollutant discharges and move toward meeting water quality standards. A TMDL is the sum of the allowable loads of a single pollutant from all contributing point sources and nonpoint sources, including a margin of safety and accounting for seasonal variations in water quality.

total suspended solids (TSS) Particles, both mineral (clay and sand) and organic (algae and small pieces of decomposed plant and animal material), that are suspended in water.

toxic Poisonous, carcinogenic, or otherwise directly harmful to life.

treatment Processing of water for removal or reduction of solids or other pollutants by various means such as infiltration into vegetated ground, settling, bacterial decomposition, aeration, chlorination, ozonation, filtration, etc.

trophic level A scheme of classifying organisms by feeding levels in a food web. Plants fill the first trophic level by using sunlight to create carbohydrates and other compounds. In the second trophic level, plants are consumed by plant-eating animals (herbivores), which in turn become food for predators in the next trophic level, and so on.

turbidity A measure of the reduced transparency of water caused by the suspension of minute particles such as algae, silt, or clay, typically expressed in nephelometric turbidity units (NTU).

two-year storm event A 2-year storm event occurs every 2 years on average or has a 50 percent chance of occurring in any given year.

upland The general term used for land areas in the upper portions of a watershed or basin, above watercourses, rivers, lakes, wetlands, and other water bodies.

urban runoff Stormwater from streets and adjacent developed properties that may carry pollutants of various kinds into storm drains and receiving waters.

Washington Administrative Code (WAC) The codified regulations of the state of Washington.

wastewater A combination of liquid and waterborne pollutants from residences, businesses, industries, or farms; or a mixture of water and dissolved or suspended solids.

water column In a water body, the water contained between the interface with the atmosphere at the surface, and the interface with the sediment layer at the bottom.

watercourse A network of open stream channels, pipes, ditches, and culverts in which surface water is transported to a receiving water body. Watercourses include small lakes, bogs, streams, creeks, and intermittent artificial or constructed components but do not include receiving waters (Seattle Municipal Code 22.801.240).

water quality Generally, the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

water quality criteria Elements of state water quality standards, expressed as quantitative constituent concentrations, levels, measures, or descriptive statements, representing a quality of water that supports a particular use. When criteria are met, water quality generally protects the water's designated use.

water quality parameter One of a set of properties of water that are routinely measured and analyzed to assess water quality, such as temperature, turbidity, conductivity, pH (acidity), dissolved oxygen content, phosphorus concentration, fecal coliform bacteria concentration, and others.

water quality standards Provisions of state or federal law consisting of designated uses for a water body, and water quality criteria based upon such uses, pursuant to the federal Clean Water Act. Water quality standards are established to protect public health or welfare, enhance the quality of water, and serve the purposes of the Clean Water Act.

water resource inventory area (WRIA) Any of the 62 watershed-based geographical areas composing the state of Washington, identified for administrative and planning purposes of the Department of Ecology and others (see WAC 173-500-040).

watershed A geographical region bounded by topographic high points within which water drains into a particular river, watercourse, or body of water. Watersheds can be as large as those identified and numbered by the state of Washington as water resource inventory areas (WRIAs), or they can be identified as smaller or larger drainage areas.

water table The upper surface or top of the saturated portion of the soil or bedrock layer, indicating the uppermost extent of ground water.

weir A device for regulating or measuring the flow of water.

wetland An area that is inundated or saturated by surface water or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

wet ponds, wet vaults Drainage facilities for water quality treatment that contain permanent pools of water, which fill during the initial runoff from a storm event. Wet ponds and wet vaults are designed to optimize water quality by providing retention time in order to 1) settle out particles of fine sediment to which pollutants such as heavy metals adsorb, and 2) allow biological activity to occur that metabolizes nutrients and organic pollutants.

woody debris Logs, stumps, or branches that have fallen or been cut and left in place.