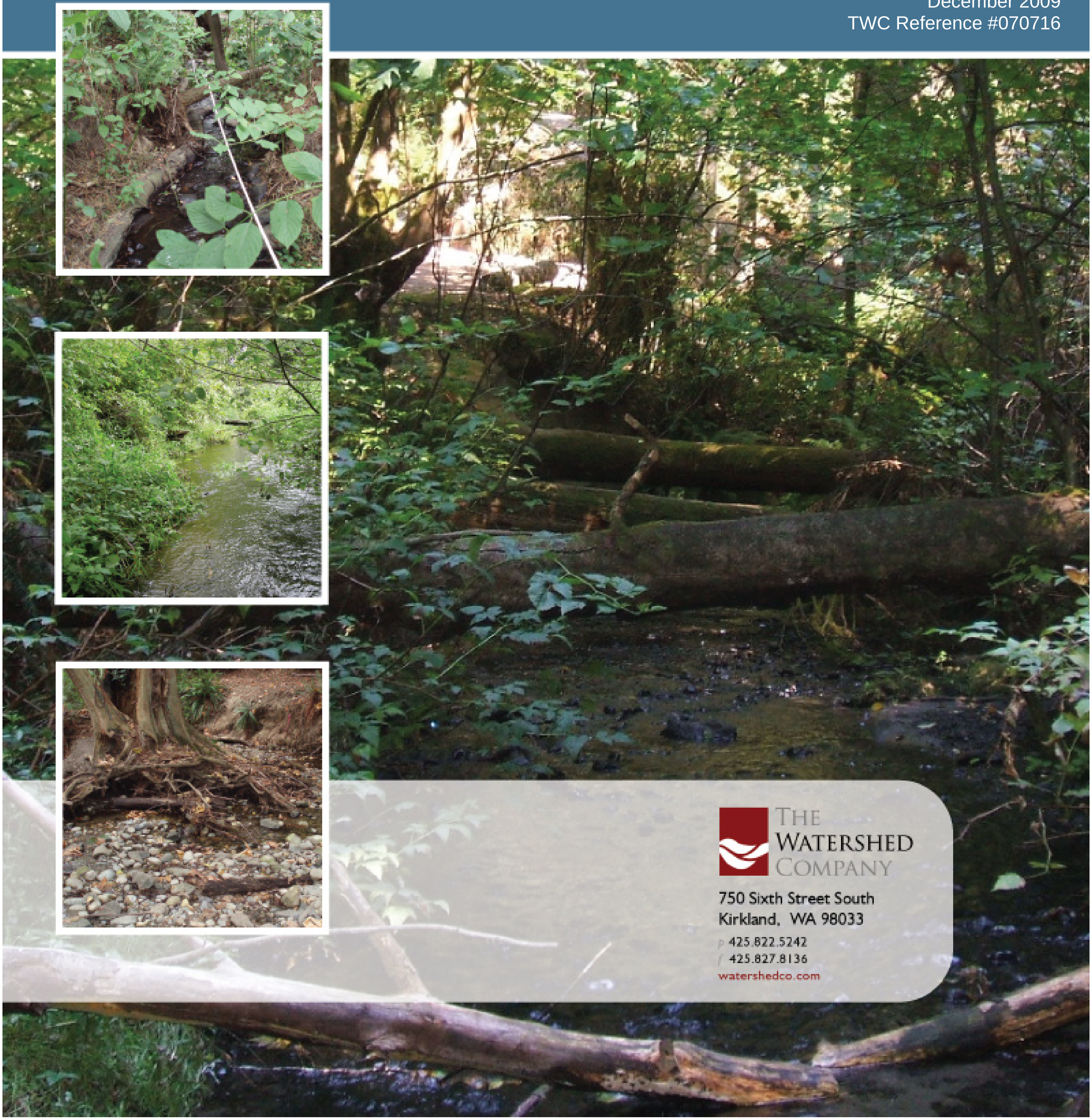
FINAL

2007 BIOASSESSMENT REPORT
Biological and Habitat Assessment of Shoreline Streams

Prepared for:

City of Shoreline
Public Works Department
Surface Water and Environmental
Services Program
17500 Midvale Avenue N
Shoreline, WA 98133

December 2009
TWC Reference #070716



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BIOLOGICAL AND HABITAT ASSESSMENT OF SHORELINE STREAMS

EXECUTIVE SUMMARY

The City of Shoreline's Surface Water and Environmental Services Department routinely monitors the quality of stream systems and surface waters within the City of Shoreline. This report summarizes the results of biological (benthic invertebrates), physical habitat and Water Quality Index assessment of Shoreline's streams. The Benthic Index of Biotic Integrity (B-IBI) is an important component of the City's monitoring program, and the B-IBI was utilized in 2003 and 2007 to assess temporal changes in water quality and overall stream health. In concert with the B-IBI, a suite of physical stream habitat parameters were also measured in 2003 and 2007. In 2007, the water quality of the streams was approximated using the Department of Ecology Water Quality Index scoring matrix.

The objectives of this report are to 1) document current biological and physical conditions in the City's streams and 2) identify any positive or negative trends in the ecological health of these stream systems over time. The results of these monitoring efforts will help determine whether habitat and water quality improvement programs are effective and current practices sustain or improve conditions. For this study, water quality parameters, physical stream habitat and biotic diversity were assessed at five sites in various City of Shoreline streams: Thornton Creek, McAleer Creek, Boeing Creek, and Storm Creek. In 2003, the B-IBI indicated that all five streams were degraded, and samples from each survey site were rated as "extreme", with the exception of McAleer Creek, which scored slightly higher and was rated as "severe." The 2007 results differed little from those reported in 2003, when low B-IBI scores ("extreme" rating) were measured at all five study sites. Although each stream surveyed in 2007 showed some evidence of historic urbanization, streams with larger riparian buffers tended to have relatively higher quality physical habitat than streams with narrower riparian buffers. Some physical habitat parameters varied slightly between 2003 and 2007, but the survey did not detect any large changes in stream habitat over time. Silt and sand were generally a dominant substrate type in many of the survey areas. High fine sediment volumes also affected the macroinvertebrate community, which were commonly dominated by species capable of living in sandy, silty substrates. Other indicators of overall stream habitat quality varied

with the size of the stream, the survey reach’s position in the watershed, and the size of each stream’s riparian buffer.

Besides physical habitat, water quality also heavily influences the biologic diversity found in streams. The water quality of the streams was approximated using the Department of Ecology Water Quality Index (WQI) scoring matrix (Appendix A). The WQI matrix is a method for summarizing water quality data in an easily expressible and easily understood format. The score and ratings obtained represent the relative water quality of the study streams. For 2007, the rating of the water quality of each stream generally agreed and supported the biological findings. Water quality scores for the streams analyzed indicated either “high concern” or “marginal concern”, exhibiting degraded characteristics typically found in urban streams. Future water scores and ratings will be compared to the 2007 results to help assess if water quality programs being implemented are helping to improve water quality as expected.

1 INTRODUCTION

The City of Shoreline is located in the northwestern corner of King County along the shores of Puget Sound. Shoreline is generally bounded by the City of Lake Forest Park to the east, the City of Seattle to the south, Puget Sound to the west, and Snohomish County to the north (including the Cities of Mountlake Terrace, Edmonds, and the Town of Woodway). Puget Sound is the City's only "shoreline of statewide significance," as defined by the Washington State Shoreline Management Act, but the City has several lakes and ponds including Echo Lake, Hidden Lake, Ronald Bog and Twin Ponds. Numerous small streams and creeks are also found within or adjacent to the City of Shoreline. Three of the most significant basins within the City are Boeing Creek basin, Thornton Creek basin and McAleer Creek basin (Figure 1).

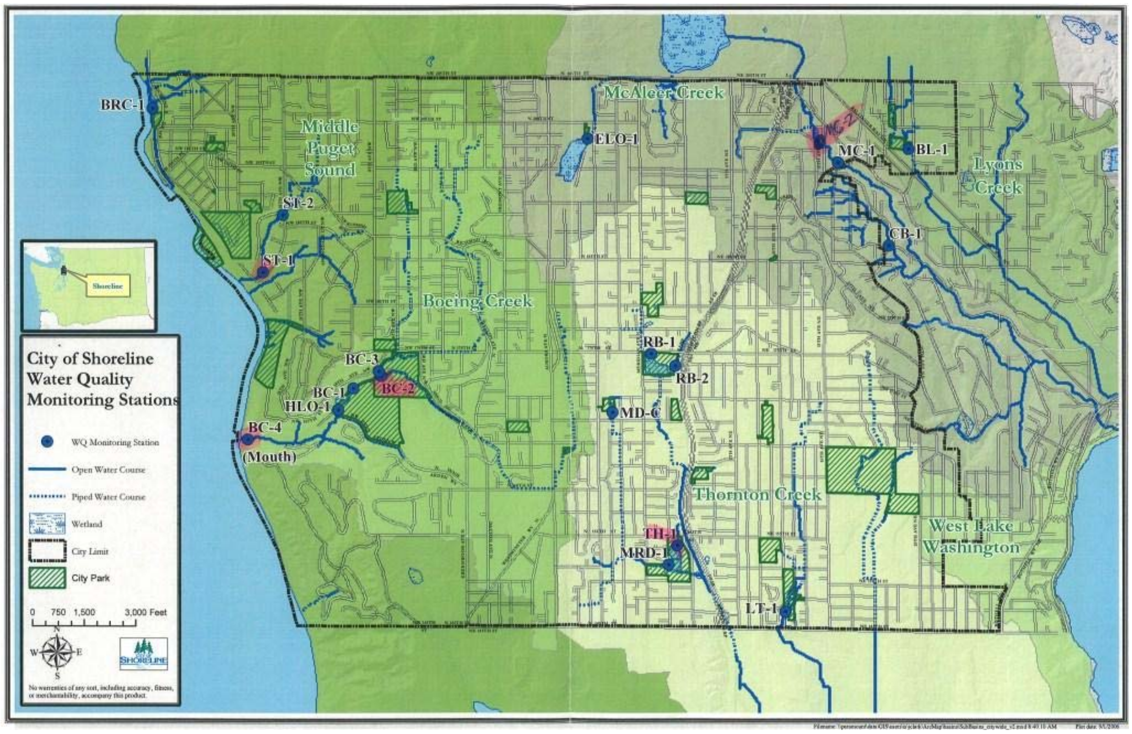

Figure 1. City basins and sample locations.

Over many years, urban development in the City of Shoreline has drastically altered the City's watersheds. Previously forested areas and wetlands have been replaced with residential and commercial land uses. Limited areas of open space remain. Shoreline's development history began with original settlements dating back to the late 1800s. As the City developed over time, most of this development took place prior to the implementation of stormwater mitigation regulations in the 1970s. Currently, the City is substantially developed, with only about one percent of the total land area remaining vacant.

Shoreline is primarily residential in character and over 50 percent of the households are single family residences. Commercial development is predominantly located along Aurora Avenue, with other neighborhood centers located at intersections of primary arterials, such as N 175th Street at 15th Avenue NE and N 185th Street at 8th Avenue NW. There is limited industrial development within City limits. Currently, development within the City is primarily in the form of redevelopment and infill. Urban development has produced a large amount of impervious surface including streets, sidewalks, parking lots, and roofs. When rain falls on these impervious surfaces the water runoff flows directly into streams and local water bodies instead of naturally being absorbed into the ground or retained by wetlands. Surface water runoff picks up soil, chemicals and other pollutants and carries them into our lakes, rivers and marine waters. This large amount of impervious surface in the City of Shoreline greatly affects the condition of the City's surface waters.

Stormwater runoff is the number one urban water pollution problem in the state, according to the Washington State Department of Ecology. The water quality of the lakes and streams in the City of Shoreline has been negatively impacted by the large volumes of urban runoff that they regularly receive (Loch 2003a). Because of this known impact, the City regularly monitors local surface waters to help determine the level of impairment. To track the condition of the City's surface waters over time, the City has been conducting monthly water quality monitoring since October 2001. In 2002 the City conducted a biological and habitat assessment to get a snapshot of the relative health of City streams (Loch 2003a). This survey included sampling macroinvertebrates (bioassessment) and the assessment of habitat factors such as substrate size, canopy cover, woody debris and channel morphology. In 2007, the same biological and habitat assessment was made and compared to the 2003 data (Data collected in fall 2002 of 2003 water year). These comparisons help to illustrate the effect of stormwater runoff on City streams.

This report will serve as an assessment of 2007 conditions and as a benchmark for comparison to future changes in water quality. The City currently implements programs to help reduce water pollution and new policies and programs will be implemented over the next five years, according to the schedule set forth in the Western Washington Phase II Municipal Stormwater Permit (i.e. the National Pollutant Discharge Elimination System (NPDES) Phase II permit) issued by the Washington State Department of Ecology. As part of the NPDES Phase II permit requirements, the effectiveness of the programs implemented must be measured. Future water quality data and studies can be compared to the 2007 conditions set forth in this report in order to determine program effectiveness and shape future programs aimed at improving water quality.

This report will serve as a tool to:

- Foster a broader awareness within the community of the condition of the City's surface waters.
- Document and protect the water quality, physical, and biological integrity of the City's surface and ground waters.
- Document channel conditions, including habitat, selected water quality measures and macroinvertebrate populations.
- Detect trends in physical, chemical, and biological integrity.
- Enhance and assist City departments (and City Council) to:
    - generate program policy and rules,
    - prioritize restorative actions, and
    - Provide direction for future monitoring.

2 SELECTED INDICATORS OF CURRENT STREAM HEALTH

2.1 Biological Integrity (B-IBI)

The City chose to focus on biological assessment as the primary indicator of the health of the City's streams. Use of biological assessment as a tool to measure and protect the ecological health of water bodies has increased locally and regionally (EPA 2002). Bioassessment is defined by the Environmental Protection Agency (EPA) as: an evaluation of the biological condition of a waterbody using biological surveys and other direct measurements of the resident living organisms (EPA 2002). The strength of bioassessment lies in its' ability to determine the health of a water body based on the in-stream biological community. These communities can communicate in great detail about the overall health of the waterbody because of their intimate exposure to all perturbations, point and non-point pollution, within their watershed. Bioassessments are the most effective way to measure the aggregate impact of stressors on waterbodies (EPA 2002). The community includes insects, worms, snails, crustaceans, and mollusks. The result, identification and count, are stratified into metrics.

Metrics are statistically correlated signals that the biological community displays in a predictable manner. The metrics used in this study have become commonly accepted to be the best indicators of stream health in the Puget Lowland Ecoregion. For example, the metric long-lived taxa can indicate conditions related to flow, chronic degradation of water quality, and drought. Their life cycle spanning more than one year makes them excellent candidates to monitor as they are subject to all human activities that influence the stream over a period of years. Metrics are scored with a 1, 3, or 5 and then summed for a biological integrity score, using the benthic index of biotic integrity (B-IBI) (Fore 1999).

2.2 Physical Stream Habitat

As an indicator of how suitable these streams are for fish and other aquatic organisms, stream morphology and habitat was also analyzed. The following physical components of stream habitat were assessed: tree canopy closure; channel morphology, including degree of erosion; pebble counts or substrate composition; particle size distribution; presence of large woody debris; and pool/riffle assessment.

The tree canopy closure and vegetation cover provides shade and keeps the water cool enough to support aquatic organisms. Channel morphology is assessed by the cross-sectional shape of the channel (i.e. deep/incised versus wide/flat). Erosion can degrade stream habitat by suspending fine sediments that can be washed downstream. The degree of stream bed erosion can be indicated by calculating entrenchment values. Pebble counts are useful to determine size distribution of the stream substrate. The particle size distribution indicates how habitable the stream bed is to aquatic organisms and fish. A survey of large woody debris and determination of pool to riffle ratio provides a measure of habitat availability to fish, organisms and other wildlife. These habitat components are can be used as indicators of stream health and can provide insight into the impacts from human development as well as focus potential recovery and restoration efforts.

2.3 Water Quality

Water quality can have a significant effect of biological diversity in streams. In 2007 the City of Shoreline began to collect stream data in order to utilize the Department of Ecology's Freshwater Monitoring Unit's WQI scoring matrix (Hallock 2002) to gauge the relative condition of City streams. Details of the WQI can be found in Appendix A. Collected water quality data is entered into the matrix and a "score" is determined by comparing individual stream data to state water quality standards (Appendix B) and expected conditions in a given Ecoregion (Omernik and Gallant 1986). The WQI yields an imperfect answer to non-technical questions about water quality. By design, this approach indicates how well water quality at a station meets expectations, not how good the absolute quality is. However, the parameters are compared to state water quality standards and those standards are designed to indicate the necessary conditions to support beneficial uses, which include the support of biological organisms. The WQI summarizes water quality data in an easily expressible and easily understood format and can help political decision-makers, non-technical water managers, and the general public understand the overall water quality at a glance.

3 STUDY AREA DESCRIPTIONS

3.1 Thornton Creek

3.1.1 Geology

The Thornton Creek watershed within the City of Shoreline drains approximately 2,418 acres and is located in the southeast quarter of the City of Shoreline (Figure 2). Interstate 5 traverses the full length of the watershed in north to south orientation. The geology of the watershed is predominantly Vashon Till with Esperance Sands along the northern half of the I-5 corridor and extending west into upper Littles Creek, a tributary to Thornton Creek. A more detailed description can be found in basin characterization report (Tetra Tech/KCM 2004a). The till acts as impermeable layer and can create wetlands where it is covered by shallow soils in depression areas. Several of these wetlands were bogs of peat soils. Bogs form when inflow of water is derived primarily through precipitation or ground water as opposed to surface water sources. This produces low nutrient waters that create habitat for select vegetation which is slow to decompose when it dies. The slow decomposition allows for accumulation of peat. The bog areas were commercially mined for peat and/or heavily modified such that they no longer retain the hydrologic regime that formed them. The peat soils remain but the bog vegetation community is gone.

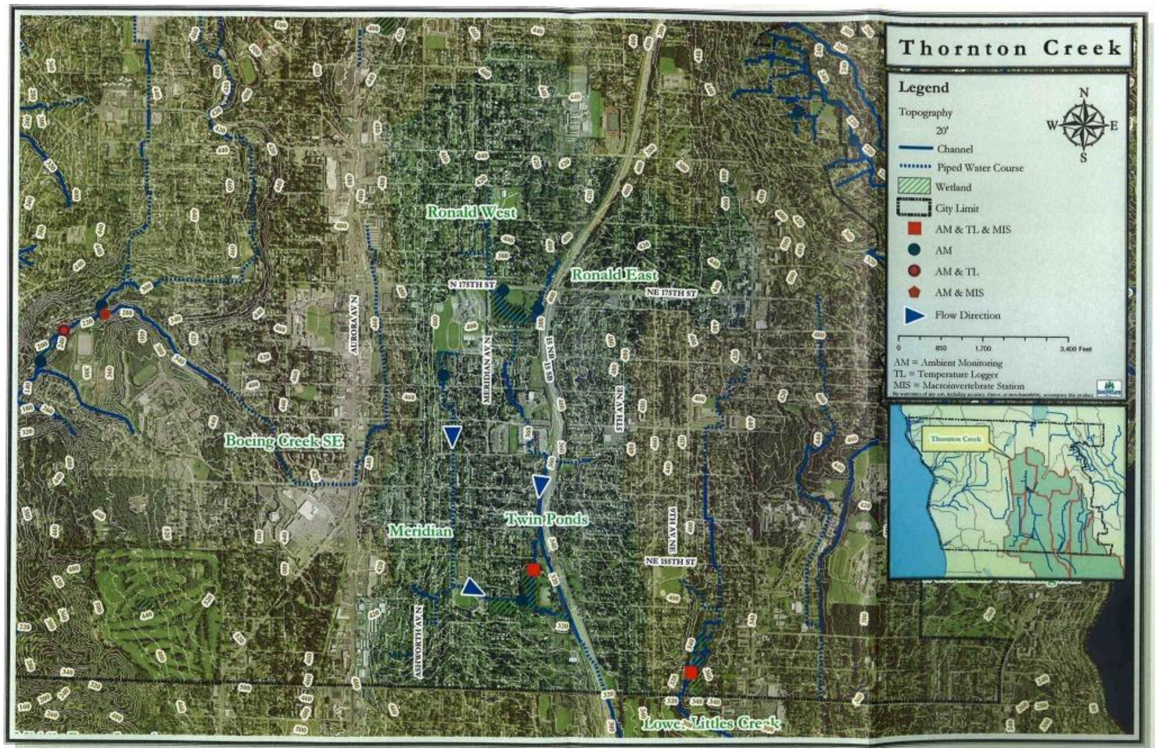

Figure 2. Thornton Creek basin

3.1.2 Land Use

Urban development and automobile transportation infrastructure are the dominant land uses in the watershed. The level of impervious surfaces in the watershed is currently at 44% (Table 1) with future build out projected at 55% (Tetra Tech/KCM 2004a). Conditions of the riparian zone are highly fragmented with a lack of high quality habitat. The largest continuous areas of high quality riparian habitat are located within city parks (Tetra Tech/KCM inc. 2004a).

Table 1. City of Shoreline Watershed Characteristics.

	Watershed Characteristics					Stream Characteristics		
Stream	Size (acres)	Impervious (%)	Roads (mi/mi^2)	Lakes/ Ponds (acres)	Wetland (%)	Piped (%)	Artificial Channel (%)	Natural Channel (%)
Thornton Creek	1,172	44	27.3	11.7*	9.7 acres (1%)	63	19	18
McAleer Creek	4,018	46	18.6	114.9**	23.4 acres (1%)	46	28	26
Boeing Creek	1,753	44	20.2	1.4	0.5 acres (.003 %)	63	11	26
Storm Creek	474	36	19.0	0	3 acres (.01%)	29	25	46

*Ronald Bog is 7.7 acres and Twin Ponds is 4 acres.

**Echo Lake is 13 acres and Lake Ballinger is 101.4 acres.

3.1.3 Landscape Stream Channel Condition

The stream channel has been highly impacted by urban development. Relative to all streams in the city, Thornton Creek contains the least amount of natural channel. Nearly 63% is found within a pipe, while 18% is considered as a natural channel (Table 1). Two large wetlands exist with a combined open water component of 11.7 acres. These wetlands, Ronald Bog and Twin Ponds, originated as peat bogs. They were commercially mined beginning in approximately the 1940s and then allowed to go fallow. Each is now within a City Park and functions a shadow bog. Shadow bogs are systems that have been modified to the extent that their hydrology and vegetation community no longer causes the formation of peat, but peat soils still dominant the wetland soils. Thornton Creek flows freely into both and no bog vegetation has been noted. Peat soils still exist at each location but to what extent the peat deposits remain is unknown.

3.2 McAleer Creek

3.2.1 Geology

McAleer Creek drains approximately 4,018 acres upstream of the monitoring station at 196th St NE (Figure 3). It has two distinct headwaters. One originates south of Echo Lake, within the City of Shoreline, and flows north out of Echo Lake and into Lake Ballinger. Several other streams, the largest being Halls Creek located on the north end of Lake Ballinger in Snohomish County, feed Lake Ballinger. McAleer Creek flows east out of Lake Ballinger through the Nile Golf course and then south back into the northeast section of City of Shoreline. The reach length contained within the City is 1,200 meters long whereupon it continues towards the south and eventually flows into Lake Washington within the City of Lake Forest Park. This watershed consists primarily of Esperance sands in the eastern portion and glacial till, hardpan, in the western half. The stream has eroded down through this layer exposing various geological deposits of glacial recessional outwash, and younger alluvium. A more detailed description of McAleer Creek's geology and soil formations can be found in the basin characterization report (Tetra Tech/KCM 2004b).

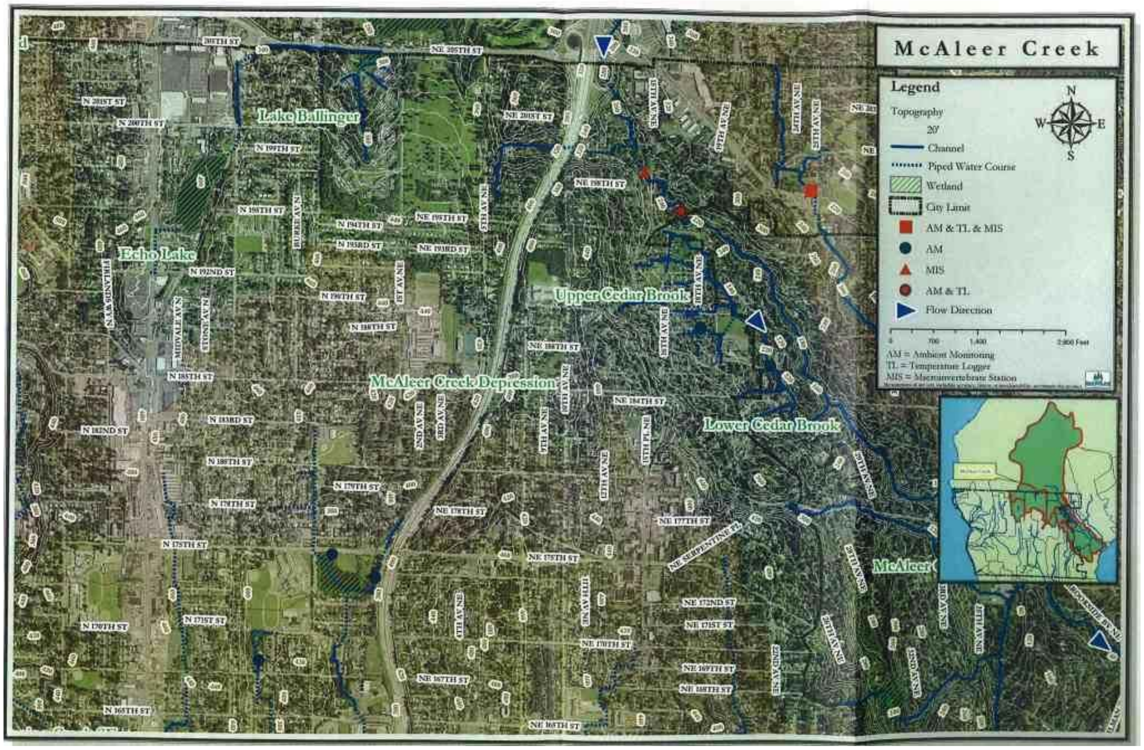

Figure 3. McAleer Creek basin

3.2.2 Land Use

Urban development dominates McAleer Creek's watershed within City of Shoreline. The level of impervious surfaces in the watershed is currently at 46% (Table 1). The northern part of Aurora Avenue, Ballinger Way, 205th, and part of Interstate 5 represent major urban modifications within the watershed. Future estimates of total impervious area (TIA) under planned build out is for 58% within the City of Shoreline. The quality of riparian habitat was assessed in the basin characterization report (Tetra Tech/KCM 2004b). While some high quality forested habitat exists within 50 feet along short reaches of McAleer Creek, the overall quality diminishes with distance from the stream. Some reaches of the stream lack high quality habitat within 50 feet due to existing single-family homes, apartments, and lawns.

3.2.3 Landscape Stream Channel Conditions

The main stem plus all contributing tributary stream channels have been heavily impacted by urban development. Natural stream channel accounts for 26% of the channel length within the city (Table 1). The length of channel buried in pipes is 46% with the remaining 28% as artificial channel. There is one dam located on the main stem of McAleer Creek at 196th NE. It is designed to alleviate peak flows by impounding stream flow during storm events. Stream flow is controlled by a sluice gate. Under normal flow circumstances, no water is impounded upstream of the dam. The entire main stem of McAleer Creek within the City of Shoreline up to I-5 is utilized by anadromous fish. Little is known about the anadromous use of the various tributaries. Other notable water features include the two lakes, Echo (13.5 acres) and Ballinger (101.4 acres). Both lakes are known for having peatland wetland systems (Kulser et al 2001 and Mike Shaw pers. comm. 2003).

3.3 Boeing Creek

3.3.1 Geology

The Boeing Creek watershed drains approximately 1,753 acres within the central portion of the City (Figure 4). The watershed is dominated by glacial till. Till is an impermeable layer formed by glacial compression of clay and fine sediment which is resistant to water infiltration. The till deposits surround the ravines and inner gorges. Till overlays the advanced outwash sand deposits which overlay transitional beds of lacustrine (lake) deposits of clays and sand. The erosive forces during high stream flows in Boeing Creek have exposed these different layers. The deepest deposit of lacustrine layer is within the deep ravines along the bluff to Puget Sound. The advanced outwash deposits occupy the upper reaches where erosion has not exposed the underlying layers of lacustrine deposits. The two underlayment zone deposits are highly prone to erosion. The till below ground can concentrate flow-producing springs. If the springs flow onto the erosive outwash and lacustrine deposits it can cause major erosion and failure of steep hill slopes. This is a primary force working on the lower reaches of Boeing Creek partially causing mass wasting of surficial soils and glacial outwash into the stream. A more detailed description of Boeing Creek’s watershed geology can be found in the basin characterization report (Tetra Tech/KCM 2004c).

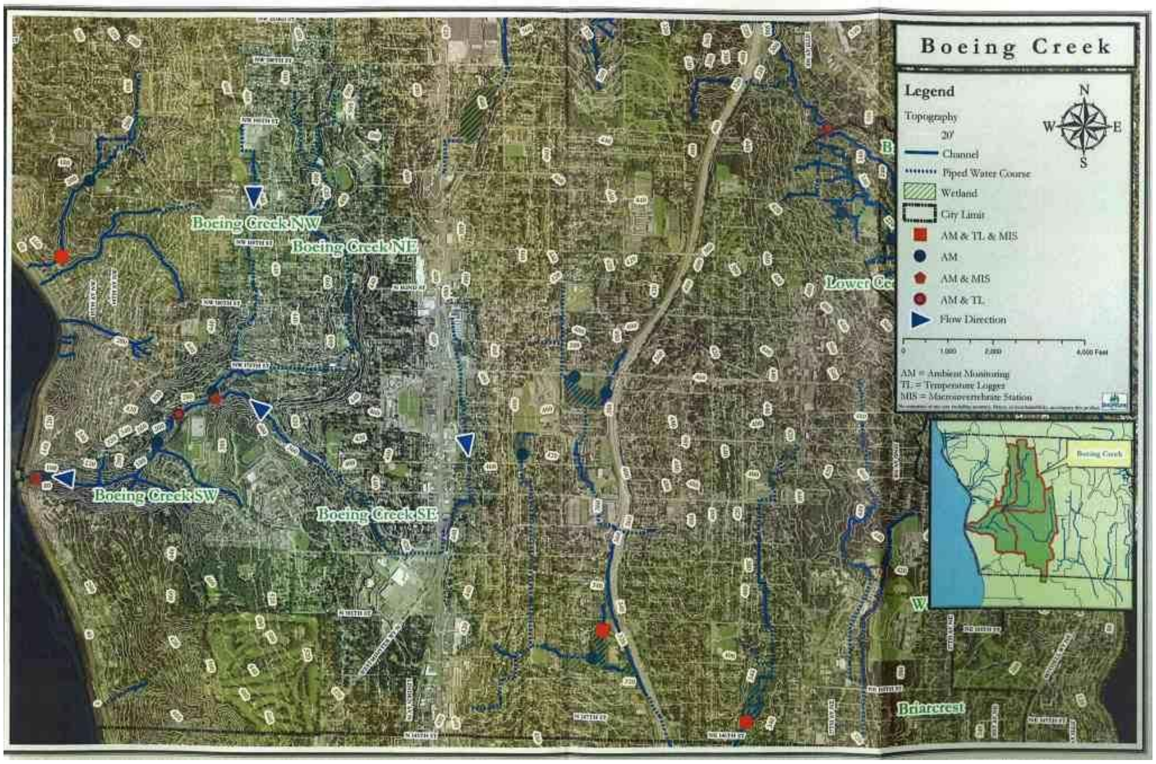

Figure 4. Boeing Creek basin

3.3.2 Land Use

Current land use is dominated by urban development. A more detailed account of current and future build out can be found in the basin characterization study (Tetra Tech/KCM 2004c). Over all, the level of impervious surface in the watershed is currently at 46% (Table 1). Future build out predicts an overall level of imperviousness at 57%. The health of the riparian zone declines as one moves up stream from the mouth to the more developed upper reaches of the stream. The lower stream reach is bounded by the steep unstable inner gorge with nearly 100% forested condition. This declines to 22% in the upper reaches. It should be noted that despite the forested component of the ravine it still delivers clays and sands from the active mass wasting and slumping of hill slopes. This can have a deleterious effect on the stream biota and channel morphology.

3.3.3 Landscape Stream Channel Condition

The entire length the stream channel has been highly impacted by urban development. Much of it has been buried in pipes or placed into artificial open channels. In all, just 26% of the stream remains as a natural channel (Table 1). Other modifications include four dams of varying proportions, functionality, and design. Only the first 701 meters of lower reach is accessible to anadromous use.

3.4 Storm Creek

3.4.1 Geology

A more detailed description of Storm Creek's watershed geology can be found in the basin characterization report (Tetra Tech/KCM 2004d) and is summarized here. Storm Creek is situated on the western edge of the Seattle drift plain, a rolling plateau that drops irregularly toward Puget Sound (Figure 5). The area is composed of glacial derived deposits of lacustrine clay-silt, proglacial sand and gravel, and till in the western edge of the drift plain. Till covers most of the plateau surface and older sediments are exposed along the coastal bluff. The lower reach of Storm Creek is eroding through these multi-layers beginning with the top layer of Esperence sand, down through the transitional beds and finally into the procession drift. The deposits other than till tend to be highly erosive. Given the water impermeable nature of till, infiltrating water tends to flow on top of the till lens and daylights down gradient along the bluff onto highly erosive deposits.

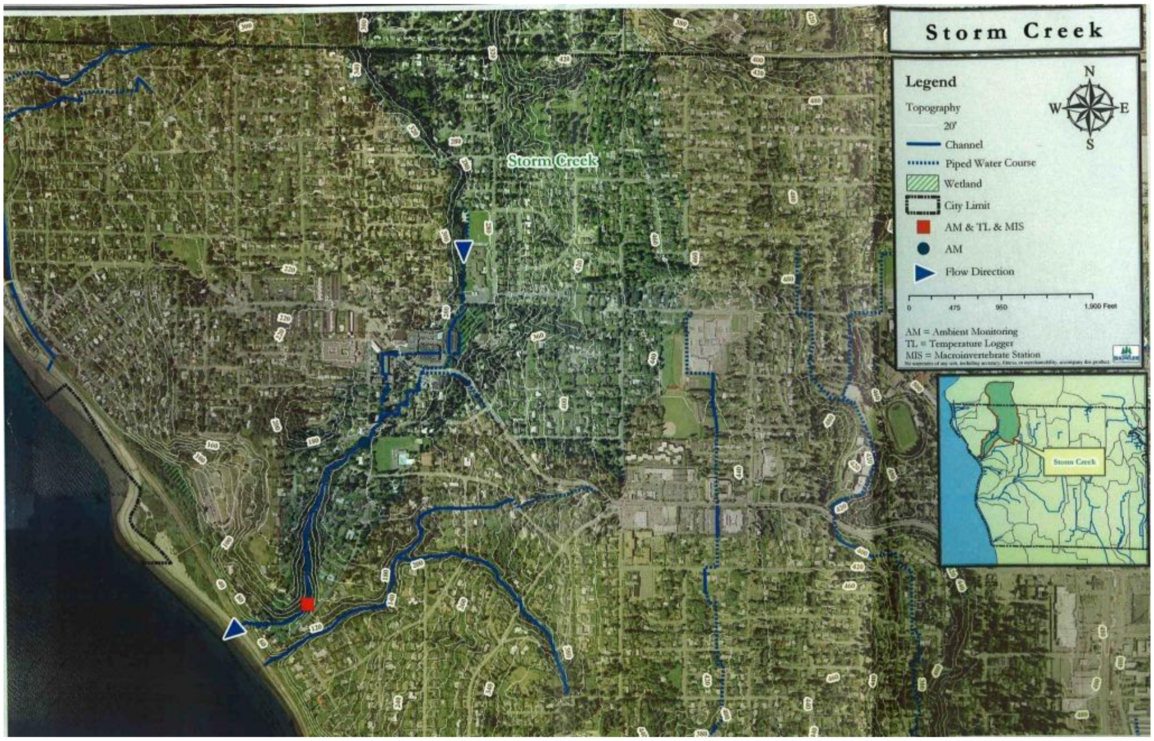

Figure 5. Storm Creek basin

3.4.2 Land Use

Current land use is dominated by urban development. A more detailed account can be found in the basin characterization report (Tetra Tech/KCM 2004d). Impervious surface levels for the watershed currently are estimated at 36%

(Table 1) with future build out predicted to result in an increase over current levels to total value of 57%. The amount and health of riparian corridor decreases as one moves inland from Puget Sound and as one moves perpendicular away from the stream as noted in Tetra Tech/KCM 2004d.

3.4.3 Landscape Stream Channel Condition

For the watershed draining to the lower downstream sampling station 42% of the stream exists in a natural channel condition (Table 1).

4 METHODS

This section describes the methods used for the following:

- Stream Segment and Sampling Station Selection
- Biological Integrity Indicators
- Physical Stream Indicators
- The Water Quality Index
- Quality Assurance and Quality Control of Collected Data

4.1 Stream Segment and Sampling Station Selection

This study focuses on four of the major drainage basins located within the City of Shoreline. This report summarizes data collected from Thornton Creek, McAleer Creek, Boeing Creek, and Storm Creek. These four basins drain approximately 80% of the City. These drainage basins were selected because most of the area west of Aurora Avenue drains into Puget Sound via Boeing and Storm Creeks, while most of the area east of Aurora drains to lake Washington through Thornton and McAleer Creeks. Although this report focuses on four of the City's largest drainage basins, additional data is also available for some smaller streams within the City (Loch 2003a). This report summarizes the conditions encountered for the time period between October 2001 and September 2007, spanning 6 water years.

Selection of individual stream sample locations was based on the representativeness of a particular basin or sub-basin and previous sampling. Five monitoring stations were selected for this study. Three of the stations selected were relatively close to the mouth of the basin stream network. Each of these three sample locations was representative of water quality throughout the basin since, with few exceptions, all creeks in the City of Shoreline are tributaries and contribute runoff that passes through these stations. An additional station on Boeing Creek was selected farther upstream to capture potential biological differences between the upper and lower basin. However, water quality data for

Boeing Creek was collected at the upper sampling station only. Physical stream characteristics varied between these two locations, which would affect the macroinvertebrate populations, but since the lower part of the Boeing Basin is less developed and would have less input from impervious surfaces, it is assumed that water quality data collected at the lower monitoring station would be similar to that collected at the upper station. Only the upper portion of the Thornton Creek basin is located within the City of Shoreline. The headwaters of Thornton Creek originate in Shoreline and contribute to the downstream water quality of Thornton Creek. The station for Thornton Creek is located along a middle branch of the Thornton Creek headwater tributaries. The land use surrounding the other two headwater tributaries is similar; therefore the monitoring station selected is representative of the health of the Thornton Creek headwaters. Stations were screened for the presence of an adequate channel length for physical and biological surveys. Stream length needed to have approximately 40 channel widths of open channel. Figure 1 shows the location of sampling stations highlighted in pink.

Thornton Creek Sample Location

One site (TH-1) was selected for monthly chemical and physical (ambient) monitoring. The site is located about 30 feet upstream of the Thornton Creek confluence with Twin Ponds (Figure 1). This location also served as the bioassessment and habitat survey reach.

McAleer Creek Sample Location

One site (MC-1) was selected for monthly chemical and physical (ambient) monitoring. The site is located upstream of 196th crossing just above the trash rack (Figure 1). This location also served as the bioassessment and habitat survey reach.

Boeing Creek Sample Location

One site (BC-2) was selected for monthly chemical and physical (ambient) monitoring. The site is located downstream of the North Pond dam confluence on the left bank fork about 30 feet upstream of the right bank fork (Figure 1). This location also served as the bioassessment and habitat survey reach. A second site (BC-4 [Mouth]) was selected for a bioassessment and habit survey reach. The site is located Upstream of footbridge along the left bank (Figure 1).

Storm Creek Sample Location

One site (ST-1) was selected for monthly chemical and physical (ambient) monitoring. The site is located 100 feet upstream of 17th Pl. NW with cross street 16th Ave NW (Figure 1). This location also served as the bioassessment and habitat survey reach.

4.2 Biological Integrity Indicators

Biological integrity assessed though macroinvertebrate sampling follows the methods of Loch (2000). In summary, each stream has a reach delineated that is at least 40 channel widths in length. Each reach is walked along the bank to flag four representative riffles. Beginning in an upstream direction each riffle is sampled using a Surber sampler. Surber samplers have a 1 square foot grid frame with an attached net to collect macroinvertebrates. The Surber is equipped with 500-micron mesh net. The Surber is placed on the stream substrate. Rocks are hand scrubbed in a manner to remove macroinvertebrates into the Surber. All rocks large enough to be hand scrubbed are completed and removed from sample grid and the sediment is agitated to a depth of 10cm. Once completed, a check is made of the inside perimeter of the frame for organisms. These organisms are then washed into the net end of the Surber. The Surber is then removed from the stream and the sample is placed into a 2000-ml polycarbonate container. Care is taken to gently concentrate the sample material into the container. Ethyl alcohol (80%) is added to the polycarbonate container to preserve the sample. After all streams were sampled the collection was sent off to an independent lab for a 500-count, identification, and analysis. In 2007, macroinvertebrate samples were sent to Rhithron Associates, Inc. (Missoula, MT) for identification and analysis.

The results are scored using Biotic Index of Biological Integrity (B-IBI) metrics (Fore 1999). The individual metrics upon which the B-IBI score is built is assessed for each stream. Using the collected data, a level of impairment is assigned, adapted from Loch (2001) and Morley (2000). Generally the lower the B-IBI score, the greater impairment of the stream. The B-IBI scores from each stream are compared to the scores below (Table 2) to determine the level of impairment for that stream.

Table 2: Benthic Index of Biotic Integrity (B-IBI Scores)

B-IBI Score	Level of Biological Impairment
≥ 10 to ≤ 19	Extreme
≥ 20 to ≤ 27	Severe
≥ 28 to ≤ 34	Moderate
≥ 35 to ≤ 42	Slight
≥ 43 to ≤ 50	None

4.3 Physical Stream Habitat Indicators

As mentioned previously, a number of physical stream habitat parameters were recorded from a single sample reach in each of the streams in 2007, with the exception of Boeing Creek, which had two sample reaches. Each sample reach measured approximately 40 channel widths in length (Table 3). These representative sample reaches were located in the same general stream location as the reaches that were measured in 2003, but did not correspond exactly with the previously surveyed areas. A summary of the physical habitat parameters and a description of how they were collected is provided below.

4.3.1 Channel Morphology & Canopy Closure

Within each sample reach, four representative stations (typically in riffle areas) were selected for channel cross-section and canopy closure measurements, which were conducted using the TFW protocol for Reference Point Surveys (Pleus and Schuett-Hames 1998). These four stations were also used as macroinvertebrate collection points. Bankfull width was measured by extending a tape horizontally across the stream channel perpendicular to the flow. The tape was then leveled and bankfull depth measurements were recorded at ten equidistant locations across the channel using a stadia rod. The "bankfull" location at the right bank and left bank of each channel cross-section was identified using a combination of three indicators: 1) floodplain, 2) bank morphology, and 3) vegetation (Dunne and Leopold 1978).

Two ratios were assessed to determine channel characteristics. Ratios were generated for bankfull width (BFW) to depth (D) and a wetted width (WW) to BFW. These two ratios provide a measure of how the channels are configured, indicating whether a channel may be narrow and deep (i.e. entrenched) or wide and shallow (i.e. slightly entrenched). Data was assessed using Rosgen (1994) findings that BFW/D ratio of less than 12 are highly entrenched, ratios between 12 and 40 are moderately entrenched and a BFW/D greater than 40 as slightly entrenched. To assess how low flows occupy the bankfull channel Plotnikoff and Ehinger (1997) suggest assessing the WW/BFW ratio expressed as a percentage. Streams with WW/BFW greater than 40% indicate wetted widths approaching the entire bankfull channel. Measures of WW/BFW less than 40% indicate wetted width occupying a narrower portion of the channel.

Canopy cover was measured at each stream by taking hand-held densiometer readings at the four cross-section locations in each sample reach following the procedures described in Pleus and Schuett-Hames (1998). Measurements were conducted in late summer when leaves were mature and riparian foliage was fullest. At each cross-section station, densiometer readings were recorded from four distinct views; upstream, downstream, left bank, and right bank. The four canopy measures at each station, and within each survey reach, are then averaged for an estimate of the percent canopy closure.

4.3.2 Pebble Counts and Particle Size distribution of Stream Substrate

Assessment of substrate particle size distribution used pebble counts conducted at the four cross-section locations within each sample reach. Pebble counts at each cross-section were conducted using protocols described in the Timber Fish and Wildlife (TFW) salmon spawning gravel scour survey (Schuett-Hames et al. 1999a). Briefly, a measuring tape was placed perpendicular to stream flow at each cross-section station and 50 pebbles were selected randomly from within the bankfull width, measured, and recorded by size class (Wolman 1954). Pebble counts were conducted at four cross-section stations per stream reach and combined as one 200-pebble count for data analysis. The categorical size class values are expressed as percent cumulative frequency and by D50 and D84 values. For example, a D50 value of 5 shows that 50% of the substrate was 5 mm or smaller. A D84 value of 19 means that 84% of the substrate was 19 mm or smaller. D50 values are useful to determine size distribution of small substrate whereas D84 values depict composition of large substrate.

4.3.3 Large Woody Debris

Overall abundance, size distribution, and location of all large wood and rootwads in the sample reach of each stream were recorded using the protocol outlined in the TFW large woody debris survey (Schuett-Hames et al. 1999b). All pieces of wood measuring 2 meters or greater in length with at least 0.1 meter of length extending into the bankfull channel were counted. Qualifying pieces of wood were subsequently stratified into three size classes based on their diameter, and rootwads were counted separately. Diameter size classes were from 10 to 19 cm, 20 to 49 cm, greater than 50 cm, and rootwads with a minimum diameter of 20cm where the bole meets the root collar. The location of the wood was recorded as zone one, within the wetted channel, or zone two, within the bankfull width.

4.3.4 Pool and Riffles

Stream habitat was quantified using the Habitat Unit Survey protocol (Pleus et al. 1999) established by the Northwest Indian Fishery Commission Timber Fish and Wildlife Monitoring Program (TFW). Briefly, stream habitat is categorized into two primary types, riffles and pools, and individual habitat units (riffles and pools) are measured for total length and average width. Surveys were conducted in the late summer/early fall when stream flows were low and stable, and a combination of hydrologic and geomorphic indicators were used to differentiate between pools and riffles (Pleus et al. 1999). Pools are further characterized based on the forming process and riffles based on gradient. Although riffle depths area not measured, the maximum depth of each pool and the depth of each pool tail crest (tail-out) are recorded and used to calculate the Residual Pool Depth (RPD).

4.4 The Water Quality Index

To utilize the WQI matrix, water quality parameters need to be collected and that data needs to be entered into the matrix spreadsheet to obtain a score. The parameters used in the WQI matrix are fecal coliform, total phosphorous, total nitrogen, total suspended solids, dissolved oxygen, pH, temperature, and turbidity. After collected data is entered into the matrix a "score" is determined by comparing individual stream data to water quality standards (Appendix B) and expected conditions in a given Ecoregion (Omernik and Gallant, 1986). The WQI score yielded by the matrix is a unitless number ranging from 1 to 100; a higher number is indicative of better water quality. Stations scoring 80 and above met expectations for water quality and are of "lowest concern" or the least impaired. Scores 40 to 80 indicate "marginal concern" or moderate impairment. Scores below 40 indicate that the stream "did not meet expectations" and are of "highest concern." After water quality data is entered into the matrix spreadsheet and a score is obtained, the score is compared to this scale to determine the general water quality of the stream.

All water quality parameters were collected once a month, year-round, by City staff. Readings for dissolved oxygen, pH, turbidity and temperature were collected in-situ using various meters. Water samples were collected at each station, concurrent with in-situ monitoring activities, and sent to a laboratory for analysis to obtain the other measurements. The laboratory reported the results of the analysis to the City. The water quality data was then entered into the matrix spreadsheet for automated calculation of the WQI score. WQI parameters for this reporting period were collected from January 2007 through December 2007. Ideally, the parameters used for WQI matrix calculations would be for a complete water year, October of a given year through September of the following year, but because this additional sampling began in January 2007 samples were not collected for the complete water year. Any future WQI scores reported will be based on the water year.

The WQI matrix compares entered data to expected water quality conditions for the region to calculate an overall score for each stream. For temperature, pH, fecal coliform bacteria and dissolved oxygen, the data entered is compared to water quality parameter levels required to maintain beneficial uses according to criteria specified in the state water quality standards (Appendix B). For nutrient and sediment measures, where standards are not specific, data entered is compared to expected conditions in a given Ecoregion (Omernik and Gallant 1986). Multiple constituents are combined and results aggregated over time to produce a single score for each sample station. Further details about the WQI can be found on the Department of Ecology Website and the spreadsheet developed for WQI calculations can be accessed through the same site (http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html).

4.4.1 Dissolved Oxygen and temperature

Measurements were collected using a YSI 85 multi meter. The meter probe was inserted into the water column and the readings are displayed electronically on the meter screen. The measurement was recorded when the number on the screen stabilized. Dissolved oxygen measurements were recorded in milligrams per liter (mg/L). Temperature was recorded in degrees Celsius.

4.4.2 pH

A YSI pH 100 meter was used for pH measurements. The meter probe was inserted into the water column and the readings are displayed electronically on the meter screen. The measurement was recorded when the number on the screen stabilized.. Results were recorded in pH units.

4.4.3 Turbidity

An Orber-Hellige portable turbidity meter Model 966 was used to collect turbidity readings. A sample of water was collected in a clear, glass vial. That vial is inserted into the meter, a cap is placed on top and a button is depressed to obtain the reading. Results are recorded in Nephelometric Turbidity Units (NTU).

4.4.4 Water Samples

Water samples were collected at each station using grab-sample techniques. Grab samples are water samples that are collected at one discreet moment in time from one discreet location. Sample containers were submerged below the stream surface, filled to within one inch of the container opening and then capped. Collected samples were then delivered to a laboratory for analysis. The laboratory analysis results were reported to City staff by the laboratory.

4.5 Quality Assurance and Quality Control of Collected Data

The assessment of physical and biological parameters was conducted by a fisheries biologist. No method was employed to determine the precision of the professional's ability to delineate and measure habitat and physical features. It is assumed that if sites were sampled for repeatability by other trained professionals those differences would be less than 10%. An independent laboratory performed the counting and identification of macroinvertebrates collected. No replicate samples were collected of macroinvertebrate samples. The laboratory conducts an internal QA/QC program. Lab staff assessed their ability to identify, count, and sort the macroinvertebrates. Results that differed more than 10% were to be rejected from further analysis.

The collection of water quality parameters was performed by the City Water Quality Specialist. To ensure the accuracy and precision of water quality data collected, all meters were calibrated at a minimum of once per month. Manufacturing suggestions were utilized for the calibration. All data collected in the field was recorded on-site in a field log book and transferred to an Excel database in the office.

Water samples that were collected were put on ice and delivered to the King County Environmental Lab within six hours of collection. Standard chain-of-custody procedures were followed. The King County Environmental Laboratory conducts an internal QA/QC program.

5 RESULTS

5.1 Biological Parameters - Macroinvertebrates

Figure 6 compares the total scores for the B-IBI among all five sites sampled in 2007, and also cites the B-IBI scores that were reported for these same sites in 2003. The B-IBI did not appear to differentiate sites well in 2007, and low scores characterized all five sites. Condition classification based on level of biological impairment (Table 2) for all five sites is "Extreme" in 2007.

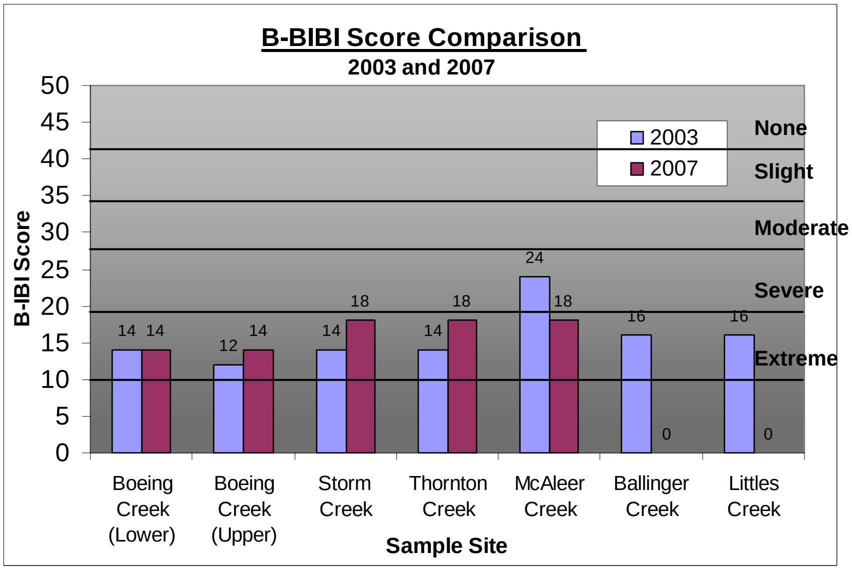

Figure 6. B-IBI Scores for sample sites in City of Shoreline streams in 2003 and 2007. Ballinger Creek and Littles Creek were not sampled in 2007.

5.1.1 Thornton Creek

As in 2003, an extreme level of biological impairment characterized the Thornton Creek site in 2007. *Tubellaria* and *Crangonyx* were the dominant species in the sample (42% and 37% respectively), and the three most abundant taxa comprised 90% of the taxa present (Figure 7 and Table 3). Turbellarians are generally detritivores, feeding on dead particulate organic material or feeding on small living invertebrates, and are often associated with eutrophic bodies of water where detritus and decaying animal matter is abundant. Scuds (*Crangonyx sp.)* are detritivorous crustaceans that often occur in small acidic lakes and other lentic boggy areas. At 1.4% of the sample mayflies were marginally represented, and then only by *Baetis tricaudatus*, indicating the possibility of nutrient enrichment or organic pollution at this site.

"Clinger" richness was zero and caddisflies (*Trichoptera*) were not present in Thornton Creek, suggesting that sediment deposition limited access to stony substrate habitats. Stoneflies (*Plecoptera*) were absent, and this group may have been eliminated by poor water quality or habitat disruption. Overall taxa richness was very low, and only 11 taxa were collected here. Low numbers of long-lived taxa were present in the sample, suggesting that catastrophic events such as dewatering may periodically interrupt long life cycles. Potential sources contributing to the degraded biota conditions are likely to include polluted water quality, loss of in-stream habitat, elevated stream temperatures, low dissolved oxygen, and high fine sediment concentrations.

Thornton Creek

Category	Count	Percent
Non-insect taxa	494	98.8
Odonata		0.0
Ephemeroptera	7	1.4
Plecoptera		0.0
Heteroptera		0.0
Megaloptera		0.0
Trichoptera		0.0
Lepidoptera		0.0
Coleoptera		0.0
Diptera	2	0.4
Chironomidae	4	0.8

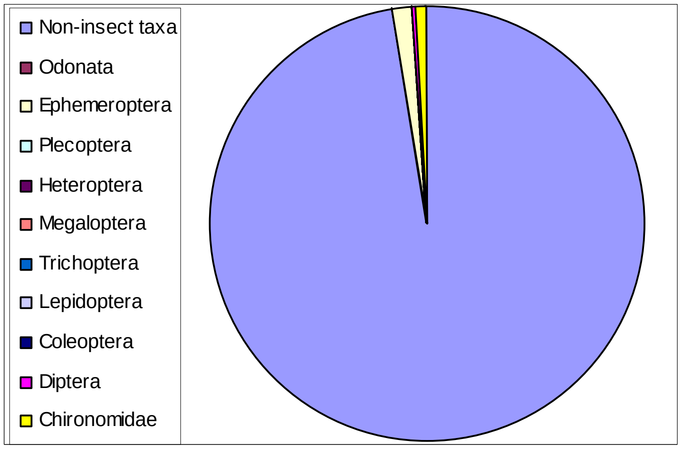

Figure 7. Taxonomic composition of the Thornton Creek Macroinvertebrate sample.

Table 3. Dominant macroinvertebrate taxa in Thornton Creek.

Thornton Creek	
Category	**Percent Abundance**
Turbellaria	41.8
Cranqonyx	36.9
Oligochaeta	15.8
Sphaeriidae	2.0
Baetis tricaudatus	1.4
Caecidotea	0.6
Brillia	0.6
Acari	0.4
Micropsectra	0.2
Dixella	0.2
Dicranota	0.2

5.1.2 McAleer Creek

Low mayfly taxa richness characterized McAleer Creek, and *Baetis tricaudatus* (10% of the sample) was the single mayfly taxon represented (Figure 8). *Simulium* sp. was the dominant taxon at 22%, followed by Cranoqonyx (18%) and Caecidotea (13%) (Table 4). This assemblage is similar to that observed in 2003, and suggests that nutrient enrichment or organic pollution continue to influence the biota at this site.

Clinger richness (7) was high relative to the other 4 streams sampled in 2007, indicating lower fine sediment loading which allows the clinger taxa to escape predators and high flows by crawling down into coarse substrate free of fine sediment. Stoneflies, however, were not well represented, and this group may have been limited by poor water quality or habitat disruption. The functional composition of the assemblage was strongly skewed toward filterers (especially *Simulium* sp.) and gatherers. This pattern is sometimes interpreted as evidence of poor water quality.

McAleer Creek		
Category	**Count**	**Percent**
Non-insect taxa	202	40.4
Odonata		0.0
Ephemeroptera	57	11.4
Plecoptera	4	0.8
Heteroptera		0.0
Megaloptera		0.0
Trichoptera	66	13.2
Lepidoptera		0.0
Coleoptera	1	0.2
Diptera	146	29.2
Chironomidae	73	14.6

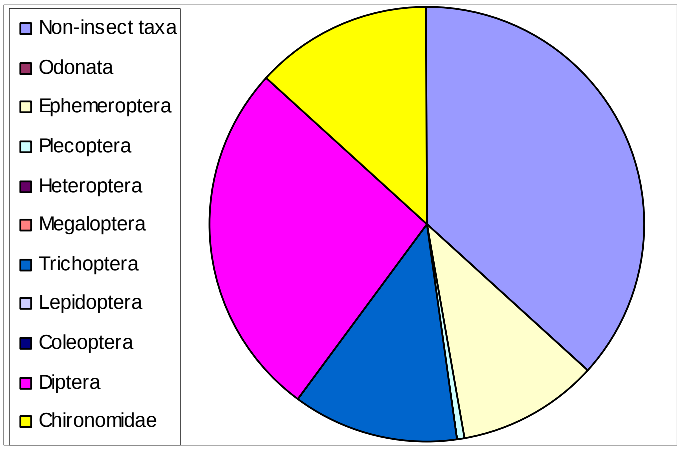

Figure 8. Taxonomic composition of the McAleer Creek Macroinvertebrate sample.

Table 4. Dominant macroinvertebrate taxa in McAleer Creek.

McAleer Creek	
Category	**Percent Abundance**
Similium	22.0
Cranqonyx	17.5
Caecidotea	13.3
Baetis tricaudatus	10.4
Micropsectra	8.6
Hydropsyche	7.8
Simuliidae	4.6
Oligochaeta	2.7
Glossosoma	2.0
Tvetenia Bavarica Gr.	1.6
Sphaeriidae	1.6
Parametriocnemus	0.9
Brillia	0.9
Pagastia	0.7
Hydropsyche	0.7

5.1.3 Lower Boeing Creek

Mayflies were represented by a single taxon at the lower Boeing Creek site; it was the ubiquitous and rather tolerant *Baetis tricaudatus* (Figure 9). Low mayfly richness (1) and moderately high biotic index value (5.49) strongly suggest that water quality was degraded by nutrient enrichment or organic pollution. The dominance of blackflies (*Simulium* sp.) supports this hypothesis (Table 5). Thermal preference for this assemblage was calculated as 14.6 degrees C.

Neither “clingers’ nor caddisflies were well-represented; low richness in these groups may be an indication of sediment deposition. Stoneflies appear to have been excluded by poor water quality. Invertebrate diversity was low (17 taxa) at this site, suggesting monotonous instream habitats; poor water quality may also have been influential in limiting taxa richness here. Periodic dewatering, thermal extremes, toxic inputs, or scouring sediment pulses cannot be ruled out, since the site supported only a single long-lived taxon. The functional composition of the assemblage was strongly skewed toward filterers (especially *Simulium* sp.) and gatherers. This pattern is sometimes interpreted as evidence of poor water quality.

Lower Boeing Creek

Category	Count	Percent Total
Non-insect taxa	32	6.4
Odonata		0.0
Ephemeroptera	113	22.6
Plecoptera		0.0
Heteroptera		0.0
Megaloptera		0.0
Trichoptera	11	2.2
Lepidoptera		0.0
Coleoptera		0.0
Diptera	297	59.4
Chironomidae	47	9.4

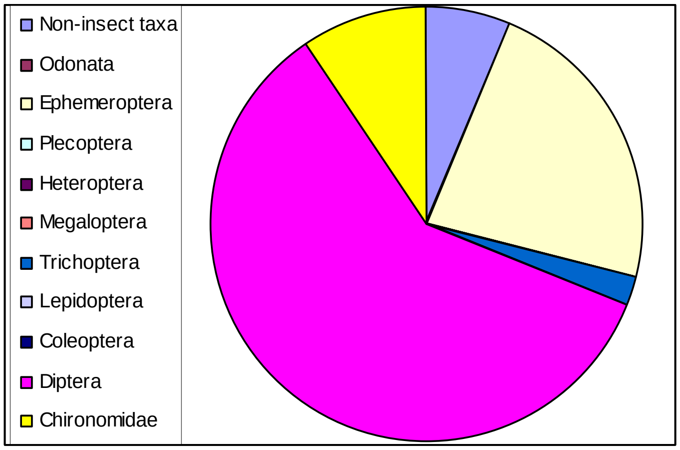

Figure 9. Taxonomic composition of the Lower Boeing Creek Macroinvertebrate sample.

Table 5. Dominant macroinvertebrate taxa in Lower Boeing Creek.

Lower Boeing Creek	
Category	**Percent Abundance**
Simulium	43.8
Baetis tricaudatus	22.6
Simuliidae	14.8
Eukiefferiella Claripennis Gr.	6.6
Turbellaria	3.2
Parapsyche elsis	2.2
Tvetenia Bavarica Gr.	1.6
Oligochaeta	1.2
Cranqonyx	1
Dicranota	0.6
Acari	0.6
Thienemannimyia Gr.	0.4
Prheocricotopus	0.4
Pagastia	0.2
Nematoda	0.2

5.1.4 Upper Boeing Creek

The Benthic macroinvertebrate community at upper Boeing Creek differed from the lower Boeing Creek site in relative abundance of species as well as overall abundance of insects, as the sample fell short of 500 individuals, and only 243 were counted (Figure 10). Mayflies (*Baetis tricaudatus)* were the dominant taxon (63.8% of the entire sample) at the Upper Boeing Creek Site, followed by *Oligochaetes* (15%) (Table 6). However, mayfly richness was low and *tricaudatus* is considered a tolerant species, indicating that water quality in upper Boeing Creek is likely degraded by nutrient enrichment or organic pollution. The relatively strong presence of aquatic worms (Oligochaetes) acts as a secondary indicator of organic pollution and/or periods of low dissolved oxygen.

Richness for both "clingers" and caddisflies (*Trichoptera*) was low and no stonefly species were present, indicating deposition of fine sediments and limited access to larger cobble and gravel substrates. Similar to the lower Boeing Creek site, taxa richness was low (15) at upper Boeing Creek, suggesting homogenous instream habitat and poor water quality. Locally catastrophic events such as dewatering, thermal extremes, toxic inputs, or severe sediment scour are likely to occur periodically in this reach of upper Boeing Creek, as very few long-lived taxa were observed in the sample.

Upper Boeing Creek		
Category	Count	Percent Total
Non-insect taxa	71	14.2
Odonata		0.0
Ephemeroptera	155	31.0
Plecoptera		0.0
Heteroptera		0.0
Megaloptera		0.0
Trichoptera	1	0.2
Lepidoptera		0.0
Coleoptera		0.0
Diptera	6	1.2
Chironomidae	10	2.0

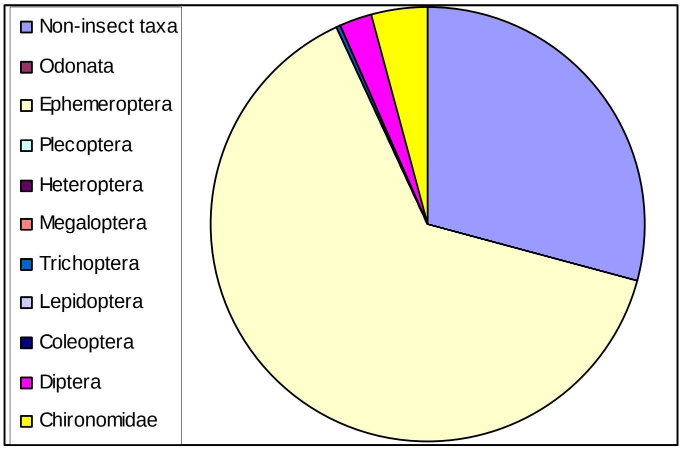

Figure 10. Taxonomic composition of the Upper Boeing Creek Macroinvertebrate sample.

Table 6. Dominant macroinvertebrate taxa in Upper Boeing Creek.

Upper Boeing Creek	
Category	**Percent Abundance**
Baetis tricaudatus	63.8
Oligochaeta	15.2
Nematoda	8.6
Acari	4.1
Pagastia	2.1
Simulium	1.7
Turbellaria	0.8
Brillia	0.8
Tipulidae	0.4
Prodiamesa	0.4
Molophilus	0.4
Eukiefferiella Claripennis Gr.	0.4
Dicosmoecus qilvipes	0.4
Chaetocladius	0.4
Amphipoda	0.4

5.1.5 Storm Creek

Low mayfly taxa richness also characterized the Storm Creek site (Figure 11). Once again, *Baetis tricaudatus* was the single mayfly taxon represented (Table 7). The taxonomic composition of this sample was very similar to the fauna at the lower Boeing Creek site. Metric indicators of water quality suggest that nutrient enrichment or organic pollution may have influenced the biota at this site. *Simulium* sp. was the dominant taxon. Thermal preference for the sampled assemblage was calculated as 13.1 degrees C.

"Clinger" richness and caddisfly (*Trichoptera*) richness were both low, suggesting that sediment deposition limited access to stony substrate habitats. Stoneflies were not well represented; this group may have been limited by poor water quality or habitat disruption. Overall taxa richness was very low; only 13 taxa were collected here. Low long-lived taxa were present in the sample, suggesting that catastrophic events such as dewatering may periodically interrupt long life cycles. The functional composition of this assemblage was dominated by filterers and gatherers, in a similar pattern to that noted for the lower Boeing Creek fauna.

Storm Creek

Category	Count	Percent
Non-insect taxa	163	32.6
Odonata		0.0
Ephemeroptera	49	9.8
Plecoptera	1	0.2
Heteroptera		0.0
Megaloptera		0.0
Trichoptera	1	0.2
Lepidoptera		0.0
Coleoptera	1	0.2
Diptera	284	56.8
Chironomidae	4	0.8

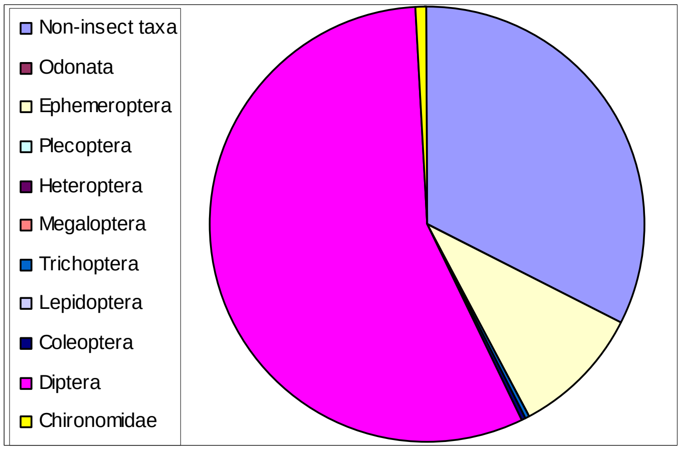

Figure 11. Taxonomic composition of the Storm Creek Macroinvertebrate sample.

Table 7. Dominant macroinvertebrate taxa in Storm Creek.

Storm Creek	
Category	**Percent Abundance**
Similium	52.7
Turbellaria	24.1
Baetis tricaudatus	9.7
Cranqonyx	6.8
Simuliidae	2.8
Oligochaeta	1.0
Tvetenia Bavarica Gr.	0.6
Dixa	0.6
Acari	0.6
Tipula	0.4
Parapsyche elsis	0.2
Malenka	0.2
Lara	0.2
Eukiefferiella	0.2

5.2 Physical Parameters

Physical parameters measured during 2007 and comparable data from 2003 are reported in Tables 3 through 5 and discussed in the following sub-sections. Physical measurements of sample reach conditions, such as bankfull width and residual pool depth, are reported in Table 8. Large woody debris counts, including the identification of wood size and type, are reported in Table 9. The physical parameters in Table 3 along with other measurements, such as pebble counts and stream gradients, are then used to report stream channel morphology characteristics in Table 10.

Table 8. Stream habitat parameters observed in each of the sample reaches.

Stream	Sample Reach Length (ft)	Wetted Width (ft)	Bankfull Width (ft)	Bankfull Depth (ft)	Residual Pool Depth (RPD)	Pool Area (%)	Large Wood (# Pieces /100M)		Canopy Closure (%)
							Zone 1	Zone 2	
Thornton Creek	227	3.2	7.0	0.9	0.5	49.4	10	9	73
McAleer Creek	503	11.8	16.7	0.9	1.0	48.1	13	12	66
Boeing Creek (Lower)	708	8.9	15.1	0.8	1.0	23.3	19	7	84
Boeing Creek (Upper)	561	8.9	18.9	0.5	0.7	12.2	26	27	79
Storm Creek	**291**	3.2	11.5	0.8	0.4	23.8	6	15	90

Table 9. Stream habitat large wood survey results, 2003 and 2007.

Stream	Rootwad				Small Log				Medium Log				Large Log				# Pieces/100M			
	Zone 1		Zone 2		Zone 1		Zone 2		Zone 1		Zone 2		Zone 1		Zone 2		Zone 1		Zone 2	
	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007
Thornton Creek	0	2	0	1	0	1	2	2	0	3	0	3	0	1	0	0	0	10	3	9
McAleer Creek	0	3	0	0	9	5	4	5	7	12	7	6	0	0	0	0	17	13	12	12
Boeing Creek (Lower)	3	8	2	2	13	13	17	5	31	12	18	8	13	9	4	0	30	19	20	7
Boeing Creek (Upper)	0	5	0	1	13	22	9	4	11	13	17	9	3	4	2	12	28	26	29	27
Storm Creek	0	1	0	2	7	2	8	5	6	2	12	4	3	0	0	2	18	6	23	15

Table 10. A comparison of stream channel morphology and canopy closure characteristics between 2003 and 2007.

Stream Name	Overall Stream Channel Conditions					Stream Morphology						Substrate Size				% Canopy Closure	
	Reach Length (feet)		% Grade	Channel Entrenchment		BFW/ Depth		WW/ BFW		RPD (Residual Pool Depth) (Feet)		D_{50} (mm)		D_{84} (mm)			
	2003	2007		2003	2007	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007	2003	2007
Thornton Creek	219	227	2.2	High	High	5	9	0.5	0.6	0.6	0.5	5	11	19	45	91	73
McAleer Creek	313	503	1.3	Mod.	Mod.	15	21	0.8	0.8	0.8	1.0	20	11	42	32	75	66
Boeing Creek (Lower)	665	708	1.3	Mod.	Mod.	16	20	0.6	0.6	0.7	1.0	11	16	28	45	97	84
Boeing Creek (Upper)	320	561	2.5	Mod.	Mod.	22	39	0.6	0.5	0.4	0.7	14	22	45	45	87	79
Storm Creek	286	291	3.7	Mod.	Mod.	13	17	0.4	0.5	0.4	0.4	15	22	42	64	93	90

5.2.1 Thornton Creek

Sample Location

One site (TH-1) was selected for monthly chemical, physical (ambient), and biological (B-IBI) monitoring (Figure 1). The sample reach is located about 30 feet upstream of the Thornton Creek confluence with Twin Ponds, and extend upstream to the culvert beneath NE 155th St. This area is located in the upper portion of the Thornton Creek watershed, near its headwaters.

Stream Habitat

The 2007 Thornton Creek sample reach measured 227 feet in length, and extended from the trail crossing (just upstream from where Thornton Creek flows into Twin Ponds) upstream to the culvert beneath NE 155th St. This reach is located near the headwaters of Thornton Creek and the stream is relatively small here, with average wetted and bankfull widths of 3.2 feet and 7 feet, respectively (Table 8). Sample photos are shown in Figure 12. Discharge readings were difficult to record due to the small channel size and low water velocity, but was measured at 0.03 cfs (0.22 gps) and visually estimated at approximately 0.25 cfs on 9/31/07 (summer baseflow conditions). A stream habitat enhancement project, involving the addition of large wood, gravel/cobble substrate, and riparian plantings, has been implemented within the survey reach within the past five years.

Figure 12. Typical habitat photos in Thornton Creek, 2007.

Channel sinuosity is low in this segment of Thornton Creek and the stream runs a relatively straight course with few meanders. Percent pool area was relatively high (49%), but was affected by the stream restoration project, which used large rock and logs to create pool habitat. Many of the pools in this segment, however, were low-quality glide habitats. A total of six pool habitats were recorded in the Thornton Creek sample reach, with maximum and residual pool depths averaging 0.6 feet and 0.5 feet respectively. Though difficult to quantify, this reach of Thornton Creek is relatively entrenched, with low berms on either side of the channel. These berms likely help control flooding, as this stream likely receives high volumes of stormwater runoff periodically.

Large Wood

A moderate amount of large wood was observed in the survey reach of Thornton Creek in 2007, but all of this wood is a result of the stream restoration project, which involved the placement of logs in, and along the stream channel. Many of the logs rated as small or medium pieces (Table 9), but were large in relation to the stream channel dimensions in this reach of Thornton Creek. This is in contrast to the previous (2003) habitat assessment, which reported little or no large wood in this reach of Thornton Creek.

Based on the survey reach (Table 11), Thornton Creek generally has 9 pieces of large wood within the wetted channel (Zone 1) and 8 pieces of large wood within the bankfull channel (Zone 2). Because a restoration project occurred here, these conditions may not be representative of other portions of Thornton Creek. Many of the logs and rootwads observed in 2007 were functional pieces, often contributing to pool formation, overhead cover, or bank stabilization. Riparian vegetation in this reach generally consists of small, young shrub species with few large trees, and future large wood recruitment potential is limited.

Table 11. Counts and size classifications of large wood in Thornton Creek, 2007.

Large Wood Size Class	Zone 1		Zone 2	
	Count	Pieces/ 100M	Count	Pieces/ 100M
Small Log (10-19cm diameter)	1	1	2	3
Medium Log (20-49cm diameter)	3	4	3	4
Large Log (>50cm diameter)	1	1	0	0
Rootwad	2	3	1	1

Channel Morphology and Canopy Closure

Similar to its condition in 2003, Thornton Creek received a high entrenchment rating in 2007 (Table 10). However, channel entrenchment in this reach of Thornton Creek has been modified during the recent stream restoration project, and may have been historically modified to convey increased stormwater runoff flows without flooding. RPD increased slightly in 2007 (compared to 2003), presumably due to the fact that many of the pool habitats in this reach of Thornton Creek were enhanced and deepened during the stream restoration project (Table 10).

Percent canopy closure was lower in 2007 than it was in 2003 (Table 10), presumably due to the stream restoration project, which involved a significant amount of riparian planting. Overhead cover was not dense in 2007, but native riparian shrubs that were planted along the stream are still in the process of filling out, and this parameter is expected to improve over the coming years.

Substrate

Thornton Creek is a relatively small low-gradient, low-energy stream in the upper watershed and substrate size will naturally be relatively small. Average substrate size observed in 2007 was significantly larger than in 2003 (D_{50} value of 5 mm in 2003, and D_{50} value of 11 mm in 2007). This average substrate size increase can likely be attributed to the stream restoration project, which involved placing new cobble/gravel substrate within the channel. Much of this substrate was larger than a stream of this magnitude could naturally transport, and inflated the D_{50} value for this sample reach. The size distribution chart (Figure 13) indicates that, although a few large pieces of sediment skew the distribution, fine sediment less than 5 mm make up a significant proportion of the total in the Thornton Creek sample reach.

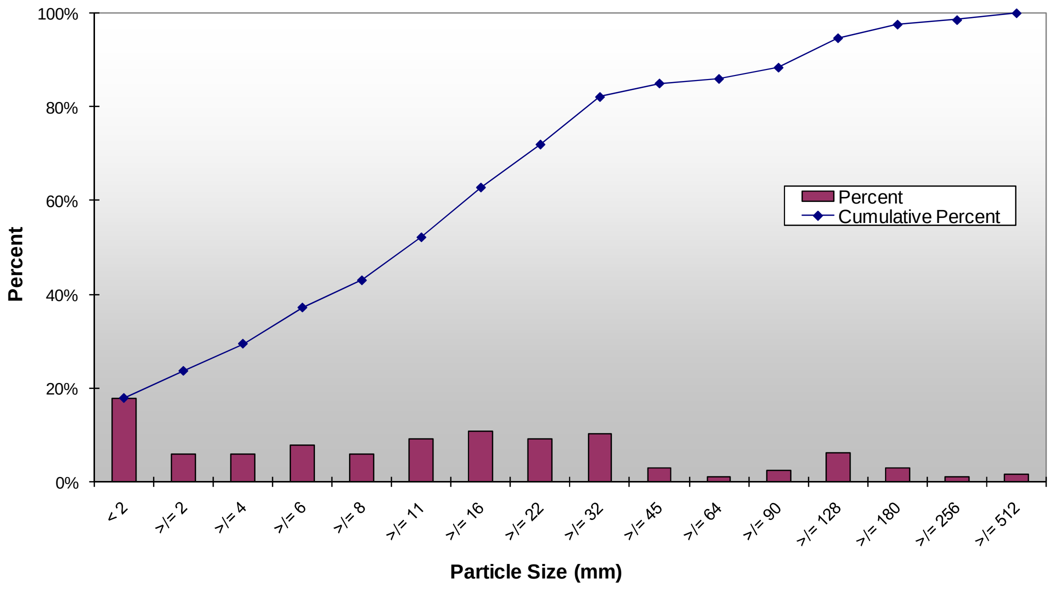

Figure 13. Size distribution for sediment measured in the Thornton Creek sample reach.

5.2.2 McAleer Creek

Sample Location

One site (MC-1) located on the main stem of McAleer Creek at 196th NE was selected for monthly chemical and physical (ambient) monitoring. This location also served as the bioassessment survey reach. (Figure 1)

Stream Habitat

The 2007 McAleer Creek sample reach measured 503 feet in length, and the downstream end was situated at the culvert beneath 196th Avenue NE. The City of Shoreline encompasses a small portion of the McAleer Creek watershed in this area, and the sample reach is located near the center of the basin. Discharge in the McAleer Creek sample reach was measured at 1.5 cfs (11.1 gps) and visually estimated at 2.5 cfs on 9/14/07 (summer base flow conditions). The stream has a relatively low gradient (1.3%) in this area, with wetted and bankfull widths that averaged 11.8 feet and 16.7 feet, respectively (Table 8). A number of narrow (5ft-15ft) fringe wetland areas occur along the streambanks in this portion of McAleer Creek. Along the lower quarter of the survey reach, the stream parallels 196th Avenue NE, which has a steep bank with riprap boulder armoring.

Percent pool area in the McAleer Creek survey reach measured approximately 48%, and RPD was approximately 1 foot. Pool area was high within the survey reach, partially due to a series of long glide-like pools created by the road culvert and a series of LWD debris jams located in the upstream portion of the survey area. Pool quality was generally good throughout the survey reach and maximum pool depths ranged from 1 foot to 2.4 feet.

Large Wood

A moderate amount of large wood was observed in the McAleer Creek survey reach in 2007, much of which was concentrated in the upper half of the survey reach (away from the road culvert). The lower portion of the survey reach was virtually devoid of large wood, but is located immediately upstream from a road culvert where logs may periodically be removed from the stream to prevent them from blocking the culvert. The 2007 counts of large wood (13 pieces/100m in Zone 1 and 12 pieces/100m in Zone 2) in the McAleer Creek sample reach are comparable to those recorded during the 2002 survey, when 17 and 12 pieces/100 meters were observed in Zones 1 and 2, respectively (Table 12). Similar to 2003, size range of large wood in 2007 consisted primarily of medium and small pieces (no large logs observed in 2003 or 2007) that were evenly distributed in Zones 1 and 2. The McAleer Creek riparian corridor is moderately forested and recruitment potential is fair. Protection of stream buffer widths along this and other creeks will likely help improve LWD recruitment potential in the future.

Table 12. Counts and size classifications of large wood in McAleer Creek, 2007.

Large Wood Size Class	**Zone 1**		**Zone 2**	
	Count	**Pieces/ 100M**	**Count**	**Pieces/ 100M**
Small Log (10-19cm diameter)	5	3	5	3
Medium Log (20-49cm diameter)	12	8	6	4
Large Log (>50cm diameter)	0	0	0	0
Rootwad (>20cm bole diameter)	3	2	0	0

Channel Morphology and Canopy Closure

Similar to its condition in 2003, McAleer Creek received a "moderate" entrenchment rating in 2007 (Table 10). Percent canopy closure was slightly lower in 2007 (66%) than it was in 2003 (75%) on McAleer Creek, which is a relatively small decrease in percent cover. This difference may be attributable to inter-observer variability, or, alternatively, some trees formerly contributing to the upper canopy may have been lost to blow down (potentially during the large windstorm that occurred in 2006). Despite the slight decrease in canopy closure, overhead shading and canopy cover is generally good in this reach of McAleer Creek. Much of the overhead shading for the creek is provided by a dense shrub layer, and supplemented by a relatively sparse overstory (Figure 14). Although overhead shading is good in the riparian zone, invasive vegetation like blackberry and knotweed are prevalent throughout the shrub layer. Riparian species associated with this reach of Boeing Creek include red cedar, red alder, bigleaf maple, Himalayan blackberry, Japanese knotweed, nightshade, willow, salmonberry, skunk cabbage, lady fern, nettle, piggyback, and a variety of grass species.

Figure 14. Typical habitat photos in the McAleer Creek survey area.

Substrate

The McAleer Creek channel has a low (1.3%) gradient and a high pool percentage (~50%) in the survey reach, and the stream's ability to mobilize sediment is limited here. The D_{50} value in 2007 was 11 mm (lower than the D_{50} value of 20 mm reported in 2003), and approximately 20% of the substrate was fine material less than 2 mm in diameter (Figure 15).

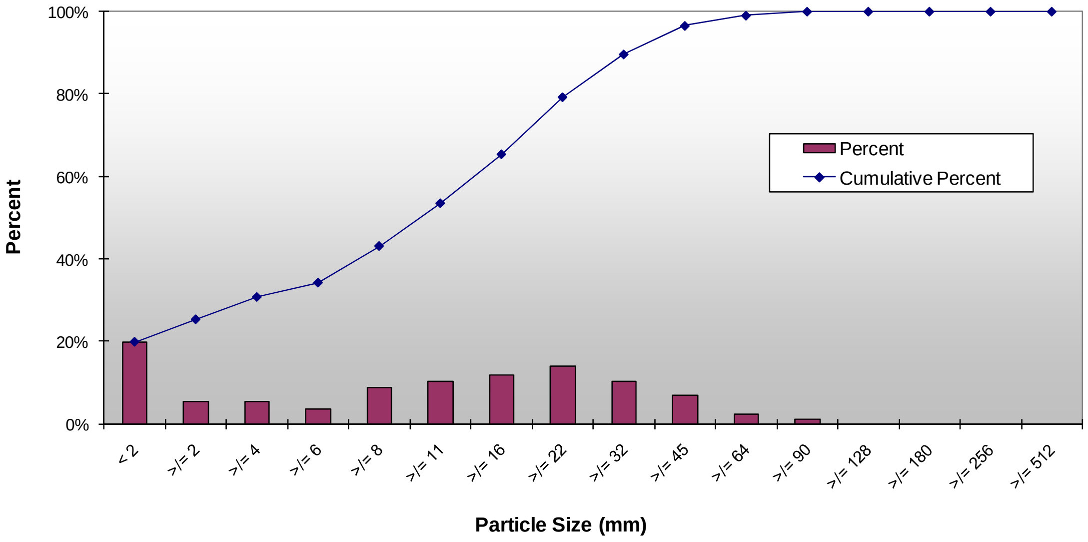

Figure 15. Sediment size distribution in the McAleer Creek sample reach.

5.2.3 Boeing Creek

Sample Locations

Two Boeing Creek sample reaches were monitored in 2007. One site was located on the south fork within Shoreview Park (BC-2) and an additional site was selected near the mouth of Boeing Creek (BC-4 [Mouth]) (Figure 1). Bioassessment surveys were conducted at both locations but ambient water quality monitoring data was collected only at the BC-2 site.

Stream Habitat

BC-2

The 2007 Upper Boeing Creek sample reach (BC-2) measured 561 feet in length, with its downstream end located at the Boeing Creek – South Fork Boeing Creek confluence. Physical habitat sampling was conducted at the Upper Boeing Creek site on August 30, 2007. This sample reach is located roughly midway in the Boeing Creek watershed and the mean wetted width and bankfull width were 9 feet and 19 feet respectively (Table 8). Although the stream is relatively wide and shallow in this area, a number of pocket-water habitats (often formed by large wood in the channel) are present in the sample reach. Discharge was measured at 1.03 cfs (7.7 gps) and visually estimated at 2 cfs on 8/30/07 (summer baseflow conditions).

Boeing Creek (South Fork) meanders through a relatively steep sided, well-forested ravine in this area. Mean bankfull widths (~19 feet) were relatively high in the sample reach, and percent pool area (~12%) was relatively low. Residual Pool Depth (0.7 feet), however, was relatively high, indicating that although pools are limited, the quality of pool habitats in the sample reach is relatively high.

BC-4 (Mouth)

The 2007 Lower Boeing Creek sample reach (BC-4 [Mouth]) measured 708 feet in length, with its downstream end located beneath the footbridge for the trail, a short distance upstream from where the railroad line crosses the creek. Physical habitat sampling was conducted at the Lower Boeing Creek site on October 5, 2007. This sample reach is located near the base of the Boeing Creek watershed, less than 100 feet upstream from the intertidal zone associated with Puget Sound, and the mean wetted width and bankfull width were 9 feet and 15 feet respectively (Table 8). Discharge was estimated at approximately 2 cfs (15gps) on 10/5/07.

The lower Boeing Creek mainstem flows through a relatively broad, well-forested ravine. The Lower Boeing Creek sample reach and riparian corridor is located in a large forested natural area administered by the Innis-Arden Association. Aside from a footpath and the railroad, which only crosses the creek near its mouth, the Lower Boeing Creek stream corridor is well forested, undeveloped, and largely undisturbed. Averaging 15 feet, bankfull widths are lower than those observed at the Upper Boeing Creek sample reach, and generally seem appropriate for a stream of this magnitude. Percent pool area in this reach of Boeing Creek is estimated at 23% (higher than observed in the Upper Boeing Creek sample reach), and RPD averaged 1.0, indicating moderate pool quantity and relatively high pool quality (Table 8).

Large Wood

BC-2

Large Wood was relatively abundant in the Upper Boeing Creek sample reach (BC-2), and much of this wood appeared to have been recruited to the stream channel naturally from trees in the riparian zone. The 2007 counts of large wood (26 pieces in Zone 1 and 27 pieces in Zone 2) in the Upper Boeing Creek site are consistent with those recorded during the 2002 survey, when 28 and 29 pieces were observed in Zones 1 and 2 respectively (Table 9). As expected, the largest portion of the wood count in 2007 was comprised of small (10cm-20cm diameter) and medium-sized (20cm-50cm in diameter) logs, with fewer large logs (Table 13). Much of the wood was situated within the wetted portion of the channel and often acted as a primary or secondary pool-forming feature. Many pieces were located in riffle areas and created small, pocket water pool habitats that did not qualify as true pools in the habitat survey. Future recruitment potential in this reach of Boeing Creek appears to be good, as the riparian area is fairly heavily wooded with a variety of mature conifers and deciduous species.

BC-4 (Mouth)

A moderate amount of large wood was present in the Lower Boeing Creek sample reach (BC-Mouth), and much of this wood appeared to have been recruited to the stream channel naturally from trees in the riparian zone. A streambank stabilization project associated with the footbridge incorporated rootwads and logs however, and these pieces were included in the total count. The 2007 counts of large wood (19 pieces/100m in Zone 1 and 7 pieces/100m in Zone 2) in the Lower Boeing Creek site are slightly lower than those recorded during the 2002 survey, when 30 and 20 pieces/100m were observed in Zones 1 and 2 respectively (Table 9). It is possible that some logs are regularly removed from the stream corridor in this area to help protect the footbridge and railroad crossing bridge from being damaged by large logs during high flow events.

As expected, the largest portion of the wood count in 2007 was comprised of small (10cm-20cm diameter) and medium-sized (20cm-50cm in diameter) logs, with fewer large logs (Table 13). Much of the wood was situated within the wetted portion of the channel and often acted as a primary or secondary pool-forming feature. Future recruitment potential in this reach of Boeing Creek appears to be good, as the riparian area is fairly heavily wooded with a variety of mature conifers and deciduous species.

Table 13. Counts and size classifications of large wood in Upper and Lower Boeing Creek, 2007.

Large Wood Size Class	Upper Boeing Creek				Lower Boeing Creek			
	Zone 1		Zone 2		Zone 1		Zone 2	
	Count	Pieces/ 100M	Count	Pieces/ 100M	Count	Pieces/ 100M	Count	Pieces/ 100M
Small Log (10-19cm diameter)	22	13	4	2	13	6	5	2
Medium Log (20-49cm diameter)	13	8	9	5	12	6	8	4
Large Log (>50cm diameter)	4	2	12	7	9	4	0	0
Rootwad (>20cm bole diameter)	5	3	1	1	8	4	2	1

Channel Morphology and Canopy Closure

BC-2

Similar to its condition in 2003, the Upper Boeing Creek site received a "moderate" entrenchment rating in 2007 (Table 10). Average RPD values in

Upper Boeing Creek increased from 0.4 feet to 0.7 feet between 2003 and 2007 (Table 10), indicating that overall pool depths are now slightly greater and that pool habitat quality may have increased.

Percent canopy closure was slightly lower in 2007 (79%) than it was in 2003 (87%), which is a relatively small decrease in percent cover. This difference may be attributable to inter-observer variability, or, alternatively, some trees formerly contributing to the upper canopy may have been lost to blow down (potentially during the large windstorm that occurred in 2006) or weakened and washed into the creek during the flood event. Despite the slight decrease in canopy closure, riparian condition, overhead shading, and canopy cover is generally very good in this reach of Boeing Creek (Figure 16). Riparian species associated with this reach of Boeing Creek include red cedar, Douglas fir, red alder, bigleaf maple, salmonberry, Himalayan blackberry, lady fern, sword fern, and a variety of grass species.

BC-4 (Mouth)

Similar to its condition in 2003, the Lower Boeing Creek site received a “moderate” entrenchment rating in 2007 (Table 10). As mentioned previously, channel morphology in Boeing Creek was likely affected by a flood event that occurred when a stormwater detention pond failed during a heavy rain event. Although the effects of this flood event were more clearly evident in the Upper Boeing Creek sample reach (the bankfull channel was very wide) than they were in the Lower Boeing Creek sample reach, this flood likely affected channel morphology (perhaps to a lesser extent) in the lower Boeing Creek mainstem as well. Average RPD values in lower Boeing Creek increased from 0.7 feet to 1.0 feet between 2003 and 2007 (Table 10), indicating that overall pool depths are now slightly greater and that pool habitat quality may have increased.

Percent canopy closure was slightly lower in 2007 (84%) than it was in 2003 (97%), which is a relatively small decrease in percent cover. This difference may be attributable to inter-observer variability, or, alternatively, some trees formerly contributing to the upper canopy may have been lost to blow down (potentially during the large windstorm that occurred in 2006) or weakened and washed into the creek during the flood event. Despite the slight decrease in canopy closure, riparian condition, overhead shading, and canopy cover is generally very good in this reach of Boeing Creek. Riparian species associated with this reach of Boeing Creek include red cedar, Douglas fir, hemlock, red alder, bigleaf maple, salmonberry, dogwood, devil’s club, red elderberry, lady fern, sword fern, nettles, piggyback, and a variety of grass species.

Figure 16. Typical habitat photos at the Upper Boeing Creek sample site.

Substrate

BC-2

The sample reach of Upper Boeing Creek is located midway in the watershed and the creek appears capable of mobilizing relatively wide range of substrate sizes. The D_{50} value was 22 mm in 2007 (Table 10), which is slightly higher than the value reported in 2003 (14 mm). Although nearly 20% of the substrate measured at channel cross-sections consists of fines (<2mm diameter), the remaining substrate particles are composed of gravels and cobbles with a relatively normal size distribution (Figure 17). Embeddedness was moderate-to-low in the wetted portion of the channel. The wide bankfull widths (and correspondingly broad floodplain areas covered with sands and silt) characterizing this sample reach contributed to the high percentage of fine substrates. Pebble counts were conducted across the bankfull channel width, and included these silty, depositional floodplain areas beyond the wetted width.

BC-4 (Mouth)

The sample reach of Lower Boeing Creek is located at the base of the watershed and the creek appears capable of mobilizing a relatively wide range of substrate sizes. The D_{50} value was 16 mm in 2007 (Table 10), which is slightly higher than the value reported in 2003 (11 mm). D_{50} values in lower Boeing Creek were slightly lower than those observed in upper Boeing Creek in both 2003 and 2007. The fact that substrate size tends to be smaller at this lower site may be due to the lower gradient in the downstream reach. Approximately 10% of the substrate measured at channel cross-sections consists of fines (<2mm diameter), and the remaining substrate particles are composed of gravels and cobbles with a relatively normal size distribution (Figure 18). Embeddedness was generally low in the wetted portion of the channel. As is the case with all the channel cross-sections, pebble counts included the entire bankfull channel width, and the silty, depositional floodplain areas beyond the wetted width contribute to the relatively large percentage of substrates <2mm in diameter.

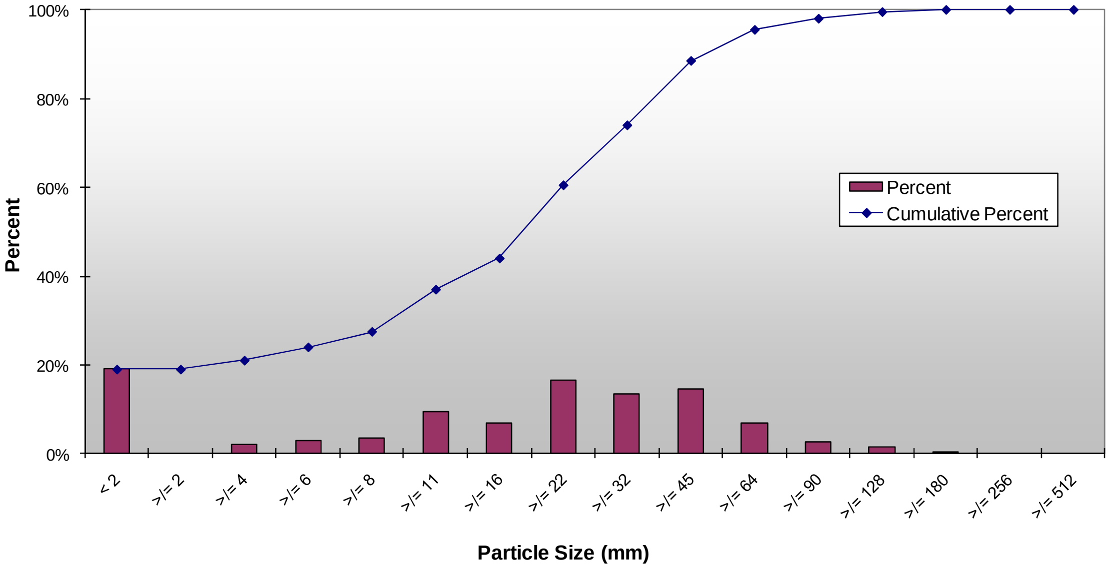

Figure 17. Sediment size distribution in the Upper Boeing Creek sample site.

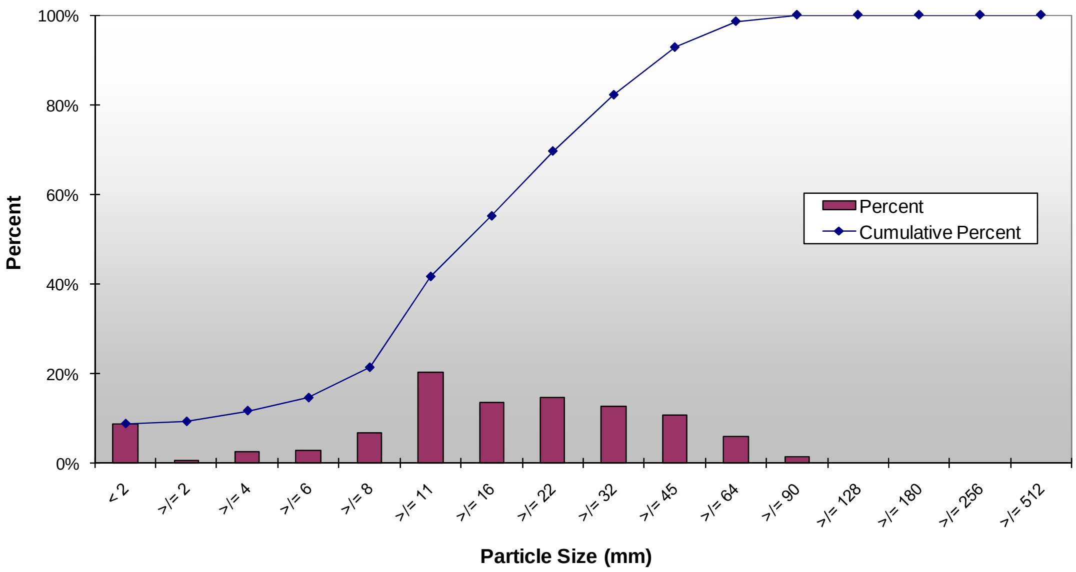

Figure 18. Sediment size distribution in the Lower Boeing Creek sample site.

5.2.4 Storm Creek

Sample Locations

One site was selected for ambient water quality monitoring. The site was located immediately downstream of 15th Avenue NW (ST-2). A site closer to the mouth of the stream, located about 30 meters upstream of 17th PL NW (ST-1) was selected for the bioassessment survey. These two sites are in close proximity of each other and data collected at each are assumed to be very similar in characteristics (Figure 1).

Stream Habitat

The 2007 Storm Creek sample reach measured 291 feet in length, and was situated approximately 30 meters upstream from the culvert beneath 17th Place NW alongside a dirt footpath administered by the Innis-Arden association. Although this reach is located near the mouth of Storm Creek (less than 1/4 mile from its confluence with Puget Sound), this is a small watershed and the stream channel is not large, and wetted and bankfull widths averaged 3.2 feet and 11.5 feet, respectively (Table 8). Discharge was difficult to record due to the small channel size, but was measured at 0.06 cfs (0.42 gps) and visually estimated at approximately 0.4 cfs on 8/28/07 (summer base flow conditions).

Percent pool area in the Storm Creek survey reach measured approximately 24%, but RPD was relatively low (0.4), indicating that pools are generally shallow and not well formed (Table 8). Many of the pools in this reach of Storm Creek were low-quality glide habitats with little overhead cover. Despite Storm Creek's small size, the stream corridor shows evidence of episodic channel-scouring high-flow events. Due to the urbanized nature of the Storm Creek watershed, it is likely that stormwater runoff accentuates peak flows in this stream and contributes to the channel scour in this area.

Large Wood

A moderate amount of woody debris was observed in the survey reach of Storm Creek in 2007, much of which was located in Zone 2 (within the bankfull channel but not in contact with the water). Based on observations from the survey reach, Storm Creek generally has 5 pieces of wood per 100 meter in Zone 1, and 15 pieces per 100 meter in Zone 2 (Table 14). Much of the wood observed in Storm Creek rated as small or medium in size, and many of these pieces appeared to be short (in relation to the channel width) and unstable, and thus likely to become mobile during high flow events. However, some of the larger pieces and rootwads were buried in the sediment, and effectively act to constrain the channel and contribute to pool formation. The survey reach of Storm Creek is located in a forested ravine where the potential to recruit new wood to the stream channel appears relatively good. Unfortunately, developments and a series of culverts upstream of this area likely prevent the delivery of new pieces of large wood from upstream.

Table 14. Counts and size classifications of large wood in Storm Creek, 2007.

Large Wood Size Class	Zone 1		Zone 2	
	Count	Pieces/ 100M	Count	Pieces/ 100M
Small Log (10-19cm diameter)	2	2	5	6
Medium Log (20-49cm diameter)	2	2	4	5
Large Log (>50cm diameter)	0	0	2	2
Rootwad (>20cm bole diameter)	1	1	2	2

Channel Morphology and Canopy Closure

Similar to its condition in 2003, Storm Creek received a moderate entrenchment rating in 2007 (Table 10). Channel morphology in this reach of Storm Creek appears to be shaped by periodic high-flow events, presumably resulting from inputs from stormwater systems. The channel appears to be down cutting in this area in response to high peak flows (Figure 19). Log structures and individual pieces of large wood (which might help slow water velocities and scour better pool habitats) were rare, or highly mobile. The 2007 RPD (0.39) was slightly higher than reported in 2003 (0.13), but was still considered low. This reach of Storm Creek displayed very poorly defined pool habitat, and pool quality was low.

Percent canopy closure did not change significantly between 2003 and 2007. Storm Creek flows through a well-forested ravine in this area and receives good shading and protection from a canopy composed of native trees and shrubs. The forested ravine is relatively deep, and (aside from a footpath paralleling the creek) the riparian buffers are very broad (more than 200 feet on either side).

Figure 19. Typical habitat photos in the Storm Creek survey area.

Substrate

The Storm Creek watershed is relatively small, but the survey reach is located near its base, and much of the upper watershed is urbanized. Sediment size in the Storm Creek study area was large (D_{50} value of 22 mm in 2007, D_{50} value of 15 mm in 2003), suggesting that periodic high flows enable the stream to mobilize relatively large materials through this area. The size distribution chart (Figure 20) indicates that, although Storm Creek is capable of mobilizing relatively large sediments, fine sediment (less than 5 mm) also makes up a significant proportion of the total.

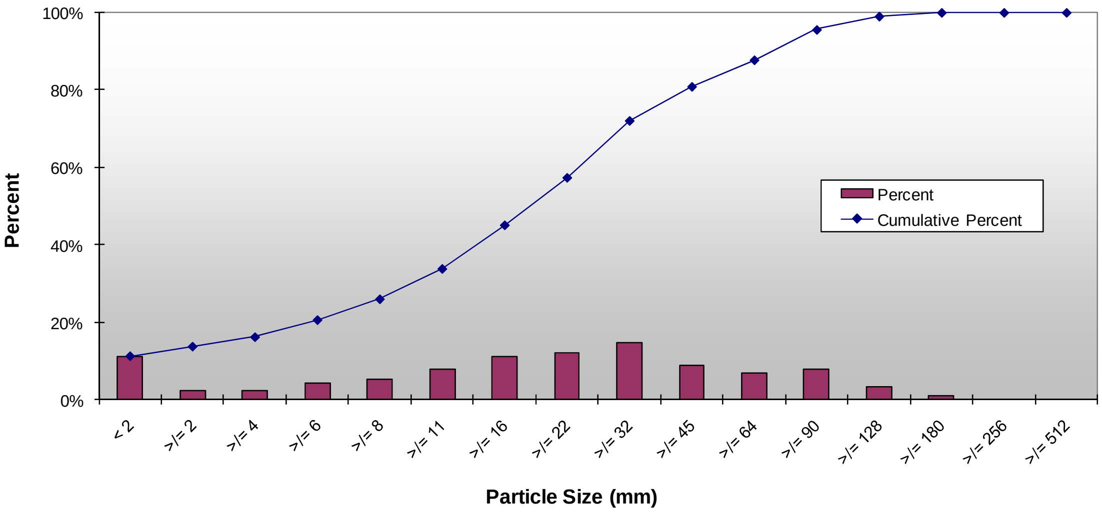

Figure 20. Sediment size distribution in the Storm Creek sample reach.

5.3 Water Quality

The WQI scores for Thornton, McAleer, Boeing and Storm Creeks are shown in Figure 21. The water quality index score for Thornton Creek is 35 which indicates that the quality of the water in Thornton Creek did not meet expectations and is of high concern. The water quality score for McAleer Creek is 38 which indicates that the quality of the water in McAleer Creek did not meet expectations and is of high concern. The WQI score for Boeing Creek is 52 which indicates that the quality of the water in Boeing Creek is of moderate concern. The water quality score for Storm Creek is 27 which indicates that the quality of the water in Storm Creek did not meet expectations and is of high concern. Of the four streams surveyed for this report, Boeing Creek exhibited the best water quality and Storm Creek exhibited the lowest. A detailed chart of water quality parameters and scores can be found in Appendix C.

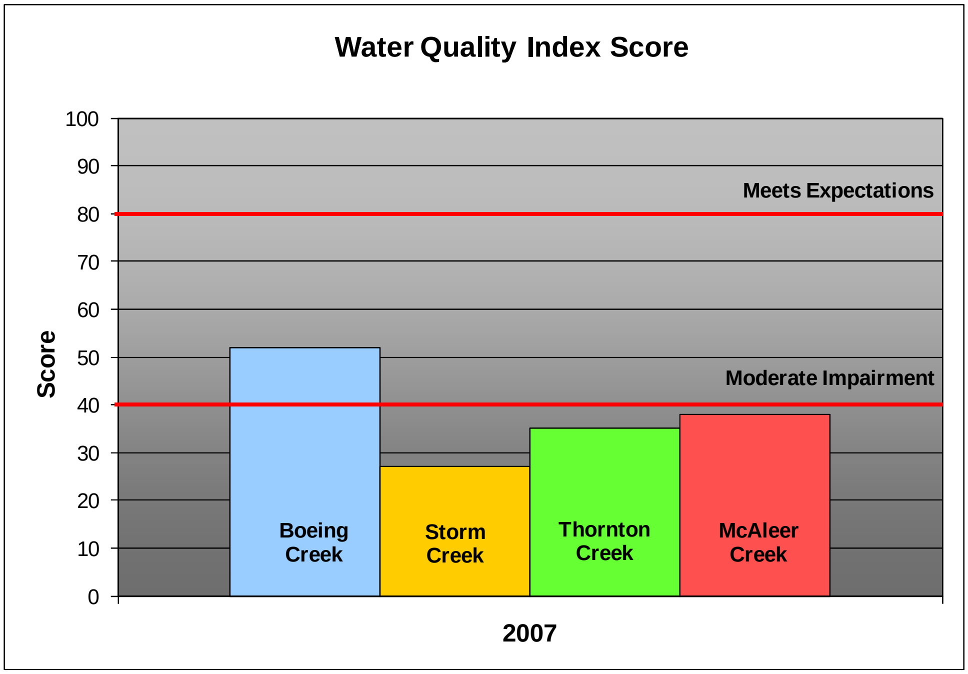

Figure 21. Water Quality Index Score of Streams

6 SUMMARY AND RECOMMENDATIONS

Physical stream habitat and biotic diversity was assessed at 5 sites in various City of Shoreline streams in 2007. The survey reaches were located in Thornton Creek, McAleer Creek, Boeing Creek (upper and lower), and Storm Creek. The 2007 habitat survey was designed to document temporal changes in physical stream habitat and biotic diversity by simulating an earlier (2003) survey that occurred in the same streams and at the same sample locations.

Each of the streams surveyed in 2007 showed some evidence of historical degradation, likely the result of urbanization. Although each stream showed some signs of degradation, the amount was highly varied among the streams. Little variation or continued degradation was observed in 2007 when compared to the study results in 2003. ***The overall effects of urbanization were most evident in the Benthic Indices of Biotic Integrity (B-IBI), where biological impairment of all five sites were rated as "extreme" in 2007.*** The 2007 results differed little from those reported in 2003, when all sites in the survey received low B-IBI scores as well. In 2003, biological impairment of all streams surveyed were also rated as "extreme" by the B-IBI, with the exception of McAleer Creek, which scored slightly higher and was rated as "severe".

Macroinvertebrate community compositions at all sites sampled in 2007 suggest that nutrient enrichment or organic pollutants are present in these stream systems. The assemblages of benthic invertebrates also indicated the presence of relatively high volumes of fine sediments in all streams sampled, which occlude interstitial spaces and degrade aquatic habitats in streams. Finally, the benthic community at all sites showed signs that catastrophic events periodically occur in these streams. These events could include thermal extremes, periodic de-watering, habitat disruption, or extended periods with low dissolved oxygen. These events limit the diversity of the macroinvertebrate community by killing large portions of the aquatic insect population on a periodic basis, with the result that longer-lived insects are not present in the samples. Evidence of catastrophic events based on the macroinvertebrate community was especially clear in Thornton Creek, Storm Creek, and at the upper Boeing Creek site. The McAleer Creek and lower Boeing Creek macroinvertebrate communities appeared to be less affected by catastrophic events.

Physical stream habitat conditions were highly variable among the streams surveyed in 2007. Although each stream surveyed in 2007 showed some evidence of urbanization, ***streams with larger, forested riparian buffers tended to have relatively higher quality physical habitat than streams with narrower riparian buffers.*** Fine sediment was a primary indicator of urbanization in 2007, as the percent fine sediment was relatively high (ranging from 10%-30% for sediment less than 5mm) at all five sites surveyed. ***Silt and sand were generally a dominant substrate type in many of the survey areas.*** High fine sediment volumes also affected the macroinvertebrate community, which were commonly dominated by species capable of living in sandy, silty substrates. The fine sediment moving through these stream systems may also be limiting the availability of spawning habitat and reducing egg-to-fry survival among any resident fish species. Other indicators of overall stream habitat quality varied with the size of the stream, the survey reach’s position in the watershed, and the size of each stream’s riparian buffer.

The WQI Scores for each stream generally supported the biological findings. The scores for Thornton, McAleer and Storm Creeks indicated that the water quality of these streams was of highest concern. The score for Boeing Creek indicated that the water quality was of marginal concern. The level of water quality concern in these streams was generally consistent with the B-IBI ratings of “extremely” and “severely” degraded.

Recommendations (City-wide)

The following recommendations are broad City-wide goals intended to help guide future restoration and enhancement efforts, improve water quality and wildlife habitat conditions within and adjacent to the City's surface waters, and prioritize future monitoring efforts. Stream specific recommendations are listed within each sub-section below.

- Continue to support implementation of water quality and stream habitat improvement projects following the City's Surface Water Master Plan (2005). Concentrate efforts to complete Priority Level I projects and begin planning efforts for Priority II projects beginning in 2011.
- Limit encroachment of the riparian zone through education and enforcement.
- Actively manage the riparian zone to encourage the establishment of at least 70% mature forest cover over the long term.
- Allow for and protect stream channel migration zones within floodplains.
- Educate landowners on improved vegetation management techniques to reduce applications of fertilizers, herbicides, and pesticides.
- Disconnect existing stormwater systems which directly discharge to City surface waters. Provide re-direction of these systems into existing or new treatment areas to increase infiltration and/or detention, both leading to attenuation of in-stream flow energy. Provide a mechanism to track completed projects within each basin in order to assess future changes to direct stormwater discharge.
- Future stream bioassessment studies should investigate fish use within each basin to gather species composition and age distribution. Results from similar studies in other local jurisdictions, such as the cities of Bellevue and Seattle, provide additional metrics from which to base overall ecosystem health while also tracking potential success and effectiveness of restoration efforts.
- The City should continue to monitor the condition of surface waters in the future. Specifically, the City should continue to sample the same reaches sampled in 2003 and 2007. To stay on a comparable schedule, the next sampling effort should begin in fall of 2010.

6.1 Thornton Creek

The study reach of Thornton Creek within the City of Shoreline is located in an urban area, near the headwaters, where the stream is relatively small (low-flow discharge estimated at less than 0.25 cfs) and has a narrow riparian buffer. ***Physical habitat in this reach of Thornton Creek is generally considered poor, but rapidly improving due to a recently installed stream habitat enhancement project.*** Habitat conditions in the 2007 Thornton Creek sample reach differed significantly from those in 2003 due to the completion of this project. The stream restoration project clearly improved indicators such as large wood, residual pool depth, pool area, and substrate quality. Despite the addition of cobble and gravel substrate as part of the stream restoration project, silt and other fine sediment (delivered from upstream) was very prevalent in this survey reach. The macroinvertebrate community in Thornton Creek was heavily dominated by silt-tolerant species, supporting the observation that fine sediment dominates this segment of the stream.

Canopy closure was low in 2007, but only because native riparian enhancement plantings are not yet mature. This is expected to increase dramatically if planted and volunteer vegetation remains successful. The stream channel and riparian corridor are currently in a transition stage as the restoration actions take hold and mature. However, because a restoration project occurred here, these conditions may not be representative of other portions of Thornton Creek.

Due to its small size and location near the headwaters, fish populations here were likely limited even historically. Currently, migration barriers located downstream (such as the long I-5 culvert) preclude or severely limit access by migratory fish, though resident salmonid fish such as cutthroat trout may be present. Additional non-salmonid fish present in Twin Ponds and Ronald Bog may also use nearby creek sections on occasion.

The WQI score for Thornton Creek indicated that the quality of the waters was of "high concern." This rating supports the biological findings which suggest that these waters are severely impaired.

Recommendations (Thornton Creek)

- Continue to monitor the vegetative growth performance of the restoration project within the Thornton Creek sample reach.
- Explore the possibility of establishing a second monitoring station outside of the restoration area in order to offer comparisons between both restored and non-restored reaches, but also continue relative comparisons to 2003 data.
- Emphasis should be given to improving riparian vegetation conditions, including expanding existing vegetated areas, whenever and wherever feasible.

6.2 McAleer Creek

The City of Shoreline encompasses a small portion of McAleer Creek, and the survey reach was located near the center of the McAleer Creek watershed. Discharge was approximately 1.5-2.5 cfs in the McAleer Creek survey reach and this stream segment was one of the largest surveyed in 2007. ***Other than a relatively high percentage of fine sediments, physical habitat in this reach of McAleer Creek appeared to be good.*** Although it had a low gradient, pool and riffle habitats were present and appeared to be well-formed. The riparian buffer, though heavily infested by non-native invasive species like Himalayan blackberry and Japanese knotweed, is relatively wide and provides a moderate amount of overhead shading. Many mature native tree and shrub species are also present in the riparian buffer. ***Protection and vegetative enhancement within the riparian buffer will help protect physical habitat in this reach of McAleer Creek in the future.*** The presence of quality pool habitats and moderate amounts of overhead shading and large wood indicate that this stream likely supports a resident fish population. Additional survey effort would be required to determine the vigor and species composition of any resident fish.

The WQI score for McAleer Creek indicated that the quality of the waters was of "high concern." This rating supports the biological findings which suggest that these waters are severely impaired.

Recommendations (McAleer Creek)

- Remove invasive vegetation within the riparian buffer and revegetate, where appropriate, with native vegetation. Preference should be given to coniferous trees where possible.
- Improvements to water quality should be a main priority. Encourage enhancement of vegetated buffers and infiltration/biofiltration of stormwater.

6.3 Boeing Creek (Lower)

Lower Boeing Creek flows through a large forested natural area administered by the Innis Arden Association. Located at the base of the Boeing Creek watershed, just upstream from the intertidal zone where the stream flows into Puget Sound, the Lower Boeing Creek sample reach had an estimated discharge of 2 cfs. The size and high quality of the forested buffer in this area of Boeing Creek provides excellent overhead shading and protection for this reach of the stream. Other than the railroad crossing and one trail crossing, ***this stream reach appears to be relatively undisturbed and most channel-forming processes are functioning normally.*** As a result, pools and riffles are well-formed within the survey reach and appear to provide good habitat for resident fish.

Despite the good quality of the physical habitat, the B-IBI score for lower Boeing Creek was low and fine sediments were observed in this part of the creek, indicating the conditions could be improved. The sediment distribution and low B-IBI score suggests that stormwater runoff from upper, urbanized areas of the watershed may be delivering organic pollutants and fine sediments to this reach of Boeing Creek.

6.4 Boeing Creek (Upper)

The Upper Boeing Creek survey reach is located roughly midway in the watershed where the stream flows through a relatively steep-sided, well-forested ravine with a discharge of approximately 1.5 cfs. Although the stream is relatively wide and shallow in this area, a number of pocket-water habitats (often formed by large wood in the channel) are present in the sample reach. ***Contrary to those observed in the lower Boeing Creek study area, physical habitat conditions were only fair in the upper reach of Boeing Creek.*** The broad riparian buffer provides excellent overhead shading, large wood recruitment, and overall protection for this reach of Boeing Creek. However the relatively wide channel widths, paucity of pool habitats, and prevalence of fine sediments suggest that this reach may be recovering from some disturbance that occurred in the past. The macroinvertebrate community composition also indicated that periodic catastrophic events may limit biotic integrity in this part of the watershed. Despite some problems with the physical habitat, this reach of Boeing Creek does appear capable of supporting a population of resident fish.

The WQI score for Boeing Creek indicated that the quality of the waters was of "moderate concern". This score indicated that the water quality in Boeing Creek was not as degraded as in the other streams studied. However, the B-IBI score indicates these waters are severely impaired.

Recommendations (Boeing Creek)

- Although most physical habitat parameters are functioning properly in Boeing Creek, both sample locations have suffered from the distribution of fine sediments. Due to the presence of highly erodible soils in the upper watershed, efforts to reduce fine sediment loads should focus on reducing peak flows within the basin, such as through increased infiltration and detention.
- Consider the installation of large wood in the upper portions of Boeing Creek to help stabilize streambanks, provide for pool formation, and create fish habitat.

6.5 Storm Creek

Although the study area was located near the mouth of Storm Creek (less than 1/4 mile from its confluence with Puget Sound), this is a relatively small watershed and discharge in the survey reach was approximately 0.25 cfs. Pool habitats in Storm Creek were infrequent and poorly formed, indicative of generally poor physical habitat quality in this survey reach overall. Despite Storm Creek's small size, the stream corridor shows evidence of episodic, channel-scouring, high-flow events. Due to the urbanized nature of the Storm Creek watershed, it is likely that stormwater runoff accentuates peak flows in this stream and contributes to the channel scour observed in the survey reach. Results from the macroinvertebrate survey also suggest the potential for organic pollutants, high levels of fine sediment, and local catastrophic events that happen periodically. ***Although the physical habitat is poor, the study reach is located in a wooded ravine with good overhead shading, large wood recruitment potential, and a very wide riparian buffer.*** Due to the low quality of the physical habitat, fish are unlikely to inhabit this reach of Storm Creek in any significant numbers.

The WQI score for Storm Creek indicated that the quality of the waters was of "high concern." This rating matches the B-IBI score and habitat findings which suggest that these waters are severely impaired.

Recommendations (Storm Creek)

- Consider the strategic installation of large wood throughout Storm Creek to help stabilize streambanks, attenuate flow energy, provide for pool formation, and create fish habitat in places where natural recruitment is diminished or unlikely.

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APPENDIX A

Department of Ecology Water Quality Index (WQI) scoring matrix

A Department of Ecology Report

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

A Water Quality Index for Ecology's Stream Monitoring Program

Abstract

The Water Quality Index (WQI) presented here is a unitless number ranging from 1 to 100. A higher number is indicative of better water quality. For temperature, pH, fecal coliform bacteria and dissolved oxygen, the index expresses results relative to levels required to maintain uses according to criteria specified in WAC 173-201A. For nutrient and sediment measures, where standards are not specific, results are expressed relative to expected conditions in a given Ecoregion. Multiple constituents are combined and results aggregated over time to produce a single score for each sample station. In general, stations scoring 80 and above met expectations for water quality and are of "lowest concern," scores 40 to 80 indicate "marginal concern," and water quality at stations with scores below 40 did not meet expectations and are of "highest concern." A spreadsheet-version for calculating the WQI is available from the author.

Monthly WQI scores are suitable for statistical trend analysis. Prior to adjusting for flow, statistically significant ($p < 0.05$) improving trends in overall (aggregated constituents) WQI scores were indicated at four stations and declining trends at one station out of 62 evaluated. Adjusting for flow increased the trend slope at nearly three quarters of the stations and resulted in statistically significant improving trends at nine stations and no declining trends. That is, trends in flow were apparently masking improving trends in overall WQI scores at many stations.

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Introduction

Political decision-makers, non-technical water managers, and the general public usually have neither the time nor the training to study and understand a traditional, technical review of water quality data. A number of indexes have been developed to summarize water quality data in an easily expressible and easily understood format (Couillard and Lefebvre, 1985). Water quality professionals are frequently resistant to the automated, uncritical summarization represented by indexes, and there are good reasons to use the results of any index with caution (see the section on “Uses and Limitations”). "[Professionals] prefer to give no answer rather than an imperfect answer that could lead to misunderstanding. Yet the layman usually prefers an imperfect answer to no answer at all" (Ott, 1978). While the use of an index may not be the best way to understand large-scale water quality conditions, it is for many the only way. Professionals must understand the need for an imperfect answer and laymen must understand and accept the answer’s limitations.

Ecology’s Freshwater Monitoring Unit’s Water Quality Index (WQI) is an attempt at an imperfect answer to non-technical questions about water quality. It is a unitless number ranging from 1 to 100; a higher number is indicative of better water quality. For temperature, pH, fecal coliform bacteria and dissolved oxygen, the index expresses results relative to levels required to maintain beneficial uses (based on criteria in Washington’s Water Quality Standards, WAC 173-201A). For nutrient and sediment measures, where standards are not specific, results are expressed relative to expected conditions in a given Ecoregion (Omernik and Gallant, 1986). Multiple constituents are combined and results aggregated over time to produce a single score for each sample station. In general, stations scoring 80 and above met expectations for water quality and are of "lowest concern," scores 40 to 80 indicate "marginal concern," and water quality at stations with scores below 40 did not meet expectations and are of "highest concern." A spreadsheet-version for calculating the WQI is available from the author.

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Several people provided advice, review comments, or laid footprints in the sand for me to follow. In the latter category are all those people involved in developing the index used in the 1980s (in particular, Ray Peterson tickled some very old brain cells to respond to my questions), as well as those who worked on Oregon’s index (most recently, Curtis Cude). Several people offered suggestions on presentation; Bill Yake delved deeper than most into the mechanics. Besides offering innovative suggestions, Eric Aroner, as the only non-government employee involved, deserves special mention for his generosity in donating his time. I also want to recognize those people that provided comments and/or completed a survey on some of the more technical issues. Among these were Chad Wiseman, Nora Jewett, Jeanette Barreca, Dewey Weaver, Bill Ward, Curtis Cude, Jim Ross, Will Kendra, and William Ehinger.

Uses and Limitations

Indexes by design contain less information than the raw data that they summarize; many uses of water quality data cannot be met with an index. An index is most useful for comparative purposes (what stations have particularly poor water quality?) and for general questions (how is water quality in my stream?). Indexes are less suited to specific questions. Site-specific decisions should be based on an analysis of the original water quality data. In short, an index is a useful tool for "communicating water quality information to the lay public and to legislative decision makers;" it is not "a complex predictive model for technical and scientific application" (McClelland, 1974). This index was developed as a tool to summarize and report our routine stream monitoring data to the public.

Besides being general in nature (imprecise), there are at least two reasons that an index may fail to accurately communicate water quality information. First, most indexes are based on a pre-identified set of water quality constituents. For example, a particular station may receive a good WQI score, and yet have water quality impaired by constituents not included in the index. Second, aggregation of data may either mask (or over-emphasize) short-term water quality problems. A satisfactory WQI at a particular station does not necessarily mean that water quality was always satisfactory. A good score should, however, indicate that poor water quality (for evaluated constituents, at least) was not chronic during the period included in the index.

Strategies

Different approaches to indexing water quality results are possible. One approach is to rate quality objectively, for example, using ranked data (e.g., Harkins, 1974). While this approach does not require developing subjective rating curves, it does not permit comparisons between values generated from different data sets. For example, results between years could not be compared unless scores were re-calculated using data from all years. Anytime additional data are added and the index re-calculated (for example, to compare years), results for the same stations and dates originally evaluated will change if the rank order changes. Also, this approach ranks results from pristine stations where high quality would be expected along with stations where water quality would not be expected to be pristine (regardless of human impacts). Hence, a score could only be interpreted in comparison to some other station of known quality (which is in itself subjective).

For management purposes, a more useful index is not one that merely ranks stations by relative water quality, but rather one that indicates whether water quality is less than expected or necessary to support uses designated for particular water bodies. There are disadvantages to this approach as well, however. This type of index requires subjective determinations of the beneficial uses that a particular stream segment should support, the level of water quality required to support those uses, and how critical a variation from that level of quality is. Another disadvantage is that, by design, this approach indicates how well water quality at a station meets expectations, not how good the absolute quality is. Comparing scores for different stations will not indicate which station has the better absolute water quality unless expectations for both stations were the same.

For several reasons, our WQI follows the second approach:

- This allowed us to build on the WQI produced during the 1980s (see "Methodology")
- This is consistent with the approach followed by Oregon (Cude, 2001)
- For several key parameters, some of the subjective determinations are already codified in Washington's Administrative Code (WAC 173-201A)--though a number of subjective decisions were still required.
- Most importantly, we believe the primary audience (the public) will find an expression of results relative to expectations, subjective as that might be, more useful than an absolute score.

Methodology

The basic methodology used to determine WQI scores was originally developed by the Environmental Protection Agency (EPA), Region 10. Initial development was documented only in the "gray" literature, but the methodology appears to be based on or similar to the well-known National Sanitation Foundation index, which uses curves to relate concentrations or measurements of various constituents to index scores and then aggregates scores to a single number (Brown, et al., 1970). The EPA curves were "a synthesis of national criteria, state standards, information in the technical literature, and professional judgment" (Peterson and Bogue, 1989).

In the 1980s, Ecology produced a WQI using the EPA methods, with further modifications of some curves to align curves with local water quality standards criteria (e.g., Hallock, 1990). A Fortran program run on an EPA mainframe computer using data in the national STORET database calculated the index. These procedures were somewhat cumbersome and Ecology stopped producing the index in the early 1990s. I recently re-programmed the WQI procedures in Microsoft Access® to assess data in Ecology's ambient stream monitoring database. Differences from the 1980s methodology are described below.

Water Quality Constituents Included in the Index

For this analysis, index scores were determined for eight constituents monitored monthly by Ecology's Environmental Monitoring and Trends (EMT) Section: temperature (T), dissolved oxygen (DO), pH, fecal coliform bacteria (FC), total nitrogen (TN), total phosphorus (TP), total suspended sediment (TSS), and turbidity.

Rather than aggregating scores for TN and TP separately, the limiting nutrient at the time of sampling was estimated from the ratio of TN:TP. The TN score was used when the ratio was less than 10, the TP score when the ratio was greater than 20, and the smaller of the two scores was used for intermediate ratios. The intent of this procedure is to assess the water quality impact of the nutrient concentration. A consequence of using the limiting nutrient is that the non-limiting nutrient may increase indefinitely without affecting the overall score. Individual nutrient scores are still shown separately, however.

Because sediment-related constituents (TSS and turbidity) are highly correlated, they were aggregated using a harmonic mean ($x = 2 / [1/_{TSS} + 1/_{Turb}]$) prior to calculating the overall index score. The harmonic mean weights the lower score more heavily.

Data collection and quality control are discussed in our annual reports (e.g., Hallock, 2000).

Calculation of the Index

There are three parts to calculating the index:

1. Convert each result to an index score ranging from 1 to 100.

Every result in the selected date range is converted to an index score by a quadratic equation (coefficients are listed in Appendix A). The particular formulas used for a particular station depended on the stream class or ecoregion for that station. For temperature, oxygen, pH, and fecal bacteria, formulas were scaled to yield a score of 80 for results at the water quality criterion for that constituent. The geometric mean criterion was used for fecal coliform bacteria. For example, a temperature of 18 °C in a Class A stream would yield an index score of approximately 80. For nutrient and sediment constituents, formulas were designed so that about 20 percent of the data from long-term stations would convert to index scores below 80. (See "Converting Raw Data to WQI Scores," below, for more detail.)

2. Aggregate index scores.

WQI analyses including multiple years can be aggregated into a single score. A score for each measured water quality constituent for each month is determined as the mean of all scores for that constituent and that month (e.g., all Januaries are averaged). However, I have chosen to present annual scores individually to avoid confusion when interpreting scores from stations where data were collected during different years. The WQIs for the different constituents are then aggregated for each month by calculating a simple average and subtracting a penalty factor for monthly scores less than 80. The penalty factor is (85-WQI Score)/2. (For example, if the average WQI score in January was 89 and pH, at 75, was the only constituent below 80 , the penalty factor for pH would be (85-75) / 2 = 5 and the overall average score for that month would be 89-5=84.) The penalty factor approach is used to weight low-scoring (poor water quality) constituents more heavily and thus reduce the likelihood of one low-scoring constituent—which could have severe affects on the ecosystem—being masked by the averaging process. (Oregon uses a square harmonic mean to weight low-scoring constituents (Cude, 2001).) The overall WQI for a station is the average of the three lowest-scoring months.

A WQI is also determined for each evaluated water quality constituent. For fecal coliform bacteria and sediment and nutrient measures, the constituent score is the average of the three lowest scores for that constituent. For temperature, pH, and dissolved oxygen, the constituent score is the minimum monthly score. Unlike other measures, the distribution of these last three constituents is not particularly patchy. A single high temperature measurement is better correlated with the average 7-day minimum than is the average of three monthly grab samples. Note, however, that this procedure applies only to constituent scores, not to the overall score.

3. Apply weightings and other miscellaneous rules.

Some adjustments were made to moderate low scores that could be attributed to naturally occurring influences. The following rules are applied:

a) A harmonic mean is used to combine turbidity and suspended solids. This prevents double-weighting these strongly correlated constituents.

b) The score for the limiting nutrient is used for total phosphorus and total nitrogen. This prevents double weighting of a nutrient index.

c) A maximum penalty (20) is set for nutrient and sediment scores below 80 because these scores are based on distribution of historical data and not on environmental impact or beneficial use support. Setting a maximum penalty helps prevent nutrient and sediment scores from overwhelming the overall index.

I considered an adjustment to reduce pH scores in eastern Washington, where pH is typically a half unit higher than in western Washington (Table 1), probably due, at least in part, to geological differences. However, the pH curves are not very restrictive anyway (a score of 60 requires a pH measurement of 9.1). Instead, I elected to discuss this and other potential natural influences on scores in a narrative accompaniment to the numerical WQI.

Table 1. Distribution of pH data by ecoregion based on data collected from long-term monitoring stations between October 1990 and September 2000.

			----------PERCENTILES-------------					
Ecoregion	Number of Obs.	Min	10	25	50 (median)	75	90	Max
Coast (1)	417	6.3	7.0	7.2	7.4	7.6	7.8	8.2
Puget (2)	1427	6.2	7.0	7.2	7.4	7.6	7.7	8.6
Cascades (4)	175	6.4	6.8	7.1	7.4	7.6	7.9	8.6
Columbia (7)	1277	5.4	7.5	7.8	8.1	8.3	8.6	9.7
Rockies (8)	295	6.5	7.5	7.8	8.0	8.2	8.4	8.9

Converting raw data to WQI scores

For temperature, oxygen, pH, and fecal coliform bacteria, data were converted to index scores using the same relationships used in EPA's WQI except that the original tabulated results have been converted to quadratic equations. Because there were discontinuities in the original tables, the equations do not fit the tabulated data perfectly. Some intercepts were adjusted slightly to make a WQI score of 80 intersect with water quality criterion. For example, Figure 1 shows the old and new relationships for temperature. Some water bodies have exceptions to the standard criteria based on stream class. Separate curves were developed for these so that the special criterion will still equate to a WQI score of 80. For these parameters, therefore, the WQI score is related to the water quality standards for that water body, and, theoretically, to the support of beneficial uses.

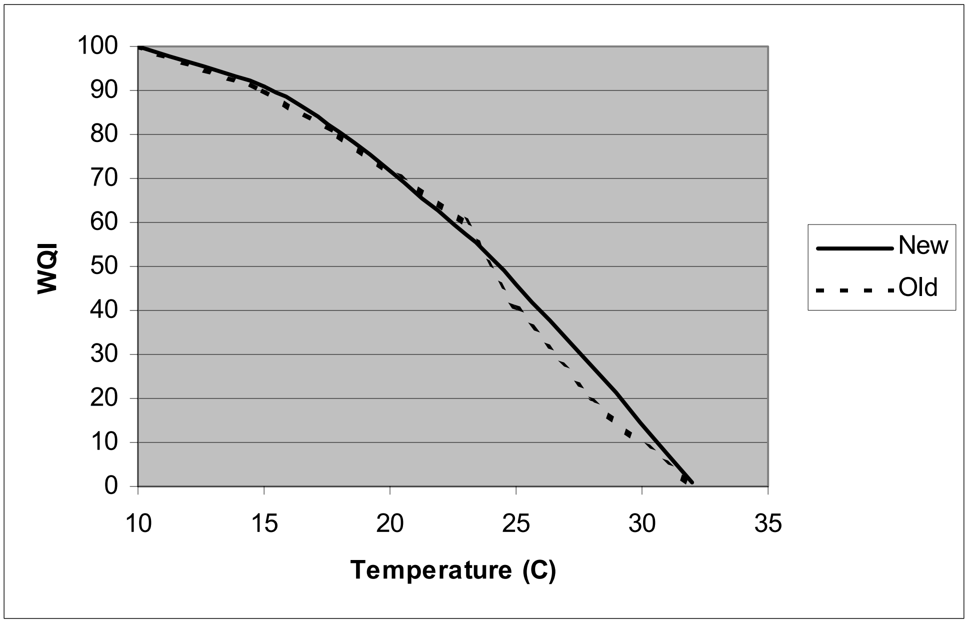

Figure 1. Pre-1991 (Old) relationship between temperature and WQI (plotted from tabulated values) and the current relationship (New) based on a quadratic regression of the old values for Class A water bodies.

I believe that the original curves for turbidity, TSS, TP, and TN are insufficiently sensitive to natural differences attributable to wide variations in geomorphology across the state. Furthermore, there are no water quality standards criteria for these constituents. I developed new curves, therefore, based on the distribution of data at stations within each ecoregion during high- and low-flow seasons. For turbidity and TSS, I considered using separate curves for stations influenced by glacial runoff, but the difficultly in identifying which stations should be considered glacially influenced, coupled with the discovery that concentrations were lower at so-called “glacial” stations as often as they were higher (Appendix B), led me to abandon this effort. Instead scores thought to be impacted by glacial influence will be discussed in a narrative. Data from long-term stations collected from October 1990 through September 2001 were used to develop the curves. WQI scores were matched to various quantiles according to professional judgment and curve appearance (Table 2). A quadratic equation was then fit to the WQI-concentration relationships using WQHYDRO (Aroner, 2002; Appendix B and Figure 2). In four cases a linear curve produced a more logical fit and in one case the coefficients were determined manually to produce a more reasonable curve.

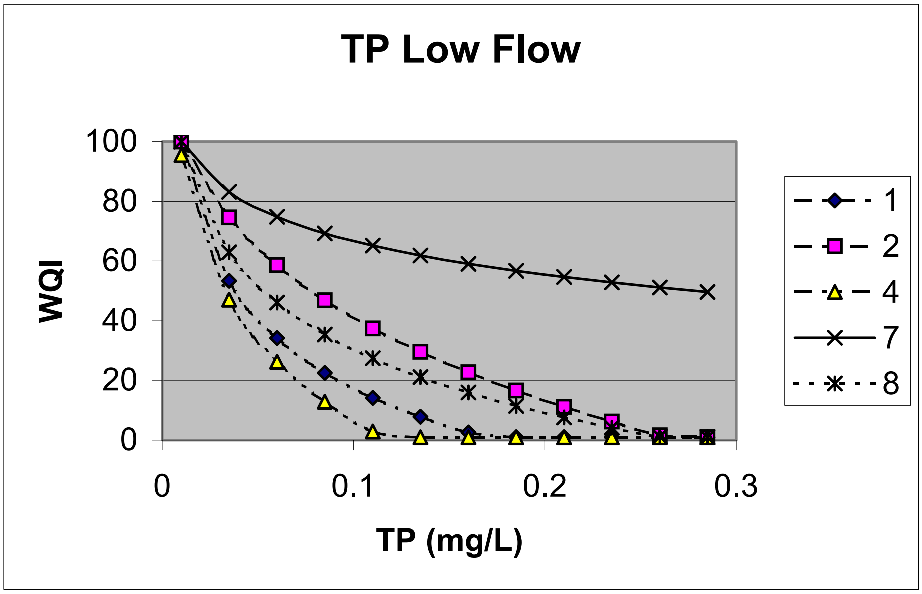

Figure 2. The relationship between total phosphorus concentration and WQI, low-flow months (June through October) for various ecoregions. The curves were based on fitting WQI scores of 100, 80, 40, and 20 to concentrations at the 10th, 80th, 95th, and 99th percentiles, respectively, at long-term monitoring stations.

Table 2. WQI scores assigned to various quantiles for curve development for TP, TN, turbidity, and TSS.

WQI	Quantile	Comment
100	10th percentile	Concentrations less than the 10th percentile are considered to be the lowest reasonably achievable. This point was frequently at or near our detection limits. (The low flow season quantile was applied to both seasons.) Concentrations below the 80th percentile are considered to be of "lowest concern" (WQI≥80).
80	80th percentile	Concentrations between the 80th and 95th percentiles are considered to be of "moderate concern" (40≤WQI<80).
40	95th percentile	Concentrations above the 95th percentile are considered of "highest concern" (WQI<40).
20	99th percentile	Approx. one percent of the data will be assigned WQI scores<20.

There were insufficient data from three ecoregions to develop independent curves. Curves developed for the Puget Lowlands, Cascades, and Northern Rockies are used for stations in the Willamette Valley, Eastern Cascades Slopes and Foothills, and Blue Mountains ecoregions, respectively (Figure 3).

Figure 3. Washington State has been divided into distinct geographic areas called 'ecoregions' based on topography, climate, land uses, soils, geology, and naturally occurring vegetation (Omernik and Gallant, 1986). In some tables, numbers have been used to represent ecoregions as follows: Puget Lowlands (1), Coast Range (2), Willamette Valley (3), Cascades (4), Eastern Cascades Slopes and Foothills (6), Columbia Basin (7), Northern Rockies (8), and Blue Mountains (9).

Because the index scores for nutrient and sediment constituents are based on the distribution of past data and not on ecological impacts or degree of degradation, poor index scores for these constituents indicate poor water quality relative to other stations in the same ecoregion, and may not necessarily indicate impairment or inability to support beneficial uses. Conversely, good index scores for these constituents may not necessarily indicate a lack of impairment or an ability to support beneficial uses.

Calculated results <1 or >100 are converted to 1 or 100, respectively.

Adjusting Overall Scores for Variability in Flow

Water quality constituents are frequently correlated with flow. During high-flow years, some constituents are typically higher (e.g., sediment) and others lower (e.g., temperature) than during low-flow years. As a result, year-to-year changes in an index could actually be attributable to variability in flow (natural or otherwise), rather than to changes in watershed conditions. Therefore, a second set of annual flow-adjusted WQI scores was calculated for long-term stations after removing variability in water quality constituents due to flow.

This was done for each station by 1) determining the residuals from a hyperbolic regression of each constituent (raw data) with flow, 2) adding the mean of each constituent back to the residuals, and 3) calculating WQIs on the adjusted data. Flow-adjustments were done with WQHYDRO (Aroner, 2002) and Access. Note that while mean pre- and post-flow adjusted raw values were the same, the WQI scores calculated from those data will not necessarily have the same central tendencies.

Differences from the Old (Pre-1991) Methodology

1. The old methodology ranged from 0 to 100, where a score of 100 was bad and 0 was good.
2. Criteria curves were tabulated with straight lines interpolated between points, rather than from regression formulas. As a result, data do not convert to quite the same WQIs as previously. Sediment and nutrient curves have been completely re-designed; they were not ecoregion-specific under the old methodology.
3. The old index set no limit to the size of the penalty for nutrient and sediment constituents assigned during the constituent aggregation process except that no penalty at all was assigned for turbidity.
4. Phosphorus and nitrogen were aggregated by the harmonic mean rather than using the limiting nutrient score.
5. Turbidity and suspended solids were each included in the overall score, rather than aggregated as the harmonic mean of the two.
6. The original index included percent oxygen saturation and unionized ammonia concentration.
7. The overall score and individual constituent scores were the average of the three lowest *consecutive* months.
8. Typically, the old index was based on an average of three year's data.

Results and Discussion

Results Based on Current Methods Compared to Results Based on Pre-1991 Methods

WQI scores were calculated using the same data used to produce the 1990 WQI (October, 1986 through September, 1989). A paired Student's t-test rejected the hypothesis that the two methods produced equivalent results ($p<0.001$). Of 78 stations evaluated, 51 stations were categorized the same (poor, marginal, satisfactory) by both procedures. The new index categorized 20 stations as marginal that the original index categorized as satisfactory, mostly because the new nutrient and sediment curves are considerably more restrictive (Table 3).

Table 3. Comparison between original and current WQI procedures showing number of stations placed in each category by an analysis of the same dataset.

		Original Procedures			
		Poor	Marginal	Satisfactory	Total
New Proc.	Poor	4	3	3	10
	Marginal	1	14	20	35
	Satisfactory	0	0	33	33
	Total	5	17	56	78

Observations on Sensitivity

Ideally, an index should not be too sensitive to a single aberrant result. (More than a single excursion beyond water quality standards criteria is also required for a station to be listed on Ecology's 303d list.) I evaluated several hypothetical scenarios:

1. When the WQI for a single FC result is set to 1 and all other results for that and other constituents are set to100, the score for FC is 67 (the average of the three lowest scoring months = [100+100+1] / 3) and the overall score is 80.

2. When the WQI for a single TSS result is set to 1 and all other results for that and other constituents are set to100, the overall score is 88. (The size of the penalty is limited for nutrient and sediments, and TSS and turbidity are averaged.)

3. For the case where the WQI for FC is set to 1 for three months and all other scores to 100, the overall score is 42. (If some other constituent was also set to 1 for three months, but those months did not coincide with the low FC months, the overall score would still be 42 because the overall score is the average of the three lowest scoring months.

4. If FC, TSS, and turbidity are all set to 1 for the same three months the overall score is 5. If all are set to 40 for the same three months, the overall score is 38.

In summary, a single extremely poor result will still yield a good to moderate overall WQI score. Extremely poor results in three different months yield a moderate to poor overall index score. Two poor-scoring constituents during the same three months will result in a very low overall index score.

Because the constituent score is an average of the three worst months (except for temperature, pH, and oxygen), it is possible to have two months where results violate the water quality criterion, yet have the constituent score indicate water quality met expectations ("low concern"). For example, two FC measurements of 230 colonies/100 mL in a Class A stream (equating to scores of 70) averaged with a score of 100 would yield an overall constituent score of 80.

Trends

A batch analysis of trends in monthly WQI scores (after aggregating individual constituents) was performed using WQHydro (Aroner, 2002). Trends were also performed on monthly scores adjusted for variability in flow, as described above. Reported probabilities include corrections for auto-correlation.

Prior to adjusting for flow, statistically significant ($p < 0.05$) improving trends were indicated at four stations and declining trends at one station (table 4). Adjusting for flow increased the trend slope at nearly three quarters of the stations and resulted in improving trends at 9 stations and no declining trends. That is, trends in flow were apparently masking improving trends in water quality at most stations. Whether that is because flows were increasing or decreasing has not been evaluated and is station-specific, depending on which constituent(s) drive the WQI at a particular station. Some constituents are positively correlated with flow (e.g., sediment and nutrients) and some negatively (e.g., temperature and pH).

Let's examine a few stations and see what is happening. (Note: In the following discussion I report p-values as an indication of the potential contribution of trends in particular constituents towards trends in the monthly WQI scores. Although these trends are not statistically significant unless the probability is ≤ 0.05, the direction and consistency of the trend, significant or not, has bearing on the aggregated trend.)

Puyallup River at Meridian Street (10A070)

Monthly WQI scores improved significantly at this station ($p=0.010$). Sediment was the most frequent contributor to low scores, though nutrients and fecal coliform bacteria scores were also moderate. Trends in the raw data (not converted to WQI scores) for these constituents are shown in table 4.

Table 4. Trends in various constituents contributing to lower WQI scores at Puyallup River at Meridian Street (significance: *=80%, **=90%, ***=95%, ****=99%).

Constituent	Slope (units/yr)	Two-sided p value
TSS (mg/L)	-1.20[a]	0.20*
Turb (NTN)	+0.065[a]	0.58
TN (mg/L)	-0.008[b]	0.09**
TP (mg/L)	+0.001[a]	0.23
FC (col./100mL)	-9.55	0.007****

[a] Significant seasonality in trend results

[b] Nitrogen was more likely than phosphorus to be the limiting nutrient

In aggregate, the overall WQI identified improving conditions. This is a reasonable interpretation of the individual trend results, above.

Palouse River at Palouse (34A170)

This station exhibited an improving trend after adjusting for flow, but no trend at all prior to flow adjustment. Although almost all constituents produced low scores on occasion, turbidity typically had worse scores than other constituents. Raw turbidity measurements (prior to converting to WQI scores) increased, though not significantly at the 95% level (p=0.11). There was a significant increasing trend in flow, however (p=0.035) and, because turbidity was positively correlated with flow, adjusting the raw turbidity values for flow resulted in a decreasing adjusted-turbidity trend (p=0.017). In other words, had flow remained stable rather than increasing during the period, turbidity might have decreased. The effect of trends in flow on overall WQI scores can be complicated, however. While some constituents, like turbidity, get worse with increasing flow, others, like temperature, may get better. Furthermore, there may be differences between seasons and some WQI transformations have seasonal components.

Methow River near Pateros (48A070)

This was the only station that exhibited a significant worsening trend in overall WQI (slope=-0.18 units/year, p<0.05; Figure 4). (Still, quality was good at this station; overall annual scores were always in the “good” category and the flow-adjusted trend was not significant.) Annually, only pH, temperature, and sediment had more than a single result in the “moderate” category. Trends in the raw data, not converted to WQI scores, are shown in table 5.

Table 5. Trends in flow and constituents included in the WQI at Methow River near Pateros (significance: *=80%, **=90%, ***=95%, ****=99%).

Constituent	Slope (units/yr)	Two-sided p value
FC (col./100mL)	-0.0000[a]	0.60
Oxygen (mg/L)	0.0006[b]	0.78
TN (mg/L)	-0.0033	0.52
TP (mg/L)	+0.0000[a]	0.09**
TSS (mg/L)	+0.0000[a]	0.88
Turb NTU)	0.024	0.23
PH (std. units)	0.017[b]	0.10**
Temp (C)	-0.080[b]	0.34
Flow (cfs)[c]	*30.7*	*0.07***

[a] A slope of zero can occur even if a trend is present when there are numerous identical results (e.g., multiple results below detection).

[b] There was significant seasonality in trend results

[c] This analysis was based on instantaneous flow at the time of monthly sampling; trends in continuous data may be different.

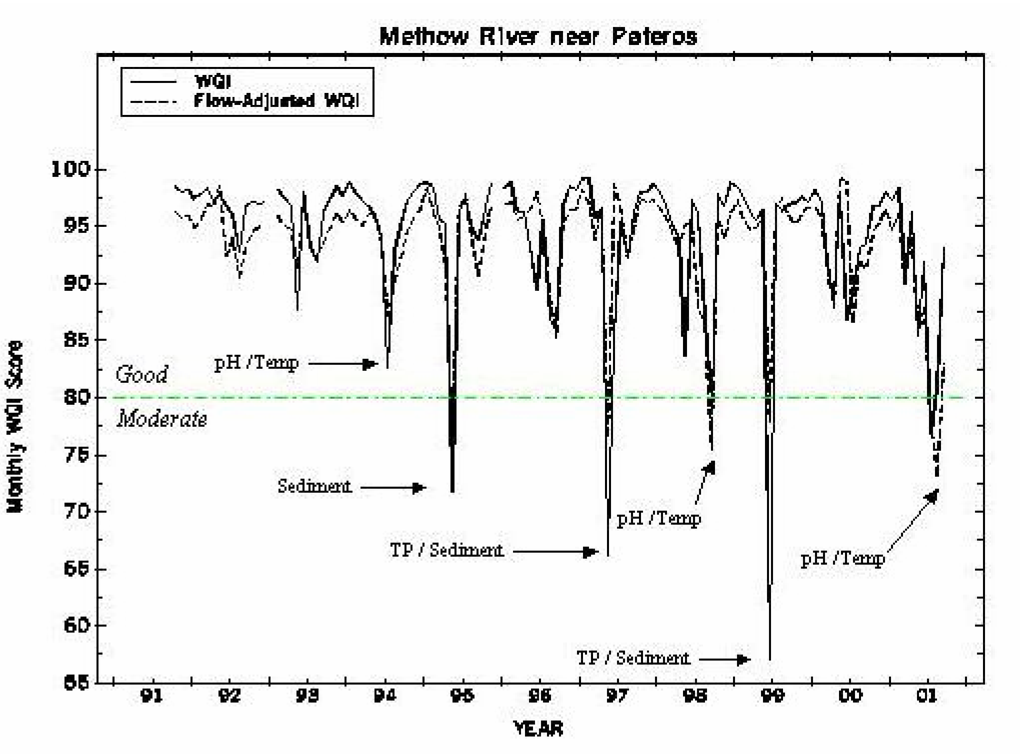

Figure 4. Monthly WQI scores at Methow River near Pateros with and without correction for flow. Constituents contributing the most to some of the lower scores are shown.

There were no statistically significant ($p < 0.05$) worsening trends in the raw data and half the constituents had slopes indicative of improvement (though not significant). Why overall WQI scores have been declining is not entirely clear from table 5. pH contributed most to the declining trend (based on comparing the effect of removing each constituent from the aggregation and trend analysis); without pH, the trend was not significant, though the slope was still negative (slope=-0.06 units/year, p=0.14).

It is difficult to identify a cause of the worsening trend in monthly WQI scores because no single constituent dominates the WQI aggregation. Sediment, pH, temperature, TP, and, to a lesser degree, FC all contribute at different times to produce the occasional moderate monthly WQI score (figure 4). Only in aggregation is there a declining trend. This may be an example of an aggregate trend reflecting subtle changes in water quality (related to flow since there was no flow-adjusted trend) not detectable by examining single constituents. I will not claim that water quality is deteriorating here without better support from the raw data, but this station warrants closer scrutiny.

Nooksack River at Brennan (01A050)

While the Methow at Pateros illustrates an overall WQI trend that is not entirely supported by the underlying data, the Nooksack at Brennan illustrates the opposite: the lack of a trend in its WQI scores even though trends in the underlying data are present. The trend in monthly WQI scores was not significant (0.63 units per year, p=0.42), yet FC counts decreased significantly (–4.7 colonies/100mL per year, p=0.012). In the Nooksack, clear improvements in fecal bacteria counts were masked by modest increases in sediment and nitrogen concentrations (Hallock, 2002).

Trends in monthly WQI scores are, like the scores themselves, useful as a communication tool for non-technical purposes, and to help focus further data analysis efforts. One should use caution when interpreting scores, however, for several reasons:

- Trends may be a result of changes in flow during the period being evaluated, and not due to anthropogenic changes in the watershed (beside those that affect flow). Likewise, improving (or deteriorating) conditions in the watershed may be masked by changes in flow. Examining flow-adjusted trends can help explain this effect, but the relationship between flow, the WQI, and trends is complicated, in part because some WQI constituents have seasonal components.

- Trends may be hidden by the transformation process. Setting maximum and minimum WQI scores to 100 and (more rarely) to 1 censors some data sets. This may make it more difficult to detect trends in data sets with very low or very high values.

- The summarization process may hide trends in individual constituents; improvements (or deterioration) in particular water quality constituents may be overlooked.

- A significant trend in WQI scores may not be statistically supported by the underlying data. This could happen when there is apparent improvement (or deterioration) in several constituents that, individually, are not significant.

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Appendix A

Coefficients of the quadratic equation $\mathbf{WQI{=}a + b_1\ (Constituent) + b_2\ (Constituent)^2}$ used to convert results to index scores. The particular formula used for a given station and constituent depends on the class (AA, A, or B), the Ecoregion, whether there are site-specific criteria (S in the "Class" column), and, sometimes, the season ("Low" = June through October, "High" = November through May except for some special curves) and result range. The "Log" column indicates whether the natural log of the constituent was used.

Constituent	Class or Ecorgn	Season	Criterion	Lower Result	Upper Result	a	b_1	b_2	Log
FC	A	All	100	0	999999	103.59	0.810055	-1.28485	Yes
FC	AA	All	50	0	999999	103.25	-0.5832	-1.35641	Yes
FC	B	All	200	0	999999	102.944	2.59723	-1.30612	Yes
Oxygen	A	All	8	0	12	-67.3255	27.5473	-1.14663	
Oxygen	A	All	8	12.001	99	100	0	0	
Oxygen	AA	All	9.5	0	12.5	-131.2	33.81	-1.22397	
Oxygen	AA	All	9.5	12.501	99	100	0	0	
Oxygen	B	All	6.5	0	8.5	-109.509	43.6529	-2.23081	
Oxygen	B	All	6.5	8.501	99	100	0	0	
Oxygen	S	Low	5	0	7.5	-64.4444	42.7778	2.7778	
Oxygen	S	Low	5	7.501	99	100	0	0	
Oxygen	S	High	8	0	12	-62.3255	27.5473	-1.14663	
Oxygen	S	High	8	12.001	99	100	0	0	
Oxygen	S2	All	5	0	7.5	-64.4444	42.7778	2.7778	
Oxygen	S2	All	5	7.501	99	100	0	0	
pH	A	All	6.5	4	7.5	-531.422	158.619	-9.92672	
pH	A	All	8.5	7.501	9.9	-338.912	128.627	-9.33089	
ph	AA	All	6.5	4	7.5	-531.422	158.619	-9.92672	
ph	AA	All	8.5	7.501	9.9	-338.912	128.627	-9.33089	
pH	B	All	6.5	4	7.5	-531.422	158.619	-9.92672	
pH	B	All	8.5	7.501	9.9	-338.912	128.627	-9.33089	
TSS	1	High	0	0	999	100.7321	-5.17377	-1.31478	Yes
TSS	1	Low	0	0	999	102.3444	-19.28875	0.087332	Yes
TSS	2	High	0	0	999	100.7779	1.47273	-2.16014	Yes
TSS	2	Low	0	0	999	109.9171	-11.2787	-0.698103	Yes
TSS	4	High	0	0	999	100.9078	-7.1956	-2.26536	Yes
TSS	4	Low	0	0	999	102.5005	-26.039	-0.768096	Yes
TSS	7	High	0	0	999	101.1482	-4.23136	-1.33006	Yes

Constituent	Class or Ecorgn	Season	Criterion	Lower Result	Upper Result	a	b_1	b_2	Log
TSS	7	Low	0	0	999	100.2034	8.49706	-5.17937	Yes
TSS	8	High	0	0	999	102.687	-17.5256	0.467769	Yes
TSS	8	Low	0	0	999	101.9152	-17.2765	-1.39424	Yes
Temp	A	All	18	-9	99	107.615	0.923907	-0.135563	
Temp	AA	All	16	-9	99	100	0.923907	-0.135563	
Temp	B	All	21	-9	99	88.1234	3.9808	-0.207885	
Temp	S	All	20	-9	99	104.8229	2.00886	-0.162453	
TP	1	High	0	0	999	-22.3043	-31.2067	-0.9088	Yes
TP	1	Low	0	0	999	-45.6435	-22.4357	2.11808	Yes
TP	2	High	0	0	999	-26.2561	-45.216	-3.80483	Yes
TP	2	Low	0	0	999	-68.0023	-57.8648	-4.57211	Yes
TP	4	High	0	0	999	-26.6586	-13.7327	3.09295	Yes
TP	4	Low	0	0	999	-82.351	-38.6091	0	Yes
TP	7	High	0	0	999	24.1568	-26.8113	-2.18636	Yes
TP	7	Low	0	0	999	28.3779	-17.2759	-0.2800899	Yes
TP	8	High	0	0	999	-57.6117	-58.0565	-5.11388	Yes
TP	8	Low	0	0	999	-39.2805	-29.7187	0.2257024	Yes
TN	1	High	0	0	999	102.3021	-43.1882	-19.7641	
TN	1	Low	0	0	999	102.9609	-95.9463	0	
TN	2	High	0	0	999	102.55	-3.86202	-61.1364	
TN	2	Low	0	0	999	103.4779	-42.5636	-51.5611	
TN	4	High	0	0	999	113.2895	-239.5035	0	
TN	4	Low	0	0	999	109.63	-296.296	0	
TN	7	High	0	0	999	100.9614	-15.1479	0.662255	
TN	7	Low	0	0	999	100	-14.14	0	
TN	8	High	0	0	999	100.3186	4.9998	-31.2691	
TN	8	Low	0	0	999	100	10	-35	
Turb	1	High	0	0	999	99.6621	-4.05247	-2.00526	Yes
Turb	1	Low	0	0	999	92.3579	-14.1133	-1.1457	Yes
Turb	2	High	0	0	999	101.1178	-0.037926	-2.61866	Yes
Turb	2	Low	0	0	999	100.2948	-5.87364	-2.06283	Yes
Turb	4	High	0	0	999	90.9645	-16.2966	-0.301131	Yes
Turb	4	Low	0	0	999	83.9815	-26.125	0.61845	Yes
Turb	7	High	0	0	999	99.1624	-6.43442	-1.31263	Yes
Turb	7	Low	0	0	999	99.6197	-4.43165	-3.1984	Yes
Turb	8	High	0	0	999	96.1118	-18.16	0.48295	Yes
Turb	8	Low	0	0	999	93.4405	-23.2416	-1.71641	Yes

Appendix B

Distribution of nutrient and sediment constituents at long-term stations from October 1990 through September 2001. (Flow season: Low-June through October, High-November through May).

Water Quality Index:				100			80		40	20

TSS (mg/L) High-Flow Season

Ecorgn	N	1%	5%	10%	20%	50%	80%	90%	95%	99%
Coast	356	1	1	1	2	4	15	50	131	497
Non-Gla	246	1	1	1	2	4	15	58	188	503
Glacial	110	1	1	2	2	6	19	48	92	581
Puget	1675	1	2	2	4	12	45	96	206	723
Non-Gla	1232	1	1	2	3	9	32	77	140	595
Glacial	443	3	5	6	8	23	84	204	385	1282
Cascades	272	1	1	1	1	2	8	16	37	108
Non-Gla	195	1	1	1	1	3	9	19	42	183
Glacial	77	1	1	1	1	1	4	11	19	88
Columbia	1469	1	1	1	2	6	27	66	127	690
Rockies	339	1	1	1	2	3	8	15	26	323

TSS (mg/L) Low-Flow Season

ECORGN	N	1%	5%	10%	20%	50%	80%	90%	95%	99%
Coast	259	1	1	1	1	2	5	7	17	88
Non-Gla	179	1	1	1	1	2	4	5	16	100
Glacial	80	1	1	1	2	3	6	12	28	95
Puget	1192	1	1	2	2	5	16	35	78	397
Non-Gla	877	1	1	1	2	4	8	13	25	137
Glacial	315	3	4	5	7	17	59	105	168	487
Cascades	190	1	1	1	1	2	4	6	8	38
Non-Gla	136	1	1	1	1	3	5	6	9	71
Glacial	54	1	1	1	1	2	4	6	8	32
Columbia	1083	1	1	1	2	6	21	40	68	133
Rockies	250	1	1	1	1	2	5	8	12	43

TURB (NTU) High-Flow Season

ECORGN	N	1%	5%	10%	20%	50%	80%	90%	95%	99%
Coast	357	0.5	0.6	0.8	1.3	3.1	11.4	33.6	80.0	231.0
Non-Gla	245	0.4	0.5	0.7	1.0	2.4	9.7	29.4	87.0	281.6
Glacial	112	0.9	1.0	1.3	2.0	5.5	16.6	45.0	80.0	192.9
Puget	1667	0.5	1.0	1.4	2.2	6.3	24.0	50.0	90.0	290.0
Non-Gla	1225	0.5	0.8	1.2	1.8	5.3	20.0	40.0	73.5	274.8
Glacial	442	1.7	2.1	2.7	3.9	10.5	34.0	75.0	140.0	623.7
Cascades	272	0.2	0.5	0.5	0.6	1.3	3.1	7.0	12.3	65.4
Non-Gla	195	0.2	0.5	0.6	0.8	1.6	4.4	9.0	14.6	91.2
Glacial	77	0.2	0.3	0.5	0.5	0.9	1.8	2.5	4.0	28.0
Columbia	1468	0.4	0.5	0.7	1.1	3.9	16.0	34.0	60.0	346.2
Rockies	338	0.4	0.5	0.7	0.9	1.7	4.7	7.7	15.2	141.7

Turb (NTU) Low-Flow Season

ECORGN	N	1%	5%	10%	20%	50%	80%	90%	95%	99%
Coast	259	0.3	0.5	0.5	0.6	1.4	3.3	7.4	14.0	55.0
Non-Gla	179	0.3	0.5	0.5	0.6	1.0	2.0	2.8	5.8	57.0
Glacial	80	0.5	0.5	0.7	0.9	3.2	9.4	13.0	18.0	55.0
Puget	1206	0.5	0.7	0.9	1.2	2.5	10.0	24.0	49.6	160.0
Non-Gla	888	0.5	0.6	0.8	1.0	1.8	4.1	8.1	17.0	91.7
Glacial	318	1.5	1.9	2.4	3.4	11.0	37.2	60.0	95.3	232.4
Cascades	189	0.3	0.5	0.5	0.6	1.1	1.9	2.5	3.5	14.9
Non-Gla	135	0.2	0.5	0.5	0.5	1.0	1.7	2.4	3.3	36.0
Glacial	54	0.5	0.6	0.7	0.8	1.4	2.3	3.1	3.8	9.2
Columbia	1082	0.4	0.5	0.7	1.0	2.6	8.8	18.0	30.0	85.0
Rockies	250	0.5	0.6	0.7	0.8	1.2	2.1	3.2	6.2	15.0

TP (mg/L) High-flow Season

ECORN	N	1%	5%	10%	20%	50%	80%	90%	95%	99%
Coast	358	0.010	0.010	0.010	0.010	0.017	0.037	0.060	0.083	0.266
Puget	1677	0.010	0.010	0.010	0.014	0.028	0.055	0.085	0.135	0.352
Cascades	269	0.009	0.010	0.010	0.010	0.011	0.020	0.031	0.046	0.111
Columbia	1450	0.010	0.010	0.010	0.013	0.041	0.117	0.192	0.341	1.315
Rockies	335	0.010	0.010	0.010	0.010	0.021	0.049	0.071	0.094	0.230

TP (mg/L) Low-flow Season

ECORN	N	1%	5%	10%	20%	50%	80%	90%	95%	99%
Coast	255	0.010	0.010	0.010	0.010	0.013	0.023	0.030	0.038	0.098
Puget	1193	0.010	0.010	0.010	0.010	0.020	0.040	0.056	0.076	0.184
Cascades	189	0.009	0.010	0.010	0.010	0.010	0.015	0.022	0.032	0.082
Columbia	1080	0.010	0.010	0.010	0.010	0.030	0.097	0.141	0.230	1.846
Rockies	249	0.009	0.010	0.010	0.010	0.014	0.029	0.038	0.051	0.151

TN (mg/L) High-flow Season

ECORN	N	1%	5%	10%	20%	50%	80%	90%	95%	99%
Coast	318	0.01	0.01	0.02	0.04	0.13	0.52	0.79	0.91	1.25
Puget	1255	0.05	0.10	0.14	0.19	0.33	0.63	0.78	0.93	1.15
Cascades	205	0.01	0.04	0.05	0.07	0.10	0.16	0.24	0.28	0.40
Columbia	1152	0.06	0.10	0.12	0.17	0.33	1.38	3.38	5.30	8.45
Rockies	268	0.02	0.07	0.09	0.12	0.20	0.95	1.28	1.41	1.71

TN (mg/L) Low-Flow Season

ECORN	N	1%	5%	10%	20%	50%	80%	90%	95%	99%
Coast	226	0.01	0.01	0.02	0.03	0.07	0.31	0.41	0.55	0.90
Puget	903	0.03	0.06	0.08	0.11	0.20	0.37	0.65	0.78	0.92
Cascades	146	0.01	0.03	0.04	0.05	0.07	0.11	0.15	0.20	0.32
Columbia	850	0.04	0.07	0.10	0.13	0.24	1.01	1.60	2.10	6.42
Rockies	200	0.04	0.06	0.08	0.10	0.16	1.18	1.34	1.41	1.61

Appendix C

Trends in monthly WQI scores at long-term stations. Positive slopes indicate improving conditions. P=probability. Statistical significance ("Sign."): 80% (*), 90% (**), 95% (***), and 99% (****).

		Not Flow-adjusted			Adjusted for Flow		
Station	STANAME	Slope	p	Sign.	Slope	p	Sign.
01A050	Nooksack R. @ Brennan	0.6255	0.4243		1.1787	0.1155	*
01A120	Nooksack R @ No Cedarville	0.3289	0.3172		0.6397	0.3353	
03A060	Skagit R nr Mount Vernon	0.1595	0.1076	*	0.4365	0.0873	**
03B050	Samish R nr Burlington	0.7984	0.1647	*	0.3761	0.4271	
04A100	Skagit R @ Marblemount	0.1216	0.6883		0.2191	0.2009	
05A070	Stillaguamish R nr Silvana	0.1048	0.8098		1.0394	0.0289	***
05A090	SF Stillaguamish @ Arlington	-0.1231	0.6252		4.4290	0.2131	
05A110	SF Stilly nr Granite Falls	0.2290	0.3421				
05B070	NF Stillaguamish @ Cicero	0.4066	0.1886	*	0.8345	0.1640	*
05B110	NF Stillaguamish nr Darrington	-0.4803	0.6579		-0.1144	0.8770	
07A090	Snohomish R @ Snohomish	0.2591	0.0363	***	0.4428	0.0071	****
07C070	Skykomish R @ Monroe	0.1590	0.0679	**	0.2560	0.0116	***
07D050	Snoqualmie R nr Monroe	0.3633	0.2805		0.7795	0.0652	**
07D130	Snoqualmie R @ Snoqualmie	0.1173	0.0916	**	0.0962	0.4392	
08C070	Cedar R @ Logan St/Renton	-0.0421	0.7558		-0.0197	0.8297	
08C110	Cedar R nr Landsburg	0.0673	0.2725		0.0156	0.6137	
09A080	Green R @ Tukwila	0.9447	0.0836	**	0.8805	0.1096	*
09A190	Green R @ Kanaskat	0.1030	0.1550	*	0.0872	0.1220	*
10A070	Puyallup R @ Meridian St	1.4928	0.0102	***	1.7195	0.0112	***
11A070	Nisqually R @ Nisqually	0.0425	0.7276		0.6388	0.0267	***
13A060	Deschutes R @ E St Bridge	-0.8074	0.2589		-0.7721	0.0870	**
16A070	Skokomish R nr Potlatch	0.2208	0.0478	***	0.2873	0.0095	****
16C090	Duckabush R nr Brinnon	0.0216	0.7585		0.0628	0.4817	
18B070	Elwha R nr Port Angeles	0.1260	0.2181		0.1537	0.1077	*
20B070	Hoh R @ DNR Campground	0.0067	0.9705		0.3461	0.1092	*
22A070	Humptulips R nr Humptulips	0.0720	0.4929		0.5351	0.0168	***
23A070	Chehalis R @ Porter	-0.3493	0.4203		-0.6246	0.0879	**
23A160	Chehalis R @ Dryad	-0.0582	0.5866		0.2385	0.3648	
24B090	Willapa R nr Willapa	0.7374	0.3083		0.3380	0.4836	
24F070	Naselle R nr Naselle	0.0464	0.8695		0.3000	0.3168	
26B070	Cowlitz R @ Kelso	-0.1572	0.7592		0.6765	0.1732	*
27B070	Kalama R nr Kalama	0.0213	0.9759		-0.8470	0.2202	
27D090	EF Lewis R nr Dollar Corner	-0.0866	0.2379		-0.0263	0.6109	
31A070	Columbia R @ Umatilla	0.0920	0.5548		0.1019	0.4820	
32A070	Walla Walla R nr Touchet	1.5411	0.0516	**	1.6406	0.0163	***
33A050	Snake R nr Pasco	0.2976	0.1792	*	0.3373	0.3034	
34A070	Palouse R @ Hooper	0.0389	0.9552		0.1454	0.7486	

		Not Flow-adjusted			Adjusted for Flow		
Station	STANAME	Slope	p	Sign.	Slope	p	Sign.
34A170	Palouse R @ Palouse	0.1369	0.6192		0.7530	0.0331	***
34B110	SF Palouse R @ Pullman	1.6408	0.0178	***	1.4500	0.0681	**
35A150	Snake R @ Interstate Br	-0.1401	0.4771		-0.0038	0.9361	
35B060	Tucannon R @ Powers	1.4140	0.1098	*	1.1226	0.1329	*
36A070	Columbia R nr Vernita	0.1690	0.3276		0.1771	0.3353	
37A090	Yakima R @ Kiona	0.0324	0.9408		0.9192	0.1822	*
37A205	Yakima R @ Nob Hill	0.2708	0.3649		-0.6141	0.1469	*
39A090	Yakima R nr Cle Elum	0.0504	0.7652		-0.0920	0.7457	
41A070	Crab Cr nr Beverly	-0.2443	0.6160		-0.3141	0.3822	
45A070	Wenatchee R @ Wenatchee	-0.2428	0.1185	*	-0.2744	0.1437	*
45A110	Wenatchee R nr Leavenworth	-0.0367	0.7987		0.0859	0.5040	
46A070	Entiat R nr Entiat	-0.0060	0.9110		0.0617	0.1696	*
48A070	Methow R nr Pateros	-0.1824	0.0151	***	-0.0736	0.2728	
48A140	Methow R @ Twisp	-0.0413	0.1915	*	-0.0241	0.7618	
49A070	Okanogan R @ Malott	0.0438	0.7836		0.2049	0.1175	*
49A190	Okanogan R @ Oroville	0.0765	0.7713		0.1537	0.4425	
49B070	Similkameen R @ Oroville	0.0371	0.8192		0.0491	0.7333	
53A070	Columbia R @ Grand Coulee	0.0781	0.1916	*	0.0645	0.2367	
54A120	Spokane R @ Riverside SP	-0.3766	0.4001		0.5544	0.0728	**
55B070	Little Spokane R nr Mouth	-1.9217	0.0633	**	-0.8903	0.0635	**
56A070	Hangman Cr @ Mouth	0.2946	0.7460		0.0060	1.0000	
57A150	Spokane R @ Stateline Br	0.0290	0.6291		-0.0744	0.3734	
60A070	Kettle R nr Barstow	0.0948	0.7690		0.1198	0.5956	
61A070	Columbia R @ Northport	0.1230	0.3502		0.3258	0.0777	**
62A150	Pend Oreille R @ Newport	-0.0236	0.8549		0.0854	0.7763	

APPENDIX B

State Water Quality Standards

Part II – Designated Uses and Criteria

173-201A-200
Fresh water designated uses and criteria.

The following uses are designated for protection in fresh surface waters of the state. Use designations for water bodies are listed in WAC 173-201A-600 and 173-201A-602.

(1) **Aquatic life uses.** Aquatic life uses are designated based on the presence of, or the intent to provide protection for, the key uses identified below in (a). It is required that all indigenous fish and nonfish aquatic species be protected in waters of the state in addition to the key species described below.

(a) The categories for aquatic life uses are:

(i) **Char spawning and rearing**. The key identifying characteristics of this use are spawning or early juvenile rearing by native char (bull trout and Dolly Varden), or use by other aquatic species similarly dependent on such cold water. Other common characteristic aquatic life uses for waters in this category include summer foraging and migration of native char; and spawning, rearing, and migration by other salmonid species.

(ii) **Core summer salmonid habitat**. The key identifying characteristics of this use are summer (June 15 – September 15) salmonid spawning or emergence, or adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and sub-adult native char. Other common characteristic aquatic life uses for waters in this category include spawning outside of the summer season, rearing, and migration by salmonids.

(iii) **Salmonid spawning, rearing, and migration**. The key identifying characteristic of this use is salmon or trout spawning and emergence that only occurs outside of the summer season (September 16 - June 14). Other common characteristic aquatic life uses for waters in this category include rearing and migration by salmonids.

(iv) **Salmonid rearing and migration only.** The key identifying characteristic of this use is use only for rearing or migration by salmonids (not used for spawning).

(v) **Non-anadromous interior redband trout.** For the protection of waters where the only trout species is a non-anadromous form of self-reproducing interior redband trout (*O. mykis*), and other associated aquatic life.

(vi) **Indigenous warm water species.** For the protection of waters where the dominant species under natural conditions would be temperature tolerant indigenous nonsalmonid species. Examples include dace, redside shiner, chiselmouth, sucker, and northern pikeminnow.

(b) **General criteria.** General criteria that apply to all aquatic life fresh water uses are described in WAC 173-201A-260 (2)(a) and (b), and are for:

(i) Toxic, radioactive, and deleterious materials.

(ii) Aesthetic values.

(c) **Aquatic life temperature criteria.** Except where noted, water temperature is measured by the 7-day average of the daily maximum temperatures (7-DADMax). Table 200 (1)(c) lists the temperature criteria for each of the aquatic life use categories.

Table 200 (1)(c)
Aquatic Life Temperature Criteria in Fresh Water

Category	Highest 7-DADMax
Char Spawning	9°C (48.2°F)
Char Spawning and Rearing	12°C (53.6°F)
Salmon and Trout Spawning	13°C (55.4°F)
Core Summer Salmonid Habitat	16°C (60.8°F)
Salmonid Spawning, Rearing, and Migration	17.5°C (63.5°F)
Salmonid Rearing and Migration **Only**	17.5°C (63.5°F)
Non-anadromous Interior Redband Trout	18°C (64.4°F)
Indigenous Warm Water Species	20°C (68°F)

(i) When a water body's temperature is warmer than the criteria in Table 200 (1)(c) (or within 0.3°C (0.54°F) of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F).

(ii) When the background condition of the water is cooler than the criteria in Table 200 (1)(c), the allowable rate of warming up to, but not exceeding, the numeric criteria from human actions is restricted as follows:

(A) Incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/(T+7) as measured at the edge of a mixing zone boundary (where "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge).

(B) Incremental temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not, at any time, exceed 2.8°C (5.04°F).

(iii) Temperatures are not to exceed the criteria at a probability frequency of more than once every ten years on average.

(iv) Spawning and incubation protection. The department has identified water bodies, or portions thereof, which require special protection for spawning and incubation in Ecology publication 06-10-038 (also available on Ecology's website). This publication indicates where and when the following criteria are to be applied to protect the reproduction of native char, salmon, and trout:

- Maximum 7-DADMax temperatures of 9°C (48.2°F) at the initiation of spawning and at fry emergence for char.

- Maximum 7-DADMax temperatures of 13°C (55.4°F) at the initiation of spawning for salmon and at fry emergence for salmon and trout.

The two criteria above are protective of incubation as long as human actions do not significantly disrupt the normal patterns of fall cooling and spring warming that provide significantly colder temperatures over the majority of the incubation period.

(v) For lakes, human actions considered cumulatively may not increase the 7-DADMax temperature more than 0.3°C (0.54°F) above natural conditions.

(vi) Temperature measurements should be taken to represent the dominant aquatic habitat of the monitoring site. This typically means samples should:

(A) Be taken from well mixed portions of rivers and streams.

(B) Not be taken from shallow stagnant backwater areas, within isolated thermal refuges, at the surface, or at the water's edge.

(vii) The department will incorporate the following guidelines on preventing acute lethality and barriers to migration of salmonids into determinations of compliance with the narrative requirements for use protection established in this chapter (e.g., WAC 173-201A-310(1), 173-201A-400(4), and 173-201A-410 (1)(c)). The following site-level considerations do not, however, override the temperature criteria established for waters in subsection (1)(c) of this section or WAC 173-201A-602:

(A) Moderately acclimated (16-20°C, or 60.8-68°F) adult and juvenile salmonids will generally be protected from acute lethality by discrete human actions maintaining the 7-DADMax temperature at or below 22°C (71.6°F) and the 1-day maximum (1-DMax) temperature at or below 23°C (73.4°F).

(B) Lethality to developing fish embryos can be expected to occur at a 1-DMax temperature greater than 17.5°C (63.5°F).

(C) To protect aquatic organisms, discharge plume temperatures must be maintained such that fish could not be entrained (based on plume time of travel) for more than two seconds at temperatures above 33°C (91.4°F) to avoid creating areas that will cause near instantaneous lethality.

(D) Barriers to adult salmonid migration are assumed to exist any time the 1-DMax temperature is greater than 22°C (71.6°F) and the adjacent downstream water temperatures are 3°C (5.4°F) or more cooler.

(viii) Nothing in this chapter shall be interpreted to prohibit the establishment of effluent limitations for the control of the thermal component of any discharge in accordance with 33 U.S.C. 1326 (commonly known as section 316 of the Clean Water Act).

(d) **Aquatic life dissolved oxygen (D.O.) criteria.** The D.O. criteria are measured in milligrams per liter (mg/L). Table 200 (1)(d) lists the 1-day minimum D.O. for each of the aquatic life use categories.

Table 200 (1)(d)
Aquatic Life Dissolved Oxygen Criteria in Fresh Water

Category	Lowest 1-Day Minimum
Char Spawning and Rearing	9.5 mg/L
Core Summer Salmonid Habitat	9.5 mg/L
Salmonid Spawning, Rearing, and Migration	8.0 mg/L
Salmonid Rearing and Migration **Only**	6.5 mg/L
Non-anadromous Interior Redband Trout	8.0 mg/L
Indigenous Warm Water Species	6.5 mg/L

(i) When a waterbody's D.O. is lower than the criteria in Table 200 (1)(d) (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the D.O. of that water body to decrease more than 0.2 mg/L.

(ii) For lakes, human actions considered cumulatively may not decrease the dissolved oxygen concentration more than 0.2 mg/L below natural conditions.

(iii) Concentrations of D.O. are not to fall below the criteria in the table at a probability frequency of more than once every ten years on average.

(iv) D.O. measurements should be taken to represent the dominant aquatic habitat of the monitoring site. This typically means samples should:

(A) Be taken from well mixed portions of rivers and streams.

(B) Not be taken from shallow stagnant backwater areas, within isolated thermal refuges, at the surface, or at the water's edge.

(e) **Aquatic life turbidity criteria.** Turbidity is measured in "nephelometric turbidity units" or "NTUs." Table 200 (1)(e) lists the maximum turbidity criteria for each of the aquatic life use categories.

Table 200 (1)(e)
Aquatic Life Turbidity Criteria in Fresh Water

Category	NTUs
Char Spawning and Rearing	Turbidity shall not exceed: • 5 NTU over background when the background is 50 NTU or less; or • A 10 percent increase in turbidity when the background turbidity is more than 50 NTU.
Core Summer Salmonid Habitat	Same as above.
Salmonid Spawning, Rearing, and Migration	Same as above.
Salmonid Rearing and Migration **Only**	Turbidity shall not exceed: • 10 NTU over background when the

Category	NTUs
	background is 50 NTU or less; or • A 20 percent increase in turbidity when the background turbidity is more than 50 NTU.
Non-anadromous Interior Redband Trout	Turbidity shall not exceed: • 5 NTU over background when the background is 50 NTU or less; or • A 10 percent increase in turbidity when the background turbidity is more than 50 NTU.
Indigenous Warm Water Species	Turbidity shall not exceed: • 10 NTU over background when the background is 50 NTU or less; or • A 20 percent increase in turbidity when the background turbidity is more than 50 NTU.

(i) The turbidity criteria established under WAC 173-201A-200 (1)(e) shall be modified, without specific written authorization from the department, to allow a temporary area of mixing during and immediately after necessary in-water construction activities that result in the disturbance of in-place sediments. This temporary area of mixing is subject to the constraints of WAC 173-201A-400 (4) and (6) and can occur only after the activity has received all other necessary local and state permits and approvals, and after the implementation of appropriate best management practices to avoid or minimize disturbance of in-place sediments and exceedances of the turbidity criteria. A temporary area of mixing shall be as follows:

(A) For waters up to 10 cfs flow at the time of construction, the point of compliance shall be one hundred feet downstream from the activity causing the turbidity exceedance.

(B) For waters above 10 cfs up to 100 cfs flow at the time of construction, the point of compliance shall be two hundred feet downstream of the activity causing the turbidity exceedance.

(C) For waters above 100 cfs flow at the time of construction, the point of compliance shall be three hundred feet downstream of the activity causing the turbidity exceedance.

(D) For projects working within or along lakes, ponds, wetlands, estuaries, marine waters or other nonflowing waters, the point of compliance shall be at a radius of one hundred fifty feet from the activity causing the turbidity exceedance.

(f) **Aquatic life total dissolved gas (TDG) criteria.** TDG is measured in percent saturation. Table 200 (1)(f) lists the maximum TDG criteria for each of the aquatic life use categories.

Table 200 (1)(f)
Aquatic Life Total Dissolved Gas Criteria in Fresh Water

Category	Percent Saturation
Char Spawning and Rearing	Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.
Core Summer Salmonid Habitat	Same as above.
Salmonid Spawning, Rearing, and Migration	Same as above.
Salmonid Rearing and Migration **Only**	Same as above.
Non-anadromous Interior Redband Trout	Same as above.
Indigenous Warm Water Species	Same as above.

(i) The water quality criteria established in this chapter for TDG shall not apply when the stream flow exceeds the seven-day, ten-year frequency flood.

(ii) The TDG criteria may be adjusted to aid fish passage over hydroelectric dams when consistent with a department approved gas abatement plan. This plan must be accompanied by fisheries management and physical and biological monitoring plans. The elevated TDG levels are intended to allow increased fish passage without causing more harm to fish populations than caused by turbine fish passage. The following special fish passage exemptions for the Snake and Columbia rivers apply when spilling water at dams is necessary to aid fish passage:

- TDG must not exceed an average of one hundred fifteen percent as measured in the forebays of the next downstream dams and must not exceed an average of one hundred twenty percent as measured in the tailraces of each dam (these averages are measured as an average of the twelve highest consecutive hourly readings in any one day, relative to atmospheric pressure).

- A maximum TDG one hour average of one hundred twenty-five percent must not be exceeded during spillage for fish passage.

(g) **Aquatic life pH criteria.** Measurement of pH is expressed as the negative logarithm of the hydrogen ion concentration. Table 200 (1)(g) lists the pH levels for each of the aquatic life use categories.

Table 200 (1) (g)
Aquatic Life pH Criteria in Fresh Water

Use Category	pH Units
Char Spawning and Rearing	pH shall be within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.2 units.
Core Summer Salmonid Habitat	Same as above.
Salmonid Spawning, Rearing, and Migration	pH shall be within the range of 6.5 to 8.5 with a human-caused variation within the above range of less than 0.5 units.

Use Category	pH Units
Salmonid Rearing and Migration **Only**	Same as above.
Non-anadromous Interior Redband Trout	Same as above.
Indigenous Warm Water Species	Same as above.

(2) **Recreational uses.** The recreational uses are extraordinary primary contact recreation, primary contact recreation, and secondary contact recreation.

(a) **General criteria.** General criteria that apply to fresh water recreational uses are described in WAC 173-201A-260 (2)(a) and (b), and are for:

(i) Toxic, radioactive, and deleterious materials.

(ii) Aesthetic values.

(b) **Water contact recreation bacteria criteria.** Table 200 (2)(b) lists the bacteria criteria to protect water contact recreation in fresh waters.

Table 200 (2)(b)
Water Contact Recreation Bacteria Criteria in Fresh Water

Category	Bacteria Indicator
Extraordinary Primary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL.
Primary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 100 colonies /100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200 colonies /100 mL.
Secondary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 200 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 400 colonies /100 mL.

(i) When averaging bacteria sample data for comparison to the geometric mean criteria, it is preferable to average by season and include five or more data collection events within each period. Averaging of data collected beyond a thirty-day period, or beyond a specific discharge event under investigation, is not permitted when such averaging would skew the data set so as to mask noncompliance periods. The period of averaging should not exceed twelve months, and should have sample collection dates well distributed throughout the reporting period.

(ii) When determining compliance with the bacteria criteria in or around small sensitive areas, such as swimming beaches, it is recommended that multiple samples are taken throughout the area during each visit. Such multiple samples should be arithmetically averaged together (to reduce concerns with low bias when the data is later used in calculating a geometric mean) to reduce sample variability and to create a single representative data point.

(iii) As determined necessary by the department, more stringent bacteria criteria may be established for rivers and streams that cause, or significantly contribute to, the decertification or conditional certification of commercial or recreational shellfish harvest areas, even when the preassigned bacteria criteria for the river or stream are being met.

(iv) Where information suggests that sample results are due primarily to sources other than warm-blooded animals (e.g., wood waste), alternative indicator criteria may be established on a site-specific basis by the department.

(3) **Water supply uses.** The water supply uses are domestic, agricultural, industrial, and stock watering.

General criteria. General criteria that apply to the water supply uses are described in WAC 173-201A-260 (2)(a) and (b), and are for:

(a) Toxic, radioactive, and deleterious materials.

(b) Aesthetic values.

(4) **Miscellaneous uses.** The miscellaneous fresh water uses are wildlife habitat, harvesting, commerce and navigation, boating, and aesthetics.

General criteria. General criteria that apply to miscellaneous fresh water uses are described in WAC 173-201A-260 (2)(a) and (b), and are for:

(a) Toxic, radioactive, and deleterious materials.

(b) Aesthetic values.

[Statutory Authority: Chapters 90.48 and 90.54 RCW. 03-14-129 (Order 02-14), § 173-201A-200, filed 7/1/03, effective 8/1/03.]

173-201A-210
Marine water designated uses and criteria.

The following uses are designated for protection in marine surface waters of the state of Washington. Use designations for specific water bodies are listed in WAC 173-201A-612.

(1) **Aquatic life uses.** Aquatic life uses are designated using the following general categories. It is required that all indigenous fish and nonfish aquatic species be protected in waters of the state.

(a) **The categories for aquatic life uses are:**

(i) **Extraordinary quality** salmonid and other fish migration, rearing, and spawning; clam, oyster, and mussel rearing and spawning; crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing and spawning.

APPENDIX C

Water Quality Parameters and Scores

Appendix C Water Quality Parameters and Scores

KEY
Input
Low Concern
Moderate Concern
High Concern

Thornton Creek: Overall Score 35

	Fecal Coliform	Dissolved Oxygen	pH	Total Phosphorous	Total Suspended Solids	Temperature	Total Nitrogen	Turbidity	Monthly
Date	col/100mL	mg/L	std. Units	mg/L	mg/L	C	mg/L	NTU	Scores
1/29/2007 9:15	2	11.45	7.08	0.0332	0.8	5.1	1.78	1.07	96
2/26/2007 8:20	250	10.68	7.8	0.0694	10.5	6.7	1.22	2.1	42
3/27/2007 8:45	63	9.45	7.12	0.0389	2.75	9.4	1.34	1.37	81
4/24/2007 9:10	560	8.62	7.24	0.0356	1.9	11.1	1.52	0.68	53
5/29/2007 8:00	47	8.55	7.29	0.0417	1.7	11.9	1.26	0.5	75
6/26/2007 8:50	270	7.83	7.68	0.0281	2	12.2	2.03	1.4	54
7/31/2007 8:55	110	7.73	7.55	0.0311	1.63	14.3	2	1.1	57
8/28/2007 8:40	510	7.59	7.5	0.0321	0.7	13.4	2.16	0.9	40
9/24/2007 6:25	620	6.76	7.39	0.0327	0.8	11.3	1.82	0.7	29
10/30/2007 9:38	910	8.1	7.33	0.025	0.8	9	1.55	1.01	44
11/27/2007 8:30	280	10.3	7.05	0.0329	1.1	5.8	1.01	1.3	73
12/18/2007 9:10	510	10.96	7.01	0.0568	9.86	5.5	0.998	13.8	37
Constituent Scores:	42	41	93	72	95	85	1	94	

McAleer Creek: Overall Score 38

	Fecal Coliform	Dissolved Oxygen	pH	Total Phosphorous	Total Suspended Solids	Temperature	Total Nitrogen	Turbidity	Monthly
Date	col/100mL	mg/L	std. Units	mg/L	mg/L	C	mg/L	NTU	Scores
1/29/2007 8:10	8	12.15	7.17	0.0365	5.56	5.1	1.31	0.3	95
2/26/2007 7:50	14	11.31	7.26	0.0305	5.5	6.9	1.1	1.4	95
3/27/2007 8:10	35	10.09	7.31	0.026	3.1	9.7	1.07	1.5	92
12/5/2001 14:35	15	9.62	6.69	0.0355	5.7	11.2	1.61	1.65	89
5/29/2007 7:10	52	8.98	7.61	0.0435	4.3	13.2	1.16	1.9	75
6/26/2007 7:45	350	8.65	7.4	0.0473	3.1	12.2	1.55	2.4	46
7/31/2007 10:05	65	8.63	7.37	0.0496	3.2	14.3	1.41	1.89	60
8/28/2007 8:05	120	8.4	7.36	0.0763	3.4	13.2	1.69	2.8	44
9/24/2007 7:15	59	7.31	7.69	0.0844	8.2	14.4	1.15	6.2	26
10/30/2007 8:30	56	10.27	7.52	0.0386	2.7	10.5	0.996	2.6	78
11/27/2007 8:00	25	10.96	7.59	0.0316	3.1	7.4	0.975	1.8	94
12/18/2007 8:10	330	11.39	7.39	0.0425	6	6.2	1.02	1.3	69
Constituent Scores:	59	51	85	54	91	85	1	89	

Boeing Creek: Overall Score 52

	Fecal Coliform	Dissolved Oxygen	pH	Total Phosphorous	Total Suspended Solids	Temperature	Total Nitrogen	Turbidity	Monthly
Date	col/100mL	mg/L	std. Units	mg/L	mg/L	C	mg/L	NTU	Scores
1/29/2007 11:00	1	9.42	7.62	0.0481	0.9	8.8	0.891	0.7	67
2/26/2007 10:05	13	9.2	7.79	0.0413	0.8	9.2	0.871	0.48	83
3/27/2007 10:35	2	9.29	7.7	0.0457	1.4	9.7	0.898	0.35	65
4/24/2007 10:20	2	9.11	7.89	0.044	0.7	10	0.844	0.47	67
5/29/2007 9:10	8	9.17	7.96	0.0406	0.8	10.1	0.854	0.3	83
6/26/2007 10:35	4	9.05	7.66	0.044	0.9	10.4	0.913	1.8	75
7/31/2007 11:15	7	8.49	7.65	0.0404	2.64	10.7	0.94	1.7	72
8/28/2007 10:25	23	9.16	7.73	0.0429	0.25	10.4	0.967	2.8	74
9/24/2007 8:45	8	7.95	7.7	0.0426	0.61	10.1	0.984	1.6	66
10/30/2007 10:50	1	7.36	7.66	0.0446	0.5	9.5	1.35	0.27	60
11/27/2007 10:30	4	8.89	7.82	0.0369	0.25	9	1.03	0.3	84
12/18/2007 10:10	1000	11.13	7.15	0.0626	16.2	6.3	0.975	21.6	29
Constituent Scores:	72	51	94	68	94	94	9	88	

Storm Creek: Overall Score 27

	Fecal Coliform	Dissolved Oxygen	pH	Total Phosphorous	Total Suspended Solids	Temperature	Total Nitrogen	Turbidity	Monthly
Date	col/100mL	mg/L	std. Units	mg/L	mg/L	C	mg/L	NTU	Scores
1/29/2007 10:10	51	11.28	7.82	0.0713	0.25	7.5	1.3	0.89	56
2/26/2007 9:15	230	10.7	8.06	0.0669	1	8.1	1.27	0.68	41
3/27/2007 9:50	14	10.37	8	0.07	1.1	9.5	1.31	0.8	58
4/24/2007 9:35	260	10.07	8.24	0.0689	1.5	10.6	1.19	0.65	39
5/29/2007 8:25	65	9.57	7.66	0.0855	1.1	11.4	1.3	0.81	51
6/26/2007 9:35	47	8.32	8.03	0.0904	1	12.4	1.29	0.89	42
7/31/2007 10:45	55	8.06	7.94	0.0927	1.2	14.3	1.33	1.8	35
8/28/2007 9:50	240	8.29	7.89	0.0826	0.5	13.2	1.17	1.1	25
9/24/2007 8:10	33	7.17	7.88	0.0955	1.24	12.5	1.15	1.5	31
10/30/2007 9:45	78	9.58	8	0.076	0.6	9.9	1.11	0.62	49
11/27/2007 9:45	47	9.8	8.06	0.0642	0.25	8.6	1.13	1.2	58
12/18/2007 9:40	1600	10.71	7.4	0.0801	18.1	6.7	0.928	18	25
Constituent Scores:	47	48	87	44	92	85	1	91	