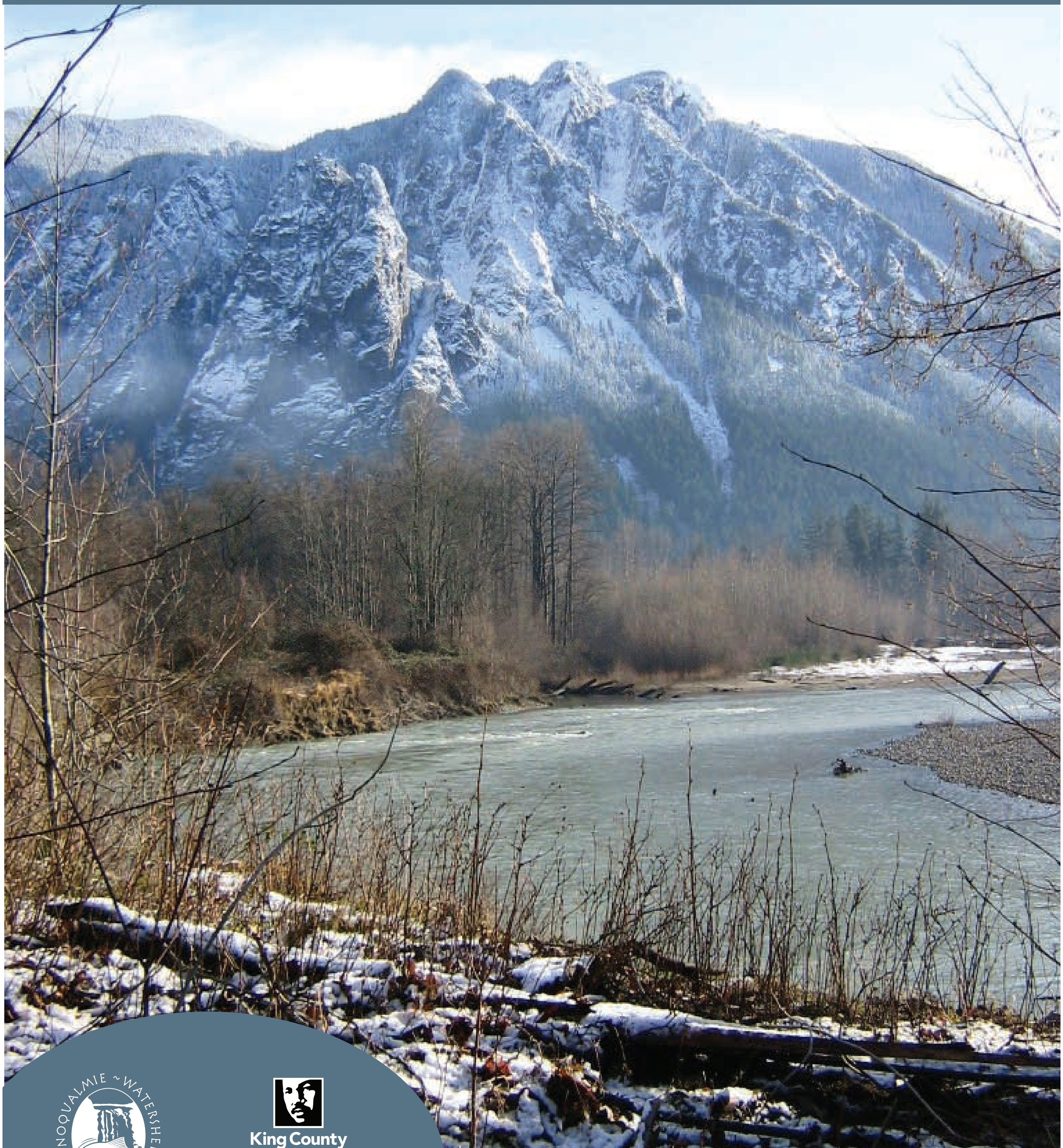
SNOQUALMIE WATERSHED WATER QUALITY SYNTHESIS REPORT



SNOQUALMIE ~ WATERSHED FORUM

King County
Department of
Natural Resources and Parks
Water and Land Resources Division

Prepared by Janne Kaje

January 2009

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EXECUTIVE SUMMARY

The Snoqualmie River watershed is known for its outstanding natural resource values and the Snoqualmie Watershed Forum is committed to protecting and enhancing that legacy. The purpose of this report is to synthesize information about water quality in the watershed and to inform the Snoqualmie Watershed Forum and partner organizations about its condition on a sub-basin level. The report brings together available water quality information in each of the key tributaries and mainstem areas to help identify priorities for on-the-ground actions. The report also identifies key data gaps that should be addressed through monitoring or targeted studies.

The Snoqualmie watershed is valued in part for its aesthetic qualities and many recreational opportunities. The watershed is also home to several species of salmon and trout, including natural populations of Chinook salmon and steelhead that are listed under the Endangered Species Act. Several emerging regional trends may place these valued assets at risk, such as population growth, changes in land-use patterns across the landscape, climate change and other factors. For all of these reasons, it is important to understand the status of water quality in the watershed and to move forward to address the most significant challenges to its long-term health.

While each city, town, rural neighborhood and agricultural area features unique assets and challenges, certain common trends are likely to play a part in shaping the future environmental health of the watershed:

- Each city in the watershed is likely to grow in area and in population, though at different rates. This may lead to higher residential and commercial densities in surrounding areas, but will also bring municipal sewer services to many neighborhoods that currently rely on on-site sewer systems.
- Growth in unincorporated residential areas is limited by the lack of infrastructure (such as sewer services) and by State and County policies that seek to concentrate growth in more urban areas. Still, many rural areas are likely to see substantial growth through the division of very large lots into smaller ones. This may lead to further loss of forest cover and wetlands, as well as habitat fragmentation.
- Agriculture in the Snoqualmie valley is no longer dominated by dairies and today's broader mix of agriculture types is likely better for water quality. However, the survival of agriculture will depend in large part on its economic viability. This is especially true for the small-scale farms that make up a large portion of the farming community in the watershed.
- Federal and state forests are not likely to be converted to other uses in the foreseeable future, and large tracts of privately held timberlands may remain economically profitable in the long-term. The highest risk of forest conversion to other uses likely lies in the smaller-tract forest parcels along the fringes of existing rural residential areas.

The analysis of water quality conditions is organized by sub-basins that range in size from Tuck Creek with an area less than 4 mi^2 to the Middle Fork Snoqualmie River at roughly 170 mi^2. For each sub-basin, the report discusses what is known about water quality in the basin, summarizes land-use and land cover information, identifies data gaps and provides recommendations for priority actions and research or monitoring initiatives, as appropriate. Each sub-basin section is accompanied by thematic maps that highlight existing landscape conditions, applicable water quality standards, known fish distribution and other pertinent information.

The table below summarizes the results of our analysis for each mainstem sub-basin and water quality parameter, arranged in a downstream to upstream direction. The "Tribs." notation for several mainstem Snoqualmie River locations refers to evidence of impairment in smaller tributaries that are not otherwise included in any of the tributary sub-basins delineated for this report.

These qualitative ratings are based on an integration of available information and professional judgment. It is important to note that a rating of "Impaired" does not mean that the entire sub-basin is impaired or that impairment is evident year-round. In many cases, water quality problems are seasonal and localized.

Sub-basin	Snoqualmie RM	Trib RM	Temp.	DO	FC	pH	Nutr.
Snoqualmie River nr. County Line	2.7			Tribs			
Snoqualmie River nr. Carnation	25.2			Tribs			
Snoqualmie River nr. Fall City	35.3			Tribs			
Snoqualmie River nr. Snoqualmie – below Snoqualmie WWTP	40.7						
Snoqualmie River nr. Snoqualmie – above Snoqualmie WWTP	42.3						
South Fork Snoqualmie – below North Bend WWTP	44.4	2.0					
South Fork above Snoqualmie – above North Bend WWTP	44.4	2.8					
North Fork Snoqualmie	44.9						
Middle Fork Snoqualmie	45.3						

	Impaired. Violation of state standards or failure to meet TMDL guidelines, as applicable.
	Basin of concern. Minor failure to meet standards. In some cases, localized problem only
	No evidence of impairment. NOTE: Data not available for many smaller tributaries.

In the mainstem Snoqualmie, high temperature during late summer is the most prevalent problem. High temperatures extend well upstream of intensively developed areas. The upper watershed is heavily forested, accounting for 67% of land cover in the Middle Fork, 70% in the South Fork and 78% in the North Fork. An additional 12-24% of the land cover in these basins consists of rock, snow, ice and open water. This suggests that the current forest condition, the legacy of past forest practices, and the role of natural conditions must be better understood for their potential contribution to high temperatures during late summer.

Although the typical level of bacteria in the mainstem meets State standards, many mainstem sites still experience occasional episodes of higher fecal coliform bacteria concentrations that exceed them. These episodes are typically associated with a heavy rain event following a prolonged dry period.

The following table summarizes the results of our analysis for each tributary sub-basin and parameter, arranged in a downstream to upstream direction.

Sub-basin	Snoqualmie RM	Trib RM	Temp.	DO	FC	pH	Nutr.
Cherry Creek	6.7						
Tuck Creek	10.3						
Ames Lake Creek	17.5						
Harris Creek	21.3						
Lower Tolt River	24.9						
North Fork Tolt	24.9	8.8					
South Fork Tolt	24.9	8.8					
Griffin Creek	27.2						
Patterson Creek	31.2						
Raging River	36.2					High	
Tokul Creek	39.6						
Kimball Creek	41.1						

	Impaired. Violation of state standards or failure to meet TMDL guidelines, as applicable.
	Basin of concern. Minor failure to meet standards. In some cases, localized problem only
	No evidence of impairment. NOTE: Data not available for many smaller tributaries.

Compared to the mainstem Snoqualmie River and the three major forks, many tributary rivers and streams in the watershed are impaired for a wider variety of pollutants and indicators. High temperature is a serious issue in several tributaries, notably Raging River, Cherry Creek and Patterson Creek.

Despite some reductions over time, nearly all tributaries appear to have excessive bacterial load, due primarily to a combination of livestock presence, manure application, failing or underperforming septic systems, pet waste, all combined with natural contributions from birds and mammals. Substantial reductions are needed in several tributaries in order to meet water quality standards.

Kimball, Patterson, Ames, Cherry and Tuck Creeks stand out for the prevalence of water quality impairment relative to other tributaries in the watershed. Each stream violates multiple water quality criteria, according to more than one study. High levels of nutrients, low dissolved oxygen and low pH (i.e., acidic conditions) are prevalent in many of these streams, along with high bacterial counts. A commons pattern across many of the floodplain tributaries that feature extensive agricultural land use is that water quality worsens as the stream flows from the upstream edge of the floodplain to the Snoqualmie River. In many streams, water quality at the mouth shows higher temperature, higher bacterial concentration, lower dissolved oxygen, higher nutrient levels and lower pH than locations further upstream.

Our analysis demonstrates the fact that sub-basins are unique, each with its own combination of history, physical context, land use patterns, development intensity and likely future trajectory. Still, certain patterns can be observed across the watershed.

- In the many sub-basins that feature agriculture in floodplain areas, we need to better understand the legacy effects of a century of farming in a formerly forested floodplain. Changes in soils and in drainage patterns may have as much to do with some of the observed impairments as current agricultural practices themselves. There is still much room for improvement, especially in terms of restricting livestock access to streams, management of manure and other fertilizers, and the need to restore riparian areas. But meaningful improvements will only occur with the help of incentives and technical assistance to improve farming practices while maintaining economic viability.

- Water quality in rural residential areas can suffer due to old and outdated septic systems. As density increases through the division of large parcels, cumulative deficiencies in septic systems may produce more noticeable impacts than we have seen to date.

- Intact wetlands and forests are the best defense against water quality degradation. Local jurisdictions should place a premium on protecting these assets in perpetuity. They also reduce flooding and bank erosion while sustaining the aesthetic beauty of rural communities.

- Like agriculture, the legacy of more than a century of logging has likely altered many rivers and streams to a profound degree, causing channels to become wider and shallower while also altering the water-retention capacity of forest soils. Moreover, the relative lack of large wood in the rivers and the habitat complexity that wood creates have reduced the supply of thermal refugia for fish during the warm summer months.

- The greatest risk of forest conversion is likely at the fringe of rural residential areas. The ability to maintain these lands in a forested condition is dependent on the economic viability of private forestry in particular. Thus, while further improvements in forestry practices and enforcement of regulations are very important, the viability of forestry is a key ingredient for the long-term protection of the watershed.

- For all types of activities and land uses, enforcement of existing regulations and compliance with permit conditions are critical components of water quality protection. Without them, all of the voluntary efforts that are being undertaken by citizens throughout the watershed will do little more than slow the rate of decline in our quality of life and environmental health.

This report should be applied by the Snoqualmie Watershed Forum and basin partners to target restoration actions, incentives, outreach and enforcement activities into areas where they are most needed. For example, the Forum is encouraged to utilize the report’s findings in an effort to solicit high-priority restoration project proposals for the grant programs that it manages in collaboration with KCD. Also, member jurisdictions should consult the report to identify high-value projects in their local areas. The report can also be utilized by the Forum to develop new partnerships with other entities, such as Public Health – Seattle & King County to address septic system issues in targeted areas.

King County is strongly encouraged to utilize the report across many different program areas. For example:

- The County's Agriculture program can use the report to inform farmers about the water quality challenges in their local areas and to target restoration actions in a way that addresses the highest priority water quality issues.
- The Watershed Stewardship program can target potential property acquisitions and restoration opportunities in rural residential areas where such actions can help to protect high-quality tributary areas.
- Similarly, the Public Benefit Rating System and Timberland incentive programs can use the report to identify potential areas of focus and to communicate with potential program participants about the water quality challenges in their local areas.
- The Ecological Services Unit that is charged with implementing most large-scale capital projects on county lands can also apply the report's findings to project design in an effort to help address high priority water quality impairments in specific locations.
- As the manager of the County's parks and natural lands, the Parks Resource Section can utilize the information to better prioritize restoration actions on County lands.
- The report should also inform the Water and Land Resources Division's Scientific and Technical Support Section work program. Several important monitoring and research initiatives have been identified in the report, some with applicability to other areas in King County.

This list is not intended to represent a comprehensive suite of the report's relevance to County programs, but it can provide a common frame of reference for better understanding the nexus between County activities and improving water quality conditions in the watershed.

Finally, as a synthesis report, this document and any future revisions or supplements are dependent on having up-to-date knowledge of available data and any new data collection efforts. We have undoubtedly missed some existing data sources in the preparation of this report that could have improved the assessment of water quality in certain areas. Our hope is that the report will foster information sharing and collaboration within and across all organizations that have an interest in the health, beauty and ecological integrity of the Snoqualmie watershed.

1 INTRODUCTION

The Snoqualmie watershed is an outstanding natural resource that the Snoqualmie Watershed Forum (Forum) is committed to protect. The purpose of this report is to synthesize information about water quality in the watershed and to inform the Forum and partner organizations about its condition on a sub-basin level. The report brings together available water quality information in each of the key tributaries and mainstem areas to help identify priorities for on-the-ground actions. The report also identifies key data gaps that should be addressed through monitoring or targeted studies.

The Puget Sound region is experiencing a number of trends that pose challenges for the preservation and restoration of environmental assets, including population growth, changes in land-use patterns across the landscape, climate change and other factors. The Snoqualmie River is a magnet for recreational activities, including swimming, rafting, tubing, fishing and wildlife viewing and an important regional forestry and agricultural resource. The aesthetic values of the watershed are what drew many of its residents to live there in the first place. Moreover, the watershed is home to animals that depend on the availability of clean water, including several species of salmon and trout. For all of these reasons, we must understand the status of water quality in the watershed and move forward to address the most significant challenges to its long-term health.

The Forum participated in the development of the Snohomish River Basin Salmon Conservation Plan (Snohomish Basin Salmon Recovery Forum, 2005) and is directly engaged in its implementation. During plan development, detailed water quality information on a sub-basin level was considered a data gap in many areas within the Snoqualmie watershed, as described in the Snohomish River Basin Salmonid Habitat Conditions Review (Snohomish River Basin Salmonid Recovery Technical Committee, 2002). This report provides a robust update to that assessment by filling data gaps with up-to-date information for many sub-basins and by providing recommendations on how to fill remaining information needs.

Due in large part to the nature of the water quality studies that have been performed in the watershed, the available information is unevenly distributed. For example, through the efforts of the King Conservation District (KCD), King County's Agriculture Program and others to assess the effects of agriculture on water quality, more data are available in several predominantly agricultural tributaries within the lower valley than in other areas. Similarly, the Washington Department of Ecology's (WDOE) recent study that evaluates the effectiveness of the Snoqualmie River Total Maximum Daily Load (TMDL) clean-up plan is focused on areas where regulated activities (such as wastewater discharges) occur, and where other, direct human influences can be readily identified.

While forest practices in the upper watershed and headwaters of tributaries may contribute to water quality impairment by raising water temperature and increasing sediment load, none of the studies reviewed for this report focus on forest management in the headwaters of the Snoqualmie River, though we have reviewed preliminary temperature data collected by the Washington Department of Ecology (WDOE) in 2006 that extends to the National Forest boundary. Where appropriate, as in the forestry example, the report highlights areas for future action or research, including issues of data coverage affecting certain geographic areas and/or land-use categories.

In many other watersheds located in King County, the County's wastewater program and associated fees are a source of funds for water quality monitoring. Historically, the County has not provided wastewater services to the Snoqualmie watershed. This explains, in part, the relative lack of data compared to other watersheds in the County.

1.1 Physical setting and development trends

The Snoqualmie River watershed covers nearly 700 mi^2 and is located almost entirely within King County with a small fraction in Snohomish County. The river originates as a west-flowing drainage from the crest of the Cascade Mountains. Its principal forks – the North Fork, Middle Fork and South Fork – come together near the city of North Bend to form the mainstem Snoqualmie River. Approximately forty miles upstream from its confluence with the Skykomish River, the Snoqualmie plunges 270 ft. over Snoqualmie Falls near the City of Snoqualmie before flowing northward past the cities of Carnation and Duvall toward the Snohomish County line. The Snoqualmie and Skykomish Rivers converge near the city of Monroe to form the Snohomish River, second only to the Skagit River in size among Puget Sound rivers. Map 1 (see Appendix) provides an overview of the watershed.

The higher elevation areas are dominated by forests in a combination of public and private ownership. The upper watershed lies mostly within the Mount Baker Snoqualmie National Forest and includes significant portions of the Alpine Lakes Wilderness. According to a 2001 analysis of land cover, nearly 70% of the watershed is forested, split fairly evenly between coniferous and mixed (i.e., a combination of coniferous and deciduous) forest cover[1]. The analysis categorized an additional 3.4% as a combination of "recently regenerated forest" (2.6%) or as "recent clear cuts" (0.8%). The percentage of forest cover varies widely by sub-basin, from a low of 49% in the Snoqualmie Mainstem to over 88% in Griffin Creek.

At the opposite end of the watershed elevation range lie the agricultural lands along the valley floor. As described further in Section 3.1, over 14,000 acres (3.9% of the watershed) are designated as an Agricultural Production District (APD) that lies mostly within the 100-year floodplain of the Snoqualmie River.

Prior to European settlement, much of the Snoqualmie floodplain was forested, particularly upstream of present-day Duvall. Historical documents suggest that the immediate riparian corridor was dominated by hardwoods, such as alder, willow, vine maple and cottonwood, with less than 10% represented by conifers (Collins and Sheikh, 2002). However, the cedar and spruce that were the dominant species among streamside conifers were far larger than other riparian trees, accounting for roughly 40% of the total basal area[2]. In 2000, forest

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[1] Land cover analysis by Marshall and Associates (2001).

[2] The basal area of an individual tree is its cross-sectional area in square units, typically measured at breast height. For a stand or forest, the term is used to refer to the cross-sectional area of all trees in the stand, divided by the unit area.

cover along the river and valley floor was estimated as comprising only 16% of its pre-European settlement level. In addition, the historic floodplain featured numerous oxbows and wetlands (Collins and Sheikh, 2002) that likely facilitated exchange between groundwater and surface water year-round. Only 19% of pre-settlement wetlands were estimated to remain in 2000.

Agricultural zones are flanked in most sub-basins by unincorporated rural residential areas, the most prevalent land use in the watershed after forestry. Residential density varies widely across the watershed. The highest densities are found in the unincorporated towns of Preston and Fall City, both located in the vicinity of the Raging River, as well as in several lakeside communities, including Lake Marcel, Lake Joy, Lake Margaret and Ames Lake. In the majority of rural residential areas, the King County Comprehensive Plan calls for a housing density range from one residence per 2.5 acres to one residence per 10 acres.

Finally, approximately 13.2 mi^2 (1.9%) of the watershed lies within the city limits of Duvall, Carnation, Snoqualmie and North Bend, and an additional 1.3 mi^2 in the City of Sammamish within the Patterson Creek sub-basin[3]. All four cities along the Snoqualmie River have a long and storied history in the watershed and still maintain a great deal of their historic character, even as residential and commercial development have expanded into surrounding areas. Their populations range from less than 2,000 in Carnation to more than 9,000 in Snoqualmie[4].

While each city, town, rural neighborhood and agricultural area features unique assets and challenges, certain common trends are likely to play a part in shaping the future environmental health of the watershed:

- Each city in the watershed is likely to grow in area and in population, though at different rates. This may lead to higher residential and commercial densities in surrounding areas, but will also bring municipal sewer services to many neighborhoods that currently rely on on-site sewer systems.
- Growth in unincorporated residential areas is limited by the lack of infrastructure (sewer services in particular) and by State and County policies that seek to concentrate growth in more urban areas. Still, many rural areas are likely to see substantial growth through the division of very large lots into smaller ones. This may lead to further loss of forest cover and wetlands, as well as habitat fragmentation.
- Agriculture in the Snoqualmie valley is no longer dominated by dairies and today's broader mix of agriculture types is likely better for water quality. However, the survival of agriculture will depend in large part on its economic viability. This is especially true for the small-scale farms that make up a large portion of the farming community in the watershed.

[3] The City of Sammamish is not a member of the Snoqualmie Watershed Forum.

[4] Data from the Washington State Office of Financial Management. Available at: http://www.ofm.wa.gov/pop/april1/default.asp

- Federal and state forests are not likely to be converted to other uses in the foreseeable future, and large tracts of privately held timberlands may remain economically profitable in the long-term. The highest risk of forest conversion to other uses likely lies in the smaller-tract forest parcels along the fringes of existing rural residential areas.

- Modern approaches to storm water, forest and farm management can ameliorate some of the impacts associated with population growth and landscape changes. Whether better practices can offset the impacts associated with growth remains to be seen.

These and other trends, as well as the backdrop of climate change, will substantially shape the future of the Snoqualmie River watershed, including its aesthetic beauty, human health and its ecological integrity.

1.2 Organization of the report

Following this brief introduction, Section 2 provides a discussion of water quality standards and their application within the Snoqualmie basin. For those not familiar with the State's water quality program, a brief discussion of 'beneficial uses', numerical water quality criteria and the State's anti-degradation policy is provided. Table 1 lists the water-bodies in the watershed that are subject to specific, numerical criteria.

Section 3 describes the State framework [based in large part on the Federal Clean Water Act (CWA)] for categorizing waters by their water quality condition, including a discussion of the CWA 303(d) list and associated classifications. Table 2 lists the water bodies in the watershed that fall into each category for specific pollutants and indicators. This section also describes the most common sources of water quality impairment in the basin.

Section 4 describes the primary sources of information used for this report. Section 5 follows with a description of the principal findings. The main themes are summarized at the watershed scale and the differences and commonalities between different areas are described. Several watershed-scale maps (see Appendix) summarize the findings and provide information about watershed characteristics.

Discussion of specific sub-basins is provided in Section 6. For each sub-basin, the report discusses what is known about water quality in the basin, summarizes land-use and land cover information, identifies data gaps and provides recommendations for priority actions and research or monitoring initiatives, as appropriate. Each sub-basin section is accompanied by thematic maps that highlight existing landscape conditions, applicable water quality standards, known fish distribution and other pertinent information.

2 WATER QUALITY STANDARDS

2.1 Why do we have water quality standards?

Water quality standards are established by State and Federal law and codified into the Washington Administrative Code (WAC 173-201A). The WAC includes both narrative and numerical water quality criteria, as well as an anti-degradation policy. The latter establishes general policy goals for maintaining water quality, but also defines standards for allowable levels of degradation due to permitted activities that are deemed in the public interest, such as National Pollution Discharge Elimination System (NPDES) permits for wastewater treatment plants, fish hatcheries and certain municipal stormwater discharges.

The State water quality standards define the types of uses and activities that the public has a right to expect from our lakes, rivers, streams and marine waters. These so-called ‘beneficial use’ categories (e.g., water supply, recreation, aquatic life) form the cornerstone of the State’s water quality standards. When standards are not met, the risks to certain beneficial uses reach levels that are deemed unacceptable.

In general, water quality standards are intended to protect both humans and animals from illness, and to support healthy aquatic ecosystems. Excessive bacteria concentrations are thought to represent the greatest risk to human health. Water quality standards are not expected to eliminate all risks. In the case of bacteria, the standards are intended to keep the frequency of human illness below specific rates deemed acceptable by the State. The bacteria standard is described further, below.

Clean water is also critical to ensure the health of livestock and other animals. Objectionable tastes, odors and suspended solids can cause animals to drink less than they should, potentially causing dehydration and higher levels of stress that may increase vulnerability to disease (Pfost et al., 2006). Clean water is especially important for dairy cattle which require five times as much clean water per day as the amount of milk produced (Faries et al., 1998).

Water quality is also critical to the health of the aquatic ecosystem and the plants and animals that live in the watershed. It is well known that the Snoqualmie River and its tributaries are home to many species of salmon – including established spawning populations of Chinook, coho, chum and pink salmon. Sockeye salmon are occasionally (though rarely) seen in the watershed as well. Several species of trout also reside throughout the watershed, including rainbow trout, as well as both resident (non-migratory) and sea-run cutthroat trout. Like salmon, steelhead (i.e., ocean-migrating rainbow trout) are limited to areas downstream of Snoqualmie Falls. Bull trout are also known to utilize the Snoqualmie River and portions of the Tolt River sub-basin in particular, but no known spawning population exists within the Snoqualmie watershed. Puget Sound Chinook salmon, bull trout and steelhead are listed as Threatened under the federal Endangered Species Act (ESA).

Salmon and related fishes (collectively referred to as salmonids) are not the only organisms that require clean water. Plants and animals that are far lower on the food chain are just as critical to watershed health, and to the health of salmonids. In fact, the abundance and species richness of certain aquatic insects are the key components of one measure of water quality, known as the Benthic Index of Biological Integrity (B-IBI). The abundance, distribution and diversity of plant and animal species, including microscopic algae, water-dwelling insects and many others, depend on clean water. Where water quality is poor, pollution-tolerant non-native 'invasive' species of plants and animals can take hold and out-compete native organisms, with cascading effects throughout the food chain.

2.2 Why do standards differ between water bodies in the same basin?

Different parts of the Snoqualmie support different beneficial uses; thus, the applicable water quality criteria need to change as well. For example, salmonids require cool water during spawning and incubation. Also, species like coho salmon and steelhead spend one or more summers rearing in streams before migrating to the ocean. Thus, certain waters that are considered to be critical for salmon spawning and rearing have a different standard for temperature than other areas where spawning is unlikely to occur.

Table 1 lists the beneficial use categories that apply to one or more water bodies in the Snoqualmie watershed, as defined in the WAC (WAC 173-201a). The uses are divided into Aquatic Life, Recreation, Water Supply and Miscellaneous categories.

The water bodies to which each category applies are listed in the third column. In general, the most protective categories (i.e., Char Spawning and Rearing, Extraordinary Primary Contact recreation) are associated with areas furthest upstream, including the North Fork and Middle Fork of the Snoqualmie River upstream of designated locations, and both forks of the Tolt River. Tributaries to waters of a particular use designation are subject to the same standards as the receiving water, unless otherwise specified in the WAC.

Map 2 (see Appendix) displays the applicable temperature and bacteria standards for each water course in the watershed. Refer to Table 1 to see how the spatial pattern of other standards varies from those for temperature and bacteria.

Table 1. Beneficial uses, applicable standards and associated water bodies in the Snoqualmie Basin (adapted from WAC 173-201a, including Table 602).

Aquatic Life Uses	Standards	Snoqualmie Waters
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.	**Temperature** (7-DADMax) 12˚C. **Dissolved oxygen.** (1-DMin) 9.5 mg/L **pH.** 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. **Turbidity.** Turbidity shall not exceed: 5 NTU over background when the background is 50 NTU or less; or 10 percent increase in turbidity when the background turbidity is more than 50 NTU.	North Fork Snoqualmie above and including Sunday Creek (at RM 17). Includes all tributaries above the junction. Middle Fork Snoqualmie above and including Dingford Creek (at RM 26). Includes all tributaries above the junction. Middle Fork Snoqualmie's tributaries at longitude -121.5629 and latitude 47.5389 North Fork Tolt above and including tributary at longitude -121.7775 and latitude 47.7183 (at RM 4). Includes all tributaries above the junction. South Fork Tolt above and including tributary at longitude -121.7392 and latitude 47.6925. Includes all tributaries above the junction. South Fork Tolt's unnamed tributaries at -121.7856 and latitude 47.6889. North Fork Creek (at North Fork Tolt RM 1) and unnamed creek at Longitude -121.8231 and latitude 47.7409 (Sec. 18 T26N R8E). All tributaries above junction. Cripple Creek (at Middle Fork Snoqualmie RM 24) and all tributaries. Pratt River (at Middle Fork Snoqualmie RM 16) and all tributaries. Taylor River (at Middle Fork Snoqualmie RM 20) and all tributaries.
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	**Temperature** (7-DADMax) 16˚C. **Dissolved oxygen.** (1-DMin) 9.5 mg/L **pH.** Same as above. **Turbidity.** Same as above.	Cherry Creek and tributaries from mouth to headwaters. Snoqualmie River and tributaries from and including Harris Creek to west boundary of Twin Falls State Park on South Fork (RM 9.1) South Fork Snoqualmie from west boundary of Twin Falls State Park (RM 9.1) to headwaters. Middle Fork Snoqualmie from mouth to Dingford Creek (RM 26).

Aquatic Life Uses	Standards	Snoqualmie Waters
by one or more salmonids; or foraging by adult and subadult 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.		North Fork Snoqualmie from mouth to Sunday Creek (RM 17). South Fork Tolt and tributaries from mouth to west boundary of T26N-R9E-Sec31 (RM 6.9). South Fork Tolt and tributaries from west boundary of T26N-R9E-Sec31 (RM 6.9) to headwaters, except for waters specifically listed in Table 602 as Char spawning and rearing. Tributaries to all waters designated Core summer salmonid habitat, or as Extraordinary primary contact for recreation. All lakes and all feeder streams to lakes, where reservoirs with a mean detention time greater than fifteen days are treated as lakes for use designation. ***All surface waters not listed in Table 602 lying within national forests, national parks and/or wilderness areas.***
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.	**Temperature** (7-DADMax) 17.5˚C. **Dissolved oxygen.** (1-DMin) 8.0 mg/L **pH.** 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. **Turbidity.** Same as above.	Snoqualmie River from mouth to junction with Harris Creek (RM 21.3). ***All other surface waters.***

Recreational Uses	Standards	Snoqualmie Waters
Extraordinary quality primary contact waters. Waters providing extraordinary protection against waterborne illness.	**Bacteria**. 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.	All waters listed above as Char Spawning and Rearing *and* South Fork Snoqualmie from west boundary of Twin Falls State Park (RM 9.1) to headwaters. Middle Fork Snoqualmie from mouth to Dingford Creek. North Fork Snoqualmie from mouth to Sunday Creek. South Fork Tolt and tributaries from mouth to west boundary of T26N-R9E-Sec31 (RM 6.9). South Fork Tolt and tributaries from west boundary of T26N-R9E-Sec31 (RM 6.9) to headwaters.
Primary Contact Recreation	**Bacteria.** 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.	Snoqualmie River and tributaries from mouth to west boundary of Twin Falls State Park on South Fork. ***All other surface waters not listed above or under the extraordinary quality primary contact water criteria.***

Water Supply Uses

Domestic Water, Industrial Water, Agricultural Water and Stock Water. All surface waters in the Snoqualmie basin are listed as providing all four beneficial water supply uses:

Miscellaneous Uses

Wildlife habitat, Harvesting, Commerce/Navigation, Boating, Aesthetics. All surface waters in the Snoqualmie basin are listed as providing all five beneficial miscellaneous uses:

2.3 What are the applicable water quality criteria in the watershed?

The report focuses on the criteria for water quality parameters associated with aquatic life uses, as well as bacterial criteria. The criteria vary by the applicable beneficial use category (Table 1). See the text below for further explanation of each standard.

Temperature

High water temperature can be directly lethal or stressful to organisms, including salmonids. High temperature can also create or exacerbate other water quality problems. For example, cold water is able to hold more oxygen in its dissolved form – the form utilized by most aquatic organisms. As water warms, dissolved oxygen levels drop. High temperature - when coupled with high levels of nutrients - can also accelerate decomposition of organic matter, which in turn can cause oxygen levels to drop.

The temperature standard is computed as the 7-day average of the daily maximum temperatures (7-DADMax), i.e., the arithmetic average of seven consecutive measures of daily maximum temperatures[5]. The use of the 7-DADMax instead of an instantaneous temperature maximum is intended to reflect the fact that most aquatic organisms can tolerate a short period of high temperature, whereas persistently warm water is more likely to cause harm. If a water body is naturally warmer than or within 0.3˚C of the criterion for that water body, human caused increases (considered cumulatively) must not increase that temperature by more than 0.3˚C. Additional limits on human-caused temperature changes are described in the WAC.

In addition to the beneficial uses and corresponding water bodies listed in Table 1, the WDOE has designated Supplemental Spawning/Incubation Criteria for water temperature in certain areas where salmonid spawning and egg development occurs. These criteria apply when the standard temperature criteria are insufficient. In these tributaries and mainstem reaches, the 7-DADMax criterion is 13˚C during specified periods. These reaches are primarily in areas where the default criterion would be 16˚C, and include portions of the Snoqualmie mainstem within Chinook spawning areas, lower portions of the Tolt River (including segments of each fork), and reaches in Cherry Creek, Patterson Creek, Griffin Creek and the Raging River. These special temperature reaches are highlighted in Map 2 and each applicable sub-basin map.

Dissolved oxygen

Dissolved oxygen (DO) concentration is an important measure of the ability of water to support life. The DO criterion is computed as the lowest 1-day minimum concentration (abbreviated as 1-DMin). Concentration is measured in units of milligrams per liter (mg/L), the equivalent of parts-per-million. As in the temperature case, limits on the amount of cumulative change caused by human activities are articulated in the WAC.

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[5] To compute the value for a particular date, the daily maxima from each of the three previous days and each of the three following days are used in the calculation.

Like temperature, dissolved oxygen criteria are set based on the needs of fish. Salmon use the waters downstream of Harris Creek primarily to migrate in and out of other areas with limited use for spawning, thus a level of 8.0 mg/L is sufficient. However, in other areas where summer rearing, spawning, and egg incubation occurs, salmon need oxygen levels of 9.5 mg/L for optimum growth.

pH

The acidity or alkalinity of a substance is typically expressed as the pH, or the negative logarithm of the hydrogen ion concentration. The pH of a water body reflects the equilibrium in acid-base concentration that results from a combination of dissolved compounds, salts and gases. A pH of 7.0 is considered 'neutral', while lower values are acidic, and higher values are alkaline. Excess divergence from near-neutral values can cause substantial harm to aquatic life directly, or by affecting the toxicity of other substances. The effect of pH on toxicity is the reason why some water quality criteria (such as those for ammonia) depend in part on the pH of the water (WAC 173-201A-240). State standards indicate that the range for pH in the Snoqualmie should be between 6.5 and 8.5 standard units.

Fecal coliform bacteria

The State of Washington uses the concentration of fecal coliform (FC) bacteria colonies as an indicator of human health risk associated with a number of other types of infectious organisms. These classes of bacteria are associated with the digestive systems of humans and other warm-blooded animals and are thus indicative of the presence of excess fecal matter in surface waters. The FC standard is composed of two parts: a limit on the geometric mean concentration[6], and a second, higher limit on the concentration of no more than 10% of samples. This latter component is often referred to as the 90% exceedance limit. The use of the geometric mean in the first component of the standard (instead of the arithmetic mean) has the effect of discounting the influence of outlier values (i.e., values that are very different from most other values). Thus, the second component of the standard focuses on the frequency of high concentrations in a particular area, even if more typical concentrations are below the geometric mean criterion.

FC concentration is somewhat problematic as an indicator of direct risk to human health. This is in part due to the fact that some bacteria that register as FC in water quality testing are not in fact associated with fecal matter. For example, at least one genus in the fecal coliform group, *Klebsiella,* is known to thrive in the presence of industrial waste waters (DuFour 1984). Also, some studies suggest that FC concentration is not the best available indicator of risk. In studies that compared total FC, *Escherichia coli* (a type of FC) and enterococci as indicators of observed human gastrointestinal illness, the other two showed fairly strong correlations with illness (i.e., they were good predictors), whereas total FC showed no statistically valid correlation (DuFour 1984). Nevertheless, most State water quality standards – including Washington's – are based on FC, and high levels of FC are certainly not a good sign for water quality. There are also tests available to determine the specific type

[6] Whereas the arithmetic mean is simply the average of a set of values, the geometric mean is the N^{th} root of N values. So, the geometric mean of two values is the square-root of their product.

of FC in a sample, and what kind of organism it originated from. Thus, it is possible to find out whether FC associated with human waste or bovine waste, for example, are in a water body, but the tests themselves are fairly expensive, and the interpretation of results is a source of disagreement among experts (R. Svrjcek, WDOE, personal communication). This type of testing has been conducted in the Kimball Creek basin (Herrera Environmental Consultants, 2004). Although the tests cannot clearly show the proportion of bacteria coming from different sources at this time, DNA analyses can be useful to identify the range of sources in general, and the specific source when we encounter consistently high bacteria values through ambient water sampling. Some of the studies reviewed for this report tested water samples for both FC and *E. coli*.

Nutrients

The primary nutrients of concern are nitrogen and phosphorus, both of which are naturally present in the ecosystem. The State has established a standard for ammonia-nitrogen that is pH and temperature dependent. There are no general water quality standards for total nitrogen or phosphorus as they would have to be developed on a site-specific basis with a better understanding of natural levels. However, seasonal and spatial patterns in nutrient levels can be informative for identifying likely sources of contamination. High levels of nutrients can trigger algal blooms and subsequent die-offs that can cause low DO levels due to decomposition. Low DO, in turn, can directly cause fish kills or render water bodies uninhabitable by fish or other organisms.

The Snoqualmie River Total Maximum Daily Load Study (Joy, 1994) established guidelines for mainstem and tributary concentrations of certain nutrients. We refer to these guidelines in lieu of standards, where applicable.

Other parameters

The aquatic life criteria associated with toxic and radioactive substances apply equally to all surface waters. These include a variety of elements and compounds, including ammonia, certain metals, polychlorinated biphenyls (PCBs) and other substances (WAC 173-201A-240, Table 240(3)). The table of criteria for toxic and radioactive substances is not reproduced in this report.

Turbidity can be thought of as the cloudiness of the water due to the suspension of sediment and various other small particles. Turbidity criteria are defined relative to the background or 'natural' turbidity level. The criteria are stated in nephalometric turbidity units (NTUs), a measure of light-penetration into water (or into another liquid). Excess turbidity can affect rates of photosynthesis, and high levels of turbidity can also have direct impacts on the ability of organisms to breathe due to the clogging of gills. As one would expect, high turbidity can be caused by a high amount of fine sediment inputs that can also smother incubating fish eggs in the stream bed.

In this report we have not analyzed turbidity data due to the lack of sufficient information on background turbidity levels in each sub-basin. Future studies in targeted sub-basins may include analyses of turbidity data.

The State also defines criteria for Total Dissolved Gas (TDG), but these criteria are applied primarily to hydroelectric dams. Dissolved gas is a measure of the pressure of dissolved gas in the water column. When spillway water from a dam plunges into the tailrace, nitrogen is forced into the water at higher than normal levels. This condition, called super-saturation, occurs when dissolved gas pressure in the water actually exceeds the atmospheric pressure. Super-saturation of gases may cause embolism and death in fish, much like a SCUBA diver who falls victim to 'the bends' due to a too-rapid ascent.

While there are hydroelectric facilities in the basin (Puget Sound Energy's Snoqualmie Falls project and Seattle City Light's facility associated with the South Fork Tolt River water supply system), neither project has the type of configuration that is typically associated with TDG. Gas super-saturation may occur naturally at the base of Snoqualmie Falls, but this would not be considered an impairment.

2.4 What is the State's anti-degradation policy?

The second key component of the State's water quality standards is the anti-degradation policy. The policy strives to maintain the highest possible quality for Washington's surface waters, while allowing for limited amounts of degradation by human activities that are deemed necessary and in the "overriding public interest" (WAC 173-201A-300). Such activities are generally limited to NPDES permits, State waste discharge permits, Federal Clean Water Act Section 401 water quality certifications, and other water pollution control programs authorized or administered by WDOE. The policy defines levels of degradation that may be allowed for several water quality parameters, including temperature, pH, DO, turbidity, bacteria and toxic or radioactive substances.

The policy identifies three tiers of protection with corresponding levels of allowable degradation. Tier I applies to all waters and all sources of pollution, and is used to ensure existing and designated uses are maintained and protected. Tier II is used to ensure that waters that are currently of a higher quality than the applicable standards are not measurably degraded, except where deemed necessary and in the overriding public interest. Finally, Tier III is used to prevent the degradation of waters formally listed as 'outstanding resource waters' and applies to all sources of pollution. Tier III is further divided into categories of waters where no degradation whatsoever is permitted, and those where minimal degradation may be permitted in specific circumstances. As of the writing of this report, WDOE has not finalized the process for the nomination and evaluation of Tier III waters in the State and thus none have been designated (R. Svrjcek, personal communication, October 2007).

2.5 When is a water body considered impaired?

One of the most recognized sources for a list of impaired waters is the so-called "303(d) list", which refers to Section 303 of the Federal Clean Water Act. However, the term "303(d) listed water" is often misused to refer generally to any waters identified by the State as impaired, regardless of whether a clean-up plan is already in place. In fact, the term correctly applies only to those waters that are considered polluted for a particular parameter, but lack a clean-up plan (see Category 5, below).

Instead of listing only impaired waters, the State of Washington assesses and reports on all available water quality data through its Water Quality Assessment process. The State's Water Quality Assessment assigns a water quality status to specific locations using five categories defined by the EPA. When a water body is impaired, the State must address the pollution problem by preparing a Total Maximum Daily Load (TMDL or water cleanup plan) or other similar mechanism. A TMDL includes a written, quantitative assessment of the water quality problem and the pollutants causing the problem. The Water Quality Assessment uses the following five categories to describe the health of Washington waters:

Category 1: Meets clean water standards. Category 1 waters meet standards for certain pollutant(s) for which they have been tested. Importantly, these waters may still be impaired for other pollutants, or, a different reach of the same stream may not qualify for a Category 1 listing.

Category 2: Waters of concern. Category 2 waters show some evidence of a water quality problem, but not enough to show a clear violation of state standards. Some of these waters may be the focus of studies by Ecology.

Category 3: No data. Any water body segment that has not been tested is assigned to this category.

Category 4: Polluted waters that do not require a TMDL. Category 4 is for waters that have pollution problems that are being addressed in one of three ways:

- "Category 4a: has a TMDL" is for water bodies that have an approved TMDL in place and are actively being implemented. The mainstem Snoqualmie and several tributaries fall into this category for some pollutants.
- "Category 4b: has a pollution control plan" is for water bodies that have a non-TMDL plan in place that is expected to solve the pollution problems. Such plans must have many of the same features as TMDLs and legal or financial guarantees must be in place to ensure that they will be implemented.
- "Category 4c is impaired by a non-pollutant" is for water bodies impaired by causes that cannot be addressed through a TMDL. These impairments include low water flow, stream channelization, and dams. These problems require complex solutions to help restore streams to more natural conditions.

Category 5: Polluted waters that require a TMDL. This is the official 303(d) list of impaired water bodies. Placement in this category means that WDOE has data showing that the water quality standards have been violated for one or more pollutants, and there is no TMDL or other qualifying pollution control plan that addresses the problem. TMDLs are typically required for the water bodies in this category.

A single water body may be listed in several categories simultaneously. For example, a location may be in Category 5 for one pollutant and in Category 2 for another.

Table 2 shows the water bodies listed under Categories 2, 4a and 5 within the Snoqualmie Basin. There are no waters listed under categories 4b and 4c. A river or stream is included in the table if one or more reaches fall into the category for a specific pollutant. Certain reaches of streams in the Snoqualmie watershed fall into Category 1, but in many cases an adjacent reach of the same stream is in an impaired category for the same pollutant. Thus, Category 1 water bodies are not shown here.

Table 2. Water Quality Assessment listings (2008) for the Snoqualmie Basin – Categories 2 (at risk), 4a (TMDL in place), and 5 (TMDL required).

Category	Pollutant	Waters
Category 2	Temperature	Snoqualmie River (also listed as Category 5) South Fork Snoqualmie River Tokul Creek
	Fecal coliform	Harris Creek Lynch Creek (S. Fork Tolt River sub-basin) North Fork Snoqualmie River Raging River Snoqualmie River South Fork Snoqualmie River Tate Creek (N. Fork Snoqualmie River sub-basin) Tolt River
	pH	Crazy Creek (S. Fork Tolt River sub-basin) Lynch Creek (S. Fork Tolt River sub-basin) Patterson Creek Raging River (high pH) Snoqualmie River South Fork Snoqualmie River (also listed as Category 5) Stossel Creek Unnamed Creek (Tributary to Cherry Creek)
	Total Phosphorus	Hull Lake (Griffin Creek sub-basin) Lake Marcel (Harris Creek sub-basin)
Category 4a	Fecal coliform	Ames Creek Cherry Creek Griffin Creek Kimball Creek Middle Fork Snoqualmie River Patterson Creek Snoqualmie River Tokul Creek Tuck Creek
	Dissolved oxygen	Kimball Creek Patterson Creek Snoqualmie River South Fork Snoqualmie River
Category 5	Temperature	Snoqualmie River (also listed as Category 2)
	pH	Cherry Creek Deep Creek (N. Fork Snoqualmie sub-basin) South Fork Snoqualmie River (also listed as Category 2)
	Fecal coliform	Lynch Creek (S. Fork Tolt River sub-basin)
	Dissolved oxygen	Snoqualmie River

Note that in the case of rivers and streams, the listings apply to specific reaches and not necessarily to the entire water body. The most recent Water Quality Assessment lists segments of water bounded within the Section/Township/Range where the impairments were found. Ecology may be changing this system in coming years.

Due to the lack of sampling in many areas, the list of waters identified above does not capture all areas that suffer from impaired water quality. For example, this report includes information on potential impairment of several streams for pollutants that are not on the list at this time. The State's official list is typically updated every two years. The WDOE issued a 2008 revision that also meets the requirements of the 2006 update cycle. The candidate 303(d) list for 2008 was submitted to the EPA for review and approval in June 2008. Table 2 is based on the proposed 2008 list.

3 SNOQUALMIE WATER QUALITY IMPAIRMENT

An individual water body may become impaired due to multiple reasons. In some cases, the source of the pollution is obvious (coming from a pipe or ditch for example), and the cause-effect relationship can be determined with some certainty. However, pollution sources are frequently hard to pin down because of the multitude of human activities and natural conditions that combine to cause impairments. Also, the interactions of different pollutants or conditions, potentially attributable to different sources, can cause water quality impairment to become more severe.

This section summarizes some of the primary sources of water quality impairment in the Snoqualmie watershed. They are not presented here in any particular order. Detailed discussions of each pollution pathway are not presented in this report. Additional information can be found in the TMDL effectiveness report (WDOE, 2008).

3.1 Agriculture practices

Changes in agriculture practices, especially in the past 10 years, have led to improvements in water quality in many areas. For example, the implementation of Farm Plans and associated Best Management Practices (BMPs) help to exclude livestock and/or manure input from streams. Still, due to the nature of agricultural activities and their prevalence in the Snoqualmie Valley, water quality is degraded in many agricultural areas.

Recently, there was a change to King County's Livestock Management Ordinance that requires livestock to be fenced a minimum of 25 feet aware from water bodies. Though exclusion fencing is required for new livestock activities in the Snoqualmie, there are many older fences that are located less than five feet from the edge of a water body.

The pollutants most commonly associated with agricultural areas are bacteria, nutrients and excess fine sediment. Each of these can contribute to other impairments, such as low DO. In addition, streams and drainage channels in agricultural areas often lack adequate riparian vegetation to maintain low water temperatures. This is not simply a function of shade, but also the fact that intact riparian vegetation lowers wind speed and thus reduces heat exchange with the atmosphere (Naiman et al., 1992).

Bacterial contamination of surface waters in agricultural areas is typically the result of poor manure storage operations, improper manure application to fields, and/or direct livestock access to streams. Typically, manure is stored during the winter for later field-application during the growing season. Bacteria can remain viable for a long time in fecal matter under the right conditions. Viable fecal coliform bacteria have been successfully cultured from fecal deposits after as long as one year (Thelin and Gifford 1983, as cited in Drapcho, C.M. and K.B. Hubbs, unpublished manuscript, 2003). With the large number of farms located in the floodplain of the Snoqualmie River and its tributaries, high winter flows can bring manure into contact with surface waters, particularly where storage practices are insufficiently protected to withstand flooding, or when flood flows occur during the growing season.

A research study of controlled manure application to fields in Louisiana compared the fecal coliform contribution from manure deposited by cattle and manure distributed as a fertilizer (Drapcho, C.M. and K.B. Hubbs, unpublished manuscript, 2003). The applications were followed by simulated rain events and water quality testing for bacterial concentration. The study found that mean FC counts in surface waters were much higher from the plots where manure had been distributed as fertilizer. On the day of the rain event, concentrations were 15-times higher, while after 30 days the concentrations were two times higher. The absolute concentrations are not reported here as the study was performed on small test plots with no vegetative buffer strips, but the findings highlight the importance of proper management with respect to fecal coliform sources even in the absence of livestock.

The type of livestock also has a bearing on challenges for manure management. For example, dairy cows require a great deal of water and produce a wet manure product that is more difficult to contain, whereas horses produce a much drier product. While dairies dominated the agricultural landscape of the Snoqualmie Valley for many decades, today only a handful remain in operation.

Farming disturbs soils, creating the potential for pollution problems. The intensity of disturbance varies widely between different types of crops and practices. Farming too close to a stream or river increases the chance that fertilizers, pesticides, sediment, or excessive sunlight will cause water quality problems. Maintaining undisturbed, vegetated buffers along streams and other drainage features can substantially reduce the amount of sediment and nutrients that enter streams, while also lowering stream temperatures. However, most farms are relatively small in the Snoqualmie watershed and drainage features are numerous. Thus, it is not always economically feasible to set aside wide buffer areas, both due to lost production and to the effects of shade on growth rates in cultivated areas. Nevertheless, many farms in the valley have planted riparian areas in collaboration with organizations such as Stewardship Partners, the King Conservation District (KCD) and King County's Agriculture Program.

Nutrient inputs from agricultural areas are typically associated with manure and fertilizer application. Certain application techniques – such as soil injection in place of spraying – can substantially reduce the amount of fertilizer that is needed and promote better retention and reduced nutrient runoff. Many farms in the area have adopted organic farming practices and have thus substantially reduced the amount of fertilizers, herbicides and pesticides that are applied to crops, but all fertilizer, organic or not, can be overused.

Agriculture in the Snoqualmie Watershed

Farms in the Snoqualmie Watershed are a major component of King County's agricultural economy. Concern about the loss of farmland came to a head in the 1970s and led to the successful Farmland Preservation Program (FPP) bond issue in 1979, which has funded the purchase of farmland development rights on over 13,000 acres within the County, with nearly 5,000 acres in the Snoqualmie Watershed. The FPP became the first voter-approved measure in the nation to protect farmland in a metropolitan area. By purchasing the development rights, the FPP keeps farmland open and available through covenants that restrict development and limit the properties' uses exclusively to agriculture and open space. The covenants "run with the land" in perpetuity so the land is protected regardless of ownership.

In 1985, the county first designated its Agricultural Production Districts (APDs), which cover roughly 42,000 acres. The Snoqualmie APD (which is divided into North and South portions) covers over 14,000 acres. APDs are contiguous blocks of farmland where agriculture is supported through the protection of agricultural soils and related support services and activities. All lands within APDs are designated primarily for agricultural activities with a zoning classification of either A-10 or A-35, i.e., one residential unit per 10 or 35 acres, respectively.

However, despite the land conservation accomplished through the FPP and the designation of the APDs, not all of the land is farmed. King County conducted a survey of agricultural activity types in the watershed in 2003 and again in 2006. The 2006 survey was limited to the APD. Based on the 2006 survey, approximately 23,000 acres of the 42,000 acres designated as APDs are being actively farmed. A 2003 survey of the Rural Area identified an additional 25,000 acres in active agriculture outside the APDs.

The so-called 'windshield survey' method applied in both studies classified farms in King County into a variety of categories, with different designations applied in the two surveys[7]. Aerial photographs were consulted to confirm activity types, but due to the nature of the methodology, some farms may not have been classified accurately. Furthermore, the agricultural landscape is rapidly changing. Several dairies have closed in recent years and the land has been converted to other agricultural activities, such as cultivation of organic food crops.

The 2003 survey of the Snoqualmie included parcels totaling 15,568 acres, with roughly 54% of surveyed agricultural acreage located within the APD (Table 3). The results show that approximately 85% of surveyed farmland was in dairy or livestock activity, with the balance in horticulture, combined and unspecified agricultural use. Dairy acreage is located almost exclusively within the APD. However, note that in the 2003 study, only 8,370 acres were surveyed of the roughly 14,500 located within the Snoqualmie APD.

Areas zoned for agriculture are generally confined to the APD, with the exception of approximately 250 acres nestled between the South Fork and Middle Fork Snoqualmie, in the vicinity of North Bend. However, as Table 3 clearly shows, agriculture is prevalent in many areas of the watershed that are not zoned for agriculture, falling mostly within areas zoned for low-density residential use.

[7] Not all agricultural properties were able to be included in the survey.

Table 3. Agricultural activity types in the Snoqualmie watershed, based on windshield surveys (King County, 2003).

Agriculture Type	Non-APD Agriculture	APD Agriculture	Total
Livestock Properties	6,000	5,362	11,362
Dairies	34	1,959	1,993
Horticultural Properties	522	1,049	1,571
Unspecified Agriculture	427		427
Multiple (Horticulture and Livestock)	216		216
Grand Total	**7,198**	**8,370**	**15,568**

The 2006 survey of the APD classified agricultural activities into more refined categories (Table 4).

Table 4. Agriculture types within the Snoqualmie APD (King County, 2006)

Agriculture type	APD (acres)
Livestock, Forage	4,308
Forested, Upland	2,368
Other (roads, buildings, water bodies, buffers, etc.)	1,936
Market Crops (Produce)	1,138
Unmanaged	1,009
Marsh or Wetland Preserve	905
Managed Field, Grassland	785
Unknown	652
Tree Farm	419
Corn	331
Too wet to farm	276
Nursery	247
Sports, Recreational	182
Orchard	1
Grand Total	**14,558**

Maps 3 and 4 aggregate the data from Tables 3 and 4 to show the distribution of agricultural activity types in the Snoqualmie Watershed.

3.2 Urban/suburban stormwater

The term 'stormwater' typically refers to the surface runoff that occurs in developed landscapes during and after rain events. Impervious surfaces, such as roads and rooftops, prevent the infiltration of rainwater into the soil, causing water to flow into both constructed and natural drainage features, collecting a variety of pollutants along the way. In highly developed landscapes, the term is something of a misnomer since even modest rain events can cause a substantial amount of runoff that would otherwise be easily infiltrated in a natural setting. Just one inch of rain on a 1,200 square-foot rooftop adds up to nearly 750 gallons of runoff.

Stormwater from areas of urban, suburban and industrial development can contain a wide variety of pollutants, depending on land-use and drainage patterns in the area. Motor oil, heavy metals from brake pads, lawn fertilizers, pet waste, detergents, paints and many other substances have been found in stormwater. In areas like the Snoqualmie watershed where septic systems represent the majority of residential sewage treatment in some areas, poorly treated sewage from aging or failing systems may also accumulate in the stormwater system where drain fields are in close proximity to drainage features.

The quality of urban stormwater is often at its worst when the first autumn rains flush accumulated pollutants into streams and rivers via open ditches and pipes. This first flush of stormwater has been implicated in pre-spawning mortality of coho salmon in various Puget Sound streams. Ongoing research has found strong correlations between land-use indicators (such as the density of arterial roads in a drainage basin) and the rate of pre-spawn mortality in coho salmon. In 2006, nearly all of the returning coho salmon in Piper's Creek in northwest Seattle died prior to spawning and exhibited clear symptoms of neurological distress (Nathaniel Scholtz and Blake Feist, National Oceanographic and Atmospheric Administration, Northwest Fisheries Science Center, personal communication). The Wild Fish Conservancy[8] has also compared rates of pre-spawning mortality in different types of tributary basins, including several rural tributaries in the Snoqualmie watershed. The rates of mortality in these tributaries was a small fraction of those found in urban settings; for more information, see Washington Trout (2004).

Apart from the direct contaminant load, stormwater discharge can also have indirect effects on water quality. In the absence of adequate detention facilities, the discharge rate in streams that receive run-off can substantially exceed natural rates. High flows erode stream banks, thereby contributing to sediment load and turbidity in downstream areas while also exacerbating other flood-related sources of contamination.

Modern stormwater management practices are intended to address both the quality and quantity of stormwater discharges. New design standards and programs represent a substantial improvement to past efforts in terms of reducing and metering runoff through infiltration and detention, and in improving water quality through enhanced treatment. Thus, new developments in many localities are subject to standards that reduce (but do not eliminate) the stormwater impacts of additional development compared to those in older communities or neighborhoods. Retrofitting old stormwater systems (e.g., catch basins, storm sewers and ditches), many of which were designed for the single purpose of water conveyance rather than treatment, is an expensive and complicated task, but one that needs to be addressed.

[8] Formerly, Washington Trout.

To help solve the stormwater pollution problem, many urbanizing areas in Washington State are now required to secure National Pollution Discharge Elimination System (NPDES) permits for their municipal storm sewer systems. King County recently received an updated Phase I Municipal Stormwater Permit that includes the Snoqualmie watershed. Currently, Duvall is the only city in the Snoqualmie watershed that is required to develop a similar program through its Phase 2 municipal stormwater permit. It is likely that the cities of Carnation, Snoqualmie, and North Bend will receive these permits in the future as their populations expand[9]. The program requires municipalities to perform a number of activities to find, resolve, and prevent stormwater pollution including:

1. Public Education and Outreach,
2. Public Involvement and Participation,
3. Illicit Discharge Detection and Elimination,
4. Construction Site Storm Water Runoff Control,
5. Post-Construction Storm Water Management, and
6. Pollution Prevention and Good Housekeeping.

Implementation of these program components could make a substantial difference in the Snoqualmie watershed in localized areas, whether as part of a specific permit requirement or as a voluntary, proactive program element by local governments. For example, illicit discharge elimination and raising public awareness about the impacts of household chemicals, fertilizers, pet waste and septic systems could result in significant improvements in water quality, particularly in some of the smaller tributaries in rapidly developing areas.

Compared to the more urbanized areas of Puget Sound, stormwater may seem like a minor issue in the Snoqualmie watershed. However, significant new development is anticipated in the future and localized impairment of tributaries in particular is already a concern in more densely developed areas. As road networks and impervious surfaces increase, the likelihood of more pronounced stormwater effects will increase as well.

3.3 Waste water treatment plants

Effective waste water treatment is a lynchpin for the protection of water quality and human health. Until recently, there were three waste water treatment plants (WWTP) in the Snoqualmie watershed, operated by the cities of Duvall, Snoqualmie and North Bend. A fourth plant in Carnation came on line in spring 2008. Formerly, the Echo Glen juvenile rehabilitation facility near Our Lake in the Raging River sub-basin operated its own treatment plant that had numerous problems and violations. Through a cooperative agreement with the City of Snoqualmie, the facility's waste water is now transferred to the Snoqualmie plant for treatment. Each of these WWTPs must receive an NPDES permit from the WDOE.

[9] In fact, the City of Snoqualmie has a larger population than Duvall, but the opposite was true at the time of the 2000 census on which the permit obligation is based.

Pollutants associated with wastewater plant discharges may include nutrients, bacteria and organic matter, among other substances. The combination of these pollutants – especially without adequate dilution – may also cause low levels of dissolved oxygen by increasing the demand for oxygen as part of decomposition processes, often referred to as Biological Oxygen Demand (BOD).

In addition to these standard pollutants associated with wastewater, the potentially serious effects of endocrine disrupting chemicals (EDC) in surface waters has emerged as a major concern in recent years. The most common EDCs found in wastewater are reproductive steroid hormones (especially estrogens) and the biodegradation products of estrogenic compounds[10]. The endocrine system is made up of glands throughout the body, hormones which are made and secreted by those glands into the bloodstream, and receptors in various organs and tissues which recognize and respond to the hormones. The system regulates a wide range of biological processes, including control of blood sugar, growth and function of reproductive systems, regulation of metabolism, brain and nervous system development, among others. For people, fish and wildlife, disruptions in hormonal balance at critical life stages may have long-lasting effects. This report does not include any discussion of EDCs specific to the Snoqualmie watershed, but it is an emerging issue that may merit attention in the future.

WWTPs are regulated facilities that must adhere to specific discharge limits for particular pollutants. In the Snoqualmie watershed, the allowable levels of discharge are detailed in each permit and depend in part on the receiving water and on the number of other permitted facilities. WDOE considered the level of allowable dilution for plant discharges, and thus the permitted concentration of pollutants at the end of the pipe.

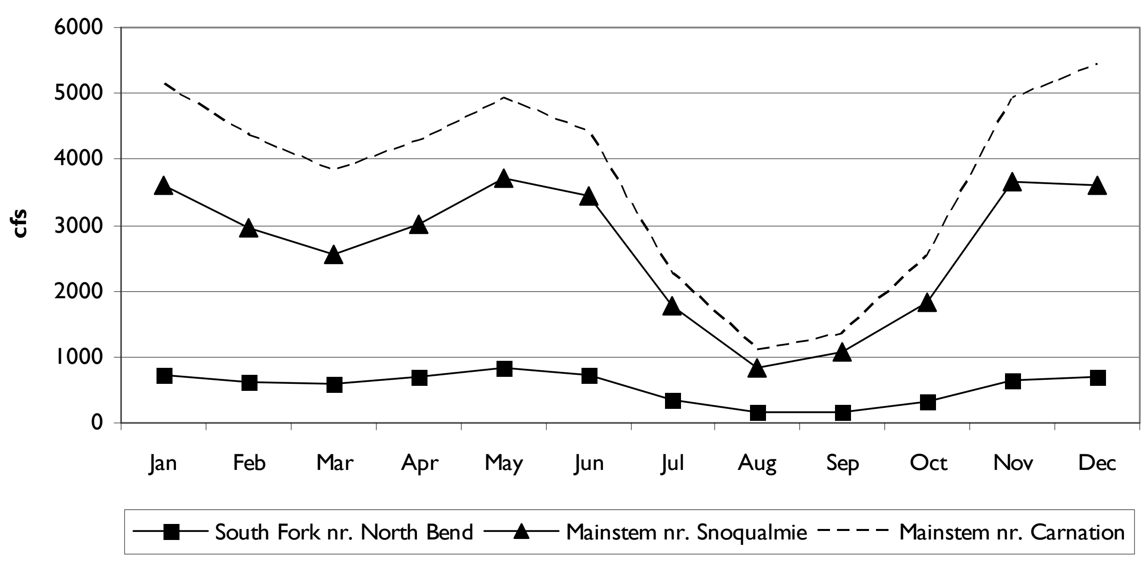

Figure 1. Mean monthly flow in the South Fork Snoqualmie and two locations on the mainstem (data from USGS gages 12144000, 12144500 and 12149000).

[10] http://www.epa.gov/nrmrl/EDC/projects/edc_ww.htm

As part of the permitting process, dilution is calculated for both chronic and acute 'mixing zones' in the vicinity of the outfall location. Among the four plants in the basin, the Duvall facility benefits from the greatest amount of natural dilution by discharging into the mainstem Snoqualmie in the lower basin. The City of Snoqualmie's plant discharges into the mainstem upstream of Snoqualmie Falls, and the North Bend plant discharges into the South Fork Snoqualmie and thus benefits from the least amount of dilution among these plants. Figure 1 shows the mean monthly flow at two locations along the mainstem and one in the South Fork Snoqualmie.

The Carnation WWTP produces high quality water treated to reclaimed-water standards before being conveyed by pipe to the Chinook Bend natural area and discharged into a wetland on the site. The water passes through the wetland area before discharging into the Snoqualmie River. An auxiliary discharge point is also available for direct discharge into the river, bypassing the wetland phase. Increasing the infiltration of water through the wetland should provide additional purification of the effluent. The Snoqualmie WWTP also treats water to a reclaimed-water standard making it suitable for use in landscape applications. During the summer in particular, the majority of the plant's discharge is used to water the Snoqualmie Ridge golf course. Although the Duvall WWTP does not currently produce reclaimed water, it uses a similar technology and produces effluent with low levels of solids, bacteria, and biochemical oxygen demand (BOD).

WWTPs settle out incoming solids and turn soluble organic matter into more solids. Those settled materials are further processed and converted to 'biosolids'. Biosolids can in some cases be used as fertilizer (such as those used in some forestry applications in King County), or they are incinerated or disposed of in landfills. Biosolids that meet state and federal disinfection standards can be used as fertilizer. Only state-permitted farms or forests can take Class B biosolids, the most commonly-produced grade. Class A biosolids, which are more-extensively treated and tested, may be used anywhere. Biosolid applications have occurred in the Cherry Creek, Griffin Creek, Tokul Creek and Tolt River basins in the past ten years and are still occurring in some of those basins today.

The growth of our communities and higher expectations for the level of wastewater treatment have led to the use of secondary and tertiary advanced treatment options that are designed to remove a high percentage of organic matter prior to discharge. In general, this is accomplished through the utilization of bacteria that are naturally present in solid waste in combination with aeration to break down harmful constituents. To complete the treatment process, some plants disinfect the remaining effluent in order to kill harmful bacteria through the use of chlorine, ultraviolet radiation, or other methods. Since chlorine itself is harmful to aquatic life, dechlorination of effluent is required prior to discharge in many areas.

The wastewater treatment process is a fairly complex one that can be compromised by a variety of factors. In many older communities with aging infrastructure, infiltration and inflow (often referred to in combination as "I/I") can overwhelm treatment plants by increasing the amount of water that enters the system, severely reducing the ability of the plant to produce clean effluent. Infiltration refers to groundwater that leaks into the sewer system through holes in pipes, joint failures, defective connections and other openings. Inflow refers to stormwater that enters the system through a variety of pathways, including catch basins and drains that have not been separated from the sewer system, illicit connections, manhole covers and others.

The City of Snoqualmie has recently completed extensive repairs to its wastewater conveyance system to address I/I (Councilmember Charles Peterson, personal communication). Prior to these repairs, flow through the City of Snoqualmie's sewer system during high-flow conditions was occasionally as much as three times higher than during normal dry-weather flows due to I/I (City of Snoqualmie, 2003). Since effective treatment relies on adequate settling and contact time with the treatment medium, excess I/I can significantly reduce the quality of plant effluent.

3.4 Waste water treatment - Septic systems

Large portions of the Snoqualmie Watershed are rural and do not have municipal or private WWTPs. Instead, homes, public institutions and businesses alike utilize on-site sewer systems (OSS), commonly referred to as septic systems. For example, as of 2001, the City of North Bend's WWTP served only 39% of the population within the City and surrounding Urban Growth Area (City of North Bend, 2001). The City of Snoqualmie's sewer system serves the entire incorporated area. Surrounding unincorporated areas are not likely to receive service in the near future. Duvall's WWTP serves the entire incorporated area and any newly incorporated areas will be required to connect to the system (City of Duvall, 2006). Similarly, the Carnation plat serves the entire city limits and is designed to allow some expansion in the future.

Septic systems come in a variety of designs and with a range of treatment options. All septic systems include a primary treatment phase analogous to the same phase in a WWTP, where solids are separated from liquid waste via flotation of lighter matter and settling of heavier substances. The remaining 'clear' effluent is then digested and transformed by bacteria that are naturally present in the effluent and in the soils of the drainfield. In the simplest systems, effluent leaves the primary septic tank and flows through perforated pipes in a drainfield before seeping into surface waters or into the local groundwater table. More advanced systems can add a variety of components following primary treatment, including aeration, recirculation, sand filters, ultra-violet disinfection and other choices. All septic systems must be pumped on a regular basis to remove solids from the tank. More advanced systems also require inspection and maintenance of other components, such as filters and pumps.

A variety of factors can compromise the ability of a septic system to do its job. Some are related to how they are used. These include: lack of maintenance, excessive use relative to capacity (e.g., home-based daycare facilities with only residential septic systems), excessive waste volume (e.g., use of garbage disposals introduces too many solids), excessive waste strength (e.g., too many oils, soaps, toilet paper), use of additives and chemicals, and potentially the use of water softeners. Other factors may not be as obvious to some system owners, such as inappropriate use of the drainfield (e.g., soil compaction, tree planting), poor soils (e.g., too porous or not porous enough) and poor drainfield location, such as when the field also receives water from downspouts, surface flow or excessive groundwater flow. Moreover, these factors are exacerbated if the vertical separation between the drainfield and underlying layers of impermeable soils below are inadequate. The amount of vertical separation – combined with soil type - essentially determines the capacity of the drainfield to provide treatment.

Perhaps the biggest challenges of owning septic systems are the lack of knowledge about appropriate use and maintenance, and the out-of-sight, out-of-mind nature of the problem. At times, homeowners may have no idea that the system is malfunctioning until raw sewage backs up into the house or seeps to the surface of the drainfield. In these scenarios, the tank or drainfield has likely been malfunctioning for an extended period, sometimes placing both surface water and groundwater quality at risk. This is especially true in areas where the 'buffer' between the drainfield and the receiving water is minimal or inadequate.

A single, malfunctioning residential septic system may not noticeably impair surface water quality, unless of course it is located in close proximity to a water course. However, the density of many residential areas – even those that are technically 'low-density' – means that some surface (or ground) waters may receive effluent from numerous malfunctioning systems. Also, the natural ground and surface water drainage network can have the effect of concentrating effluent from a broad area.

Since septic system use is fairly consistent year-round for residential users, surface water contamination is often detected as high bacterial concentration in the late summer and early fall when natural flows and resulting dilution are at their lowest.

Unfortunately, many septic systems do not effectively eliminate nutrients in the waste stream. Thus, while a well-functioning systems may virtually eliminate bacteria from entering receiving waters, the effluent may still contain high levels of nitrogen and phosphorus with implications for water quality. Some existing systems can be retrofitted with nitrogen-reducing technologies, while many advanced systems already include these components.

All of the incorporated areas – which constitute 2.1% of the watershed - have plans for sewer system expansion to include additional areas, but in some cases it may take decades to achieve full coverage due to the very high cost of retrofitting infrastructure. However, areas that fall outside of urban growth boundaries (such as Fall City, Preston and outlying areas associated with cities) have no plans to provide municipal sewage treatment at any time in the foreseeable future.

3.5 Fish hatcheries

Fish hatcheries and rearing ponds may also contribute to water quality impairment. Typically, clean water from a surface or groundwater source is used to supply different phases of the operation, such as egg incubation or rearing in concrete 'raceways' or ponds. During this process, nutrients from unconsumed feed and from fecal matter accumulate in the water, which is then discharged into surface water. Also, during summer months, water in rearing ponds may increase in temperature prior to discharge. As a result, the discharge from fish hatcheries is often higher in nutrients and in temperature than the source water.

A variety of chemicals and pharmaceuticals are often used in fish hatcheries to prevent disease outbreaks, control parasites and for other purposes. For example, Formalin – a liquid formulation of dissolved formaldehyde gas in water – can be used to control fungal infections in fish eggs as well as to control external parasites on the gills, skin and fins of fish in rearing ponds. The use of vaccines and antibiotics is also a common practice. The level of use of these and/or other substances in local hatcheries within the Snoqualmie watershed has not been reviewed for this report.

Fish hatcheries that exceed certain thresholds for production or discharge are required to have NPDES permits for their operations. Specifically, permits are required for facilities that: discharge at least 30 days per year and produce more than 20,000 pounds of fish per year, or feed more than 5,000 pounds of fish food in any one calendar month. Additionally, a permit is required if the facility is determined to be a significant contributor of pollution to waters of the state (Lori LeVander, WDOE, personal communication).

Two permitted facilities are located in the Snoqualmie: the Tokul Creek hatchery operated by Washington Department of Fish and Wildlife (WDFW), and Sea Springs (also known as Christmas Creek) hatchery, a privately owned facility located in the vicinity of North Bend.

The Tokul Creek hatchery primarily produces winter-run steelhead that are released as yearlings into the Snoqualmie and its tributaries, or are transported for rearing and release from Reiter Ponds, a WDFW facility in the neighboring Skykomish Basin. The hatchery also produces trout for the State's lowland and highland lakes stocking programs.

The hatchery uses spring water for incubation and surface water from Tokul Creek for rearing ponds (WDFW, 2002). The spring source can provide up to 200 gallons per minute (gpm), which is approximately 0.4 cubic feet per second (cfs), while the surface source can provide up to 5000 gpm (approximately 11 cfs). The hatchery discharges back into lower Tokul Creek.

The Sea Springs hatchery has a water right for up to 15 cfs (roughly 6700 gpm) from Christmas Creek (also known as Boxley Creek), a spring-fed stream that originates along the ridge that divides the South Fork Snoqualmie River sub-basin from Chester Morse Lake in the Cedar River watershed. Hatchery water is discharged back into the creek which flows into the South Fork Snoqualmie soon thereafter. The 15 cfs water right constitutes more than 50% of the mean monthly flow of the stream in September, October and November[11].

3.6 Forest practices

While forest is still the prominent land cover type in the Snoqualmie Watershed, many lowland forests within the floodplain of the Snoqualmie River and along its tributaries were logged in the mid- to late 1800s and during the first half of the 20th century. In areas that now feature agricultural lands, cities and rural residential land uses, the loss of forests along streams and rivers has likely had a profound effect on water quality.

Still, the high proportion of remaining forestlands in the Snoqualmie watershed is an integral component of the basin's aesthetic beauty and its generally high environmental quality

[11] USGS gage #12143900 - Boxley Crk. near Edgewick, WA

relative to many other basins. However, the management of forested lands can also contribute to the degradation of water quality, both directly and indirectly.

The two most direct water quality impacts of forestry are effects on water temperature and sediment load. While harvest practices have improved significantly in recent years, a decades-long legacy of aggressive harvest practices in riparian areas has contributed to elevated stream temperature and increased rates of erosion. Lack of adequate riparian shade can have substantial impacts on stream temperature, while excessive forest road-building and their inadequate maintenance contributes to slope failures and high rates of fine sediment input to receiving waters.

Forest practices may also have indirect effects on water quality. The input of excess sediment can cause stream channels to get shallower and wider, which in turn exposes the channel to increased solar radiation, and thus higher temperatures. Moreover, forests and associated wetlands serve an important storage function for precipitation that falls as rain and as snow. This 'sponge' function of forests – particularly in the upper watersheds – can serve as an important source of base flow during the dry, warm months of late summer. Thus, as mature forest cover declines and natural hydrology is altered, less water is available for streams during the dry season, further exacerbating impairment of stream temperature and associated parameters. From a hydrologic perspective, forestry is far superior to any alternative developed land use, but water quality can benefit substantially from improved forest practices on public and private forest lands alike.

Finally, forestry practices also involve the use of herbicides and fertilizers. For this report, we have reviewed only limited water quality data in forested areas, primarily related to the nutrient impacts associated with the application of biosolids. Other forestry-related, localized impairments cannot be ruled out.

3.7 Natural conditions and other factors

The preceding sections do not provide a comprehensive list of sources for water quality impairment. In many cases, a combination of factors leads to low water quality, while in others a single, identifiable activity may be to blame. In each of the sub-basin summaries (Section 6), we have attempted to identify likely sources of impairment where possible, but in many cases further study is required.

Moreover, natural conditions can also contribute to reduced water quality. For example, though slope failures and stream bank erosion are certainly exacerbated by numerous land-use practices, the Snoqualmie basin is young in a geologic sense and is naturally prone to erosion. Evidence of extremely dynamic systems that feature migrating channels can be found in many of the streams and rivers in our watershed. High-frequency disturbance can also cause channels to widen and thus to become exposed to higher solar radiation. Also, the effect of a lack of trees in the riparian zone – whether natural or not – depends in part on the aspect of the valley, so that east-west oriented channels tend to receive far more sunlight during summer days than do north-south oriented ones. In fact, valley aspect has been suggested as a contributing factor to the observed higher temperatures in the Middle Fork Snoqualmie as compared to the North and South Forks (Watershed Sciences, 2007), all of which are substantially forested.

Finally, a major hydrologic feature of the Snoqualmie basin is flooding. Flooding itself is of course not a form of pollution, but the interaction of flooding with human activities can have notable effects on water quality. In addition to stormwater effects and I/I impacts on treatment plants, inundation of the floodplain can cause a variety of human activities to come in contact with surface waters. These include storage of industrial and household chemicals, manure storage, agricultural fertilizer and pesticide storage, fuel tanks and vehicles trapped by floodwaters. While this report does not specifically focus on flood-related water pollution, an initiative by King County Hazardous Waste is currently underway in the Snoqualmie and other basins to inventory, characterize and eventually to help minimize the water quality risks associated with flooding. Future updates to this report may include a more detailed discussion of flood-related pollution risks.

4 SOURCES OF INFORMATION

This section describes the principal sources of information that contributed to the assessment. To develop a sub-basin levels synthesis of water quality conditions, we consulted a wide range of studies and datasets. Since investigations and monitoring programs typically are developed with a particular program or purpose in mind, each study focuses on a slightly different set of parameters and some utilize different protocols to collect and analyze data. In general, however, most of the data were collected via periodic 'grab samples' at specific monitoring locations, although there are a limited number of continuous monitoring stations in the watershed, as well as a small number of studies that collected continuous data for a specific time period. Some parameters, such as temperature, are measured in the field, whereas others, like bacteria, are evaluated in a laboratory setting.

We also reviewed a variety of more general reports that provided valuable information about watershed conditions as they relate to water quality, such as the Snohomish River Basin Salmon Conservation Plan (Snohomish Basin Salmon Recovery Forum, 2005), the Snohomish River Basin Salmonid Habitat Conditions Review (Snohomish River Basin Salmonid Recovery Technical Committee, 2002) and the Snoqualmie Watershed Aquatic Habitat Conditions Report (King County, 2002).

4.1 WDOE TMDL Study and TMDL Effectiveness Monitoring Report

Beginning in the late 1980's, WDOE conducted several water quality investigations in the Snoqualmie watershed. The studies were performed in recognition of pending population growth and land-use conversion in the basin from historically prominent forestry and agriculture to residential, commercial and industrial uses in many areas. The basin had long been recognized as having outstanding natural resource values, but future growth presented a potential threat to water quality. Also, prior studies indicated potential violations of water quality standards for dissolved oxygen, pH and fecal coliform in several areas. WDOE's studies culminated in the Snoqualmie River Total Maximum Daily Load Study (TMDL Study, Joy 1994). The TMDL Study combined field sampling and mathematical modeling to better understand basic water quality features in the basin and to predict the river's response to different potential wastewater loading allocations. The analysis focused on conditions during the annual low flow period of late summer and early fall, the 'critical period' for water quality in the basin. The study resulted in the calculation of 'waste load allocations' for point-sources (e.g., WWTP) and non-point source 'load allocations' for three different pollutants: ammonia, fecal coliform and biological oxygen demand (BOD). These waste allocations - combined with associated recommendations to address pH and DO - constituted the TMDL clean-up plan for the Snoqualmie River and several tributaries.

The Clean Water Act also requires the State to evaluate whether a TMDL is working. In 2003-2005, WDOE collected water quality samples at 19 locations and three WWTPs in the Snoqualmie basin to undertake such an evaluation (WDOE, 2008). Of the studies reviewed for this synthesis report, the TMDL Effectiveness Report is the most geographically extensive assessment of current water quality conditions in the basin.

The TMDL Effectiveness report focuses on several categories of pollutants – including bacteria and nutrients - as well as water quality indicators, such as dissolved oxygen and pH. The report presents the results of water quality sampling in the mainstem and tributaries and evaluates the effectiveness of certain measures taken since 1994 under the TMDL clean-up plan, as well as the effects of other changes in the basin, such as the closure of numerous dairy farms. The analysis is based on the collection of grab samples from a variety of locations during the critical period and also during the wet season. For a detailed description of the study methodology, please refer to the Quality Assurance Project Plan (Onwumere and Batts, 2004) and the report itself (WDOE, 2008).

4.2 Studies by King County and King Conservation District in agricultural areas

King County has completed two recent reports that focus on water quality within tributaries that drain agricultural lands, primarily in the lower Snoqualmie Valley, downstream of Snoqualmie Falls (King County, 2005; 2007). The later study was funded by the King Conservation District. These studies sought to: characterize water quality problems in tributaries influenced by agriculture, compare wet-season and dry-season data to help identify likely sources of impairment, and to collect baseline data that can be used at a later date to evaluate effectiveness of Best Management Practices on adjacent farmland.

The 2005 study also attempted to characterize the relative influence of agricultural lands located in the lower portions of the tributary basins to that of the rural residential areas located further upstream. Specifically, the study compared water quality data collected upstream of the Agricultural Production District (APD) and analogous data collected by WDOE near the mouth of each tributary. Differences in water quality at the paired locations would infer a potential effect that is attributable to agricultural activities within the APD.

During the preparation of this report, draft results for the Ames Lake Creek sub-basin were presented to the KCD and members of the Ames Creek farming community. In response, KCD and local landowners funded an effort to collect additional water quality data in the area during summer 2008, focusing on bacteria. The results of that effort are described in the Ames Lake Creek section of the report.

4.3 WDOE temperature TMDL study (ongoing)

As explained in Section 3, certain reaches of the Snoqualmie River are on the 303(d) list (Category 5) of impaired waters for water temperature and other reaches are listed for temperature as Waters of Concern (Category 2). In response, WDOE is currently conducting a study of water temperature in the Snoqualmie and its tributaries as part of developing a temperature TMDL for the basin.

The ongoing effort has three principal components: continuous water temperature data collection at several mainstem and tributary sites during the summer of 2006; airborne thermal infrared remote (TIR) sensing of water temperature along the mainstem and the Middle Fork, conducted in August 2006 (Watershed Sciences, 2007); and the development of a numerical temperature model of the basin that will be used to identify a suite of actions to address the temperature problem. Our report describes some of the results from both field study efforts in 2006. Numerical modeling, data interpretation and reporting are still under way by WDOE and are expected to be completed by late 2009 (Ralph Svrjcek, WDOE, personal communication).

4.4 King County Roads Maintenance Section data

The King County Roads Maintenance Section (KCRMS) of the King County Department of Transportation collects water quality data at a variety of sites in the Snoqualmie Basin. The sampling sites are located where county roads cross streams and other drainage features. The KCRMS has collected baseline data from approximately 95 sites on a rotating basis since 1998, and additional data at targeted locations under the Road Impacts assessment program. Aquatic invertebrate data (B-IBI) has also been collected at 45 sample locations in the watershed.

4.5 King County Hydrologic Monitoring Program data

The King County Water and Land Resource Division's Hydrologic Monitoring Program has collected flow and water quality data at over 500 sites countywide since 1987. The data collection consists of continuously recording stream gages on rivers and streams, rain gages, visually checked staff and crest stage gages in wetlands, lakes and detention facilities, recording and non-recording groundwater wells, and water quality sampling.

Currently, the program maintains more than a dozen active stream flow gages in the Snoqualmie Watershed; several sites also record water temperature. All of the gages are located along tributaries in the lower basin, including Harris, Ames, Patterson, Canyon (a tributary to Patterson Creek), Griffin, Tuck, and Cherry Creeks, as well as several unnamed tributaries that drain the plateau and slopes that border the western edge of the lower valley.

4.6 Watershed-scale reports and sub-basin studies

Water quality conditions have also been evaluated in a variety of watershed-scale reports as well as special studies that focus on specific sub-basins. Examples of broader scale assessments include the Snohomish River Basin Salmon Conservation Plan (Snohomish Basin Salmon Recovery Forum, 2005) and associated technical appendices, such as the Ecological Analysis for Salmonid Conservation (EASC). King County has also produced a report on aquatic habitat conditions in the Snoqualmie watershed (King County, 2002). All of these reports consider water quality as a key element of fish habitat, and thus focus on parameters like temperature, sediment load and DO.

Studies specific to sub-basins or portions of the watershed have been conducted for a variety of reasons. For example, the City of Snoqualmie – together with Herrera Environmental Consultants – produced a series of reports related to water quality in Kimball Creek, a tributary to the mainstem Snoqualmie above the falls that drains portions of unincorporated King County and portions of the City of Snoqualmie (Herrera Environmental Consultants, 2004). Similarly, King County collected water quality data in 2003-2004 along the Snoqualmie River between the Tolt River and the Chinook Bend Natural Area as part of the

Carnation Wastewater Treatment Plan Project (King County, 2005b). In the Cherry Creek sub-basin, the Wild Fish Conservancy (formerly known as Washington Trout) has been working with the Tulalip Tribes to assess water quality conditions in the primarily agricultural areas of the lower drainage, focusing in particular on low DO issues. In 2004, King County prepared an extensive rural reconnaissance report of the Patterson Creek sub-basin to identify rural drainage issues and prioritize capital projects to benefit fish habitat and drainage problems (King County, 2004). These and other reports are cited primarily in the context of our sub-basin summaries in Section 6.

It was not possible to review all available water quality information for the watershed for this report. For example, a variety of State Environmental Policy Act (SEPA) and National Environmental Policy Act (NEPA) compliance documents may provide additional information for specific locations. We hope that by identifying priority issues in each sub-basin, future efforts may include a more detailed review of available information in specific drainages.

5 RESULTS

This section summarizes the principal findings associated with water quality in the mainstem and in tributaries. The focus here is on common themes, trends over time and commonalities observed across different portions of the basin. Basin-specific findings are described in the following section (Section 6).

When water quality is measured at a specific location in a river or stream, the results reflect the combined effects of natural conditions, land use, non-point source pollution and point-source pollution across a large area that constitutes the drainage. Thus, while it is tempting to focus on conditions along the immediate riparian corridor, in many cases the impairment of water quality is attributable to conditions further upstream or in upland areas. Where specific activities or facilities are the focal point of analysis, water quality samples can be collected from locations upstream and downstream of the activity. This type of analysis has been conducted within portions of the Agricultural Production District (APD) by King County and King Conservation District, and by WDOE in the South Fork Snoqualmie in relation to the North Bend WWTP.

Much of the water quality data reflected in this report has been collected at sampling locations at or near the mouth of specific tributaries. This means that the conclusions described in this section and in Section 6 must be considered in a broad sense as reflecting the cumulative effects within the entire sub-basin.

5.1 Sub-basin delineation

We have divided the Snoqualmie Watershed into fourteen sub-basins for purposes of analysis (Table 5). The tributary sub-basins range in size from Tuck Creek at 3.4 mi^2 to the North Fork Tolt River at 49.3 mi^2 . In some instances, a single sub-basin could reasonably have been divided further into smaller sub-basins. We selected the sub-basin delineation based on a combination of distinct drainages and the availability of water quality data. Future, detailed analyses of specific sub-basins may benefit from further division of drainage areas into smaller catchments.

The Snoqualmie River sub-basin category includes the three forks of the Snoqualmie River and the mainstem itself. The Middle Fork is the largest of all at 170 mi^2. Geographically, the Snoqualmie Mainstem sub-basin is an anomaly in that it is not a distinct drainage per se. This sub-basin captures the entire mainstem and its floodplain from the County line north of Duvall to the confluence of the North and Middle Forks near North Bend. The mainstem also captures many small independent drainages, some of which could arguably be treated as their own sub-basins. This latter category includes streams like Weiss Creek, Coe-Clemons Creek in Duvall, and Wallace Creek, Adair Creek and many others that drain the western slopes of the lower valley. In general, these drainages are smaller than the units chosen for this synthesis report.

Map 5 shows the sub-basin delineations used in this study. The fourth column of Table 5 (total stream length) is the sum of all mapped watercourses within the sub-basin, from rivers and large streams to small watercourses, including some that may be seasonal in nature.

These same watercourses are shown graphically in each of the sub-basin maps (Maps 11-25). The basin area and stream length calculations are based on King County's Geographic Information Systems (GIS) data. Particularly in the case of stream length, these estimates may have variable amounts of error, depending on the complexity of local topography and the extent of field verification.

Table 5. Sub-basin delineation, drainage area and total stream length within sub-basin.

Sub-basin	Acres	Sq. Mi.	Total stream length (mi.)
Tuck Creek	2,281	3.6	14.4
Ames Lake	5,176	8.1	29.1
Kimball / Coal Creek	5,580	8.7	23.4
Harris Creek	8,356	13.1	46.1
Griffin Creek	10,889	17.0	45.4
Patterson Creek	12,950	20.2	65.2
Cherry Creek	17,976	28.1	95.2
Raging River	20,454	32.0	115.4
Tokul Creek	21,800	34.1	62.2
Tolt River - *Lower*	12,523	19.6	66.9
- South Fork	20,231	31.6	122.8
- North Fork	31,570	49.3	158.9
Tributary Sub-Total	**169,633**	**265.0**	**845.1**
Snoqualmie Mainstem	41,018	64.1	224.4
South Fork Snoqualmie River	54,641	85.4	304.6
North Fork Snoqualmie River	66,250	103.5	381.8
Middle Fork Snoqualmie River	109,142	170.5	544.1
Snoqualmie River Sub-Total	**271,052**	**424.0**	**1,454.3**
Grand Total	**440,685**	**688.6**	**2,299.4**

The data show that on average there are more than 3.5 miles of mapped watercourses per square mile of area in the watershed, though the rate per basin varies from a low of 1.8 mi/mi^2 to a high of 5.3 mi/mi^2.

5.2 Water quality summary maps

Maps 6-10 graphically summarize the water quality assessment for each of the primary pollutant and indicator categories. <u>Note that the ratings (e.g., Impaired, Basin of Concern) assigned to each sub-basin are based on a qualitative integration of available data sources</u>. As described in the legends that accompany each map, a rating of "Impaired" includes not only those sub-basins that have been specifically placed in a category of impairment by the

State, but may also include areas where the preponderance of available evidence suggests that there is a problem, regardless of the State listing category that may apply.

Also, many water quality issues manifest during specific times of year. Late summer is the most common period of impairment for many pollutants and indicators due to high temperature and low natural flows which provide less dilution. Thus, a rating of "Impaired" on the map does not mean that the sub-basin is always impaired. The seasonality and other aspects of the rating are described for each sub-basin in the following section.

Finally, in many cases, a particular water quality problem is present only in one portion of the sub-basin, but the maps show the entire sub-basin as a single color. Thus, the maps provide only an overview of water quality condition and their interpretation must be accompanied by a careful reading of the applicable sub-basin synthesis section of this report.

5.3 Mainstem Snoqualmie, North Fork, Middle Fork, South Fork

Table 6 summarizes the results of our analysis for each mainstem sub-basin and parameter, arranged in a downstream to upstream direction. Note that Table 6 provides greater spatial detail for the Snoqualmie River and South Fork Snoqualmie sub-basins than the associated maps. This is possible primarily due to WDOE's sampling design during the TMDL Effectiveness study. The agency maintained several monitoring locations along the mainstem, as well as two locations on the South Fork Snoqualmie upstream and downstream of the North Bend WWTP. The river mile (RM) for each of the two sampling locations in the South Fork are included in the table.

Table 6. Water quality summary table for mainstem sub-basins.

Sub-basin	Snoqualmie RM	Trib RM	Temp.	DO	FC	pH	Nutr.
Snoqualmie River nr. County Line	2.7			Tribs			
Snoqualmie River nr. Carnation	25.2			Tribs			
Snoqualmie River nr. Fall City	35.3			Tribs			
Snoqualmie River nr. Snoqualmie – below Snoqualmie WWTP	40.7						
Snoqualmie River nr. Snoqualmie – above Snoqualmie WWTP	42.3						
South Fork Snoqualmie – below North Bend WWTP	44.4	2.0					
South Fork above Snoqualmie – above North Bend WWTP	44.4	2.8					
North Fork Snoqualmie	44.9						
Middle Fork Snoqualmie	45.3						

	Impaired. Violation of state standards or failure to meet TMDL guidelines, as applicable.
	Basin of concern. Minor failure to meet standards. In some cases, localized problem only
	No evidence of impairment. NOTE: Data not available for many smaller tributaries.

The "Tribs." notation for several mainstem Snoqualmie River locations refers to evidence of impairment in smaller tributaries that are not otherwise included in any of the tributary sub-basins delineated for this report.

In the mainstem sub-basins, high temperature during late summer is the most prevalent problem. This problem extends well upstream of intensively developed areas. During continuous monitoring performed in 2006 as part of the ongoing temperature study, the 7-DADMax recorded by WDOE (unpublished data) reached a high of 21.7˚C in the Middle Fork upstream of the North Fork confluence. Both the North and South Forks were cooler during the same period, though still above standard at 19.0 and 18.8˚C, respectively. During the TMDL Effectiveness study, the South Fork met standards for temperature while the Middle and North Forks did not (WDOE, 2008). This suggests that while the standard may not be violated every year, all three forks appear to be very close to doing so during the late summer months.

The upper watershed is heavily forested, accounting for 67% of land cover in the Middle Fork, 70% in the South Fork and 78% in the North Fork. An additional 12-24% of the land cover in these basins consists of rock, snow, ice and open water (2001 land cover data, from Marshall and Associates). This suggests that the current forest condition, the legacy of past forest practices, and the role of natural conditions must be better understood for their potential contribution to high temperatures during late summer.

The TIR data collected by Watershed Sciences (2007) shows that certain tributaries and groundwater sources provide localized cooling to the mainstem and forks, but in general, it is fairly difficult to lower the temperature of a large river absent many large, cool tributaries and high levels of shading, neither of which are prevalent in the lower river in particular. Figure 2 shows the cooling effect of the South Fork Snoqualmie on the mainstem. Note that this is a single snapshot in time that does not necessarily reflect typical conditions in terms of magnitude, but it appears that the net effect of the South Fork is a cooling one.

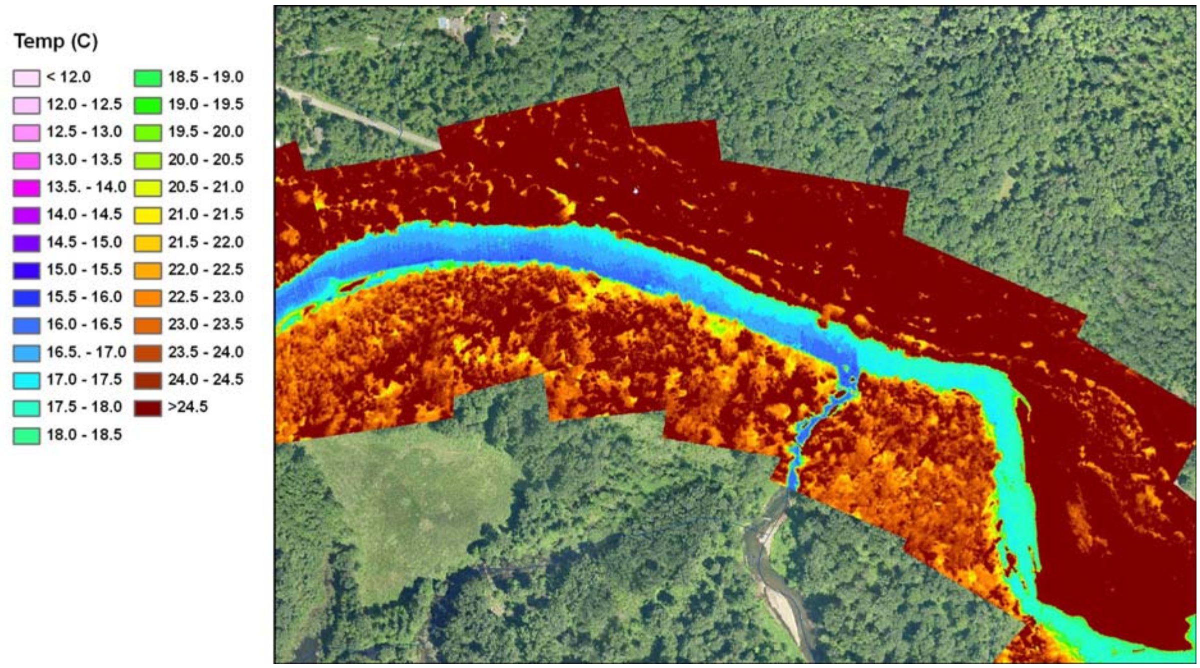

Figure 2. Thermal infrared imagery of the South Fork Snoqualmie River confluence (data from Watershed Sciences, 2007).

As described in the Introduction, much of the Snoqualmie floodplain was historically forested with both hardwoods and conifers and also featured extensive oxbows and wetlands. These historical floodplain conditions likely combined to produce much cooler surface water conditions than are seen today, even in the lower portions of the watershed. Many oxbows and some wetlands are still present, but the hydrologic connections have been substantially disrupted by drain tiles, ditches, bank armoring and other alterations to the drainage network.

For some parameters, water quality has improved during the past ten years in the Snoqualmie River mainstem. According to WDOE's TMDL Effectiveness report, the amount of bacteria has decreased over time, with a long-term trend downward in bacterial concentration. WDOE (2008) credits improved dairy management, the closure of several dairies, implementation of farm plans, improved sewage treatment and riparian restoration activities with the reductions in bacterial load. While the decrease is not equally evident in all areas, the long-term record in the mainstem Snoqualmie at RM 2.7 captures the combined effect of reductions in upstream areas. Figure 3 is from the WDOE TMDL Effectiveness report (WDOE, 2008). The two dashed lines refer to the two components of the bacterial standard, i.e., the 100 CFU/100 ml geometric mean criterion and the 200 CFU/100 ml 90% exceedance criterion (see Section 2 for details about the standard).

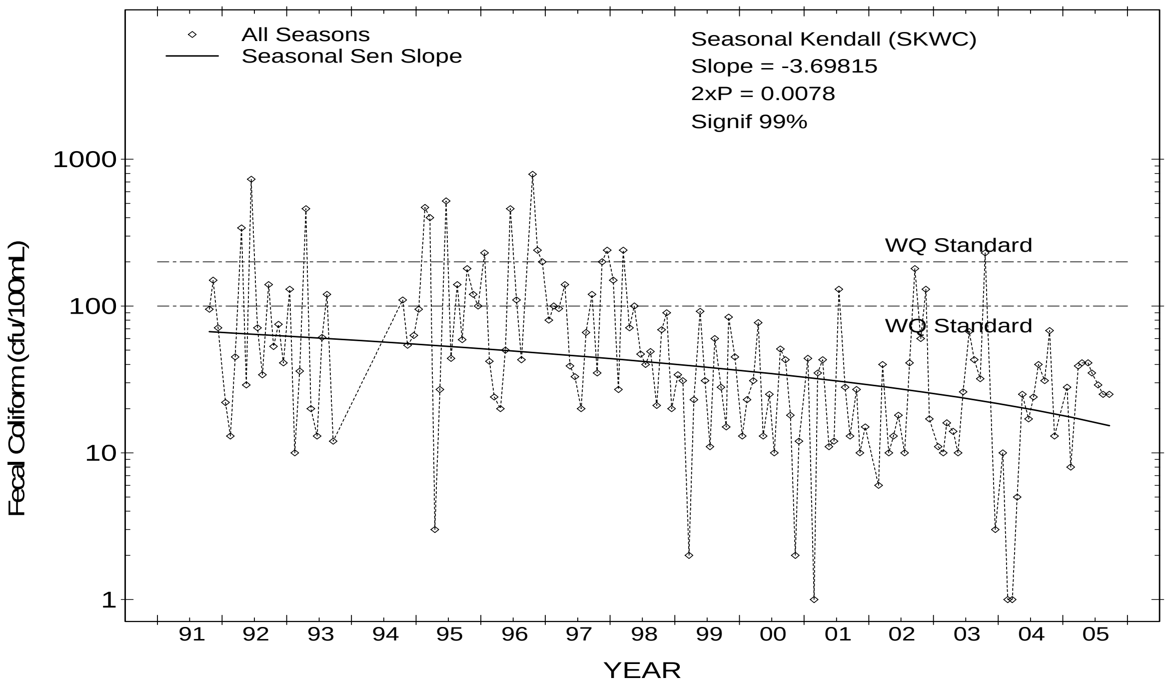

Figure 3. Water year 1991 – 2005 Snoqualmie RM 2.7 trend analysis results for fecal coliform bacteria (WDOE, 2008).

Although the typical level of bacteria in the mainstem meets State standards, many mainstem sites still experience occasional episodes of higher fecal coliform bacteria concentrations that exceed them. These episodes are typically associated with a heavy rain event following a prolonged dry period. The TMDL Effectiveness study found that every sampling location in the mainstem and all three forks (North, South, Middle) violated the 90% exceedance criterion once during the period of the study; nearly all were associated with a single event in August 2004. WDOE collected data on a weekly schedule for the effectiveness study and found that one week after the observed spike in concentration, bacteria levels had decreased to below the standard at all sites in the mainstem and three forks. Only one site – the South Fork Snoqualmie downstream of the North Bend WWTP – was found by the study to have violated the geometric mean criterion (August only), in addition to violating the 90% exceedance criterion in August as well as September.

While WDOE's report focuses on the FC concentration as the basis for the water quality standard, the agency also tested the samples for *E. coli*. In the majority of high-concentration events, *E. coli* were measured at concentrations ranging from 85-100% of the total FC level (WDOE, 2008 - Appendix F). In general, WDOE's data shows a very close correlation between the concentrations of *E. coli* and total FC.

WDOE (2008) also reports improvements in dissolved oxygen conditions in the mainstem since 1994, but specific causes cannot be identified with current data. All sites measured during the study met standards. However, the testing did not occur during the extreme low-flow conditions considered 'critical' for determining DO compliance. Specifically, the standard should be attained during 7Q20 flow conditions – the lowest 7-day mean flow level with a 20-year recurrence interval (Ralph Svrjcek, WDOE, personal communication). Though WDOE does not propose to remove the Snoqualmie from Category 4(a) for dissolved oxygen, the DO improvement is an important sign of progress.

A more detailed discussion of the mainstem and each of the three forks is provided in Section 6.

5.4 Tributary rivers and streams

Tables 7 summarizes the results of our analysis for each tributary sub-basin and parameter, arranged in a downstream to upstream direction. In the case of the Tolt River, Table 7 includes data specific to the North Fork and South Fork Tolt, in addition to the Lower Tolt sub-basin. The river mile of the North Fork / South Fork confluence is provided as a reference.

Table 7. Water quality summary table for tributary sub-basins

Sub-basin	Snoqualmie RM	Trib RM	Temp.	DO	FC	pH	Nutr.
Cherry Creek	6.7						
Tuck Creek	10.3						
Ames Lake Creek	17.5						
Harris Creek	21.3						
Lower Tolt River	24.9						
North Fork Tolt	24.9	8.8					
South Fork Tolt	24.9	8.8					
Griffin Creek	27.2						
Patterson Creek	31.2						
Raging River	36.2					High	
Tokul Creek	39.6						
Kimball Creek	41.1						

	Impaired. Violation of state standards or failure to meet TMDL guidelines, as applicable.
	Basin of concern. Minor failure to meet standards. In some cases, localized problem only
	No evidence of impairment. NOTE: Data not available for many smaller tributaries.

Compared to the mainstem Snoqualmie River and the three major forks, many tributary rivers and streams in the watershed are impaired for a wider variety of pollutants and indicators. It is important to recognize that the impacts of human activities and landscape alterations can be much more concentrated for tributary streams. For many smaller streams in particular, a much higher percentage of the drainage is directly impacted by non-point source pollution and by landscape alterations, such as urbanization, agriculture and rural-residential development. Moreover, these smaller streams are unable to dilute pollutants to a large degree, particularly in late summer when flows are naturally low and air temperature is high, while pollution inputs may be as high or higher than during the remainder of the year. Finally, most regulations – such as local ordinances to protect critical areas – afford the least amount of protection to the smallest streams. Thus, it is no surprise that water quality impairment is commonplace amongst smaller streams.

High temperature is a serious issue in several tributaries, notably Raging River, Cherry Creek and Patterson Creek. King County conducted a field study during the summer of 2008 to investigate the Raging River temperature issue in an effort to inform restoration priorities in the basin (King County, 2008). The County also collected continuous temperature data in several tributaries in 2008 that traverse the predominantly agricultural Snoqualmie River floodplain after flowing through more forested and residential uplands (Kollin Higgins, personal communication). The purpose of this pilot study is to quantify the amount of temperature increase that occurs within the floodplain portion to help inform riparian planting prioritization and to allow comparison between contrasting floodplain conditions. The results from these recent efforts will be used in the near future to supplement the information contained in specific sub-basin chapters of this report.

However, data collected by KCRMS also show that many small tributaries have very cool water year-round (see North Fork Snoqualmie and Middle Fork Snoqualmie discussions for examples). This highlights the importance of securing protection for the many small, often unnamed, streams that act as the capillaries of the stream network. A core component of protection is to ensure that existing regulations are correctly applied to all affected water bodies. Specifically, incorrect stream classification (i.e., incorrect water typing) can lead to a reduced level of protection (or none at all) from surrounding land uses. In addition, the connectivity of small tributaries to the mainstem rivers should be restored where impaired by bank hardening or floodplain alteration.

Despite some reductions over time, nearly all tributaries appear to have excessive bacterial load, due primarily to a combination of livestock presence, manure application, failing or underperforming septic systems, pet waste, all combined with natural contributions from birds and mammals. Substantial reductions are needed in several tributaries in order to meet water quality standards. WDOE estimated needed reductions to range from an estimated 10% in Harris Creek to 86% in Ames Creek. Only Tokul Creek appears to meet fecal coliform standards during all months according to the WDOE (2008) study, and the Tolt River had only a single exceedance during an anomalous dry-season rain event during the study period. This is not surprising in that both sub-basins are dominated by forestry rather than residential or agricultural development.

Kimball, Patterson, Ames, Cherry and Tuck Creeks stand out for the prevalence of water quality impairment relative to other tributaries in the watershed. Each stream violates multiple water quality criteria, according to more than one study. High levels of nutrients, low dissolved oxygen and low pH (i.e., acidic conditions) are prevalent in many of these streams, along with high bacterial counts. However, the specific conditions and likely causes and locations of impairment within each sub-basin (e.g., lower floodplain vs. upper watershed) differ between tributaries. For example, within the Kimball/Coal Creek sub-basin, Coal Creek appears to have much better water quality than Kimball Creek.

Unlike most other tributaries, low dissolved oxygen conditions in Ames and Cherry Creeks sometimes persist during the winter months, suggesting that high temperatures are not a primary cause for low oxygen levels. In fact, Ames Creek appears to be cooler than many other lowland tributaries. Studies by King County suggest excess decaying organic matter and nutrients in the streams as possible causes. The role of discharges from drain tiles located in deoxygenating soil types (such as peat) should also be investigated. In Cherry Creek, fecal coliform counts and phosphorus loading also continue well into the winter months. Livestock manure (or its use as fertilizer), septic systems and fertilizers are likely to be important contributors.

In some streams, such as Patterson and Harris Creeks, phosphorus levels decrease with higher rainfall. This suggests that overland flow may not be the source of excess phosphorus in these locations. Instead, septic systems or manure storage facilities may be responsible for the observations. Further source identification may be needed in these areas to provide a robust basis for recommendations.

A commons pattern across many of the floodplain tributaries that feature extensive agricultural land use is that water quality worsens as the stream flows from the upstream edge of the floodplain to the Snoqualmie River. In many streams, water quality at the mouth shows higher temperature, higher bacterial concentration, lower dissolved oxygen, higher nutrient levels and lower pH (i.e., more acidic) than locations further upstream.

The Raging River has recorded anomalously high pH (i.e., alkaline conditions) on occasion, according to the recent WDOE study, though these conditions seem to be prevalent only near the river's confluence with the Snoqualmie mainstem near Fall City. The cause is not evident and the agency recommends investigation of potential causes. One hypothesis implicates excessive periphyton growth (the layer of small plants and animals that often coats the bottoms of streams), possibly due to excess nutrients coupled with high water temperature.

In sum, many tributary streams suffer from a wider array of impairments than do larger rivers in our watershed. However, it should be noted that tributary data are largely limited to those streams that are in close proximity to developed areas, whether in agricultural, residential or urban landscapes. So, the data are biased toward streams that are most likely to be impaired in the first place. Limited data from forest-dominated tributaries (such as Tokul Creek and Griffin Creek) suggest that fewer impairments are commonplace in these areas, although temperature and sediment functions have likely been worsened by forestry activities.

Some action recommendations - such as tree planting activities in impaired riparian areas or livestock exclusion from streams - are appropriate to undertake in all sub-basins. However, given the unique circumstances in each sub-basin, specific recommendations to address impairments and data gaps are provided in each sub-basin discussion in the following section.

6 SUB-BASIN SCALE RESULTS

The sub-basin summaries are presented in a roughly downstream-to-upstream sequence. Each of the summaries utilizes a set of thematic maps to illustrate land use patterns, fish distribution, topography, applicable water quality standards and other relevant data (see Appendix, Maps 11-25. The Mainstem sub-basin has been divided into two maps (Maps 24 & 25) for better display of details.

Each sub-basin map page is divided into three frames:

Land use designation in County Comprehensive Plan

The first map illustrates the land use designation for the sub-basin based on the King County Comprehensive Plan. For those sub-basins that extend north beyond the County line, we have also included analogous data from Snohomish County. These designations do not capture current uses in all areas, but they are a good indicator of the potential medium- to long-term land-use for the area. For example, residential areas may currently contain parcel sizes that are much larger (i.e., less densely developed at this time) than the maximum allowed under the land-use designation.

Why not use zoning instead? Like Comprehensive Plan designations, current zoning also does not always reflect the intensity of actual uses on the ground. Rather, zoning is a better indicator of potential, near-term land-use. For example, a one-acre parcel may only have a single residence on it, but a zoning classification of R-4 (i.e., up to four residential units per acre) suggests that the parcel could potentially be sub-divided fairly easily. If, on the other hand, the parcel is zoned R-1, a change to higher density would require a rezone by the applicable jurisdiction. Such requests may be granted by the local jurisdiction if the requested zoning classification remains consistent with the underlying Comprehensive Plan designation for the area.

If an applicant requests a legislative change in the underlying land use designation to support a different level of use, the process requires a change in the Comprehensive Plan itself, a more complicated and lengthy undertaking. When Comprehensive Plans are revised from time to time as required by the Growth Management Act, land-use designation can change and potentially allow higher-intensity land uses.

For purposes of understanding water quality factors, the report uses Comprehensive Plan designation as the better indicator of potential risk due to its relative stability over time.

Nearly 98% of the Snoqualmie watershed is unincorporated, though eight of sixteen sub-basins are partly within incorporated areas. We have not included land-use designations or zoning information for incorporated areas due to the inconsistency of categories across jurisdictions. However, sub-basin discussions summarize in-city conditions where appropriate. Incorporated areas account for more than 10% of the drainage in only one sub-basin - Kimball/Coal Creeks - where nearly 40% of the area falls within the combined city limits of Snoqualmie and North Bend.

Aerial photograph and fish distribution

The second map provides an aerial image of each sub-basin, coupled with data that show the distribution of high-priority anadromous salmonids (e.g., Chinook, coho, steelhead) for streams below Snoqualmie Falls and of resident fish (e.g., rainbow trout, whitefish, lamprey) in areas upstream of Snoqualmie Falls. King County has several aerial photograph datasets from different years. Due to inconsistencies in the extent of coverage and in data quality, we have utilized photographs from different years across sub-basins, ranging from 2002 to 2007. In some cases, a single map may contain portions of aerials from different years. Thus, the aerial photographs are meant to provide a general view of the basin rather than an up-to-date snapshot with accurate details.

The fish distribution data are from the Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) that characterizes salmonid habitat conditions and distribution of salmonid stocks in Washington. SSHIAP is co-managed by the WDFW and the Northwest Indian Fisheries Commission. Since many fish species utilize the same streams, the fish distribution datasets overlap in many areas. In most sub-basins, coho salmon and steelhead tend to migrate into areas furthest upstream, while Chinook salmon tend to remain in larger, downstream reaches for spawning in particular. This is only a generalization as fish distribution in any specific river or stream is also affected by stream gradient, substrate size, temperature, local fish population abundance, and other factors. Also, it should be noted that juvenile Chinook salmon utilize small tributaries extensively for rearing. In fact, restoration of juvenile rearing areas in tributaries within the Snoqualmie River's floodplain is a high priority in the Snohomish Basin salmon recovery plan (Snohomish Basin Salmon Recovery Forum, 2005).

Note that all sub-basins are extensively utilized by resident fish, including areas that are accessible to anadromous fish. To increase visual clarity, resident fish distribution has been omitted from those sub-basins where anadromous fish are present.

LiDAR topography and water quality standards

The third map shows the topography of the sub-basin using LiDAR (Light Detection and Ranging) data, coupled with the water temperature standard (7-DADMax) for each reach in the drainage. LiDAR is an optical remote sensing technology that uses laser pulses to find the distance to a target. In concept it is similar to radar which uses radio waves in place of laser light. Both calculate distance based on the time delay between signal emission and the arrival of the reflected signal. LiDAR has made it possible to get incredibly detailed representations of topography and other features in both natural and developed landscapes.

As described in Section 2, the standards for 7-DADMax water temperature vary by location and in some cases by time of year. The maps show the applicable temperature limits for the sub-basin. The default limit is shown as a narrow, color-coded line, while the seasonal 13ºC maximum (where applicable) is shown as a wider line.

Finally, key water quality monitoring sites (i.e., KCRMS, WDOE, King County) are marked and labeled, as appropriate.

Cherry Creek (28.1 mi^2)

Sub-basin Description

Land Use (Unincorporated areas)[12]	
Forestry	54.5%
Rural Res. 1 DU/2.5-10 acres	33.6%
Agriculture	5.5%
Rural Res. 1 DU/20 acres	5.1%
Rural City UGA	1.2%
Mining	0.1%

Cherry Creek is an east-to-west oriented stream that enters the Snoqualmie River just north of Duvall, approximately seven miles upstream of the river's confluence with the Skykomish River near Monroe. The sub-basin spans the border between King and Snohomish Counties, with roughly 70% of basin area in King County. Just under 3% of the sub-basin lies within the City of Duvall. Map 11 (left frame) shows the land use classifications for the sub-basin with data from both King and Snohomish counties. Some of the data has been generalized to reduce the number of categories displayed on the map.

The sub-basin features three primary types of land use: agriculture in the lower valley bottom, rural residential areas that flank the agricultural land and extend further upstream into the basin, and forestry in the headwater areas. The headwaters of Margaret Creek, a significant tributary, drain forested areas within Snohomish County before entering rural residential areas around Lake Margaret, a 53-acre lake on the King County side of the border that serves as a domestic water supply for lake area residents. The creek discharges from the lake and eventually joins Cherry Creek.

During high-flow conditions in the Snoqualmie River, Cherry Valley experiences flooding that extends well upstream from the river confluence. The designated Agricultural Production District (APD) within Cherry Valley coincides closely with the mapped 100-year floodplain of the Snoqualmie River which extends roughly two miles into the Cherry Creek sub-basin.

Five species of anadromous salmonids have been documented in Cherry Creek, including Chinook, coho, pink and chum salmon, as well as steelhead. Coho salmon and winter steelhead are known to spawn in the upper portions of Cherry Creek, while the other species tend to utilize the lower portions of the sub-basin for spawning and rearing. In the Snohomish River Basin Salmon Conservation Plan, Cherry Creek is classified as a "Rural Stream – Primary Restoration" sub-basin that offers moderate potential use by Chinook salmon and a high level of use by coho salmon (Snohomish River Basin Salmonid Recovery Technical Committee, 2005). Along with the West Fork of Woods Creek (a tributary to the Skykomish River near Monroe), Cherry Creek is thought to provide the highest potential to support Chinook salmon among lowland tributaries in the broader Snohomish Basin, but habitat condition needs to be improved substantially.

Like many tributaries in agricultural areas, extensive portions of Cherry Creek within the valley have been straightened, rerouted and diked to benefit agriculture. In addition, a network of drainage channels traverses the floodplain, some transporting flow from smaller

[12] Includes both King County and Snohomish County land-use designations.

tributaries and others draining fields before joining Cherry Creek. Cherry Creek's floodplain water levels are also regulated by a pump station at the downstream terminus of Lateral A, one of the primary drainage channels within the floodplain.

Water quality

Based on many studies conducted in the past fifteen years, including the most recent WDOE TMDL Effectiveness report (WDOE, 2008), water quality in Cherry Creek is seriously degraded compared to most other Snoqualmie watershed tributaries. Multiple parameters violate state water quality standards, particularly in late summer and early fall. Cherry Creek is designated as core summer salmonid habitat by WDOE – see Table 1 for the applicable water quality standards.

Temperature: Impaired

King County has maintained a continuous temperature gage in Cherry Creek since 2001 (Gage 05A), located at the upstream edge of Cherry Valley. The 16°C standard is typically exceeded for much of the July-September period, with occasional daily temperature maximums exceeding 20°C, particularly in late July and early August[13]. KCRMS collects regular grab samples at the same location (Site E1238), as well as at other county road crossings further upstream on various tributaries to Cherry Creek. These data also show that temperature exceeds the standard, particularly in August. WDOE's TMDL study measured temperature at the mouth of Cherry Creek and found a similar pattern.

Further upstream, the temperature pattern varies by location. Temperature in the outlet of Lake Margaret (KCRMS Site E1297) is generally much higher than any other site monitored by KCRMS in the Cherry Creek sub-basin, averaging more than 19°C in August and nearly 18°C in September during the 2002-2006 period. This is not unexpected since the lake discharges from its surface where water is warmest, particularly in the summer when thermal stratification occurs.

In contrast, the North Fork of Cherry Creek is substantially cooler according to KCRMS data, with average grab-sample temperatures less than 15°C during the same period (Site E1078). These data were collected approximately one mile upstream of the floodplain edge where Mountain View Rd. crosses the North Fork (Site E1078). A separate study prepared by King County on behalf of King Conservation District (King County, 2007) found that the floodplain portion of the North Fork within the agricultural area exceeded standards in early August, though by less than 1°C (Site Cherry 2, located approximately ¼ mile from the floodplain edge). This suggests that the transition from a more canyon-like, wooded stream corridor to the agricultural valley floor marks a distinct break in the temperature profile of the stream.

Map 11 shows that a seasonal (February 15 – June 15) 13°C temperature standard applies to the mainstem from the North Fork confluence to slightly upstream of the Margaret Creek confluence. The purpose of the standard is to protect the spring spawning season for

[13] Data available at: http://dnrp.metrokc.gov/WLR/Waterres/hydrology/GaugeTextSearch.aspx

steelhead and other trout (other salmonids in the basin spawn in the fall). Data from the King County continuous monitoring site (Site 05A) show that the mean temperature rises during June by at least a few degrees, and sometimes by as much as 5°C. The mean June 1-15 temperature across years slightly exceeds the 13°C standard. Again, KCRMS measurements at the Lake Margaret outlet have recorded June temperatures that are several degrees warmer than other sites during the same period, exceeding 18°C in June 2005 while all other sites remained below 15°C.

Dissolved oxygen: Impaired

Due to its designation as core summer salmonid habitat, the minimum one-day oxygen concentration in Cherry Creek must exceed 9.5 mg/L to meet standards. During WDOE's TMDL effectiveness study, the monitoring location at the mouth of the creek failed to meet this standard on 6 out of 13 occasions and two additional measurements were right at the 9.5 value (WDOE, 2008). Moreover, all of the measurements were taken in the afternoon hours, whereas the lowest daily concentrations of dissolved oxygen tend to occur in the early morning hours[14]. This suggests that minimum oxygen concentrations may have been lower than reported.

Data collected by KCRMS shows that with the exception of the Lake Margaret site, all other sites in the sub-basin have met the 9.5 mg/L standard on nearly all occasions since 2001, with only a few readings just below that level. However, none of the KCRMS sampling locations are within the floodplain. The Lake Margaret outlet has not met the standard at any time in August or September during the period of record. It should be noted that it is not unusual for lake water to have a lower level of DO, and that the water may become re-oxygenated quite quickly as it flows through the fairly steep canyon reach before joining Cherry Creek nearer to the valley floor, but it is also warmer and will hold less oxygen until the lake water is cooled.

Serious DO problems are generally most prevalent in the low-gradient, slow moving reaches within the floodplain. The Wild Fish Conservancy conducted a juvenile salmon survival study at the pump station where Lateral A conveys tributary flows into Cherry Creek.. As part of the study, experimental control fish were held overnight in a holding pen within Lateral A – the fish died and subsequent water quality measurements revealed very low dissolved oxygen concentrations. A similar incident of fish mortality also occurred in spring 2008 (K. Beardslee, Wild Fish Conservancy, personal communication), again in Lateral A. In the latter case, the dead fish in question were not part of the study and were not physically confined in any way. The Tulalip Tribes and Wild Fish Conservancy are currently conducting additional water quality studies in Cherry Creek and its associated drainage features, with results expected in 2009.

King County measured dissolved oxygen as part of the study prepared for the King Conservation District (King County, 2007). Cherry and Ames Creeks had the lowest DO levels during the study. The investigation found that low DO persisted in Cherry Creek into

[14] Aquatic plants produce oxygen during the day, which is then consumed by aquatic fauna and decomposition processes during the night, typically producing the daily minimum concentration in the early morning hours.

late fall, even as temperatures dropped significantly. In late October 2005, DO was measured as 6.0 mg/L despite a water temperature of 7°C. This suggests that DO in Cherry Creek is not driven purely by temperature and that other factors may need to be investigated, such as a potential excess of decaying organic matter and nutrients in the stream due to surrounding agricultural activities and/or other factors. In the fall, the lowest measured DO concentrations were at the North Fork Cherry Creek floodplain site (King County Site Cherry 2).

<u>Fecal coliform: Impaired</u>

Cherry Creek also fails to meet standards for fecal coliform bacteria during the late summer months. Potential sources include dairy and other livestock operations, manure spreading on fields as fertilizer, wildlife and possibly failing or underperforming septic systems. Only the small fraction of the basin (2.8%) that lies within the City of Duvall has access to a wastewater treatment plant – thus, all other residences, businesses and farms rely on septic systems for treatment.

The failure to meet fecal coliform standards was most recently confirmed by King County (2007) with sampling performed in 2005-2006. The study found that while all three sampling locations met the chronic, geometric mean criterion (i.e., less than 100 CFU/100 ml)[15], two of the sites failed the second part of the standard as more than 10% of the samples contained concentrations in excess of 200 CFU/100 ml. The highest recorded value during the study was 1200 CFU/100 ml at the North Fork Cherry sampling location (Cherry 2). In fact, 9 out of 27 (33%) of the measurements at this location exceeded 200 CFU/100 ml. WDOE (2008) confirmed the failure to meet the FC standard at the mouth of the creek in 2003 and 2004. Prior studies have also documented the problem (McHugh, 1999).

According to King County (2007), Cherry Creek was the only location in the study where fecal coliform concentration occasionally persisted well into the winter months. In other words, dilution by higher flows was offset by higher bacterial inputs. This suggests that surface runoff is contributing to additional bacterial inputs, possible due to deficiencies in manure management relative to local-scale drainage features, such as the management of corrals and pastures and any associated drainage channels.

<u>pH: Impaired</u>

The lower portions of Cherry Creek within the agricultural area also suffer from occasionally low pH, i.e., the water is too acidic, albeit slightly. The problem seems mostly confined to the valley itself rather than upland areas. The KCRMS data is collected at several upstream sites in addition to one location (E1238) just upstream of the floodplain edge; these data show no excursions below the 6.5 criterion at any sites between 2003 and 2006. Prior to 2003, some sites show occasional, minor violations (values > 6.0), primarily in the months of November, March and April.

[15] CFU: colony forming units

The results are different at sampling stations in the valley. In 2004, King County (2005) measured pH at stations just upstream of the agricultural production district (APD) boundary (Site Cherry 1) on the same days that WDOE (2008) measured pH at the mouth of the Cherry Creek. The study found that pH values were lower (worse) at the mouth and that the upstream locations in Cherry Creek did not violate the standard. In comparison, the WDOE study found that the 6.5 criterion had been violated at the mouth. A separate study by King County (2007) recorded very minor excursions below the standard and generally concluded that pH is not a major concern in Cherry Creek. Figure 4 [reproduced with permission from King County (2007)] shows the range of measured values as well as the seasonal pattern that was also observed in the KCRMS data with the lowest values in late fall and spring.

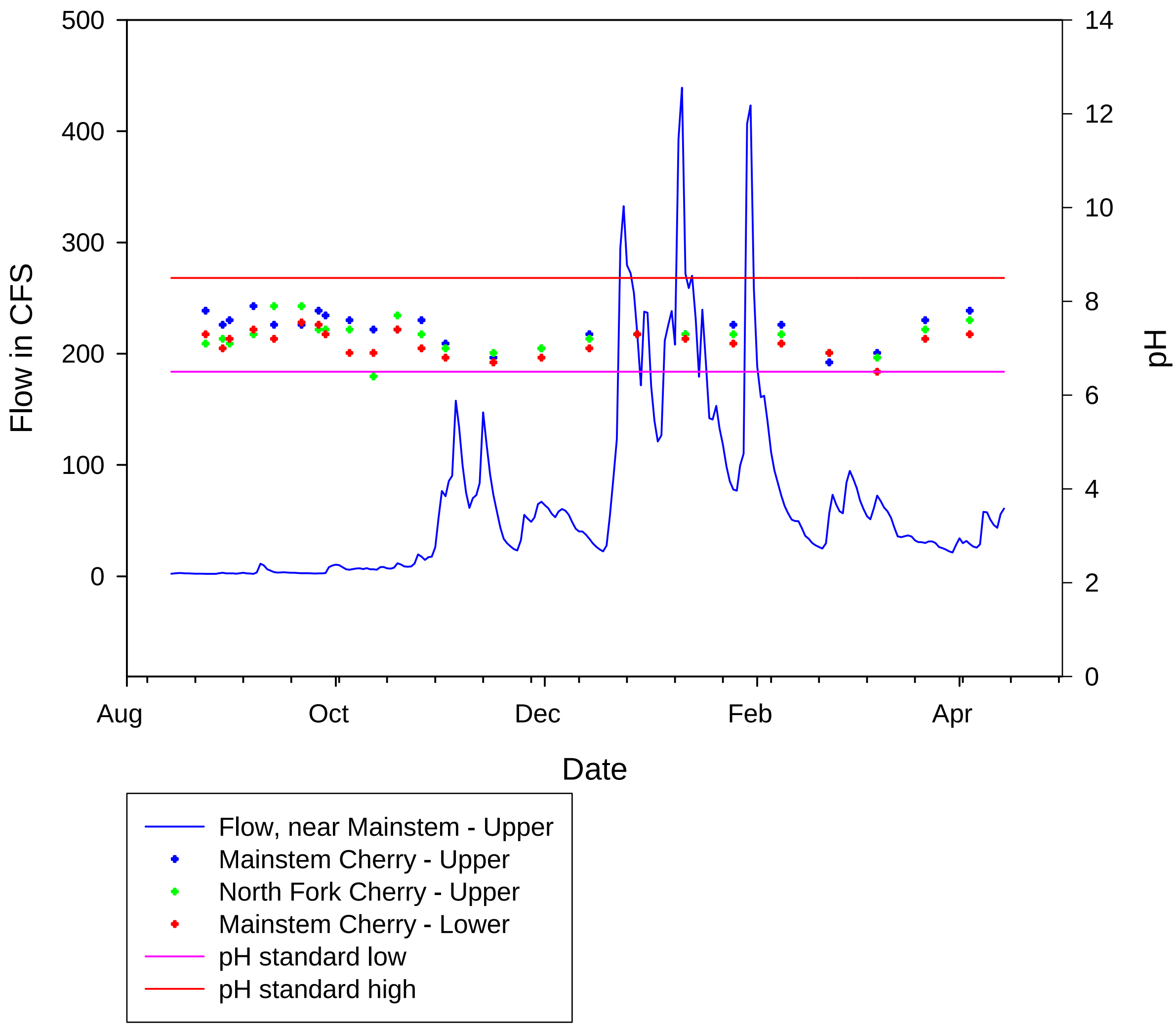

Figure 4. Cherry Creek pH and flow (cfs) in 2005-2006 from King County (2007).

Nutrients: Impaired

As discussed in Section 2.3, there are no specific water quality criteria for total nitrogen and phosphorus, the primary nutrients of concern, although a pH-dependent standard is in place for ammonia-nitrogen. Excess nutrients can cause algal blooms that in turn lead to low DO levels due to decomposition of dead algae. Nutrient monitoring helps to identify potential sources and seasonal patterns in nutrient loads that can inform strategies for addressing potential problems.

King County (2007) found that phosphorus levels were highly variable in Cherry Creek, especially during the wet season. Specifically, nutrient levels appeared to vary much more between sites during the winter months than during late summer. The mouth of Cherry Creek has the highest levels year-round, but in winter those values increase slightly while the upstream sites decrease in concentration during higher flows. This suggests that there are wet-season phosphorus inputs in Cherry Valley that are sufficient to keep concentrations high despite higher levels of dilution, and is consistent with a similar finding regarding fecal coliform.

Nitrogen levels were consistent during the fall and tended to increase with rain events at all three King County study locations (King County 2007). In contrast to the phosphorus case, the highest values tend to be found at the North Fork Cherry Creek site (Site Cherry 2).

WDOE's TMDL effectiveness study conducted minimal nutrient sampling in Cherry Creek. The ammonia-nitrogen levels were found to be somewhat elevated but just below the standard. Nitrite-nitrate concentrations were found to be higher than most other sites sampled during the study.

Benthic invertebrates (B-IBI)

KCRMS has collected data on benthic invertebrates in streams at several of the monitoring locations in the Cherry Creek sub-basin (Table 8). Three sites have a longer record of B-IBI measurements from 2000-2006, whereas other stations were only measured beginning in 2004. B-IBI scores are based on a 10-metric protocol (50 point maximum), with results that range from a rating of 'poor' to 'good'. Some sites appear to show improvement over time, but the data have not been reviewed for the presence of statistically significant trends. Moreover, as KCRMS sampling sites are largely limited to sites associated with road crossings, the samples are not unbiased or necessarily representative of conditions in other portions of the same stream.

Table 8. B-IBI Scores for selected sites in the Cherry Creek sub-basin. Data from KCRMS. Blank cells indicate that no data are available.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E1076	Trib. To Mainstem Cherry	28	24		36	42	38	30
E1078	North Fork Cherry Creek	20	24	24		36	40	34
E1238	Mainstem Cherry	24	28	24	28	34	30	34

Site	Location	2000	2001	2002	2003	2004	2005	2006
E1239	Tributary to North Fork					32	30	36
E1297	Lake Margaret Outlet[16]					18	24	12

Excellent	Good	Fair	Poor	Very Poor

None of the B-IBI sites are in the floodplain portion of Cherry Creek. This makes sense in that the sampling protocol is intended to be applied in riffle habitat which generally is of a higher gradient than the stream channel in the lower valley floor. Thus, the B-IBI data appears to confirm that water quality is fairly good upstream of the floodplain edge, but it does not shed any new light on conditions further downstream.

Synthesis and recommendations

Temperature and dissolved oxygen are the problems of greatest concern in Cherry Creek, followed by episodic spikes in fecal coliform concentration. Based on the available data, the more serious water quality problems appear to be limited in large part to the floodplain portions of the stream as upper basin sampling locations reflect better water quality. One notable exception is the Lake Margaret outlet and its role as a potential contributor to high temperatures in downstream areas. As mentioned above, high temperatures are not unusual in a lake environment, but downstream effects should be more closely evaluated, possibly by comparing stream temperatures in mainstem Cherry Creek both upstream and downstream of the Margaret Creek confluence.

For purposes of protecting aquatic life, addressing the dissolved oxygen problem in the lower valley should be the top priority. As temperature and dissolved oxygen are linked, efforts to reduce summer stream temperature - via intensive riparian planting or other means – will also have benefits for dissolved oxygen. However, the persistence of low DO when temperatures drop suggests that the level of organic matter and/or nutrients is high enough even in the wet months to cause excessive decomposition that may reduce oxygen to lethal levels at some locations. Improved farming practices and compliance with existing farm plans should be strongly encouraged in this basin, along with stronger enforcement of existing regulations regarding runoff and manure management.

The fecal coliform issue is of lower concern as the risk of recreational human exposure is fairly low, bacteria levels are not extremely high and tend to be mostly episodic. However, this, too, points to farm management as a high priority area of improvement. The fact that FC levels spike following high flows suggests that overland sources are a bigger contributor than potentially failing septic systems, though septic inspections and regular maintenance should also be strongly encouraged, particularly for parcels in close proximity to water

[16] The low scores at the Lake Margaret outlet do not necessarily indicate poorer water quality. The B-IBI protocol is applied in riffle habitat within streams. As the sampling location at Lake Margaret is immediately downstream of the lake outlet, the ability of the stream to support invertebrates is not directly comparable to other sites.

courses. It should be noted that while water quality sampling typically focuses on the major tributaries, there are numerous smaller drainages that bisect both rural residential and agricultural parcels before draining into one of the larger water courses. We have no data from these locations.

WDOE (2008) notes that one of the remaining dairies in Cherry Valley applies manure to fields via injection rather than spraying or spreading – this technique should help to lessen water quality impacts of the 150 acre facility. The farm has also received funds to add a liner to its undersized manure lagoon (WDOE 2008), although this action has not yet taken place (Claire Dyckman, King County, personal communication).

Priority actions for Cherry Creek:

- Significantly reduce nutrient inputs that are likely attributable to farming practices, including manure storage and application as fertilizer. Farm plan development and compliance should be strongly encouraged.
- Perform extensive riparian restoration along Cherry Creek itself as well as drainage channels where possible. Species selection, planting density and planting area width should take into account long-term goal of temperature reduction and short-term potential to help reduce nutrient inputs via overland flow.
- Exclude livestock from access to stream and other drainage channels.
- Investigate water quality in key tributaries (e.g., Rasmussen and Water Wheel Creeks) to identify specific sources and locations of impairment.
- Encourage proper septic system operation and maintenance through landowner incentives, education and technical support.

Tuck Creek (3.6 mi^2)

Sub-basin Description

Land Use[17]	
Rural Res. 1 DU/2.5-10 acres	84.4%
Agriculture	15.6%

At only 3.6 mi^2, the boot-shaped Tuck Creek sub-basin is the smallest of the sub-basins discussed in this report. The drainage is located in the northwest corner of the watershed with a small portion located in Snohomish County. The mainstem originates in Tuck Lake before draining the primarily rural residential uplands that flank Woodinville-Duvall Rd. The rural residential area is also home to horse farms and other small-scale livestock operations. Like many other tributaries, the lower portion of Tuck Creek is within the APD, where it is joined by a number of agricultural drainage channels and smaller tributaries.

Chinook salmon are known to occupy the floodplain portion of the basin as juveniles, but spawning is not known to occur in Tuck Creek. In contrast, coho and steelhead ascend into the upper portions of the stream for both spawning and rearing. The APD portion of Tuck Creek is within the 100-year floodplain of the Snoqualmie River.

Water Quality

Available data for Tuck Creek show that the stream is impaired for several different water quality indicators, including pH, fecal coliform and nutrients. Recent water quality data (WDOE, 2008) shows that water quality appears to have degraded in Tuck Creek since the original WDOE TMDL study (Joy, 1994).

Temperature: Basin of concern

Tuck Creek appears to meet the 17.5°C temperature standard at most stations. Grab samples collected by KCRMS along the mainstem upstream of the valley floor include occasional readings in August that exceed the standard, but by less than 0.5°C. The average monthly temperature during the June-September period (based on KCRMS data) does not exceed 15°C at any of the monitoring locations. However, WDOE's TMDL Effectiveness study recorded a grab-sample temperature at the mouth of the creek of 20.1°C, though the large majority of summer samples met the standard. The highest readings in both datasets corresponded with the same month (August 2004). In comparison, August temperatures in other years as measured by KCRMS were substantially cooler.

WDOE collected continuous temperature data during the summer of 2006 at the mouth of Tuck Creek as part of an ongoing temperature TMDL study. The draft data show that the 7-DADMax standard was exceeded for approximately one week during a particularly warm spell in July 2006. Nearly all stream and river locations in the Snoqualmie watershed monitored by WDOE during the study exceeded their respective temperature standards during the same one-week period.

[17] Includes both King County and Snohomish County land-use designations.

Dissolved oxygen: Impaired

The dissolved oxygen concentration fails to meet standards at the mouth of Tuck Creek, according to WDOE (2008). In contrast, KCRMS data reflect good DO levels in the mainstem and in a smaller unnamed tributary at the edge of the floodplain. This pattern is fairly similar to those in other floodplain tributaries in that DO conditions appear to be good upstream of the floodplain, but degrade further downstream. However, measured values in Tuck Creek appear higher than those in Cherry and Ames Creeks, although the number of data points is much lower in Tuck Creek.

Fecal coliform: Impaired

Based on data collected by WDOE (2008) and King County (2005), Tuck Creek fails both parts of the fecal coliform standard at the mouth of the stream. The highest recorded concentration is 1300 CFU/100 ml, thirteen times higher than the geometric mean standard. WDOE's TMDL effectiveness report calls for 39% reduction in fecal coliform during the late-summer critical period in order to meet the standards.

During the same-day sampling performed by King County and WDOE at the upstream floodplain edge and creek mouth, respectively, mean values collected at the upstream site met standards while the downstream location did not. Agriculture within lower Tuck Creek comprises corn fields, a poplar tree farm and other crops, but little if any livestock. Higher bacterial concentrations may potentially be explained by a combination of manure application as fertilizer and by contributions from natural sources, such as waterfowl and other wildlife. Further investigation of the sources and distribution of FC within the basin is warranted.

pH: Impaired

Tuck Creek also fails to meet the pH water quality standard at the mouth (WDOE 2008), although the excursions below 6.5 are fairly minor, with a minimum value of 6.2 during the study. Similarly, KCRMS data suggest that the pH standard is met at nearly all sampling locations, with one minor excursion to 6.3 at a tributary sampling location in the upper watershed. The lowest pH values in Tuck Creek have been recorded in December and January.

Nutrients: Impaired

Nutrient sampling has been very limited in Tuck Creek. According to WDOE (2008) and King County (2005), Tuck Creek met the standard for ammonia-nitrogen. However, concentrations of total nitrogen and total phosphorus exceeded guidelines on all sampling occasions.

King County's more recent study (2007) did not include Tuck Creek. Thus, seasonal data analogous to those collected in Cherry, Ames, Patterson and Harris Creeks are not available. However, same-day sampling (King County, 2005) shows that on all but one sampling date, ammonia-nitrogen levels increased significantly between the floodplain edge and the mouth of the creek. Identification of nutrient sources and concentrations within different drainage channels and tributaries should be investigated.

Benthic invertebrates

KCRMS has collected invertebrate data at only two locations in Tuck Creek, with data limited to the 2004-2006 period (Table 8).

Table 9. B-IBI Scores for selected sites in the Tuck Creek sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E540	Approx. 1/3 mile upstream of floodplain edge					34	36	26
P752	Tributary approx. 1 mile upstream of floodplain edge					38	40	36

Excellent	Good	Fair	Poor	Very Poor

Both sites are in the upland portion of the basin which is fairly wooded with a moderate stream gradient. The scores range from 'poor' to 'good' with a decline in score at both sites during the most recent sampling event. Conclusions about trends over time are not possible absent a longer dataset.

Synthesis and recommendations

Tuck Creek suffers from moderate impairment for several water quality parameters. Similar to other tributaries that traverse the Snoqualmie River floodplain through predominantly agricultural areas, excessive nutrients appear to be a driver of other observed impairments, such as low dissolved oxygen. However, the DO levels in Tuck Creek appear significantly better than in Cherry and Ames Creeks.

Bacteria levels are noticeably high in lower portions of Tuck Creek. In the absence of significant livestock concentrations, the management of fertilizers should be evaluated in this area. In addition, the presence of natural sources should also be investigated. Septic systems cannot be ruled out as contributors, but samples from the upstream locations that should reflect the effects of residential land-use have much lower bacterial counts than samples collected near the mouth. Also, the occasional very-high spikes in bacterial concentration suggest that sources are mobilized by rainwater, implicating surface sources of contamination.

King County collected continuous temperature data at several locations in Tuck Creek during summer 2008 that will supplement the draft data collected by WDOE in 2006. Although temperature does not appear to be chronically and severely impaired in Tuck Creek, efforts to improve temperature, such as riparian plantings, will help to reduce nutrients and bacteria.

Priority actions for Tuck Creek:

- Investigate sources and spatial distribution of nutrients in the lower sub-basin. Include both maintained drainage channels and natural watercourses.
- Enhance riparian conditions in floodplain areas where possible to help control nutrient and sediment inputs and to provide temperature benefits.
- Evaluate role of natural sources as contributors to bacterial concentration.
- Assess spatial distribution of bacterial concentration in the lower Tuck Creek sub-basin drainage network.
- Work with landowners to ensure that appropriate nutrient management practices are being applied to crops of all kinds in the lower portions of the sub-basin, as well as horse farms and other livestock operations in the rural residential portions of the sub-basin.
- Encourage proper septic system operation and maintenance through landowner incentives, education and technical support.

Ames Lake Creek (8.1 mi^2)

Sub-basin Description

Land Use	
Rural Res. 1 DU/2.5-10 acres	69.9%
Agriculture	30.1%

The mainstem of Ames Lake Creek (also referred to simply as Ames Creek) is horseshoe shaped, draining primarily rural residential uplands before traversing the APD across the floodplain of the Snoqualmie River. The upper reach is fairly steep as it roughly follows Union Hill Rd. before entering Ames Lake. Ames Lake measures 76 acres and is ringed with homes on over 100 lots that range in size from roughly ⅓ acre to some that are greater than 1 acre in size. The creek continues northward from the lake outlet as it descends to the valley floor.

Like many other tributaries in the APD, the floodplain portions of Ames Creek and its tributaries have been deepened and straightened over the years to benefit agriculture along the valley floor. While numerous small tributaries and drainage channels enter Ames Creek throughout its course, Sikes Lake Creek[18] is a key tributary that drains the northeast portion of the basin and Sikes Lake before joining the mainstem in the floodplain a short distance upstream from the creek mouth. As described below, water quality in the Sikes Lake Creek drainage differs from the mainstem for some parameters.

Chinook salmon, coho salmon and steelhead are known to utilize Ames Creek to different degrees. Chinook juveniles rear in the floodplain portions of the creek, while coho are known to ascend up to Ames lake and beyond for spawning and rearing. Steelhead use is believed to be less extensive than coho salmon in this basin, but more extensive than Chinook.

Figure 5. Ames Creek at 100th Ave NE during high-water conditions in the Snoqualmie River.

The Ames Creek floodplain is low-lying and thus prone to flooding when the Snoqualmie River is running high. Even when the Snoqualmie River has not overtopped its banks, the water level in the river can be high enough to flood Ames Creek, beginning at the creek mouth and flooding back into the valley. The photograph above (Figure 5, photo by K. Higgins) shows floodwaters spilling across NE

[18] Like many other local names, Sikes Lake Creek is a locally derived, unofficial name for the stream.

100th Street from north to south (right to left), while the creek itself flows from south to north (left to right). The majority of the APD within the Ames Creek basin is within the 100-year floodplain of the Snoqualmie River.

The Snohomish River Basin Salmon Conservation Plan highlights the need to protect and restore hydrologic and sediment processes in the Ames Creek sub-basin, neighboring Patterson Creek and other similar areas. The riparian corridor has been heavily altered in floodplain areas in particular, but upland areas also feature substantial encroachment of residential and agricultural development into riparian areas, loss of functional wetlands and mature forest cover. These types of changes tend to contribute to water quality degradation by increasing stream temperature as well as the input of pollutants and sediment. The loss of wetlands to filling can exacerbate flood flows in the stream while decreasing summer low flows.

Water Quality

As in Cherry Creek (which is more than three times as large), several studies suggest that Ames Creek has poor water quality for several different water quality parameters. There are, however, differences in quality between different portions of the basin and patterns that differ from those found in Cherry Creek. Also, Ames Creek is classified as supporting "Salmon spawning, rearing and migration", but is not considered "core" habitat. Thus, the standards for temperature, dissolved oxygen and pH are somewhat less restrictive.

Temperature: Basin of concern

The temperature standard for Ames Creek downstream of Ames Lake is 17.5°C, measured by the "7-DADMax"condition as explained in Section 2.3. Upstream of the lake, the standard is 16°C due to the special consideration that the State standards give to the feeder streams of lakes [WAC 173-201A-600 (1)(a)(ii)][19].

There are no long-term, continuous temperature gages in the basin. Thus, it is not possible at this time to say with certainty that the creek meets the water quality standard. Available data suggest that Ames Creek is cooler than some other tributaries and appears to stay below the temperature threshold. A review of data from completed studies shows that - with the exception of Ames Lake itself and the lake outlet - stream temperature stays below the 17.5°C level. In fact, KCRMS data shows that temperatures tend to stay below 16°C at all stations, with the exception of the lake outlet. At the mouth of Ames Creek, the 17.5°C standard has been exceeded on occasion according to KCRMS data, but the exceedance has been minor.

WDOE collected continuous temperature data for the temperature TMDL that is currently under development. The data were collected near the mouth of Ames Creek during the summer of 2006. The results show that the 7-DADMAX exceeded 17.5°C for approximately

[19] Not all feeder streams to lakes have the same standards. The Ames Lake feeder streams fall into a category of streams that are not specifically named in Table 602 of WAC 173-201A, and thus the so-called "general" designation criteria are applied to these waters.

one week in late July when air temperatures neared 31°C (88°F). The highest calculated 7-DADMax during that period was 19.1°C.

The fact that temperature appears to meet the standard most of the time with only minor, irregular excursions does not mean that the temperature of the stream has not been altered from its natural condition or that actions to improve temperature would not be beneficial, but based on available information, temperature is not the most immediate concern in Ames Creek.

<u>Dissolved oxygen: Impaired</u>

In contrast to temperature, the dissolved oxygen (DO) condition in Ames Creek is poorer than in other tributaries. A review of different data sources suggests that while most portions of the stream system meet the standard of 8.0 mg/L , the lower portion of the Ames Creek mainstem consistently fails to meet the standard.

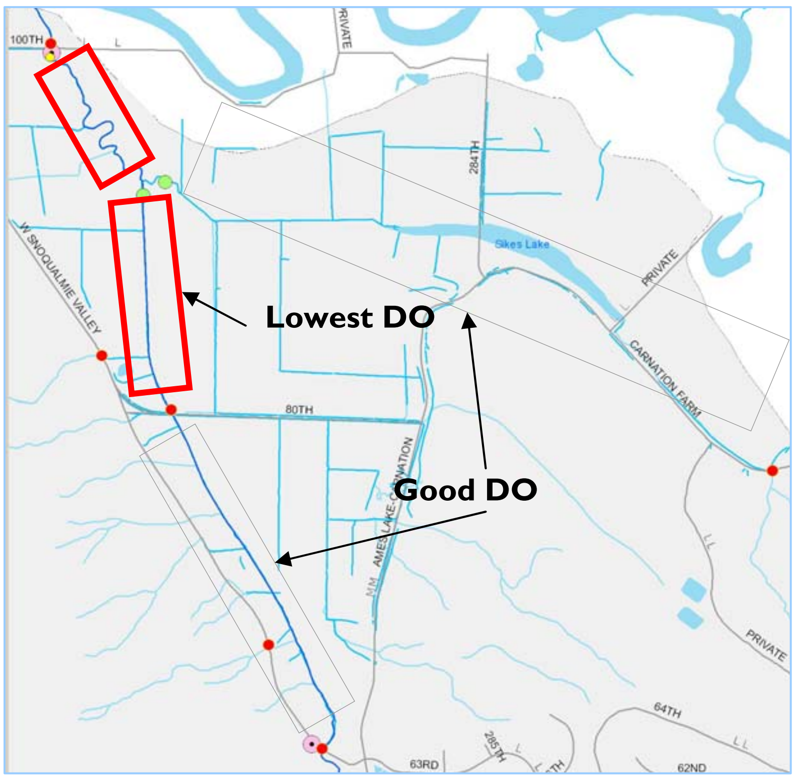

Figure 6. Locations of apparent dissolved oxygen impairment in Ames Creek.

King County (2007; 2005) and WDOE (2008) concluded that Ames Creek fails to meet the DO standard at the mouth. However, King County (2007) shows a distinct difference in DO condition between Sikes Lake Creek and the mainstem. The data suggest that DO levels meet standards in Sikes Lake Creek but fail the standard in the mainstem just upstream of the Sikes Lake Creek confluence.

A review of KCRMS data helps to narrow down the problem area further. Data collected at the upstream end of the floodplain and at the NE 80th Street crossing suggest good DO conditions at both locations. Thus, the lower half of the mainstem (downstream of NE 80th St.) appears to be the focal point of the DO problem (Figure 6).

In most streams, as temperature drops in the fall and early winter, DO levels will rise from their seasonal, late-summer lows. However, the King County (2007) data show that the DO level remains low in the mainstem of Ames Creek well into the winter, even more so than in Cherry Creek. During the study period, DO remained below standard through February at the mainstem location upstream of the Sikes Lake Creek confluence, but met standards at the mouth earlier in the fall/winter season.

As in the Cherry Creek case, low DO suggests excessive nutrients in the stream that trigger algae blooms and subsequent build-up of decomposing organic matter in the stream. However, algae production is largely absent in the winter months due to a lack of sunlight and lower temperatures. Thus, the low winter DO could be accounted for in part by other factors, such as continuing decomposition of built up organic matter in the stream, or direct inputs of low-oxygen water. Poorly oxygenated water could potentially come from agricultural drain tiles located within peat soils (a deoxygenating environment), or perhaps natural conveyance of groundwater from low-oxygen soils (Sally Abella, King County Water & Land Resources Division, personal communication).

Fecal coliform: Impaired

Ames Creek fails to meet fecal coliform bacteria standards in the lower mainstem as well as in Sikes Lake Creek. WDOE (2008) estimates that fecal coliform (FC) would need to be reduced by 86% in the Ames Creek basin to meet standards. The highest observed values in the King County (2007) study were found in the Sikes Lake Creek drainage, which also captures many of the tributaries that cross the floodplain.

Following fall rains, bacteria levels spike to high levels; WDOE (2008) recorded a concentration of 7,000 CFU/100 ml at the mouth of the creek, 70 times the geometric mean standard concentration.

No genetic analysis of bacteria has been carried out in Ames Creek to identify the host organisms in question. While livestock use of the floodplain is lower than during the heyday of dairies in the Snoqualmie Valley, other sources may also be contributing to high baseline levels, such as high waterfowl concentration in Sikes Lake, application of manure as fertilizer, horse farms located in the floodplains and uplands, and extensive rural residential areas served by septic systems.

The fact that bacterial levels spike following rain events suggests that overland sources – such as animal manure, are likely contributors, but poorly designed or failing septic systems cannot be ruled out as adding to the problem. However, the King County (2005) monitoring location at the upstream edge of the floodplain (same as KCRMS Site E898) appears to meet standards for bacteria. This site captures runoff exclusively from areas or rural residential land use.

In mid-2008, during preparation of this report, the draft results for Ames Creek were presented to local landowners. As a result of that meeting, farmers and the KCD took the initiative to collect more detailed bacterial data from Ames Creek during the remainder of the summer and early fall. The KCD contracted with the King County Lake Stewardship Program to collect *E. coli* samples at a number of sites along Ames Creek, Sikes Lake Creek and incoming tributaries. Samples were collected once in August and once in September. The August sample had been preceded by a rain event a few days earlier, a scenario that often leads to high bacterial counts in late summer. The highest concentration of *E. coli* was found at the west end of Sikes Lake in August, measuring 1,770 CFU/100 ml. Of eleven sites sampled in August, nine exceeded the 100 CFU criterion[20] and 5 exceeded the 200 CFU criterion. In general, September values were lower at most locations, but nine of fourteen sites still exceeded the 100 CFU criterion, with a maximum value of 270 CFU/100 ml. Several small tributaries that drain into Ames Creek from the western hillside had elevated values on both occasions, including a concentration of 710 CFU/100 ml at one location in August. There are horse farms located along the upper portions of the hillside in question, but specific sources of bacteria cannot be determined on the basis of this study. Further studies may be conducted in summer 2009.

pH: Impaired

In the case of pH, mostly minor excursions below the 6.5 threshold were recorded during the King County (2007) study in the lower mainstem of Ames Creek. Similarly, KCRMS data shows that pH occasionally falls below 6.5 at site E2040 near the mouth of the stream. WDOE recorded a noticeably lower value of 5.8 in October 2003 that coincided with the record low DO during the study for Ames Creek of 4.6 mg/L . According to the stream gage in Cherry Creek[21] (King County Gage 05A), the sampling date (10/28/2003) followed roughly one week of high flows due to rainfall.

It is quite unusual to have such low levels of DO during apparently high or moderate flow conditions. The relationship of the pH minimum to low DO is not entirely clear.

Nutrients: Impaired

King County (2007) compared nutrient levels in several tributaries with predominantly agricultural floodplain land uses. Of the four sub-basins in the study, Ames Creek had the highest levels of phosphorus. This finding is consistent with the King County data from 2005. However, nitrogen levels appear to be lower on average than other agricultural tributaries. WDOE (2008) confirmed that both phosphorus and nitrogen fail to meet the TMDL guidelines for these nutrients, and that Ames Creek concentrations are higher than most other sites (which included non-agricultural tributaries). King County (2005) also showed that total nitrogen and total phosphorus levels at the upstream end of the floodplain exceeded federal guidelines on all sampling occasions. High levels of nutrients can contribute to algae blooms that in turn may lead to low levels of dissolved oxygen due to high rates of decomposition.

King County (2007) shows that in the lower mainstem of Ames Creek and at the mouth, both nitrogen and phosphorus concentrations spike following the onset of fall rains and remain at a higher level during the winter. In contrast, Sikes lake Creek shows a less stark increase in nitrogen and a decrease in phosphorus concentration during the rainy season. These patterns suggest that in the mainstem of Ames Creek, nutrients are mobilized by rains, implicating overland sources, whereas the Sikes Lake Creek nutrient levels may be associated with more constant sources.

[20] The state criteria are of course for total fecal coliform, of which *E. coli* are a subset.

[21] King County has no long-term continuous monitoring stations in the basin.

It is important to recognize that geology and vegetation can also play a role in the 'natural' nutrient levels in a stream, and that nutrient inputs outside of the growing season may have different implications for increases in stream productivity, but the available data suggest that nutrients may be a primary contributor to other observed impairments, especially low DO.

Benthic invertebrates

Available data on benthic invertebrates is very limited in Ames Creek. The data collected by KCRMS shows that the B-IBI index score was very low from 1999-2002 at the upstream edge of the floodplain (Site E898, Table 10). This contrasts with the fact that most other water quality indicators - such as DO, pH and temperature – suggest relatively good water quality at the same site. However, as noted above, nutrient levels (total nitrogen and total phosphorus) appear to be elevated at this location according to King County (2005). Also, the KCRMS monitoring effort may have been associated with a specific road construction or maintenance project that could have had a localized effect on the invertebrate population. Moreover, the second site (E2032) is located within a low-gradient floodplain reach and does not therefore appear suitable for the B-IBI protocol. This may explain in part the low scores recorded at the site.

Table 10. B-IBI Scores for selected sites in the Ames Creek sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E898	Ames Creek upstream floodplain edge	14	14	18				
E2032	Ames Creek at NE 80th St.					24	24	24

Excellent	Good	Fair	Poor	Very Poor

Absent same-year benthic invertebrate data in Ames Creek, it is not possible to say whether the higher (though still poor) scores at the NE 80th St. crossing (Site E2032) are a result of higher water quality.

Synthesis and recommendations

The greatest concern in Ames Creek is the low level of dissolved oxygen, particularly in the lower mainstem. The low DO level persists even as temperature drops, suggesting that temperature is not a primary driver of the problem. In addition, the lowest measured DO concentration was taken during a relatively high flow condition (based on gage data from neighboring basins). This, too, is alarming in that high flows typically oxygenate the water in areas that may have been stagnant prior to such flows. Additional data should be collected along the mainstem at a larger number of sites to narrow down the likely source of the problem.

The dissolved oxygen level is often directly related to the amount of nutrients in the stream. While the specific nutrient sources are not entirely clear in different portions of the basin, Ames Creek appears to have the highest nutrient levels of the tributaries in the watershed that have been sampled to date. Elevated levels have been measured at all sites in the floodplain, including the upstream edge that captures flow from primarily residential areas and Ames Lake. More intensive sampling of nutrients along the length of the stream could help to inform this issue. An analysis that couples soil types and depths with the locations of drain tiles could also help to confirm the role of low-oxygen soils as contributors to the dissolved oxygen problem.

As the types of agriculture in Ames Creek have shifted partly away from dairies and other livestock to crops of various kinds in recent years, additional bacteria data would be useful to determine whether these changes have reduced bacterial concentration. If not, then sources are more likely to be located in upland agricultural areas (horse farms, etc.), residential areas, or associated with wildlife/waterfowl. The recent sampling efforts in fall 2008 (funded by landowners and KCD) are an excellent first step toward that assessment.

In the meantime, efforts to encourage responsible manure and nutrient management should be increased in this sub-basin, along with enforcement of existing regulations. These efforts should not be limited to floodplain properties, but also to upland livestock operations.

For the upper mainstem of Ames Creek (upstream of the floodplain), elevated nutrient levels coupled with seemingly low bacterial counts suggest that septic systems may in fact be working as intended, but most older septic systems in particular do not effectively address nitrogen or phosphorus. Additional investigation of nutrients in this primarily rural residential area would be useful to help separate the influence of natural sources from septic systems, residential fertilizer application and other factors.

<u>Priority actions for Ames Creek:</u>

- Significantly reduce nutrient inputs that are likely attributable to farming practices, including manure storage and application. Farm plan development and compliance should be strongly encouraged.
- Exclude livestock from access to Ames Creek, Sikes Lake as well as other tributaries and drainage channels.
- Investigate role of soil types and agricultural drainage systems (e.g., drain tiles) as contributors to oxygen depletion.
- Collect dissolved oxygen data from several locations (possibly in tandem with bacterial sampling) to better characterize the spatial pattern of oxygen conditions.
- Continue bacterial sampling initiated in 2008 to locate specific areas of impairment.
- Perform extensive riparian restoration along Ames Lake Creek and Sikes Lake Creek as well as drainage channels where possible. Species selection, planting density and planting area width should take into account long-term goal of temperature reduction and short-term potential to help reduce nutrient inputs via overland flow.

Harris Creek (13.1 mi^2)

Sub-basin Description

Land Use	
Rural Res. 1 DU/2.5-10 acres	85.9%
Forestry	9.0%
Agriculture	5.1%

Harris Creek drains a broad upland terrace that features extensive wetlands as well as several lakes and ponds, including Lake Joy. From approximately RM 4 to RM 2, the creek flows through a steeper canyon section to the valley floor, before meandering for two miles through current and former agricultural lands within the Snoqualmie River floodplain. The final mile of the creek flows through the WDFW Stillwater Wildlife Area.

The uppermost reaches of the mainstem feature forestry as the primary land use, including both State-owned and private forest lands. The bulk of the sub-basin comprises rural residential land uses, entirely within unincorporated King County. The highest densities are found around the two largest lakes – Lake Joy and Lake Marcel, where most lot sizes range from 0.3-1.0 acre in size. Like many other tributary sub-basins, there are numerous small farms within the rural residential portions of the drainage. The entire sub-basin is served by on-site septic systems.

Stillwater Creek is the second major stream in the Harris Creek sub-basin. The creek flows into and out of Lake Marcel, before flowing through a canyon reach to the floodplain. Stillwater Creek joins Harris Creek just before it enters the Stillwater Wildlife Area.

The documented distributions of coho salmon and steelhead extend into the upper watershed where extensive wetlands and ponds likely provide excellent rearing habitat. Chinook salmon are presumed to utilize floodplain portions of the stream as juveniles, but spawning is not known to occur in Harris Creek. Coho salmon are also known to ascend Stillwater Creek as far as the Lake Marcel outlet.

Water Quality

Water quality in Harris Creek is intermediate within the range of conditions observed in other lowland sub-basins. Nutrients appear somewhat elevated in the lower portion of the basin and dissolved oxygen levels are somewhat depressed in the wetland-rich portions of the upper basin during summer months. However, the lack of data (with the exception of limited temperature data) from the floodplain sections of the stream leave important questions unanswered.

Temperature: Basin of concern

As a stream with core summer salmonid habitat designation, the 16°C 7-DADMax standard is applied to Harris Creek. As with other sub-basins, WDOE's TMDL Effectiveness study (WDOE, 2008) was focused on water quality conditions in the lower reaches of the stream. In this case, WDOE sampled Harris Creek at SR 203, nearly two miles upstream of the mouth.

Compared to other basins, Harris Creek remained fairly cool even during warm weather. Most of the recorded temperature readings remained below 15°C. WDOE (2008) concluded that the stream appears to meet standards for temperature, although a definitive conclusion cannot be made without continuous temperature data. A shortcoming in WDOE's study was that sampling was not initiated until August of 2003 and again in August 2004. July data collected by King County and by WDOE as part of the draft temperature TMDL study suggests that though temperatures are lower than in many other tributaries, Harris Creek may not meet the standard after all. Data collected by King County in 2008 may provide additional insight to temperature conditions in the floodplain portions of Harris Creek.

WDOE collected continuous temperature data in 2006 at two sites in the lower basin – the SR 203 crossing, and a location further downstream where the creek passes under the Snoqualmie Valley Trail. Both locations exceeded the 7-DADMax standard during the sampling period. The SR 203 site exceeded the standard for approximately one week on two occasions in late July and August, though the 7-DADMax never exceeded 18°C. The lower site exceeded the standard continuously for roughly six weeks during the same time frame, with a maximum index value of nearly 19°C. As with other tributaries that meander slowly through the floodplain, the water temperature appears to rise substantially in the lower portions of Harris Creek (Figure 7).

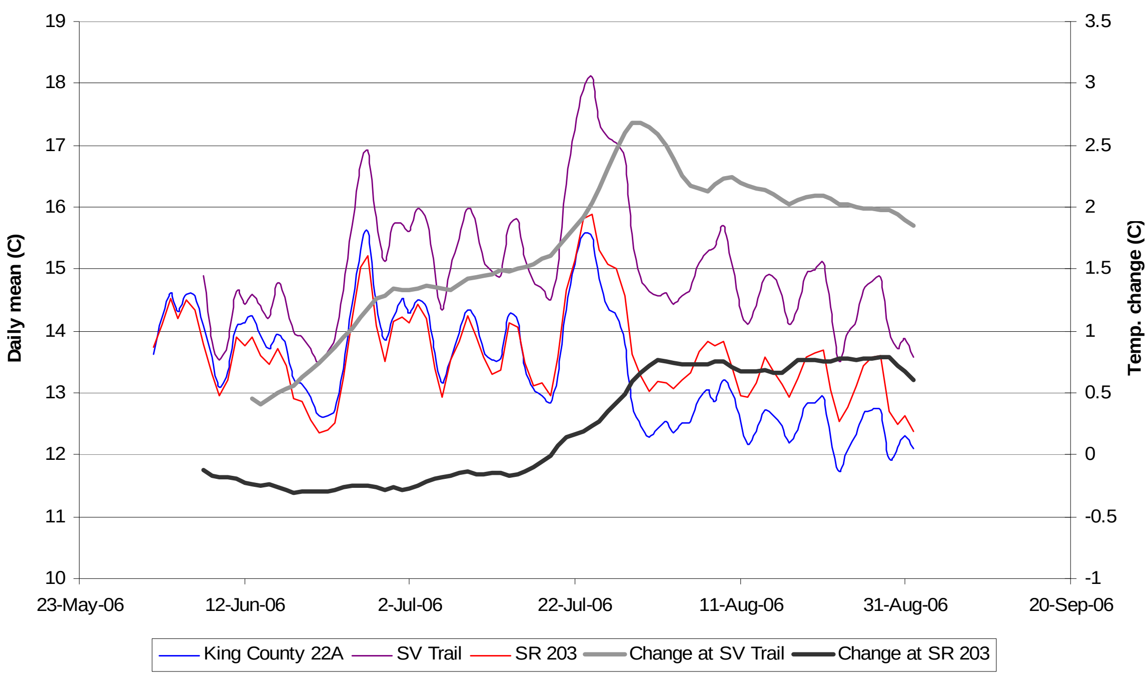

Figure 7. Daily mean temperature at three sites in Harris Creek: King County 22A (furthest upstream), WDOE at SR 203 (edge of floodplain), and WDOE at the Snoqualmie Valley trail (lower floodplain). The temperature difference between the King County site and the two lower basin sites is shown on the right axis as a smoothed 7-day average.

Figure 7 shows that as average temperature increases, the difference between upstream sites and downstream sites increases as well. At the Snoqualmie Valley Trail site, late July temperatures are up to 2.7°C (4.9°F) higher than at King County's upstream location. The majority of the difference is attributable to the floodplain portion of the stream, as the SR 203 station temperature is less than 1°C higher than the upstream location.

KCRMS maintains several monitoring locations in the sub-basin, mostly along the upland plateau portion of the stream and associated tributaries between RM 3 and RM 7. Though the temperature varies somewhat from station to station, average monthly temperature does not exceed 16°C at any location, though occasional higher temperatures have been recorded at most stations.

Dissolved oxygen: Basin of concern

According to WDOE's data collected at SR 203, Harris Creek meets standards for dissolved oxygen at this location. This is not surprising in that the stream passes through a moderate-gradient canyon reach just upstream of this location at the floodplain edge. Similarly high DO readings are found in analogous locations in other sub-basins (e.g., Ames Creek floodplain edge).

However, the KCRMS data from the wetland-dominated upper portion of the basin shows that moderate DO impairment occurs at several stations. Summertime monthly mean values remain above 7.5 mg/L at all sites, but much lower values have been recorded from time to time along the section of the stream that follows Kelly Rd. through the large wetland complex along the plateau. As the stream begins its descent to the valley floor, DO concentration quickly rebounds to higher levels.

Fecal coliform: Basin of concern

Harris Creek meets the fecal coliform geometric mean standard of 100 CFU/100 ml year-round (WDOE 2008). However, as is the case for most tributaries in the watershed, the stream occasionally exhibits higher bacterial concentrations following storm events during the dry season. WDOE estimates that a 10% reduction in bacterial loading is needed in order to meet standards. This is a low value compared to many other sub-basins. However, it should again be noted that unlike other sub-basins, the sampling did not take place at the mouth of the stream. Thus, the reported values only capture the effects of bacterial loading that occurs in the forested and rural residential portions of the upper sub-basin.

King County (2007) also measured fecal coliform in Stillwater Creek, upstream of Lake Marcel. This area features rural residential properties as well as small-scale livestock operations. It appears that bacterial concentrations are notably higher in this portion of Stillwater Creek than other sites in the sub-basin and likely violates the state standard (Figure 8).

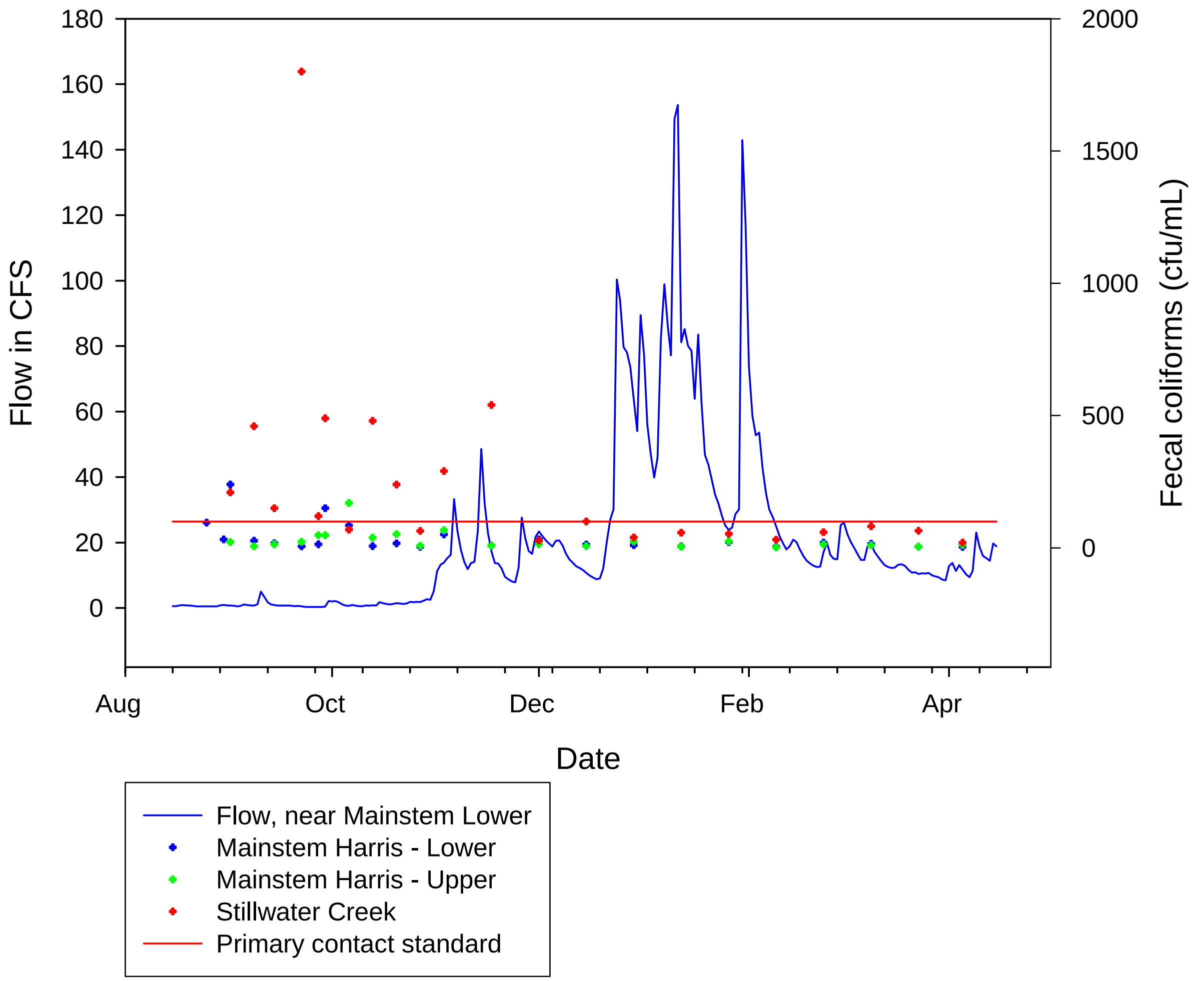

Figure 8. Fecal coliform concentration in Harris Creek and Stillwater Creek (from King County, 2007).

pH: Not impaired

According to WDOE (2008) and King County (2007), Harris Creek appears to meet standards for pH at all locations throughout the year. Similarly, a review of KCRMS data from seven locations in the upper basin and Stillwater Creek show that since 1999, only a few very minor excursions to a pH level of 6.4 have occurred in isolated instances.

Nutrients: Impaired

Both WDOE (2008) and King County (2007) report elevated nutrient levels in Harris Creek. However, the state standard for ammonia-nitrogen was not exceeded.

Total nitrogen concentration appears to be highest in Stillwater Creek, and rises slightly with higher flows. Note that fecal coliform concentrations are also elevated in this reach suggesting that septic systems or livestock manure may be associated with both problems. In contrast, total phosphorus is highest at the edge of the floodplain, but concentrations decrease substantially as flows increase. These data suggest that nitrogen sources may be mobilized by overland flow, whereas phosphorus may be attributable to more constant sources.

In general, with the exception of Stillwater Creek, the concentrations of total nitrogen are lower in Harris Creek than in other mostly agricultural tributaries sampled by King county (2007). Phosphorus levels are also lower on average, but still higher than applicable federal guidelines.

Benthic invertebrates

KCRMS has collected B-IBI data from a handful of locations in Harris Creek (Table 11). Sites E1105 and E1107 are in the upper portion of the basin and are primarily influenced by forestry land uses. The poor-to-fair scores at these locations suggest that water quality and substrate condition has likely been affected adversely by logging activities. However, the suitability of the sites for the B-IBI protocol has not been examined for this study.

Site E1088 is located at approximately RM 3.2, within a canyon reach downstream of the large wetland complex. Other indicators of water quality are generally very good at this location, consistent with the fair-to-good B-IBI scores in 2004-2006. This site is also the location of the King County stream flow and continuous temperature station 22A.

Table 11. B-IBI Scores for selected sites in the Harris Creek sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E1088	Big Rock Rd.					42	36	34
E1105	Upper basin near RM 6.5	16	30	28	28	28	36	28
E1107	Upper basin - Stossel Creek Rd. and 351st			22	36			

Excellent	Good	Fair	Poor	Very Poor

Synthesis and recommendations

The lack of data from the mouth of Harris Creek precludes the assessment of conditions along the majority of the floodplain section of the stream. If patterns observed in other streams (such as Ames Creek and Cherry Creek) are also present in Harris Creek, lower dissolved oxygen, higher nutrient concentration, higher bacterial concentration and higher temperature at the mouth are likely. However, despite the historical prevalence of agriculture in the lower reaches of Harris Creek, today WDFW is the primary landowner downstream of SR 203 and active agriculture is fairly limited. This may result in lower levels of bacteria and nutrients than in some of the more agriculture-dominated tributaries, but the lack of data from the creek mouth precludes a definitive characterization of water quality in this reach. WDFW should be encouraged to conduct water quality monitoring in their portion of the floodplain.

The fairly high level of fecal coliform observed by King County in upper Stillwater Creek is a concern for human health, particularly in the vicinity of Lake Marcel. Lake Marcel is a shallow, 33-acre lake ringed with homes. Thus, the risk of recreational exposure is fairly high, especially during summer months when the bacterial levels appear to be at their peak. Livestock farming practices and residential septic systems should be evaluated for potential corrective action via education, incentives or enforcement of regulations. However, if there are no additional sources of bacteria, the concentration observed in Stillwater Creek will be reduced to a small fraction by dilution in the lake itself.

Nutrients are elevated in Harris Creek, including areas upstream of the APD (we have no data for nutrients within the floodplain). This suggests that residential use of fertilizers, septic systems and livestock operations in the rural residential zone may be to blame. Nutrient inputs can cause or exacerbate low dissolved oxygen conditions, particularly in the low-gradient reaches of the sub-basin where physical aeration via turbulent flow does not occur, and temperatures are likely to be highest. Outreach to residential and agricultural landowners in the upper basin is highly recommended with an emphasis on nutrient management practices, focusing on fertilizer use, livestock exclusion from streams, and maintaining vegetated buffers on all streams.

Priority actions for Harris Creek:

- Collect water quality data at the mouth of Harris Creek for all key parameters, especially during summer months.
- Work with landowners to ensure that appropriate nutrient management practices are being applied in upland portions of the sub-basin, including horse farms, other livestock operations and residential areas. Special emphasis should be given to Stillwater Creek.
- Encourage proper septic system operation and maintenance through landowner incentives, education and technical support, particularly in densely developed areas around Lake Joy and Lake Marcel.
- Restore and enhance riparian areas along tributaries in the rural residential portions of the basin.
- Conduct bacterial sampling in areas of high residential density or livestock concentration, particularly areas where no data are currently available.

Tolt River (100.5 mi^2) – Lower Tolt, North Fork, South Fork

Sub-basin Description

The Tolt River sub-basin is one of the largest in the watershed. At 100 mi^2 it is larger than the South Fork Snoqualmie and roughly the same size as the North Fork Snoqualmie. The sub-basin is significant and unique on a number of fronts. The South Fork Tolt reservoir is a core component of the regional water supply system and the sub-basin is one of the most significant spawning areas for Snoqualmie Chinook salmon and for other salmonids. Also, the Tolt River is home to the only known naturally occurring spawning population of summer steelhead in the watershed. More than 90% of the basin is forested under both public and private ownership.

The South Fork Tolt reservoir began supplying north Seattle and the eastside in 1964 and provides approximately 30% of the water supply for Seattle Public Utility District (Seattle PUD). The average daily demand on the Seattle PUD system is roughly 140 million gallons per day (MGD), with peak one-day demand of 250 MGD. While the proportion of supply provided by the Tolt reservoir varies, 30% of the average and maximum demand equate to 42 MGD (62 cfs) and 75 MGD (116 cfs). According to Seattle PUD, the Tolt reservoir can provide a maximum of 100 MGD (155 cfs), enough to supply 571,000 households at 175 gallons per day. Only the northern portion of the Snoqualmie watershed, including the City of Duvall, is supplied by Seattle PUD. Other water districts in the watershed rely primarily on groundwater wells.

Land Use				
	Lower	**North Fork**	**South Fork**	**Total**
Forestry	69.7%	99.7%	94.4%	92.3%
Rural Res. 1 DU/2.5-10 acres	29.1%	-	-	5.5%
Other	0.2%	0.3%	5.6%	2.0%
Agriculture	1.1%	-	-	0.2%

Forestry is the primary land use within the sub-basin. In an effort to protect water quality in the reservoir, the City of Seattle has purchased and traded for lands surrounding the reservoir and currently owns the entire drainage upstream to the national forest boundary. Most of the basin is in second-growth forest.

The North Fork Tolt basin is almost entirely forested. The steep headwater areas are within the Mount Baker – Snoqualmie National Forest, but the majority of the basin is in private, industrial forestry, primarily owned and managed by John Hancock Life Insurance Company. According to a 2001 land cover analysis by Marshall and Associates, 3.5% of the North Fork Tolt sub-basin falls within the "recent clear cut forest" classification (the highest rate in the watershed) and an additional 5.8% in the "recently regenerated forest" classification, compared to 0.8% and 2.6%, respectively, for the watershed as a whole.

In 2004, King County purchased the development rights to roughly 90,000 acres of forest land from the John Hancock company to prevent future conversion to residential or other land uses. The purchase includes most of the privately owned forest lands in the Tolt River sub-basin, as well as extensive tracts in the Griffin, Tokul and the North Fork Snoqualmie River sub-basins. The Washington State Department of Natural Resources (WDNR) owns and manages forest lands in the northwest portion of the basin, primarily within the North Fork Creek drainage.

For purposes of this analysis, the Lower Tolt River comprises the mainstem and tributaries downstream of the North Fork/South Fork confluence. Stossel Creek is the most significant tributary to the Lower Tolt. In addition, Langlois Creek (also known as Indian Creek) is an independent tributary to the Snoqualmie River that formerly flowed into the Lower Tolt River, prior to being rerouted. A brief discussion of Langlois Creek is included in this section.

A majority of the Lower Tolt area is forested, but nearly one-third of the basin falls within the rural residential land-use category. In addition, roughly 1.4% of the Lower Tolt is within the City of Carnation. Unincorporated residential land uses are primarily concentrated within the Langlois Creek drainage, and along the lower seven miles of the Tolt River.

The Tolt River is a core spawning area for the Snoqualmie population of Chinook salmon. Chinook are known to utilize the entire Lower Tolt, the South Fork to the dam and approximately the two lower miles of the North Fork for spawning and rearing. Steelhead ascend somewhat farther upstream into the North Fork, but a natural, impassible barrier near RM 3.5 prevents further upstream migration. Resident cutthroat and rainbow trout are known to occupy areas upstream of the barrier.

In addition to the mainstem areas and the two Forks, Steelhead and coho salmon utilize several named and unnamed tributaries, including Stossel Creek, lower North Fork Creek and Lynch Creek, a tributary to the South Fork. Pink and chum salmon utilize the lower mainstem for spawning.

According to the SSHIAP database (maintained by WDFW and the Northwest Indian Fisheries Commission), Dolly varden/bull trout are also known to utilize the Tolt River, including the lower portions of both forks below impassible barriers. However, utilization appears to be limited to foraging. There are no known occurrences of spawning bull trout in the Snoqualmie watershed.

The Lower Tolt is a very dynamic river with a very active channel migration zone. King County and the City of Seattle have acquired a large number of residential parcels from private property owners who have suffered repetitive property damage during floods. Parcels acquired by King County are collectively managed as the Tolt River Natural Area, a discontinuous collection of parcels totaling 240 acres that are mostly within the Tolt River's 100-year floodplain.

Moss Lake Natural Area, located along a right-bank tributary to the Lower Tolt, is a King County Department of Natural Resources and Parks (DNRP) Ecological Land. The site is located 3.5 miles northeast of Carnation. This 372-acre site contains high-quality wetland and forested upland habitats. An extensive Class 1 wetland complex encompasses a large sphagnum bog, beaver dams, open water and forested wetland. The lake and associated bog and wetland comprise a rare habitat type in King County, and the fact that the site is relatively unaltered makes it a unique resource. In addition, the surrounding upland forest provides valuable wildlife habitat. Several King County species of concern - including bald eagle, Vaux's swift, red-tailed hawk, pileated woodpecker, bandtailed pigeon, western toad and Beller's ground beetle – are known to utilize the area.

Water Quality

Water Quality in the Tolt River sub-basin is very good compared to most other sub-basins in the watershed. The geology of the basin - combined with historical and current forestry practices - have resulted in a history of landslides and erosion, with likely impacts on turbidity, particularly during high flows. The water quality effects of forestry are discussed further in Section 3.2.

Temperature: Impaired (Lower), Basin of concern (North and South Forks)

North Fork and South Fork.

As explained in Table 1, the temperature standard in the Tolt sub-basin is more protective (12°C 7-DADMax) in the upper portions of both forks than in the lower basin where the more typical 16°C standard applies. However, a seasonal supplemental standard of 13°C also applies to portions of the lower basin and forks from September 15 – June 15 (see Map 15).

The U.S. Geological Survey (USGS) maintains several streamflow gages in the basin, and some are also equipped with continuous temperature monitoring equipment. Three such gages are located on the South Fork and one on the North Fork:

- South Fork - USGS 12147600. Upstream of the reservoir. 12°C standard year-round.
- South Fork - USGS 12148000. 1.6 miles downstream of the reservoir. 12°C standard year-round.
- South Fork – USGS 12148300. 4.5 miles further downstream, below the point at which flow reenters the South Fork from the re-regulating basin[22]. 16°C standard, June 16-September 14. 13°C standard, September 15-June 15.
- North Fork -USGS 12147500. 16°C standard year-round at gage location, but located only one mile downstream of 12°C standard zone.

Additional gages are located in the Lower Tolt, but these do not collect temperature data.

A review of maximum daily temperatures at all four locations from 1999-2007 indicates that:

- The North Fork site has not recorded a 7-DADMax that exceeds 16°C during the 1999-2007 period. However, the 12°C standard that is applicable a short distance upstream is

[22] Water from the reservoir flows into the re-regulating basin where it is allowed to settle prior to entering the treatment facility. Excess flow is returned to the river via pipeline.

exceeded for extended periods every year. In 2004, the standard was exceeded for 86 consecutive days[23].

- Site 12147600 (above the reservoir) also exceeds the 12°C 7-DADMax standard every year. The longest continuous period above the standard lasted 78 days in 2006. The 7-DADMax at this site has also exceeded 16°C on occasion, including a period of 15 days in 2003.
- Site 12148000, below the reservoir, shows a similar pattern. The longest continuous period above the 12°C standard lasted 95 days in 2005. During the 1999-2007 period, this site has only exceeded 16°C in 2003, for a period of 19 days. This is in part due to the ability of Seattle PUD to partially regulate discharge temperature from the reservoir (described further below). The highest recorded value for 7-DADMax is 17.7°C in 2003.
- Site 12148300, located further downstream, has exceeded the 16°C standard in 3 of the 9 years examined for this report, with a maximum continuous period of 12 days in 2003. The seasonal 13°C maximum has been exceeded in 5 of 9 years, including a maximum continuous period of 27 days in 2003.

Seattle PUD can utilize intakes at different depths in the reservoir to help control water temperature as it enters the lower South Fork. <u>We have not discussed the specific operations with Seattle PUD for this report</u>. Figure 9 shows the average difference in daily maximum temperature between the downstream and upstream locations. Values have been averaged for each calendar month for the 1999-2007 period. The graph shows that in the warmest months of July and August, the water is cooler coming out of the reservoir than it is going in. The opposite is true for the remainder of the calendar year.

These data show that both forks of the Tolt River exceed their respective temperature standards, particularly the 12°C year-round limit applied to the upper watershed. The primary intent of the low limit is to protect potential spawning waters of char (including Dolly varden and bull trout) and other salmonids that require especially cold temperatures. While the presence of resident rainbow and cutthroat trout are documented in the upper basin, the status of char species is unknown.

[23] This does not mean that the temperature remained above 12°C around the clock, but that the 7-DADMax value exceeded 12°C on 86 consecutive days.

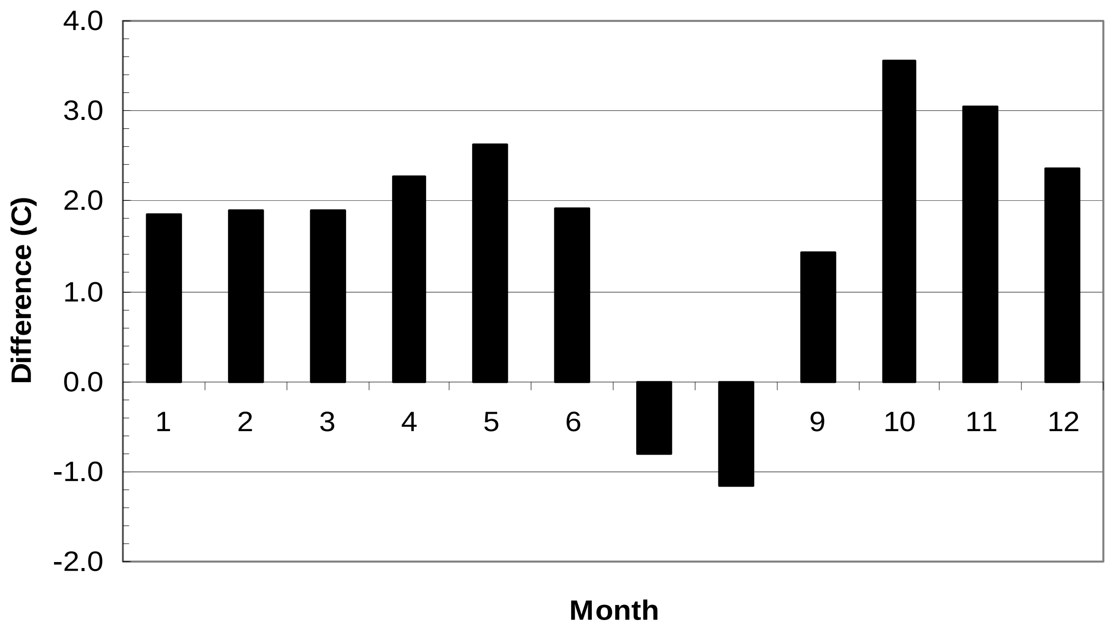

Figure 9. Monthly difference in temperature between sites 12148000 (below reservoir) and 12147600 (above reservoir). Calculated as the average difference between daily maxima at the two sites across years, 1999-2007.

Logging practices and natural conditions are likely responsible for temperatures higher than the state standard in the upper South Fork and North Fork. Maintaining cool temperatures in a forested area is not simply a matter of ensuring adequate riparian buffers. Landslides and bank erosion due to road building and other activities can alter the width and shape of the river channel, resulting in a wider, shallower channel that is more exposed to sunlight. Wild Fish Conservancy and the University of Washington have performed temperature control projects – such as bank stabilization and riparian restoration – in the upper South Fork Tolt (WDOE, 2008).

Reservoir operations can affect downstream temperatures in both a positive and negative way. Direct effects are the result of discharge operations at the dam and at the re-regulation basin. Indirectly, the reduction in flow that results from the withdrawal also may cause temperatures in the lower Tolt to be higher during the summer months in particular. A more detailed review of temperature data and the effect of Seattle PUD operations would be beneficial. In any case, it is clear that at the present time the seasonal temperature standard in particular is not being met below the reservoir due to both natural conditions and possibly project operations.

Lower Tolt

For this report, the review of temperature data for the Lower Tolt is limited to grab samples collected by WDOE in 2003-2005, draft continuous temperature data collected by WDOE in 2006 at the SR 203 crossing, and tributary data from KCRMS.

WDOE's (2008) samples from the mouth of the Tolt River met the 16°C general standard and 13°C seasonal standard on all occasions. However, late summer samples (2003-2005) were collected before noon on all occasions, hours before the typical daily maxima. Also, no samples were collected in July when some of the highest temperatures have been recorded in the watershed.

WDOE's continuous data from 2006 tell a very different story. The sampling did not begin until June 28, but the first day's maximum temperature was 18.7°C. The 7-DADMax exceeded the 16°C standard continuously through September 10, reaching a high of 22°C in late July. The site also exceeded the seasonal 13°C standard until early October.

A comparison of the 7-DADMax temperatures between the SR 203 site and two USGS gage sites shows that the temperature increase in the Lower Tolt reached nearly 6.4°C in late July (Figure 10).

KCRMS has collected monthly data in a tributary that enters the Tolt from the right bank at approximately RM 3.5 (Site P569). The highest recorded temperature at the site is 14.7°C in August 2004. This highlights the importance of maintaining and/or restoring the connectivity of the river with incoming tributaries – they have an important role in providing cool water even during summer months. The Tolt features several miles of levees that are intended to provide flood protection, but also may disrupt hydrologic continuity between the river and its floodplain and tributaries, and limit the ability of riparian vegetation to provide critical shade.

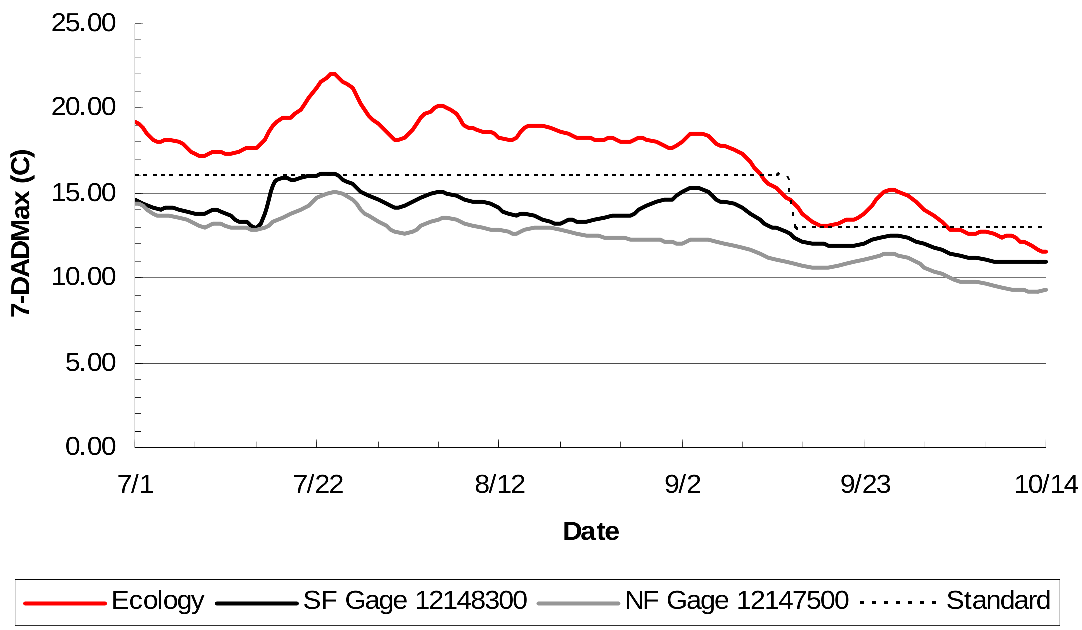

Figure 10. Comparison of same-day 7-DADMax values from SR 203 (WDOE), lower South Fork (#12148300) and lower North Fork (#12147500). Data from 2006.

KCRMS has also collected data in upper Langlois Creek, near 344th Ave NE (Site E1073). This small stream, too, displays very cool temperatures. Apart from an outlier data point in

September 1999, none of the monthly values at the site have exceeded 13.6°C since that time.

In the lower, agricultural portions of the Langlois and Indian Creek drainages, stream channels appear to have been relocated around the Snoqualmie Valley Trail from time to time as part of farming activities. Until mid-2001, KCRMS collected data at the mouth of Langlois Creek where it flowed into the Tolt River (Site E1065). While the exact circumstances and timing are unknown, the majority of the flow from the stream was rerouted across private farm land into Indian Creek which empties directly into the Snoqualmie River a mile upstream of the Tolt River. In essence, there is now only one stream where there used to be two and the proper name of the stream that is left is unclear. Prior to the relocation, July-September temperatures at the site occasionally reached as high as 21°C, but remained cool for the rest of the year.

Dissolved oxygen: Not impaired

WDOE collected dissolved oxygen data near the mouth of the Tolt as part of the TMDL effectiveness study. The river met the 9.5 mg/L standard on all occasions during the study.

KCRMS data shows that DO levels at sites P569 (tributary to mainstem near RM 3.7) and E1073 (upper Langlois) are generally very high, with only occasional, minor excursions below the 9.5 mg/L level. The site at the former mouth of Langlois Creek within the APD has a history of more checkered results for dissolved oxygen, with values often less than 6.0 mg/L in summer months and occasionally less than 2.0 mg/L during extremely low flow conditions.

Fecal coliform: Not impaired

Available fecal coliform data for the Tolt River sub-basin is fairly limited. Of the nearly 40 samples collected by WDOE near the mouth of the river, the geometric mean concentration was only 17 CFU/100 ml, and only one sample exceeded the 100 CFU/100 ml geometric mean standard. That one sample measured 840 CFU/100 ml, and coincided with the same date on which nearly every sampling site in the entire watershed experienced their peak value after a storm event that followed an extensive warm, dry period. One week later, the concentration had returned to <20 CFU.

King County has collected FC samples in Lynch Creek – a tributary to the South Fork – as part of its Biosolids Forestry Program at Hancock Snoqualmie Forest (King County, 2007b). Samples collected for ambient monitoring and following storm events show that the mean concentrations are extremely low both upstream and downstream of biosolids application sites. A small number of storm samples have slightly exceeded the 200 CFU/100 ml level, but all sites in Lynch Creek easily meet the second component of the FC state standard.

pH: Not impaired

According to WDOE, the Tolt River meets the pH standard at the mouth. During the TMDL effectiveness study, one sample fell slightly below the numerical standard at 6.4, but all others were well within the range prescribed by the standard.

KCRMS data shows that sites P569 and E1073 have met standards for pH on all occasions since 1999. The site at the mouth of Langlois Creek – like many others in agricultural, floodplain areas in the basin – shows slightly acidic conditions with values occasionally as low as 6.1.

Nutrients: Not impaired

During WDOE's 2003-2005 study, the Tolt River had very low nutrient concentrations compared to other sites in the watershed. Ammonia-nitrogen was consistently below detection limits, and the one sample of orthophosphate collected during the study was below the TMDL guideline for tributary waters.

King County (2007b) has recorded similarly low nutrient levels while monitoring the effects of biosolids application in the Lynch Creek basin.

Benthic invertebrates

KCRMS has collected macro-invertebrate data at the upper Langlois Creek (E1073) site for several years. The data results are somewhat mixed, but suggest a potential trend toward improving conditions, but followed by a significant drop in the last year of sampling.

Table 12. B-IBI Scores for one site in the Tolt River sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E1073	Upper Langlois Creek			16	32	42	40	26

Excellent	Good	Fair	Poor	Very Poor

Synthesis and recommendations

While water quality in the Tolt sub-basin is generally very good, high water temperature in late summer and early fall is a concern. In the North and South Forks, temperature does not appear to reach levels that are of acute concern for fish or other organisms, but the spawning suitability of those areas for char and other cold-water salmonids may be compromised. Perhaps more importantly, temperature in the Lower Tolt is profoundly affected by the temperature in each of the forks. Thus, efforts to address temperature impairment in the headwaters – primarily via improved logging practices and restoration – should be strongly encouraged.

In the South Fork below the reservoir, a more detailed review of reservoir discharge practices and thermal profiles could help to inform future operations and their effects on downstream temperature.

Downstream of the forks, a detailed analysis of temperature in the mainstem and in incoming tributaries would help to identify the primary locations, sources and causes of temperature impairment in the lower river. This type of analysis would help to prioritize restoration and protection efforts in tributaries, and to better understand the effects of bank hardening and flood protection on the thermal regime in the mainstem.

Priority actions for the Tolt River:

- Monitor and enforce compliance with forest management practices throughout the sub-basin on private and public lands.
- Conduct a detailed analysis of temperature in the Lower Tolt to identify significant cold-water input sources and areas of localized warming.
- Protect and enhance intact riparian areas and wetlands in both forested and rural residential areas through the use of incentives, acquisitions, restoration and enforcement of regulations.
- Restore degraded riparian areas throughout the sub-basin, including floodplain tributaries such as Langlois/Indian Creek.

Griffin Creek (17.0 mi²)

Sub-basin Description

Land Use	
Forestry	92.5%
Agriculture	4.1%
Rural Res. 1 DU/2.5-10 acres	3.1%
Mining	0.1%
Other	0.1%

Griffin Creek is a predominantly forested sub-basin that flows for approximately ten miles in a southwesterly direction from its headwaters before turning northwest roughly three miles before its confluence with the Snoqualmie River. All of the forestry areas in the sub-basin are under private ownership. According to the 2001 land-cover analysis by Marshall and Associates, 13.2% of the sub-basin is classified as either "recent clear cut forest" or "recently regenerated forest", second only to the neighboring Tokul Creek sub-basin.

Like many other tributaries in the watershed, the lowest reaches of Griffin Creek are within the APD which includes portions of the Snoqualmie's 100-year floodplain. Upstream of the APD, roughly 1.5 miles lies within a rural residential land use designation, an area that includes King County's Griffin Creek Natural Area. The transition from agricultural to rural residential land use is marked by a crossing of the Snoqualmie Valley Trail as it traverses Griffin Creek along a trestle.

Although Chinook salmon utilize the lower reaches of Griffin Creek, it is known primarily as a thriving steelhead and coho salmon stream, with both species ascending well into the headwaters. In the forested reaches, riparian vegetation is primarily composed of native species (King County, 2002).

Water Quality

Compared to other tributaries in the lower watershed, Griffin Creek has good water quality, but the available data is very limited. Forestry operations and associated roads can have a major impact on the sediment regime in a sub-basin like Griffin Creek. In the 1990s, fine sediment input from forest roads were known to affect spawning gravel quality (Weyerhauser, 1995). Fine sediment can also clog the gills of fish and other aquatic organisms. King County (2004b) reported that the gravel and cobbles in the lower, residential portion of the stream were substantially embedded in fine sediment.

The only readily available water quality information for Griffin Creek consists of the grab-sample collections made by WDOE (2008), the draft continuous temperature data collected by WDOE as part of the ongoing temperature TMDL study, and the King County gage that collects continuous flow and temperature data at this location.

Temperature: Basin of concern

During WDOE's TMDL effectiveness study (data collected in 2003-2004), Griffin Creek met the 16°C standard based on grab samples. However, the 2006 continuous data shows that the 16°C threshold for 7-DADMax was exceeded for much of the summer sampling period (Figure 11). In both cases, the data were collected at the State Route 203 crossing of Griffin

Creek which is located roughly one mile upstream from the mouth. Land use below this point is mostly agricultural, while upstream areas are a mix of small-scale agriculture and rural residential uses for approximately 2 miles.

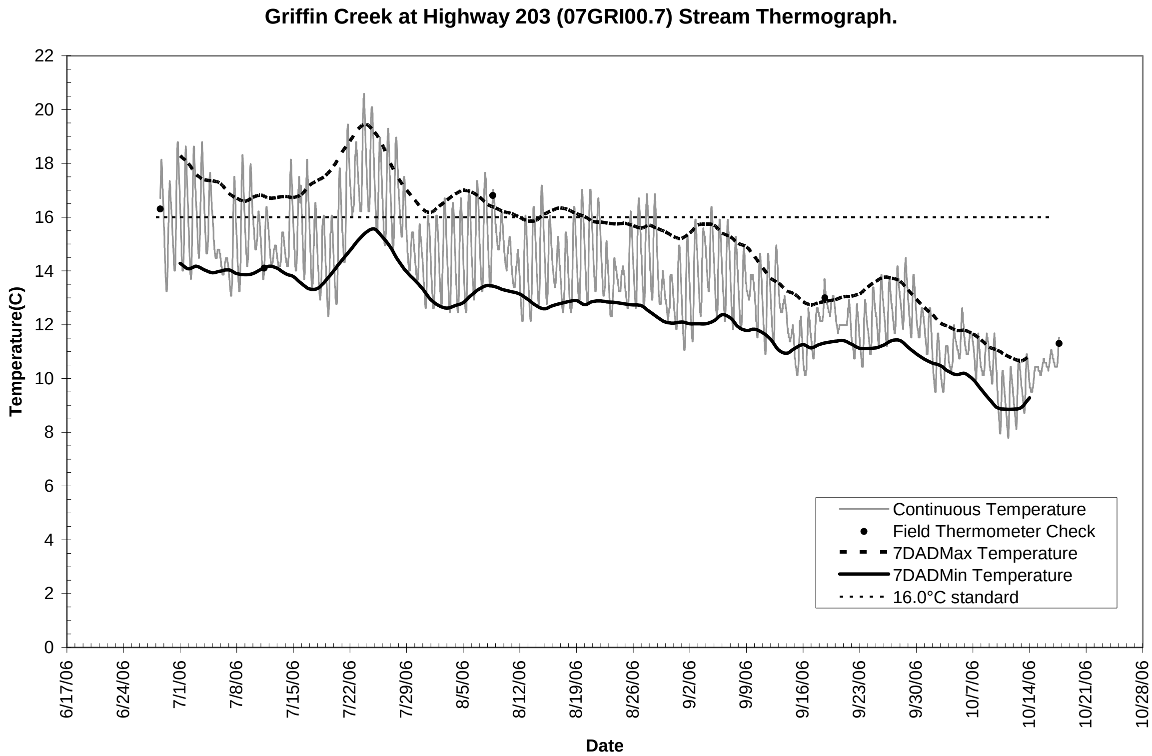

Figure 11. Griffin Creek temperature in summer 2006 (data from WDOE).

King County's temperature gage is located slightly upstream of SR 203. The data confirms the 2006 findings by WDOE. The record also shows that the standard has been exceeded during portions of every summer since 2004.

Given the basin's forested condition, the exceedance of the temperature standard is somewhat surprising. Two factors, one natural and one artificial, may contribute to this condition. A three-mile section of Griffin Creek, between approximately river mile six and nine, features a complex of large, broad wetlands. The mapped wetland extent along this section covers 170 acres with the largest single wetland measuring roughly 100 acres in size[24]. The wetland complex was formed as a result of an ice dam at the mouth of Griffin Creek following the latest period of glaciation (Weyerhauser, 1995). These wetlands may explain in part the affinity of steelhead and coho for Griffin Creek. Wetlands not only provide substantial rearing habitat in the form of beaver ponds and other slow-water areas, but also produce a host of invertebrates that may drift into downstream areas as food supply. Moreover, wetlands sustain flows during the late summer months that are critical for stream-

[24] Based on King County GIS data.

rearing species. However, broad wetlands are also exposed to solar radiation and the slow-moving waters may become quite warm during the daytime in summer months.

In addition to the large wetland complexes in the basin, many upland areas feature wide (>100 ft.), low-gradient reaches that are not well shaded even in the absence of logging, simply due to the relationship between tree height, effective shade and the width of the water body (Weyerhauser, 1995). These wide, slow-moving reaches may further contribute to warming.

Forestry practices may also play a role in increasing water temperatures. Even if stream buffers are intact in a manner consistent with current forestry regulations, extensive clear-cuts and early seral stage areas within the basin likely increase water temperature compared to natural conditions. Moreover, it takes decades for forests to recover from harvest, so the legacy of past practices may persist for a very long period.

A seasonal 13°C temperature standard applies to a portion of lower Griffin Creek from approximately State Route 203 to river mile 2 during the February 15 – June 15 period to support steelhead spawning. King County gage records show that daily maxima often exceed the standard, sometimes as early as late April, but the daily mean temperature generally appear to stay below 15°C until late May.

<u>Dissolved oxygen: Not impaired</u>

Dissolved oxygen data for Griffin Creek is limited to the grab samples collected by WDOE (2008) as part of the TMDL effectiveness study. The data suggest that DO levels meet standards year-round and that oxygen conditions are generally much better in Griffin Creek than in many other tributaries.

<u>Fecal coliform: Impaired</u>

According to WDOE (2008), Griffin Creek fails to meet the fecal coliform standard during the late summer and fall critical period. WDOE's analysis suggests that a 43% reduction in loading is required in order to meet standards.

The lack of multiple data collection points complicates the identification of likely sources of fecal contamination. Upstream of the SR 203 crossing, only a short distance of the stream is located within an agricultural area, suggesting that livestock and manure management are not the most likely sources. Further upstream, rural residential properties abut the stream and are served by septic systems. However, the density of residences is very low. Other basins (such as the upper mainstem of Ames Creek) have much higher residential densities but appear to meet fecal coliform standards in those areas.

Fecal coliform may also be attributable to natural sources. For example, as described above, extensive wetlands are located along a substantial section of Griffin Creek within the otherwise forested upper watershed. High densities of beaver, waterfowl and other wildlife may contribute substantial inputs of fecal matter to the stream during late summer months. Sampling in the upper watershed would help to resolve this issue.

pH: Not impaired

pH data for Griffin Creek is limited to the grab samples collected by WDOE (2008) as part of the TMDL effectiveness study. The data suggest that the pH level meets standards year-round.

Nutrients: Not impaired

Available nutrient data is also limited. King County (2004b) surveyed the lower three miles of Griffin Creek during summer 2002. The report notes that within the rural residential area algae covered most of the stream bottom, suggestive of excess nutrient inputs, possibly due to septic inputs. Also, some residential parcels featured mowed lawns that extended to the stream edge, suggesting that the use of residential fertilizers may be a contributing factor.

However, based on limited grab samples by WDOE (2008), Griffin Creek appears to meet guidelines for nitrogen and phosphorus, unlike other lowland tributaries in the watershed

Benthic invertebrates

No data are available regarding benthic invertebrates in Griffin Creek.

Synthesis and recommendations

In general, Griffin Creek appears to have very good water quality compared to many other tributaries in the Snoqualmie watershed. Temperature exceeds the 7-DADMax standard in late summer, but the stream still supports stream-rearing coho and steelhead that may make use of the extensive wetland complexes in the basin. The width and quality of stream buffers in the forested portions of the basin has not been evaluated for this report. Importantly, dissolved oxygen appears to remain high even during warm temperatures.

Fecal coliform levels are of moderate concern, but further investigation should be carried out to discriminate between potential sources of contamination. As a starting point, data collection both above and below the rural residential zone would help to rule out or confirm the role of septic systems and fertilizers as contributors. Alternatively, the data may help to characterize the bacterial load as natural, possibly stemming from concentrated wildlife use in the wetland complexes further upstream. Agricultural inputs cannot be ruled out in the lower portions of the stream, although extensive riparian plantings have taken place in this area that should help to reduce agricultural inputs.

Though nutrient levels appear to be fairly low, outreach and education to streamside landowners in the rural residential area could help to reduce nutrient inputs due to fertilizers and septic systems.

Priority actions for Griffin Creek:

- Monitor and enforce compliance with forest management practices throughout the sub-basin on privately owned timberlands.

- Conduct a longitudinal study of fecal coliform concentration during the late summer months to identify likely sources of bacterial inputs.
- Collect additional continuous temperature data at locations further upstream in order to better understand the thermal profile of Griffin Creek and to help prioritize restoration actions.
- Protect and enhance intact riparian areas and wetlands in both forested and rural residential areas through the use of incentives, acquisitions, restoration and enforcement of regulations.
- Conduct water typing assessments to ensure that forestry regulations are applied appropriately to all watercourses. According to the analysis performed for Table 5, Griffin Creek has one of lowest watercourse densities in the watershed. While this may well be a consequence of local topography, it is also possible the watercourses in the sub-basin have not been comprehensively mapped to date.

Patterson Creek (20.2 mi^2)

Sub-basin Description

Land Use	
Rural Res. 1 DU/2.5-10 acres	85.4%
Agriculture	8.5%
Urban Res. Low - R1	5.6%
Rural Town	0.4%
Urban Res. Med - R4-12	0.2%

Patterson Creek is the largest left bank tributary to the Snoqualmie River downstream of Fall City. Located along the western edge of the watershed, Patterson Creek flows in a southeasterly direction for most of its length before turning north and traversing the Snoqualmie River's floodplain through farmland. 5.4% of the sub-basin lies within the City of Sammamish where it features medium-density urban residential land uses. In addition, roughly 5% of the sub-basin lies within an unincorporated area with a low-density residential zoning designation. Located on the southwest flank of the sub-basin, the area is home to the Members Club at Aldarra golf course and associated residential developments.

Like many other tributaries in the watershed, the lower portions of Patterson Creek are dedicated to agriculture by way of their APD designation. Outside of the agricultural area, Patterson Creek is one of the most rapidly developing sub-basins in the Snoqualmie Watershed (Haring, 2002).

The sub-basin has a broad elevation range from 70 feet above mean sea level to 1400 feet in the southwest corner of the basin (King County, 2004). As a result, the basin has many small tributaries that descend through steep ravines before reaching the valley floor. The mainstem itself originates in a broad, low-gradient catchment on an upland plateau before descending through a ravine to form the much lower gradient stream course that roughly follows State Route 202. The stream itself is very small for the size of the valley that it occupies. This is because the valley itself was carved by glaciers rather than by the stream itself. It is thought that the stream channel once served as the outlet for glacial Lake Snoqualmie (Bethel, 2004). The main channel features many lateral wetlands that extend nearly the entire length of the stream from Redmond-Fall City Road to the Snoqualmie River confluence (King County, 2004).

Salmonids make extensive use of the Patterson Creek sub-basin. Steelhead and coho salmon occupy the mainstem and several key tributaries for both spawning and rearing. Canyon Creek, a major tributary that flows through the Aldarra golf complex, is not only an important stream for coho and steelhead, but is also known to support Chinook salmon. Chinook also utilize a substantial portion of the mainstem of Patterson Creek. For purposes of state water quality standards, Patterson Creek is considered Core summer salmonid habitat (See Section 2, Table 1 for the applicable standards).

Fish habitat conditions in the mainstem of Patterson Creek are generally regarded as poor, with riparian degradation, fish passage barriers and the lack of large wood in the stream among the biggest problems (Haring, 2002). The basin was historically largely forested, but the valley floor in particular features only a modest fraction of historic forest cover due to previous logging, agricultural and land clearing activities. The amount of active agriculture appears to have declined in the last decade or so and many areas of the mainstem floodplain appear to be undergoing a slow transition from agriculture back to their original emergent and forested wetland conditions.

Due to the prevalence of agriculture and low-density residential land uses, impervious area accounts for only 3.2% of the sub-basin, with a projected increase to 4.9% (a 53% increase) under a full build-out scenario, assuming current land-use designations (King County, 2004). This fairly low level of imperviousness suggests high potential for restoring hydrologic processes in the basin. Key actions include forest and wetland retention, floodplain reconnection and riparian restoration (King County, 2004; Snohomish Basin Salmon Recovery Forum, 2005).

In recent years, King Conservation District and King County's Agriculture Program have worked with landowners in lower Patterson Creek to improve riparian conditions and to reduce threats to water quality posed by agricultural operations. These efforts have produced roughly 1.5 miles of fencing to control livestock access to streams, establishment of several composting and heavy-use protection areas, over 4 acres of riparian restoration and the preparation of more than 30 farm plans.

Water Quality

Patterson Creek suffers from several categories of water quality impairment, including high water temperature in specific areas, excess bacteria and nutrients, as well as low dissolved oxygen.

Temperature: Impaired

In addition to the default 16°C 7-DADMax standard, Patterson Creek has a seasonal maximum temperature standard of 13°C that extends from the mouth upstream for approximately 4.5 miles during the February 15 – June 15 period.

King County (2004) summarized temperature data collected as grab samples by KCRMS and by WDOE during the 1990s. KCRMS sampling locations are distributed throughout the watershed, while WDOE maintained only one site in the southern portion of the basin near Fall City along East Fork Patterson Creek. Most locations recorded maximum temperatures higher than the current 16°C standard, but none exceeded 18°C. Our review of more recent KCRMS data shows a similar pattern. Nearly all stations exceed the 16°C standard on occasion during late summer, but values remained mostly below 18°C. During WDOE's TMDL effectiveness study, temperature near the mouth of Patterson reached 19.2°C on one occasion, but all other grab samples were below the standard.

Continuous water temperature data is required for a more robust assessment of stream temperature. WDOE collected continuous data near the mouth of the creek in 2006 as part of its ongoing temperature TMDL study of the watershed. The data shows that the 7-DADMax temperature exceeded 16°C continuously from late June to early August, and reached a high of 18.1°C in late July.

King County's Hydrologic Information Center has maintained three gages in Patterson Creek since 1990 that collect continuous water temperature and discharge data. One is located in the upper basin along the mainstem (Gage 48c, Map 17). Summer flows at this location are very low (less than 1 cfs) and thus the water temperature is fairly sensitive to air temperature. In most years, the average temperature exceeds 16°C during portions of July. In 2004, temperature reached a high of 21°C at this location and exceeded the standard from mid-July to early September. Gage 48a is also in the mainstem, but much further downstream near Aldarra golf course, just above the Canyon Creek confluence. This gage, too, typically exceeds 16°C during a substantial portion of the summer months. The third gage (48b) is located in Canyon Creek, also near the Aldarra golf complex. In contrast to the mainstem gages, Canyon Creek appears to be substantially cooler and may play an important role in reducing the temperature within the floodplain portion of the stream. Figure 12 shows simultaneous hourly temperatures at the two locations during the summer of 2006. The cool temperature in Canyon Creek may explain, in part, why stream-rearing salmonids like coho and steelhead are attracted to the stream.

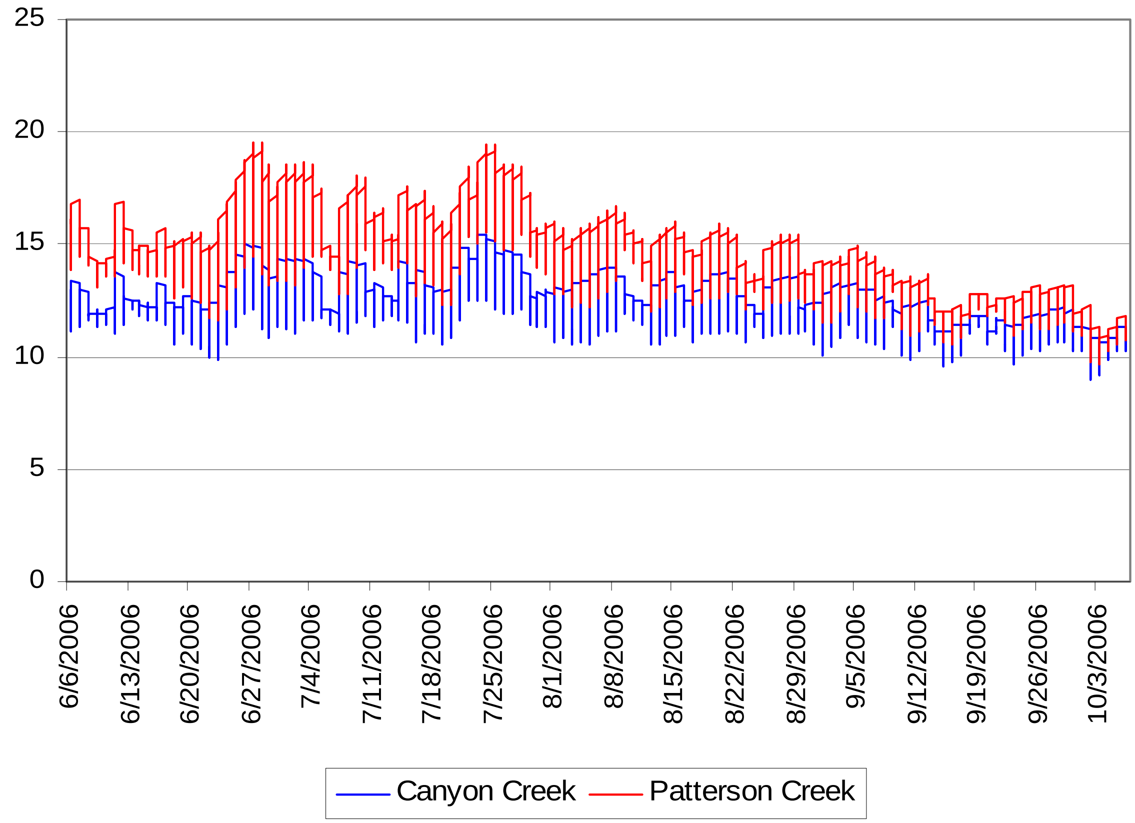

Figure 12. Hourly temperature data (2006) from King County gages 48a (Patterson Creek at Aldarra) and 48b (Canyon Creek at Aldarra).

During the February-June period when the 13°C supplemental temperature standard is in place, King County gage site 48a along the mainstem frequently exceeds that standard beginning in mid-May, while Canyon Creek stays below the threshold throughout the period.

In summary, the mainstem of Patterson Creek appears prone to exceeding the 16°C temperature standard during the summer months along much of its length. With the exception of the 2006 data collected by WDOE, continuous data from the mouth of the creek is not available. Canyon Creek – and possibly other tributaries that descend from the surrounding hillsides - are a source of cooler water for the floodplain portion of Patterson Creek. This highlights the importance of protecting intact wetlands and riparian areas throughout the sub-basin, and focusing restoration actions along the mainstem.

<u>Dissolved oxygen: Impaired</u>

As a core salmonid habitat area, the one-day minimum DO standard for Patterson Creek is 9.5 mg/L . The pattern of DO values in Patterson Creek differs from some of the other tributaries that feature agricultural land use along the floodplain portions of the stream, such as Ames and Cherry Creeks. While DO does not meet the standard during the late summer, conditions appear to meet standards as flows increase in the fall, and continue to do so through the winter. Moreover, the lowest observed values do not appear to be near the mouth of Patterson, but along the mainstem in the upper basin.

WDOE's TMDL effectiveness study collected DO samples near the mouth of the stream in 2003-2004. While none of the readings met the standard, the lowest observed value was 7.7 mg/L , far higher than the minima recorded in some other tributaries.

A direct comparison of DO in Canyon Creek and the mainstem of Patterson is precluded by a lack of data at appropriate locations[25]. However, KCRMS data collected just below the confluence of the two streams (Station P562) reflects some of the best DO values in the basin, suggesting that Canyon Creek may be partly responsible for improved DO conditions in the lower portion of the mainstem. The data show that summer DO at this location typically ranges from 8.5-9.3 mg/L , with only one recorded observation below 8.0 during the warm, dry summer of 2004.

The lowest values recorded by KCRMS were consistently found at station E960, located at a mainstem road crossing at 264th Ave NE. August values have not exceeded 2.0 mg/L during the 1999-2006 period.. Through this stretch of the stream, the channel is slow-moving and choked by vegetation. Historical channel straightening and dredging along with deforestation have severely altered conditions along this reach. Riparian planting projects have taken place within the Patterson Creek Natural Area, but invasive reed canary grass is still prevalent. A review of the field notes that accompany KCRMS data show that the water is often stagnant at the sampling location, or little visible flow is evident.

<u>Fecal coliform: Impaired</u>

Patterson Creek fails to meet the geometric mean criterion for fecal coliform during the critical August-October period (WDOE, 2008). During the WDOE study, late summer rain events are followed by the highest bacterial concentrations, with a peak measured value of 1900 CFU/100 ml. However, Patterson Creek appears to meet standards during the wet season from November to April (WDOE, 2008). WDOE estimates that FC concentration would need to be reduced by 64% in order to meet both parts of the FC water quality standard.

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[25] The King County gage sites (48a and 48b) collect only temperature and flow data.

King County (2007) measured fecal coliform at three locations: the mouth of the creek, along the mainstem below the Canyon Creek confluence, and along East Fork Patterson Creek which drains the southernmost portion of the basin and joins the mainstem within the floodplain portion of the stream. These data show a similar pattern of higher concentrations during the early fall, but fairly consistent, low values at all three sites beginning in the late fall (Figure 13). The East Fork recorded the three highest values during the study, likely due to direct livestock access to the stream near the sampling location (K. Higgins, King County, personal communication).

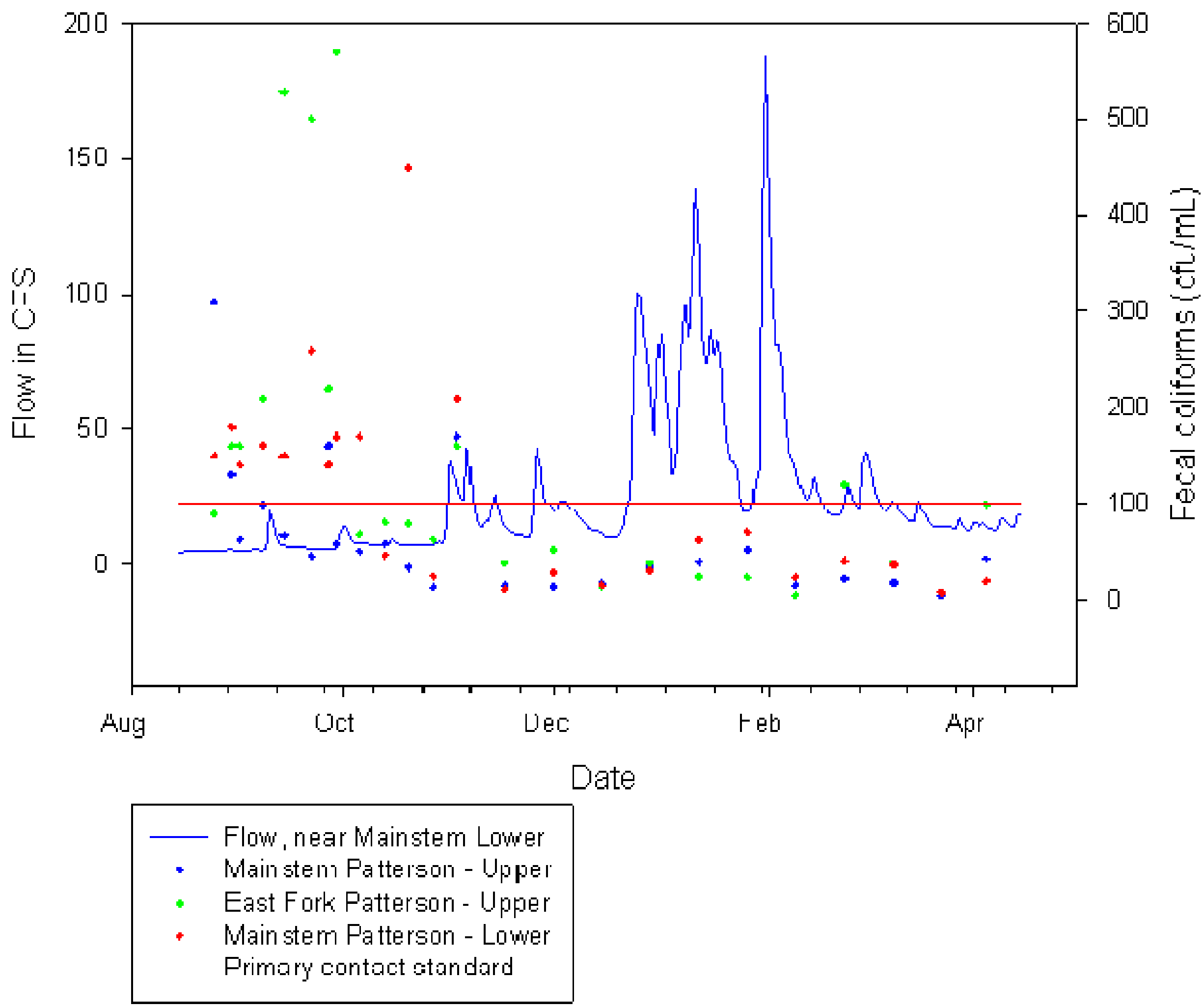

Figure 13. Fecal coliform concentration at three locations in the Patterson Creek sub-basin (from King County, 2007).

Absent data for fecal coliform from upper portions of the basin, it is not possible to infer the relative importance of agricultural and other sources of bacterial contamination.

pH: Basin of concern

Patterson Creek appears to meet standards for pH throughout the year according to WDOE (2008). The seasonal pattern is similar to other tributaries in the watershed, with annual minima in late fall and spring.

KCRMS data shows that occasional pH excursions to just below the 6.5 standard occur infrequently at some locations, including E960 where DO concentrations are lowest. King County (2004) reported a minimum reading of 5.9 at the site, based on KCRMS data.

In general, pH does not appear to be of substantial concern in Patterson Creek. However, the upper mainstem in the vicinity of station E960 appears to merit greater investigation of local conditions that reduce both pH and DO.

Nutrients: Impaired

Available data on nutrient concentrations in Patterson Creek are limited to the lower portions of the sub-basin. Data from WDOE (2008) and King County (2005; 2007) indicate that Patterson Creek meets the standard for ammonia nitrogen, though the number of samples is small. Federal guidelines for nitrogen and phosphorus were exceeded at all times and locations.

According to King County (2007), East Fork Patterson Creek has the lowest total nitrogen levels during the summer months. The concentration increases approximately 4-fold following fall rains to levels higher than those at the mouth or along the mainstem below the Canyon Creek confluence.

Total phosphorus concentration in the East Fork is roughly half that found in the mainstem sites throughout the year, based on one year of sampling (King County, 2007). Following an initial high-spike after fall rains, concentrations at all three sampling locations appear to attenuate during the rainy season.

Due to the location of the upper of two mainstem sites (just below Canyon Creek), it is not possible to distinguish the likely sources of nutrients between the mainstem and Canyon Creek. Canyon Creek passes through the golf resort along the lower portion of the stream and medium-density residential areas in the uplands along Issaquah – Fall City Road and also receives inputs from higher-density incorporated neighborhoods in Sammamish. Thus, fertilizers as well as septic systems in unincorporated areas may contribute to nutrient inputs.

In contrast, the mainstem of Patterson Creek and the East Fork flow from areas of mixed agricultural and low-density rural residential development, though upland areas in the mainstem feature somewhat higher density residential areas. Thus, agricultural sources as well as septic systems may contribute to the problem. Sampling in Canyon Creek contemporaneously with the mainstem would help to discriminate the role of each basin in contributing nutrients to Patterson Creek.

<u>Benthic invertebrates</u>

B-IBI data is only available for one site in the sub-basin, KCRMS site E949 in upper Canyon Creek. The results are highly variable over time, ranging from 'poor' to 'good' (Table 11).

Table 13. B-IBI Scores for one site in the Patterson Creek sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E949	Upper Canyon Creek	30	32	36	22	44	40	40

Excellent	Good	Fair	Poor	Very Poor

Most other water quality indicators suggest that Canyon Creek is in generally better condition that most other portions of the sub-basin. Additional years of data should help to shed light on the overall trend in B-IBI condition within the Canyon Creek area.

Synthesis and recommendations

Due to the high percentage of rural residential land use in the basin, the risk of degradation due to intensified development is high in Patterson Creek, particularly in the vicinity of incorporated areas (City of Sammamish). Forested areas and wetlands along Canyon Creek and other tributaries should be protected via incentives, strategic acquisitions and enforcement of critical area regulations.

Absent additional data collection along the mainstem of Patterson Creek, development of specific action recommendations will be difficult. The low DO level in the middle to upper mainstem is of greatest concern for purposes of supporting aquatic life. Additional field sampling should be conducted along the mainstem upstream of Canyon Creek to help refine the spatial patterns associated with low DO, pH, nutrient load and temperature. Sampling should extend up to and beyond sampling station E960 to help characterize the combination of factors that may be responsible for the low DO values at that location. By locating sampling sites strategically relative to tributary inputs and changes in land use, it may be possible to identify priority areas for restoration, landowner outreach and enforcement of regulations.

Canyon Creek is clearly an important tributary as a contributor to downstream water quality, and as a core area for stream-rearing salmonids in particular. Protecting the habitat and hydrologic conditions in this portion of the basin is a high priority. Wetlands and mature forest cover should be protected via regulations, acquisitions and incentives. Moreover, stormwater management in the expanding residential areas should seek to provide the best available protection for this area via application of Low Impact Development techniques and water quality treatment for stormwater.

Restoring riparian conditions and general stream health along the mainstem is also a high priority. Although coho and steelhead are known to access the upper watershed for both spawning and rearing, elevated temperatures and other water quality impairments likely make portions of the mainstem less hospitable to rearing juveniles, particularly in the late summer months.

Riparian planting, livestock fencing and other practices to reduce the water quality impacts of agriculture should be continued, not only in the APD but on the many agricultural parcels in the broader watershed.

<u>Priority actions for Patterson Creek:</u>

- Protect exiting functional forested areas and wetlands along tributaries.
- Focus restoration efforts along the Patterson Creek mainstem to address temperature impairment.
- Conduct longitudinal sampling to better characterize spatial patterns of DO and pH impairment.
- Continue to work proactively with farmers in both the APD and rural residential areas to reduce livestock impacts via fencing coupled with intensive riparian restoration.

Raging River (32.0 mi^2)

Sub-basin Description

Land Use	
Forestry	74.1%
Rural Res. 1 DU/2.5-10 acres	24.3%
Other	0.8%
Rural neighborhood R1-R4	0.5%
Mining	0.2%

The Raging River sub-basin lies along the western edge of the Snoqualmie watershed and is separated by a ridge from the eastern flank of the Cedar River watershed. The river flows from its headwaters in a northwesterly direction before turning eastward near the town of Preston and descending to join the Snoqualmie River at Fall City[26].

Land-use in the sub-basin is primarily composed of forestry in the upper watershed southward of the Interstate 90 crossing, while low-density rural residential land use dominates the lower basin. The unincorporated towns of Preston and Fall City feature somewhat higher density residential areas as well as commercial and industrial uses.

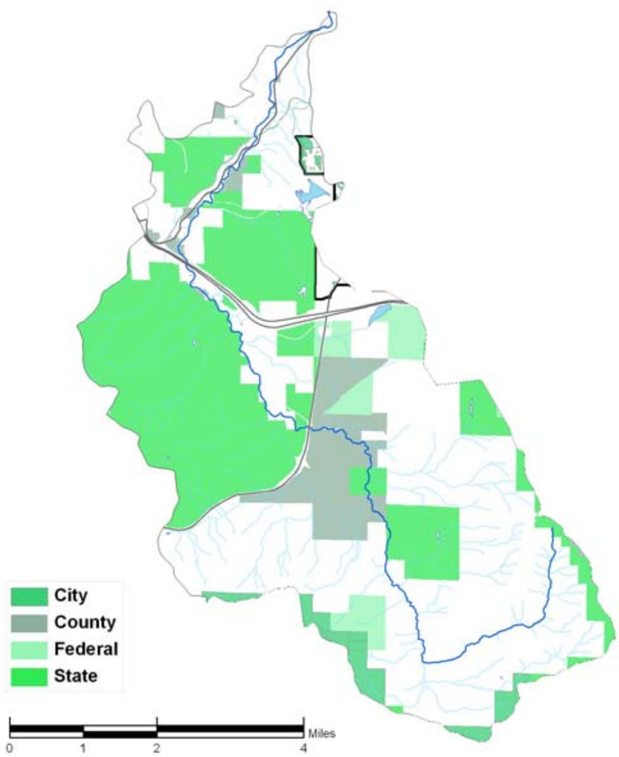

Figure 14. Lands owned by public entities in the Raging River sub-basin.

A large proportion of the Raging River is under public agency ownership (Figure 14). The Washington Department of Natural Resources owns and manages large blocks of forested lands in portions of the basin, including some areas classified as rural residential land-use under the King County Comprehensive Plan. Forested lands in the upper watershed are mostly under private ownership. The City of Seattle owns minor portions of the basin along the southwestern edge for purposes of protecting water quality in Chester Morse Lake and the Cedar River, the primary source of potable water for the Seattle metropolitan area.

The Raging River is one of the core spawning areas for Snoqualmie Chinook salmon as well as populations

[26] Preston and Fall City are unincorporated areas within King County.

of steelhead and coho. Restoration and protection actions to protect spawning habitat and to improve juvenile rearing habitat are considered high priorities in the Snohomish Basin Salmon Recovery Plan.

One of the watershed's most successful habitat restoration actions to date was completed in the Raging River sub-basin in 2006. The removal of the Carlin levee near Preston reconnected the river to several acres of its historical floodplain, restored natural river processes along an important spawning reach and created new off-channel rearing habitat for juvenile salmonids.

Water Quality

Water quality conditions in the Raging River are intermediate within the range observed for tributary basins in the watershed. High temperature in the lower river is a serious concern, and high pH – a condition unique to the Raging River based on available information – merits further investigation.

Temperature: Impaired

In addition to the 16°C default standard for 7-DADMax, the seasonal 13°C standard is also applied to portions of the basin. Between February 15 and June 15, the mainstem upstream of RM 10 (approximately one mile upstream of the SR 18 crossing) as well as Deep Creek (approximately RM 7.3 between the I-90 and SR 18 crossings) must meet the enhanced standard to support steelhead spawning. From September 15 – June 15, the mainstem from the mouth to roughly RM 10 must meet the 13°C standard.

Temperature data for the mainstem of the Raging River is currently limited mostly to samples taken near the mouth in the vicinity of Fall City. During WDOE's TMDL effectiveness study, grab samples in August 2003 and 2005 regularly exceeded 20°C with a high of 24.4°C in August 2004. WDOE's draft continuous data collected in 2006 show a similar pattern. Of all the sampling locations in the watershed, the Raging River had the highest 7-DADMax of 24.7°C.

KCRMS sampling stations in the basin are mostly along tributaries that cross beneath county roads. Based on grab samples, Lake Creek – a key tributary for salmonids that enters the raging River at approximately RM 6.5 – appears to maintain temperatures below the 16°C standard throughout the summer months (Site E818). Similarly, data collected from an unnamed left bank tributary (WA Stream number 07.0390) in the vicinity of Preston at approximately RM 4.5 also shows summer temperatures between 11-16°C (Site E800). While these locations represent only a small fraction of the tributary inputs to the river, they suggest that tributary inputs may not be the primary drivers for high temperatures in the basin.

The high temperatures in lower Raging River may be partly explained by the physical characteristics of the river channel, combined with basin hydrology. As its name suggests, the Raging River is a very dynamic river with a very active channel during high-flow events. The gradient is relatively steep and the slopes of the river valley are prone to landslides. As a predominantly rainfall, rather than snowfall, dominated basin, flows in the Raging River can be fairly flashy during the wet season, while summer flows are not sustained by snowpack. As a result, summer flows are generally very low compared to winter flows and peak annual flows. The mean flow in August (USGS Gage 12145500) is only 19 cfs, compared to the January mean flow of 270 cfs. The mean annual peak flow measures over 2100 cfs and has been recorded as high as 6000 cfs in November 1990. The combination of a highly active, wide river channel and a rain-dominated hydrograph result in late summer flows that are very low relative to the width of the active channel where tree canopy is in short supply in certain areas. Thus, the stream may be prone to rapid warming during daytime hours. The continuous data collected by WDOE show daily temperature fluctuations of greater than 7°C during portions of July and August.

The channel condition of the Raging River may also have been influenced by a legacy of timber harvest practices with impacts to stream temperature. Landslides and bank erosion due to road building and other activities can alter the width and shape of the river channel, resulting in a wider, shallower channel that is more exposed to sunlight.

In an effort to better understand the temperature profile of the river and to identify potential strategies to address the problem, King County deployed continuous temperature monitoring devices (i.e., thermistors) at approximately 15 locations in spring 2008 along the Raging River. The thermistors remained in place through September 2008. The study also includes wide-angle 'fish eye' photographs to document the amount of shade at each sampling location, as well as synoptic measurements of dissolved oxygen and temperature during a more intensive 1 or 2 day period. The data has not been fully analyzed as of the publication of this report.

Dissolved oxygen: Not impaired

Dissolved oxygen concentration appears to meet standards most of the time at most locations in the Raging River sub-basin, though available data are limited. During WDOE's TMDL effectiveness study, DO measurements were not taken on all dates, including some that featured very warm water temperature. Moreover, possibly due to the logistics of the sampling regime, none of the DO measurements were taken during the morning hours when concentrations tend to be at their lowest. Nevertheless, only one excursion below the 9.5 mg/L standard was recorded during the study (WDOE, 2008).

KCRMS data also indicate fairly good DO conditions. At the lower mainstem sampling location (Site E845), only minor excursions have been recorded in monthly grab samples since 2001 (values >9.0 mg/L), and only one value lower than 8.0 mg/L has been recorded since sampling began in 1999. Lake Creek also appears to have excellent DO conditions.

The apparent lack of a chronic oxygen problem is somewhat surprising given the very high temperatures in the lower river, coupled with high pH (see below) which may indicate excess algal growth and decomposition. However, the relatively high gradient all the way down to the Snoqualmie River and coarse substrates that are characteristic of the Raging River likely help to maintain well-aerated conditions, even when flows are fairly low and temperatures are high. This is a stark contrast to the smaller low-gradient tributaries like Ames and Cherry Creeks that inch slowly across the Snoqualmie River's floodplain during a portion of the year.

Fecal coliform: Basin of concern

Compared to many other sub-basins in the watershed, bacteria concentrations are fairly low in the Raging River. The river meets the geometric mean concentration criterion with most values well below 100 CFU/100 ml. However, like nearly every other sub-basin, occasional higher concentrations following high-flow events cause the Raging River to fail the second portion of the standard during late summer and early fall. However, the maximum values recorded in the basin are lower than many other locations and appear to recede quickly. For example, the highest recorded value (during the WDOE study) of 1100 CFU/100 ml on October 20, 2003 was followed by a concentration of 28 CFU/100 ml one week later.

Agricultural activities in the sub-basin are limited to small-scale operations, mostly within rural residential areas. Thus, agriculture is not necessarily a major contributor to spikes in bacterial concentrations. Municipal sewage treatment is not available in the basin and all residences and businesses rely on septic systems, with the exception of the Echo Glen juvenile detention center near Our Lake which receives sewage treatment services form the City of Snoqualmie. The generally low bacterial concentration suggests that septic systems are not the primary contributor to occasional spikes within the basin. In the Raging River, wildlife use of the river corridor during the summer months may be a contributing source of bacteria in the fall months.

However, as discussed in the Snoqualmie Mainstem section, localized bacteria concentrations near Fall City may be attributable to sources in the lower Raging River (WDOE, 2008). WDOE recommends further, detailed study of bacteria concentrations in the area.

pH: Impaired (High pH)

The Raging River is unique in the Snoqualmie watershed as the only sub-basin that appears to fail the pH standard due to high (alkaline) values. During WDOE's TMDL effectiveness study, pH at the mouth of the Raging River consistently exceeded the 8.5 standard in August and September, with a maximum value of 9.7 during the study. As noted in the DO discussion, the measurements were taken in the afternoon when pH is likely to be highest, as described further, below. As part of study, WDOE also conducted a 2-day intensive monitoring survey in August 2005 of all sites that included morning and evening measurements. Again, the Raging River appears unique in that the difference between A.M. and P.M. readings is higher than for other sites. On day 1 of the survey, pH increased from 8.1 to 9.1 within a four hour period; on day 2, pH increased from 7.7. to 8.9 in just over five hours (WDOE, 2008 - Appendix Table E-6).

WDOE (2008) concluded that excessive periphyton (attached algae) growth may be to blame for the observed pH condition. During daytime hours, the process of photosynthesis tends to cause the pH level to increase, while respiration during nighttime hours leads to daily pH minima in the morning.

KCRMS data from tributaries in the basin do not reveal a similar pattern. In fact, no values higher than 8.5 have been recorded at any stations since data collection began in 1999. Furthermore, data from KCRMS site E857 – located on the mainstem Raging River at SE

68th St. near RM 2.7 – also does not include any unusually high values, though data were collected for only two years (2000-2001). This suggests that the pH phenomenon in the Raging River is primarily concentrated in the lowest reaches of the river where WDOE collected the data. Additional investigation is highly recommended.

Nutrients: Not impaired

Nutrient concentrations are generally low in the Raging River, although available data are fairly limited. WDOE (2008) found that ammonia-nitrogen remained below detection limits on all occasions. Other nitrogen parameters were also generally low, and the only orthophosphate sample obtained was less than the TMDL guideline level of ≤ 20 µg/l (i.e., micrograms per liter).

Benthic invertebrates

The only location in the sub-basin with more than one data point for invertebrates is the Lake Creek monitoring site (Table 14). According to KCRMS data, the B-IBI index value has increased in recent years, suggesting improvements in water quality. The observed low temperatures and high DO levels are consistent with the 'good' scores observed in 2004-6.

The creek originates in Echo Lake which is located in close proximity to the I-90 corridor and is surrounded by a mix of U.S. Forest Service land and private residential parcels. From the lake outlet, the stream passes through roughly one third of a mile of low density rural residential areas before entering a combination of federal and state-owned forest lands. The final half-mile prior to joining the Raging River is also rural residential in character.

Table 14. B-IBI Scores for one site in the Raging River sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E818	Lake Creek	26	18	32	34	38	38	44

Excellent	Good	Fair	Poor	Very Poor

Synthesis and recommendations

The primary water quality concern in the Raging River is the very high temperature observed in the lower river during late summer and early fall. As a key spawning area for Chinook salmon, high temperatures may delay migration or increase stress for returning adults. The data collected by King County (summer 2008) should provide important additional information about the severity and longitudinal profile of the high-temperature condition and hopefully point toward potential solutions.

While natural conditions may contribute to the observed high temperatures, changes in land use could further exacerbate the problem. In particular, forested conditions are strongly preferable to other land use alternatives for purposes of maintaining cool temperatures and other beneficial water quality characteristics. Forestry activities can of course produce their own water quality impacts, including high temperature if riparian buffers are inadequate, excessive sediment input due to bank erosion and poor road maintenance practices, as well as changes in hydrology.

The anomalous high-pH condition observed in the Raging River merits further study. The phenomenon was also noted in the studies conducted by WDOE in the early 1990s for the original TMDL plan. Thus, the conditions that have created the problem are not new and may include a combination of both natural and human-caused factors.

<u>Priority actions for the Raging River:</u>

- Investigate potential sources of pH impairment in the lower Raging River, including natural factors as well as anthropogenic influences.
- Due to the very high temperatures that may occur in this core area for fall-spawning salmonids, conduct instream restoration projects (such as large wood jams and boulder cluster placement) that encourage pool formation to create thermal refugia for adult salmonids. In addition, these actions may promote hyporrheic flow which has also been shown to lower stream temperature (Seedang et al., 2008).
- Analyze King County temperature data (summer 2008) to identify focal areas of temperature impairment to help inform restoration priorities.
- Protect and enhance intact riparian areas and wetlands in both forested and rural residential areas through the use of incentives, acquisitions, restoration and enforcement of regulations. Focus on the mainstem as well as key cool-water tributaries, such as Lake Creek.

Tokul Creek (33.8 mi^2)

Sub-basin Description

Land Use	
Forestry	96.6%
Rural Res. 1 DU/2.5-10 acres	2.9%
Mining	0.5%
Rural City UGA	0.1%

Tokul Creek is the last major tributary below Snoqualmie Falls. The sub-basin is almost entirely within privately owned forest lands.

According to the 2001 land-cover analysis by Marshall and Associates, 14% of the sub-basin is classified as either "recent clear cut forest" or "recently regenerated forest", the highest combined rate for these classifications in the watershed. The lower 1.7 miles of the stream are within a low density rural residential designation.

The mainstem of Tokul Creek is roughly 14 miles in length with two major tributaries in Ten Creek and Beaver Creek. The Washington Department of Natural Resources (WDNR) owns and manages a block of land in the middle of the basin under the Natural Area Preserves (NAP) program. NAP lands are intended to protect the best remaining examples of many ecological communities including rare plant and animal habitat. NAP sites are identified by the WDNR Natural Heritage Program. The Kings Lake NAP, totaling 309 acres, preserves sphagnum bogs and a 2-acre "eyelet" pond[27], which represent ecosystems that are now extremely rare in the region. The site protects populations of few-flowered sedge, a state Sensitive plant, Hatch's click beetle, and Beller's ground beetle, both state Threatened animal species only found in very good condition sphagnum bogs[28].

WDFW operates the Tokul Creek Fish Hatchery near the mouth of the creek. According to WDFW, anadromous fish are limited to the lower 1.4 miles of the stream below an impassable waterfall. Chinook, coho, pink and chum salmon, as well as both summer-run and winter-run steelhead are known to utilize Tokul Creek. Approximately 190,000 winter-run steelhead smolts are produced annually at the hatchery, primarily to support a local sport fishery. Most of the fish are released from the hatchery, while roughly 20,000 are released near the confluence of the Tolt and Snoqualmie Rivers, and 20,000 in the Raging River near Preston. In addition, approximately 60,000 summer steelhead are released annually from the hatchery (R2 Resource Consultants, Inc. 2008) .

Water Quality

Water quality in Tokul Creek is generally very good compared to other tributaries in the watershed. The impact of hatchery effluent on water quality in the lower portion of the stream has not been fully evaluated, though the hatchery is in compliance with its NPDES permit (see Section 3.2).

Several landslides have occurred along the left bank of Tokul Creek between RM 0.0 and 0.5. The armoring of the right bank to protect the WDFW facility likely contributes to the

[27] Eyelet ponds are open water areas bounded by a quaking mat of sphagnum peat.

[28] http://www.dnr.wa.gov/AboutDNR/ManagedLands/Pages/amp_na_kings.aspx

erosion of the toe-of-slope on the left bank. Major slope stabilization efforts have been conducted along this reach.

Temperature: Basin of concern

As a core salmonid spawning and rearing area, the 16°C 7-DADMax standard is applied to Tokul Creek. In addition, the portion accessible to anadromous fish also must meet the 13°C seasonal standard from September 15 – June 15.

Limited temperature data are available from three locations in the lower basin: WDOE's TMDL effectiveness data collected at the mouth, WDOE's continuous temperature data collected in 2006 at the SR 202 crossing (approximately RM 0.5) and at the mouth, as well as KCRMS data that has been collected at the Tokul Rd. crossing since 1999 (approximately RM 1.5).

The KCRMS site is located near the downstream edge of the forested portion of the watershed. Since 1999, only one instance of water temperature higher than 16°C (17.1°C) has been recorded at the site, during the very warm summer of 2004 that produced high temperatures in many tributaries within the Snoqualmie watershed. In general, recorded summer temperatures at the site have remained well below the standard.

WDOE's continuous monitoring data shows that in the lower portion of the sub-basin, the standard is exceeded more regularly. During July and August 2006, the SR 202 site exceeded the 7-DADMax standard on two occasions for a 1-2 week period. The same pattern was observed at the mouth of the stream where the 7-DADMax exceeded 18°C. This is not a lethal temperature level for salmonids and it is several degrees cooler than the maxima observed in other tributaries, but it nevertheless suggests that the lower portion of the sub-basin is not meeting standards.

At the mouth of the stream, WDOE's grab samples in 2003, 2004 and 2005 showed a small number of readings above 16°C, almost entirely limited to August 2004. The highest recorded temperature was 17.5°C.

Tokul Creek appears to meet the supplemental 13°C seasonal standard.

Dissolved oxygen: Not impaired

According to both WDOE and KCRMS data, Tokul Creek appears to have very good dissolved oxygen conditions year-round. KCRMS data shows that a few minor excursions below 9.5 mg/L occurred in 1999 and 2000 during the late summer, but the site has met standards on all occasions since that time. WDOE's data collected at the mouth exceeded the standard on all occasions. Similar to the Raging River, the creek has a relatively high gradient and does not have a significant floodplain reach in its lower section.

Fecal coliform: Not impaired

Tokul Creek appears to have some of the lowest concentrations of fecal coliform and *E. coli* in the watershed. During much of the year, bacterial counts are in the single digits or low double digits in CFU/100 ml. WDOE recorded a few instances of concentrations above 100

CFU/100 ml, but none above 200. This is fairly unique in that most other tributaries experienced much higher late summer spikes following rain events. Thus, the stream meets both the geometric mean and 90% exceedance criteria. This is likely because there are extremely few human uses occurring in the basin other than forestry.

pH: Basin of concern (mouth only)

pH in Tokul Creek appears to remain within the prescribed range (6.5-8.5) year-round. KCRMS data show that Tokul Creek has a somewhat higher average pH level than other tributaries, with typical values between 7.4 and 7.8, leaning toward slightly alkaline conditions, whereas other tributaries in the lower watershed in particular are slightly acidic. Also, the pH of the basin at the KCRMS site appears very stable across months and years. WDOE recorded one minor exceedance of the upper limit at 8.6 during the TMDL effectiveness study (WDOE, 2008).

As explained in Section 2.3, the state's pH standard also limits the allowable human-caused variation to 0.2 units from background conditions. A comparison of KCRMS data collected at Tokul Rd. and WDOE data from the mouth of the stream shows that pH tends to increase along that 1.5 mile stretch which includes the outfall for the WDFW hatchery. While same-day measurements are not available from the two sites, several measurements taken in August 2003 and 2004 showed a difference of 0.4 to 0.6, with higher readings at the mouth.

One possible explanation for the difference is the effect of nutrient laden effluent from the hatchery on algae production in the lower portion of the stream. Excessive periphyton growth may lead to high pH values in surface waters (WDOE, 2008). Same day measurements of pH and nutrients would help to shed light on this issue.

Nutrients: Not impaired

The only nutrient data available for Tokul Creek are from the mouth of the stream (WDOE 2008). WDOE found nutrient levels to be somewhat elevated, though not of great concern. The standard for ammonia-nitrogen was not exceeded. The absence of nutrient data from upstream areas precludes quantification of the effect of hatchery effluent or of residential septic systems on nutrient levels.

Benthic invertebrates

KCRMS has collected invertebrate data on lower Tokul Creek since 1999. With the exception of 2002, the site has scored in the Fair and Good categories of the B-IBI index (Table 15). Considering the mostly undeveloped condition of the watershed, even higher scores might be expected. However, sediment input from forest roads and forestry activities may compromise substrate quality with direct effects on invertebrate production.

Table 15. B-IBI Scores for one site in the Tokul Creek sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E1017	Tokul Rd. SE		32	24	44	36	38	38

Excellent	Good	Fair	Poor	Very Poor

Synthesis and recommendations

Based on data reviewed for this report, the only area of concern in the Tokul Creek sub-basin is the role of nutrients from hatchery effluent or other sources as contributors to the observed pH increase in the lower portion of the stream. Alternatively, it is conceivable that other conditions may be responsible for the observed increase, but same-day measurements of pH and nutrients should be carried out both upstream and downstream of the hatchery in particular. An additional monitoring location further upstream could help to discriminate hatchery effects from potential inputs of nutrients from rural residential areas via septic systems or fertilizers.

According to the GIS analysis performed for Table 5, Tokul Creek has the lowest watercourse density of any sub-basin in the watershed at only 1.8 mi/mi^2, half of the watershed average. While this may well be a consequence of local topography, it is also possible the watercourses in the sub-basin have not been comprehensively mapped to date. As a private forestry-dominated sub-basin, accurate stream mapping is critical for ensuring that forestry regulations are applied appropriately. The accuracy and completeness of wtare course maps should be evaluated in this sub-basin.

Priority actions for Tokul Creek:

- Conduct water typing assessments to ensure that forestry regulations are applied appropriately to all watercourses.
- Conduct same-day sampling upstream and downstream of the hatchery to evaluate potential effects on pH and nutrient levels.

Kimball/Coal Creeks (8.7 mi^2)

Sub-basin Description

The Kimball Creek/Coal Creek sub-basin is unique in that it falls largely within city limits and features a variety of land uses within a fairly small basin. Approximately 37% of the sub-basin lies within the City of Snoqualmie and less than 2% within North Bend. An additional 16% is designated as an Urban Growth Area that may become incorporated if area residents elect to be annexed in the future.

Land Use (Unincorporated areas)	
Rural Res. 1 DU/2.5-10 acres	45.3%
Forestry	31.2%
Rural City UGA	23.3%
Other	0.2%
Incorporated (see text)	38.2%

Land use within Snoqualmie city limits was not analyzed for this report, but in the older sections of the city along SR 202, land use generally consists of open space, residential and commercial uses. Further development in this portion of the city is severely constrained by the fact that it is largely within the 100-year floodplain of the Snoqualmie River. The more recently developed upland areas (e.g., Snoqualmie Ridge) feature multiple uses, including higher-density housing, retail and golf courses.

Coal Creek drains the northwestern portion of the sub-basin with its headwaters in a forested area on the south side of Interstate 90. The mainstem of Coal Creek passes through unincorporated rural residential areas and a portion of the UGA before joining Kimball Creek approximately 1.25 miles upstream of the Snoqualmie River. Several small tributaries to Coal Creek originate in the Snoqualmie Ridge area of the City of Snoqualmie.

Kimball Creek is a meandering, low-gradient stream that originates in a nearly 100-acre wetland complex in unincorporated King County northwest of the Nintendo corporate campus in North Bend. The wetland area is partly within King County owned parcels and privately held rural residential areas. The wetland is fed by several small streams that drain the slopes along the I-90 corridor. The stream flows through both incorporated (City of Snoqualmie) and unincorporated low-density residential areas before passing through city-owned open space lands just prior to entering the Snoqualmie River.

Kimball Creek (but not Coal Creek) is almost entirely within the 100-year floodplain of the South Fork and mainstem of the Snoqualmie River. Since 1996, King County has purchased several properties in the lower sub-basin that were subject to repeated inundation during floods.

Kimball Creek is the first major tributary upstream of Snoqualmie Falls; thus, anadromous fish do not have access to the sub-basin. Western brook lamprey and resident cutthroat are known to utilize both Kimball and Coal Creeks. Beaver activity is abundant in the basin.

Water Quality

Kimball Creek has fairly poor water quality for several parameters. The City of Snoqualmie has conducted a variety of studies in the basin to help identify potential causes and solutions to the problem. In 2001, Herrera Environmental Consultants (Herrera) conducted an inventory of available data in the sub-basin on behalf of the City (City of Snoqualmie, 2001). The studies reviewed for that report are not summarized here, but some of the findings of that effort are highlighted as well as supplemented by more recent data.

As described below, water quality appears to be much better in the Coal Creek portion of the basin, but fewer data sources are available for Coal Creek.

Temperature: Impaired

The 7-DADMax temperature standard for Kimball Creek is 16°C. Data for WDOE's TMDL effectiveness study was collected near the mouth of the stream at the SR 202 crossing (Figure 15). Based on grab samples, the stream did not meet standards for temperature during the month of August.

WDOE also collected continuous data at the same location in 2006 as part of the ongoing Temperature TMDL study. Kimball Creek was one of the warmest tributaries in the study. The 7-DADMax standard was exceeded continuously for a period of 2.5 months, with a peak value of 20.3°C for the 7-day index.

KCRMS has collected data at four locations in the sub-basin: 1) lower Coal Creek at 378th Ave SE (Site E1191), 2) Kimball Creek below the Coal Creek confluence at SE 80th Street (Site E1190), 3) upper Kimball Creek at 384th Ave SE (Site N3674), and 4) a tributary to Kimball Creek near Meadowbrook Way SE (Site E2519). Both of the mainstem Kimball Creek sites have violated the temperature standard on most July and August sampling events since 1999 with several readings above 19°C. In contrast, temperature at the Coal Creek site is 1-2°C lower on average, with samples collected at nearly the same time. Though Coal Creek exceeds 16°C on occasion, only one value above 17.5°C has been recorded since 1999.

The lowest temperatures have been recorded in the small independent tributary near Meadowbrook Way, with a maximum value of 16.4°C since 1999. However, absent discharge data, it is not possible to estimate the magnitude of the cooling effect of the tributary on the mainstem of Kimball Creek.

Dissolved oxygen: Impaired

Dissolved oxygen conditions are extremely poor in the upper portion of Kimball Creek. According to KCRMS data, average DO concentration at the 384th Ave SE location (Site N3674) has been less than 5.0 mg/L from May through October since 2001, with occasional readings below 2.0 mg/L . According to the comments that accompany field data sheets, water is often fairly stagnant and turbid at this location during the late summer months. Low DO values were also recorded in the same area by Herrera (City of Snoqualmie, 2001).

Again, the contrast with Coal Creek is dramatic. Since 2001, the lowest recorded value has been 9.2 mg/L , while most readings have exceeded 10.0 mg/L . Similarly, site E2519 also has met standards on nearly all occasions.

Site E1190 captures the combined flow from Coal Creek and Kimball Creek. Not surprisingly, the results are intermediate. Average monthly values fall short of the 1-day minimum standard in all months except January-March, but with most individual readings above 6.5 mg/L .

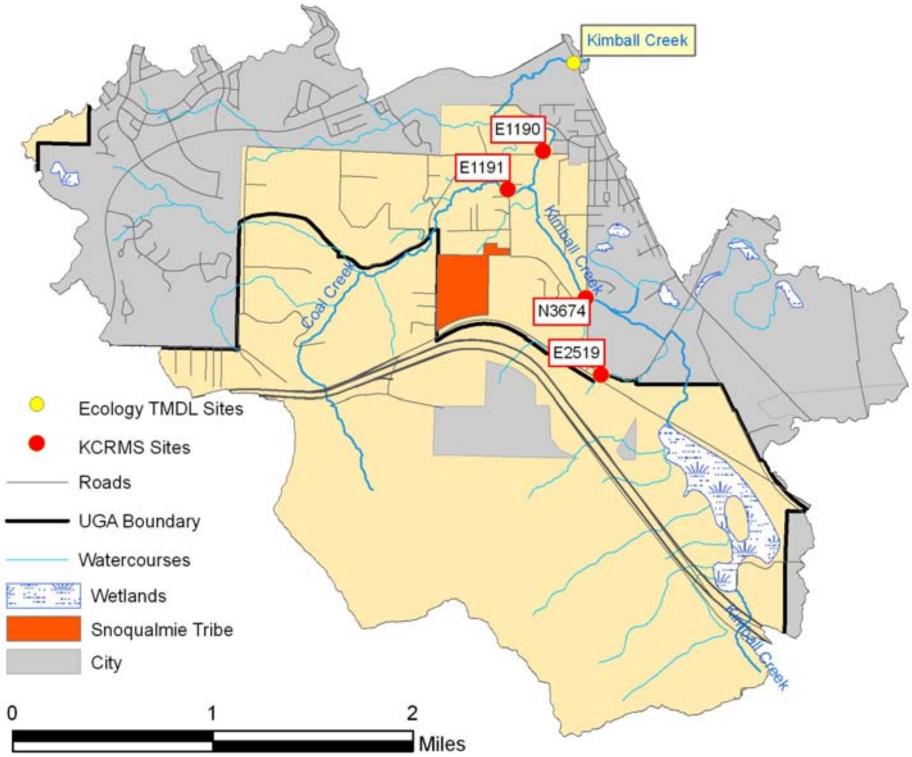

Figure 15. Kimball/Coal Creek sub-basin water quality data locations.

WDOE's data from the SR 202 crossing are fairly similar to the KCRMS values at Site E1190, generally failing to meet standards, but nowhere near as low as the values observed in the upper portion of Kimball Creek.

It is not uncommon to have low DO concentrations in slowly draining wetland areas. WDOE (2008) noted that at the Meadowbrook Way crossing Kimball Creek featured a considerable amount of iron oxidizing bacteria (orange-colored bacterial growth) that is associated with mineral-rich, low-oxygen groundwater inputs in many streams and ditches in western Washington. KCRMS data includes measurements of specific conductivity, one indicator of the influence of groundwater. The data show that conductivity is somewhat elevated in late summer, suggesting that groundwater represents a larger proportion of overall flow during that time period. However, no such signal is apparent in the spring months but dissolved oxygen remains well below standards. Even with the potential role of natural conditions as contributors to low DO, the values observed in the upper portion of Kimball Creek are cause for concern.

Fecal coliform: Impaired

Much of the water quality sampling and analysis in the sub-basin has focused on bacteria. WDOE reported a geometric mean concentration of 190 CFU/100 ml near the mouth during the TMDL effectiveness study, well above the standard, but also much lower than values observed in the early 1990s. The peak observed value in 2003-2004 was 2900 CFU/100 ml, second only to one observation in Ames Creek. Herrera recorded a maximum value of at least 3113 CFU/100 ml[29]. WDOE (2008) calculated that a 77% reduction in fecal coliform concentration is needed in order to meet standards.

Herrera (2004) collected water quality data at six stations in Kimball Creek between March 2003 and January 2004, but not during the summer months[30]. The 2004 study found that FC concentrations generally met standards in the upper portion of Kimball Creek, upstream of the 384th Ave SE crossing, but exceeded standards at all other locations downstream. This suggests that wildlife use of the wetland complex at the upstream end of Kimball Creek is not the most likely source of wet-season fecal contamination. Rather, hobby farms and septic systems may be the most likely contributors. Upstream of 384th Ave SE, residential areas within City limits are all served by public sewers, while downstream of that point, the stream flows through unincorporated residential areas that utilize septic systems. These neighborhoods are within the UGA and are slated for eventual inclusion in the City's sewer service area, if residents elect to be annexed into the City in the future.

Herrera's 2004 study also utilized genetic techniques to identify the host species of fecal coliform samples collected in Kimball Creek. The samples contained bacteria from many different wild and domesticated animals – such as birds, dogs, cats, horses, beavers, cows and raccoons - as well as bacteria from humans.

pH: Impaired

As with temperature and DO, the pH conditions differ between the upper mainstem of Kimball Creek and Coal Creek. Data collected by KCRMS, Herrera (2004) and City of Snoqualmie (2001) all show that pH in the wetland-dominated area of the stream are slightly acidic and violate the 6.5 standard. Most recorded values are 6.2 or higher. In contrast, mean monthly values from lower Coal Creek range from roughly 7.0 to 7.5. Not surprisingly, KCRMS Site E1190 shows intermediate values (Figure 16).

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[29] According to the report, this value was likely an underestimate due to the fact that one of the samples had a concentration 'too high to count', which typically means >5000 CFU/100 ml. For purposes of calculation, 5000 was used as the nominal concentration for the sample.

[30] Much of the sampling was performed by local high school students; thus, summer sampling did not take place.

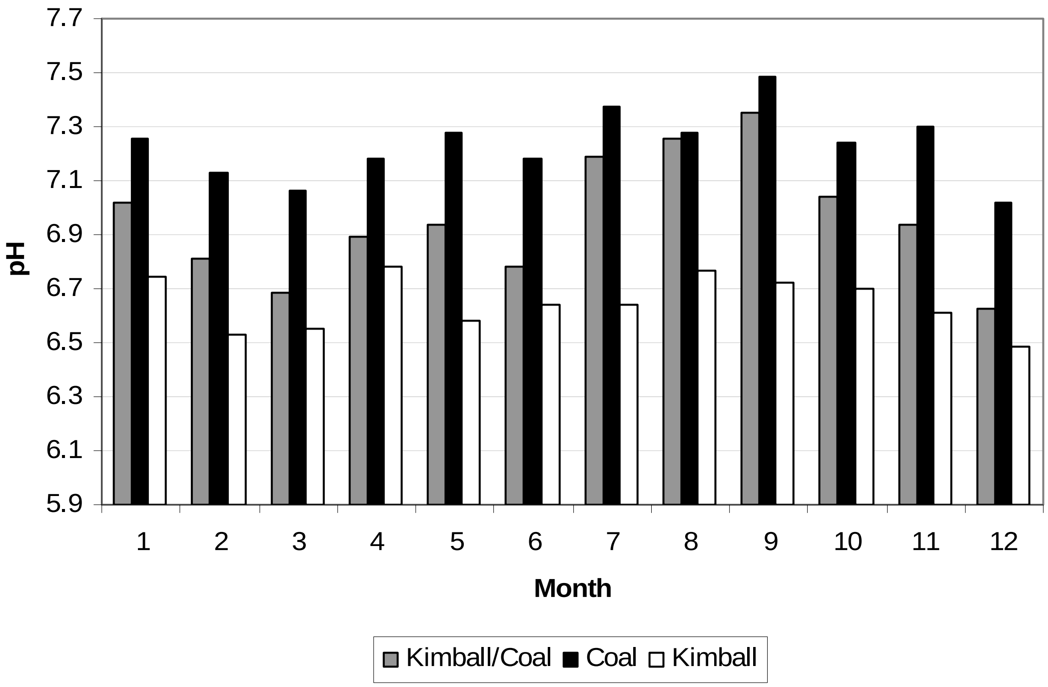

Figure 16. Monthly mean pH values from Kimball and Coal Creeks (data from KCRMS, 1999-2006).

During the late summer months, the pH at the combined downstream site is much closer to the pH of Coal Creek than of upper Kimball Creek, suggesting that Coal Creek represents a higher fraction of the overall flow during that period.

Nutrients: Basin of concern

Herrera reported significantly elevated phosphorus and ammonia concentrations at a sampling location in lower Kimball Creek. These values were higher than those typically observed in King County streams (City of Snoqualmie, 2001). WDOE (2008) also noted that ammonia-nitrogen was slightly elevated at the mouth of Kimball Creek compared to other sites, but it did not violate the state standard.

Benthic invertebrates

Invertebrate samples were collected by KCRMS in 2004 and 2005 at the Coal Creek site (Table 16). The 'fair' to 'good' results are consistent with the generally good water quality in the Coal Creek portion of the basin.

Table 16. B-IBI Scores for one site in the Kimball/Coal Creek sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E1191	Coal Creek - lower					38	36	40

Excellent	Good	Fair	Poor	Very Poor

Synthesis and recommendations

Due to the prevalence of rural residential land use and the high percentage of incorporated areas in the sub-basin, future degradation due to increased development is a serious concern for Kimball/Coal Creeks. The fairly good water quality in Coal Creek could be compromised by fragmentation of intact riparian areas and by increased stormwater input.

The low dissolved oxygen conditions in upper Kimball Creek are a serious concern for aquatic life in that portion of the sub-basin. The degree to which conditions are attributable to natural vs. human-caused conditions should be investigated via aquatic chemistry, soil analysis and groundwater testing. Groundwater is very shallow in this area and may play a role in the observed conditions, although groundwater generally becomes re-oxygenated upon contact with air. However, the high turbidity reported by WDOE and KCRMS, coupled with abundant iron-oxidizing bacteria suggests that something is exacerbating the situation, such as excessive nutrient inputs.

Currently, residential uses, including small farms, dominate the lower sub-basin. The County and City should work closely with landowners to encourage improved livestock management, pet waste containment, reduced use of fertilizers, and proper septic system maintenance. The very-shallow groundwater in this area amplifies the risks associated with failing septics. Riparian planting projects should be continued in order to address late summer high temperatures in the stream, and to help reduce sediment and nutrient inputs.

Water quality in Coal Creek appears to be excellent compared to the mainstem of Kimball Creek. Maintaining that high quality is very important not only to Coal Creek itself, but also to lower Kimball Creek. A significant portion of Coal Creek lies within the UGA of the City of Snoqualmie. Eventual incorporation may generate pressure for higher-density development in this area. New development in the area will likely be accompanied by sewer service which should help alleviate any impacts of septic systems from this area (although no fecal coliform data has been collected to our knowledge in Coal Creek). However, other changes, such as smaller lots, higher percentage of impervious surfaces, additional roads and loss of vegetation could compromise the quality of Coal Creek. The City is strongly encouraged to recognize the high value of Coal Creek to the Kimball Creek sub-basin for purposes of protecting human health and aquatic life. Application of Low Impact Development techniques should be strongly encouraged in this area. Prior to incorporation, the County should likewise work to ensure the long-term health of Coal Creek through outreach and education with landowners and by maintaining a high level of protection for riparian areas and the largely forested stream corridor.

Priority actions for Kimball / Coal Creeks:

- Enhance riparian conditions along Kimball Creek through removal of invasive plants and extensive riparian planting.
- Install fencing to exclude livestock from the stream.
- Investigate soil and water characteristics as well as surrounding land-use in upper Kimball Creek to identify potential causes of very low DO concentrations, low pH and the observed prevalence of iron-oxidizing bacteria in this portion of the stream.

- Protect and enhance intact riparian areas and wetlands in the Coal Creek drainage through incentives and enforcement of existing regulations.
- Provide outreach and technical support to landowners regarding proper septic system operation and maintenance.

North Fork Snoqualmie River (103.5 mi^2)

Sub-basin Description

Land Use	
Forestry	97.4%
Rural Res. 1 DU/2.5-10 acres	2.0%
Other	0.5%

Like the other sub-basins that border the eastern edge of the Snoqualmie watershed, the North Fork Snoqualmie River is almost entirely forested within a patchwork of federal, state and private ownership. The North Fork's headwaters flow from Lake Kanim near the crest of the Cascade Range within the Mount Baker – Snoqualmie National Forest (MBSNF), and a good portion of it within the Alpine Lakes Wilderness. After descending through steeper terrain, two major headwater tributaries – Lennox Creek and Sunday Creek – join the North Fork within the first 12 miles of its course westward in a long, broad valley that contains Fitchener Slough.

The aforementioned mountain valley is also the site of the WDNR Snoqualmie Bog Natural Area Preserve, a 111-acre site that protects a sphagnum moss bog which is now extremely rare in the Puget Trough. The site also protects mountain bladderwort and few- flowered sedge, both sensitive plant species, and Beller's ground beetle, a sensitive animal species. A small strip of natural old growth forest with western hemlock and western red cedar remains along one edge of the bog. At the west end of the valley, the river is joined by Deep Creek and later several lake-fed tributaries as it continues southward in a more confined valley toward Mt. Si and the Three Forks Natural Area.

The southern edge of the sub-basin features the north face of Mt. Si, perhaps the most easily recognized physical feature of the Snoqualmie watershed, or a close second to Snoqualmie Falls. The WDNR Mount Si Natural Resource Conservation Area (NRCA) encompasses 9,522 acres of land within the North Fork and Middle Fork sub-basins and is composed of steep, rugged and mountainous terrain. NRCAs protect outstanding examples of native ecosystems, habitat for endangered, threatened and sensitive plants and animals, and scenic landscapes. Four mountain peaks are located within the Mount Si NRCA, including Mount Si, Mount Teneriffe, Green Mountain, and Little Si, ranging from 1,600 to 4,800 feet in elevation. The NRCA supports a variety of wildlife including native mountain goats, cougar, and black bear. The area also safeguards unique geologic features, examples of old growth forests, and sensitive plant species.

The final 2.5 miles of the North Fork flow through designated rural residential areas that include small-scale livestock and other agricultural operations. Near its confluence with the Middle Fork Snoqualmie in the Three Forks Natural Area, the North Fork is joined by Tate Creek, a right bank tributary that passes through both private forest and rural residential areas. KCRMS maintains two water quality sites on Tate Creek.

The 418-acre Three Forks Natural Area is located at the confluence of the three forks of the Snoqualmie River. It includes over five miles of riverfront and is dominated by riverine and riparian habitat while providing habitat for a broad range of wildlife including black bear, elk, cougar, eagle, deer, and river otter. The Natural Area also plays a role in providing recreation opportunities for local and regional visitors. Larger natural recreation areas such as Mount Si and Rattlesnake Lake Scenic Area are nearby and regional trails converge on and near the site including the Snoqualmie Valley Trail, which runs directly through the western portion of the park.

According to WDFW, cutthroat trout are known to ascend into headwater tributaries of the North Fork, while rainbow trout and non-native eastern brook trout are also found in lower elevation areas.

Water Quality

Water quality is generally very good in the North Fork, though data are limited to a small number of sites in the lowest reaches of the river. However, despite the forested nature of the basin, high water temperature is a concern during summer months.

Temperature: Basin of concern

The 16°C 7-DADMax standard applies to the North Fork as far upstream as the Sunday Creek confluence, in the middle of the valley described above. The 12°C standard applies to the river and associated tributaries further upstream.

During WDOE's TMDL effectiveness study, temperature near the mouth of the North Fork (at 428th Ave. SE) exceeded the 16°C standard on a few occasions, but summer sampling was limited to the month of August. WDOE's draft temperature TMDL study collected continuous data in the summer of 2006 at the same location. The standard was exceeded for approximately three weeks in July, with a maximum 7-DADMax value of 19.0°C. Lacking data from locations upstream, the spatial extent of the temperature problem is unclear, and we cannot determine if the upper basin is meeting the more stringent 12°C standard. Based on comparable data from the Middle Fork and from the Tolt River sub-basin, violations of the more stringent standard are highly likely.

The North Fork is cooler than the Middle Fork by several degrees, according to WDOE's continuous data from July 2006 (Figure 17). That finding is supported by thermal infrared data collected during the same period – the North Fork has a discernible cooling influence on flow from the Middle Fork (Figure 18).

KCRMS has collected data at two tributary road crossings in the lower North Fork sub-basin within rural residential areas in close proximity to the Three Forks Natural Area. The temperature in these very small tributaries appears decidedly cooler than the North Fork itself. The site at SE 92nd Street (E1051) has a maximum recorded temperature of only 13.5°C, measured in August 2001. The second location at 436th Ave SE (E1015) generally remains below 16°C, but in most years it is running too low to measure for much of July – September.

KCRMS has also measured temperatures at two locations in Tate Creek (E1001, E1002). These sites also have cool temperatures year-round, with average temperatures of less than 13°C in all months, and recorded maximums of 15.5°C and 13.5°C, respectively.

These observations highlight the importance of protecting and restoring small tributaries so that they can continue to provide cool-water refugia for fish while also reducing mainstem temperatures.

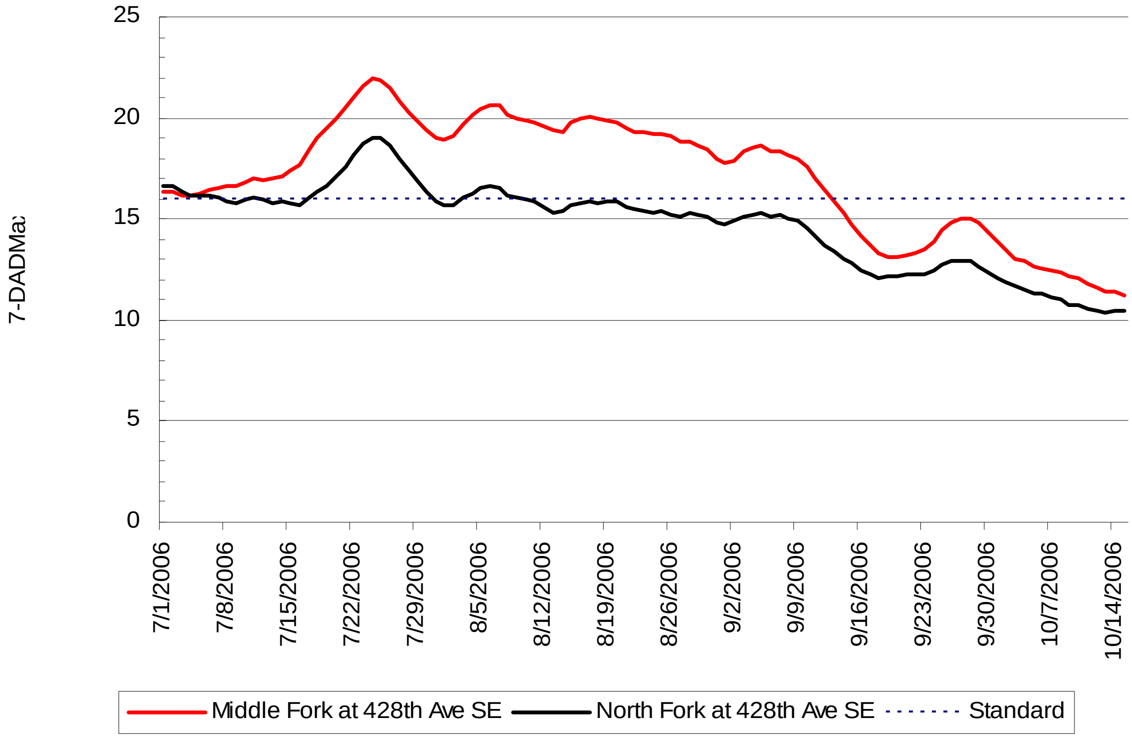

Figure 17. Same day 7-DADMax temperatures for the Middle and North Fork Snoqualmie River.

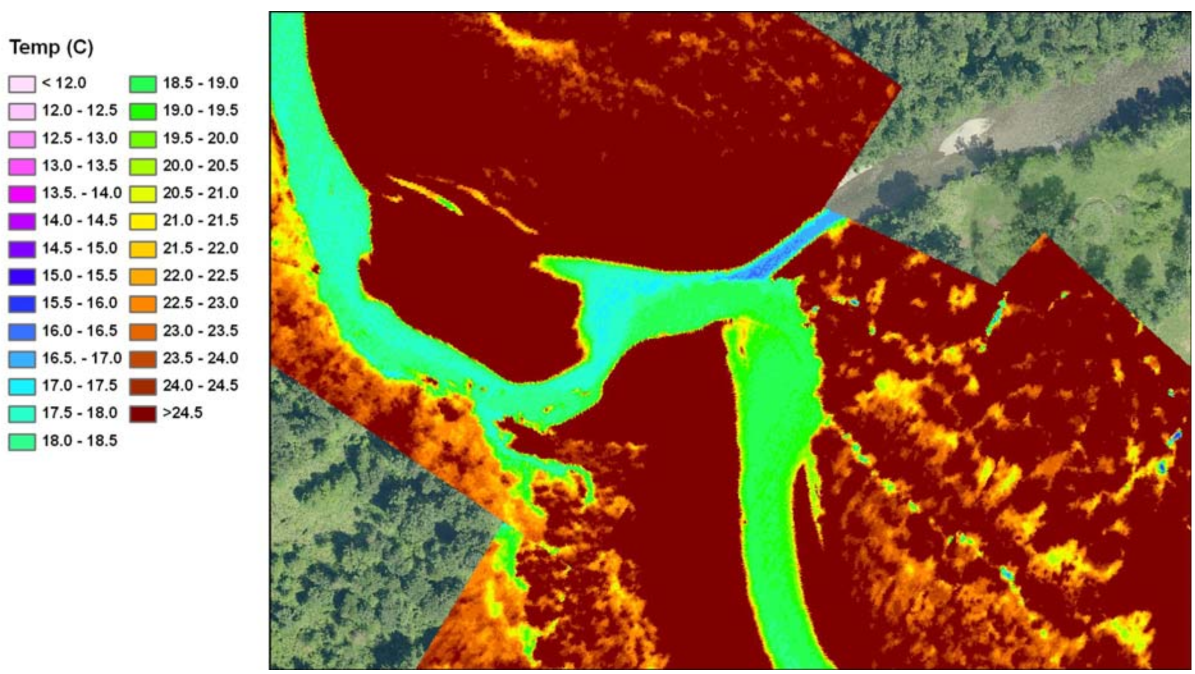

Figure 18. Thermal infrared imagery from the North Fork – Middle Fork confluence.

Dissolved oxygen: Not impaired

Available data shows that dissolved oxygen concentration meets state standards in the North Fork. KCRMS has recorded very high DO year-round at the Tate Creek monitoring locations (>10 mg/L). Unnamed tributary site E1051 has also recorded high values with no excursions below the standard since 2000. The fourth KCRMS site (E1016) has similarly high values during winter and spring, but the site is often nearly dry in summer and has recorded occasional lower values during very low flow periods.

WDOE's TMDL effectiveness study concluded that the North Fork meets the DO standard based on data collected at the 428th Ave SE location.

Fecal coliform: Not impaired

The entire length of the North Fork is classified as Extraordinary Primary Contact for purposes of fecal coliform standards. This means that the applicable fecal coliform limits are lower by half than most areas in the watershed, i.e., 50 CFU/100 ml for the geometric mean standard, and no more than 10% of samples shall exceed 100 CFU/100 ml.

According to WDOE, the North Fork had a geometric mean concentration of only 7 CFU/100 ml during the 2003-2005 study (WDOE 2008). Like most other locations in the watershed, the North Fork experienced a relative spike in concentration following a rain event after a prolonged dry spell in August 2004. The "spike" measured only 130 CFU/100 ml, much lower than the South Fork (500 CFU/100 ml) on the same date and other sites, such as Kimball Creek, which measured 2300 CFU/100 ml, which is probably not surprising given how few human activities occur within the North Fork Subbasin, with the exception of forestry.

pH: Not impaired

According to WDOE (2008), the North Fork mainstem meets standards for pH, as do tributary sites monitored by KCRMS.

Nutrients: Not impaired

Nutrient levels in the North Fork Snoqualmie are generally low compared to other sites and are lower than guideline concentrations (WDOE, 2008).

Benthic invertebrates

B-IBI samples have been collected by KCRMS near the transition from private industrial forest lands to rural residential areas in lower Tate Creek (Table 17). The 'fair' results are somewhat lower than what might be expected at a site with otherwise high water quality, but potential fine-sediment inputs due to forestry-driven erosion may compromise habitat quality for benthic invertebrates. Also, the suitability of the site to the B-IBI protocol has not been evaluated for this report.

Table 17. B-IBI Scores for one site in the North Fork Snoqualmie River sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E1001	Lower Tate Creek					28	34	36

Excellent	Good	Fair	Poor	Very Poor

Synthesis and recommendations

Occasionally high late-summer stream temperature is the only notable concern in the North Fork Snoqualmie, although temperature conditions appear better than in the Middle Fork. A longitudinal temperature study would help to characterize the temperature profile of the North Fork, and to determine whether the more stringent 12°C standard is being met in the upper basin.

Forestry practices and natural conditions are the most likely causes of high temperatures. As reflected in the tributary temperature data collected by KCRMS, tributaries can be an important source of cool water even in the lower portion of the sub-basin. If tributaries are inadequately protected from forestry practices due to erroneous water-typing on forest lands[31] or other factors, the temperature regime of the mainstem North Fork may also be compromised.

The presence of a broad, low-gradient, east-to-west oriented valley in the upper basin may also naturally promote warm temperatures. The valley aspect is very exposed to late summer solar heating, and the effect may be compounded by a slow, meandering river channel. The MBSNF should be contacted for additional data and for potential partnership in investigating the temperature regime in the upper basin.

Tributaries should be protected and restored in both forested and residential portions of the lower basin to promote cool-water inputs into the critical Three Forks area and into the mainstem Snoqualmie River.

<u>Priority actions for the North Fork Snoqualmie River:</u>

- Protect and enhance intact riparian areas and wetlands in both forested and rural residential areas through the use of incentives, acquisitions, restoration and enforcement of regulations. Focus on the mainstem as well as key cool-water tributaries, such as Tate Creek.
- Conduct water typing in forested areas to ensure proper application of forestry regulations and best practices.

[31] WDNR's water typing system is used to categorize streams according to their utilization by fish and by the nature of the flow regime (perennial or intermittent/seasonal). The designated water type is often used to determine the required level of protection in the form of stream buffers and other forestry practices.

Middle Fork Snoqualmie River (170.5 mi^2)

Sub-basin Description

Land Use	
Forestry	97.3%
Rural Res. 1 DU/2.5-10 acres	2.1%
Other	0.3%
Rural City UGA	0.2%
Agriculture	0.1%

The Middle Fork Snoqualmie is the largest sub-basin in the Snoqualmie watershed at 170 mi^2. Like the other sub-basins that form the eastern headwaters of the watershed, the Middle Fork is mostly forested. Unlike the North Fork, the Middle Fork has very few private forest lands. From approximately RM 16 to the river's headwaters at RM 40, the Middle Fork lies within federal lands as part of the MBSNF, with much of the higher elevation areas within the Alpine Lakes Wilderness. In the lower basin, apart from areas in close proximity to the City of North Bend, nearly all lands are within WDNR timber lands or in the Mount Si NRCA (described in the North Fork section). King County also owns and manages roughly 644 discontinuous acres along the Middle Fork as part of the Middle Fork Snoqualmie Natural Area.

From its confluence with the North Fork, the first mile or so of the Middle Fork lies within the King County Three Forks Natural Area. A small amount of designated agricultural area lies between the Middle and South Forks. Upstream of the Natural Area, the river is flanked largely by unincorporated rural residential areas to RM 7, including areas along the south (left) bank that are within the UGA of North Bend.

The Middle Fork has numerous significant tributaries, most notably the Pratt and Taylor Rivers, and a host of smaller streams, including Dingford, Granite, Cripple and Rock Creeks.

Cutthroat trout are distributed throughout the sub-basin, including headwater tributaries, while rainbow trout are thought to occupy the mainstem up to approximately Rock Creek at RM 28 (WDFW resident fish distribution data). Mountain whitefish, a native salmonid, are also known to occupy the lower Middle Fork.

Water Quality

Much like the North Fork, the Middle Fork has very good water quality with the exception of seasonal high temperatures that extend into the upper watershed.

Temperature: Impaired

Seasonally high temperatures have been recorded in the Middle Fork Snoqualmie as part of WDOE's TMDL effectiveness study, and in the agency's draft temperature TMDL data collection effort in the summer of 2006.

The 16°C 7-DADMax standard applies to the Middle Fork mainstem to its junction with Dingford Creek in the upper watershed near RM 26. Upstream of this location, the more protective 12°C standard applies to the Middle Fork and all tributaries. The 12°C standard also applies to Taylor River and Pratt River.

WDOE collected continuous temperature data at six locations on the Middle Fork, from approximately RM 0.3 at the 428th Ave SE crossing in the Three Forks area, to approximately RM 30, just upstream of Goldmeyer Hot Springs near Burntboot Creek. The 12°C standard applies only at the location furthest upstream.

A comparison of 7-DADMax temperatures at the six sites shows that all six followed a very similar pattern during the warm July-August period in 2006. However, although temperatures are progressively warmer further downstream, the bulk of the temperature increase appears to manifest between RM 30 and RM 15.4 near the MBSNF boundary (Figure 19).

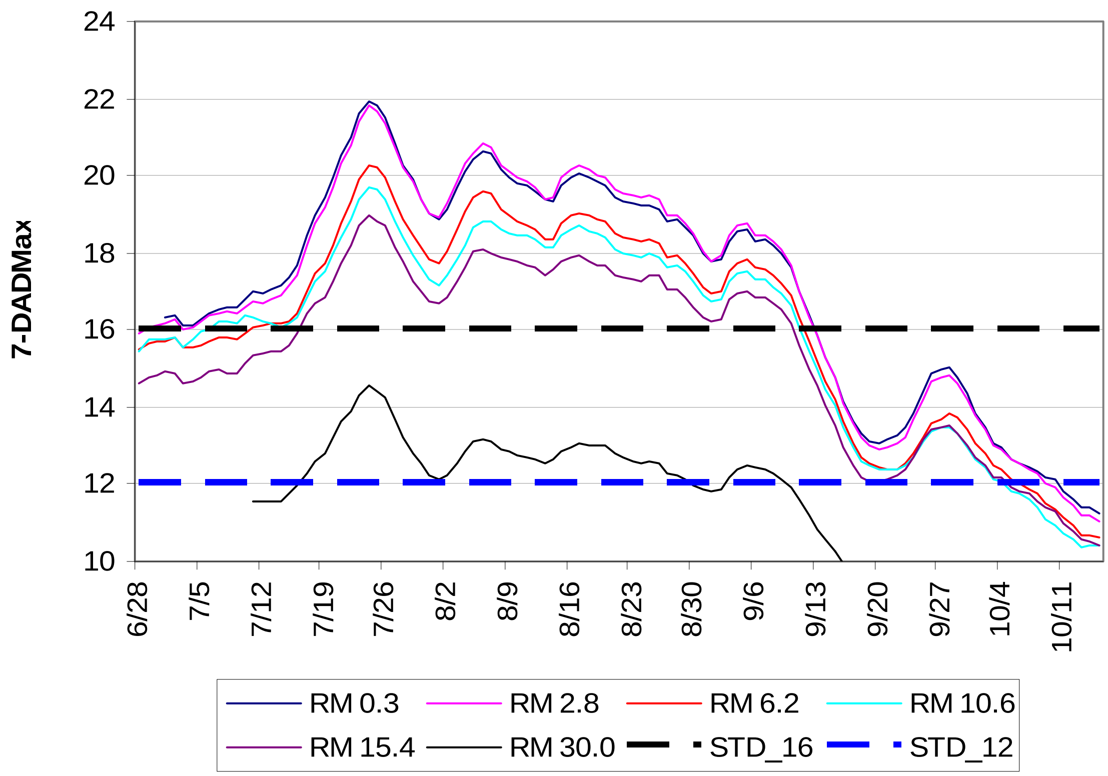

Figure 19. Continuous temperature data (7-DADMax) from six locations in the Middle Fork Snoqualmie River, summer 2006 (data from WDOE).

All six sites exceeded their respective temperature standards for a period of approximately two months. In the Three Forks Natural Area, even the 7-day minimum temperature (7-DADMin) exceeded 16°C for a period of one week.

Clearly, the high temperatures in the Middle Fork are not attributable to land uses in the lower basin. Rather, a combination of past forestry practices on federal lands and natural conditions are likely responsible. The presence of hot springs in the upper basin suggests the possibility of natural warm-water inputs along portions of the river, but the extent of the phenomenon is unknown. Also, the east-to-west valley aspect of the Middle Fork also lends itself to high solar exposure during summer months. Absent data from key tributaries – such as Taylor River and Pratt River – the relative role of different areas and other factors is difficult to determine at this time.

Much like the North Fork, the Middle Fork also receives inflow from cool-water tributaries. Figure 20 shows the plume of cold water entering the Middle Fork from the Granite Creek drainage via thermal infrared imagery.

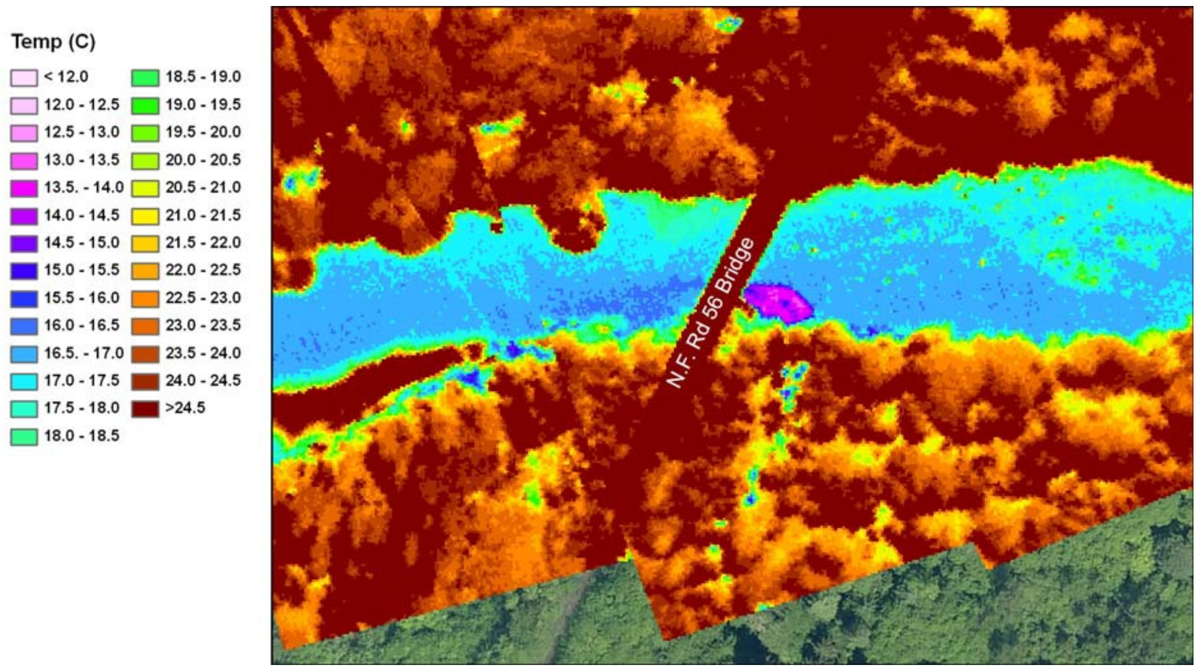

Figure 20. Thermal infrared imagery from the confluence of Granite Creek and the Middle Fork Snoqualmie (data from Watershed Sciences, 2007).

Cool water also flows in small tributaries in the lower portion of the sub-basin. KCRMS site E1058 along SE Mount Si Rd. is on a right-bank tributary that flows from the southern flank of Mt. Si. The mean temperature in August is less than 15°C, and only three minor excursions above 16°C have been recorded since 1999. Similarly, site N3872, a left-bank tributary near RM 8 along SE Middle Fork Rd., has recorded a maximum temperature of 13.2°C since 2002. This pattern highlights the importance of protection and restoration actions that target small tributaries and maintain their connectivity to the river during the late summer months.

<u>Dissolved oxygen: Not impaired</u>

The Middle Fork appears to meet state standards for dissolved oxygen. WDOE recorded two very minor excursions below the 9.5 mg/L standard in the Three Forks Area. Both occurred during particularly warm conditions and the lowest measured concentration was 9.3 mg/L .

The two tributaries monitored by KCRMS also appear to be well oxygenated year-round. Site E1058 along the right bank has dipped just below 9.0 mg/L on a few occasions during warm, low flow conditions, but average values range from 9.5 mg/L in August to more than 12.0 mg/L during winter months.

KCRMS's second site further upstream (N3872) has recorded only one reading less than 10 mg/L (9.1) since monitoring began at this site in 2002.

Fecal coliform: Not impaired

Fecal coliform in the Middle Fork follows a very similar pattern to the North Fork. Mean values are very low year-round, often in single digit concentrations, and easily meet the applicable 50 CFU/100 ml standard. A single exceedance of 130 CFU/100 ml occurred on the same date that maxima were observed across the watershed. This is a very low value for a 'peak' event.

pH: Not impaired

The pH standard was met at the WDOE sampling site on every sampling event during 2003-2005. KCRMS sites report very stable pH values between 7.0-7.5 at both locations, with only a few minor excursions below 6.5 since 1999.

Nutrients: Not impaired

Like the neighboring North Fork, nutrient concentrations appear very low relative to other sub-basins (WDOE, 2008).

Benthic invertebrates

B-IBI data from the two KCRMS sites show mixed results (Table 18). The Mount Si Rd site has ranged from 'very poor' to 'fair', while the SE Middle Fork Rd. site has recorded the only 'excellent' score in the watershed.

Table 18. B-IBI Scores for selected sites in the Middle Fork Snoqualmie sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E1058/1059	RB tributary at SE Mt. Si Rd.	22	34	32	16	24	34	34
N3872	LB tributary near RM 8					42	36	46

Excellent	Good	Fair	Poor	Very Poor

Synthesis and recommendations

Summer temperature is the only water quality concern in the Middle Fork. As the largest sub-basin in the watershed, temperature in the Middle Fork has a profound influence on areas downstream. According to USGS gage data, the Middle Fork provides more than half of the combined flow of all three forks year-round, and nearly 60% during the July-August period. Contributions from the North and South Forks are roughly equal.

A detailed temperature assessment of the middle portion of the river (approximately RM 30 to the national forest boundary), including tributary temperature and discharge, would help to identify the role of channel conditions, forestry and tributary inputs to the observed temperature increase.

Tributaries are an important source of cool water to the Middle Fork, especially during summer months. In areas with active forestry, the status of tributary buffers should be evaluated for compliance with existing regulations. Moreover, stream typing should be performed in pilot study areas to assess whether smaller streams are correctly categorized in these areas.

Finally, the role of natural conditions – including valley aspect, geology and inputs from hot springs – should be more closely evaluated.

<u>Priority actions for the Middle Fork Snoqualmie River:</u>

- Conduct a detailed longitudinal temperature evaluation from approximately RM 30 to the national forest boundary (near RM 12) including significant tributaries.
- Conduct water typing in forested areas to ensure proper application of forestry regulations and best practices on State and federal forest lands.
- Implement instream restoration projects (such as placement of large wood jams and boulder cluster) that encourage channel complexity and promote hyporrheic flow which has been shown to be an effective means of lowering river temperature (Seedang et al., 2008).

South Fork Snoqualmie River (85.4 mi^2)

Sub-basin Description

Land Use (unincorporated areas)	
Forestry	84.0%
Rural Res. 1 DU/2.5-10 acres	11.0%
Rural City UGA	2.5%
Other	1.9%
Agriculture	0.3%
Rural Town	0.2%
Incorporated (see text)	3.9%

The South Fork Snoqualmie descends from its headwaters near Snoqualmie Pass for over 30 miles before joining the mainstem Snoqualmie near the city of North Bend. For most of its length the South Fork follows Interstate 90, at times flowing within the quarter-mile gap between east-bound and west-bound lanes. With the exception of the highway corridor itself, most of the surrounding land is within the Mount Baker – Snoqualmie National Forest, though the river also flows through Olallie and Twin Falls State Parks on its way westward.

Overlooking the lower South Fork is the 1,771-acre Rattlesnake Mountain Scenic Area that forms part of the southern mountainous ridge of the Snoqualmie Valley. This highly scenic area is co-managed and owned by WDNR and King County. The site provides scenic and visual resources, and protects cliff terrain, wildlife habitat, numerous riparian systems, and pockets of old growth forest.

After exiting Twin Falls State Park near RM 10, the river enters unincorporated rural residential areas that flank the highway corridor, before entering the UGA of the City of North Bend near RM 8 and the current city limits at roughly RM 4.

The South Fork flows through the heart of North Bend before passing through King County owned Tollgate Farm[32], Mount Si Golf Course and a small portion of the Three Forks Natural Area at the mouth of the river. North Bend's wastewater treatment plant is located at approximately RM 2.2, between the Snoqualmie Valley Trail and Bendigo Boulevard. The plant's outfall is between the two sampling locations utilized by WDOE at RM 2.0 and 2.8 (see Table 6).

Resident cutthroat trout, rainbow trout and mountain whitefish are found in the mainstem and numerous tributaries to the South Fork, with cutthroat ascending into headwater areas.

Water Quality

Water quality in the South Fork Snoqualmie River is generally good, though available data is largely limited to the lower river in the vicinity of North Bend. The City of North Bend's wastewater treatment plant (WWTP) operates under a NPDES permit issued by the Department of WDOE; thus, the agency's TMDL Effectiveness study focused in part on the impacts of the plant's discharge on water quality in the lower South Fork. A subset of WDOE's findings are summarized in this report, but detailed data and analysis can be found in the agency's own report (WDOE, 2008).

[32] Portions of Tollgate Farm within North Bend City limits are due to be transferred to City ownership.

Temperature: Basin of concern

The South Fork appears to be cooler during summer months than the North and Middle Forks. Unlike these neighboring basins where higher elevation portions are designated as "char spawning" areas with a 12°C 7-DADMax standard, the 16°C temperature standard applies to the entire South Fork.

WDOE collected temperature grab samples at two locations in the lower river: 1) approximately RM 2.0 at the Snoqualmie Valley Trail crossing, a short distance downstream of the WWTP discharge location, and 2) RM 2.8 at Bendigo Blvd. During the 2003-2005 study, all samples met the standard at both locations. However, the sampling period did not include July, and nearly all samples were collected before noon, potentially missing the daily maximum temperature conditions (WDOE, 2008; Appendix E-4).

WDOE collected continuous data at three locations in the summer of 2006 as part of the ongoing temperature TMDL study. In contrast to the earlier grab samples, the data show that the South Fork exceeded the standard for a period of 2-3 weeks near RM 9 (468th Ave. SE), and roughly 6 weeks near RM 2. However, the peak temperatures were not nearly as high as those in the neighboring Middle Fork.

Thermal infrared data collected by Watershed Sciences (2007) on behalf of WDOE shows that the South Fork has a cooling influence on the mainstem Snoqualmie (Figure 2, Section 5.3). Note that the South Fork confluence is roughly 3 miles downstream of the North Fork/Middle Fork confluence. Figure 2 shows how the colder water plume from the South Fork is approximately 2°C cooler and that the influence of the inflow persists for some distance downstream. The imagery shows surface temperature only, so the effect on the full water column in unknown.

KCRMS data from tributary sampling locations reveals a pattern familiar from the North and Middle Forks. Most tributary sites remain cool year-round, often several degrees cooler than the mainstem, although without continuous data at these sites, a direct comparison of daily maxima is not possible. For example, site E1045, located on a tributary to Boxley Creek, recorded its highest temperature since sampling began in 1999 in August 2004 of only 11.6°C.

Dissolved oxygen: Not impaired

According to WDOE's data, the lower South Fork meets standards for dissolved oxygen. Only one minor excursion below the 9.5 mg/L standard was recorded during the study.

DO levels at KCRMS sites are generally good, with mostly minor excursions below the limit. The one exception is site E3085/3084, located on a small, unnamed tributary near the 468th Ave SE and Edgewick Rd intersection. This site often fails to meet the standard between May and October, with minimum values higher than 6.5 mg/L .

While WWTP discharges raise some concerns regarding other parameters, such as nutrients (see below), it is a good sign that oxygen levels meet standards in the lower South Fork.

Fecal coliform: Impaired

The fecal coliform standard in the South Fork is more stringent in headwater areas than in the lower river. Specifically, the west boundary of Twin Falls State Park marks the transition from "Primary contact" to "Extraordinary primary contact" beneficial uses (see Table 1, Section 2).

WDOE's data shows that the upstream (RM 2.8) site met the geometric mean standard of 100 CFU/100 ml during all months of the study, but the station located at RM 2.0 downstream of the WWTP failed the standard in the month of August. In all summer months, FC concentration was higher at the downstream site.

Both sites failed the 90% exceedance standard in the month of August (i.e., more than 10% of samples had a concentration greater than 200 CFU/100 ml). The maximum recorded concentrations were 500 and 680 CFU/100 ml at the upstream and downstream sites, respectively. These values are much lower than the maxima in many smaller tributaries, such as Kimball Creek and Ames Creek, but significantly higher than the observed maximum of 130 CFU/100 ml in the North and Middle Forks. The likelihood of exposure via swimming and wading may be higher in the South Fork during summer months due to its proximity to the cities of North Bend and Snoquaalmie.

WDOE also monitored the WWTP discharge itself for fecal coliform and showed that concentrations were generally very low, with geometric mean values less than 15 CFU/100 ml (WDOE, 2008). However, one sample in November 2003 returned a concentration in excess of 25,000 CFU. To put the value in perspective, the mean effluent discharge from the plant is approximately 400,000 gallons per day – about 0.6 cfs (although inflow and infiltration can raise the volume considerably – see Section 3.2). In November 2003, the South Fork's average discharge was 831 cfs. So, following dilution within the receiving water, the WWTP discharge equates to an increase in concentration of only 18 CFU/ml. This does not mean that spikes in FC concentration are irrelevant, only that the concentration of effluent must be considered in the context of dilution, even though dilution is not instantaneous[33]. It is important to note that this occurrence was clearly an anomaly as typical FC concentrations in the plant's discharge are quite low.

pH: Basin of concern

The South Fork appears to meet standards most of the time for pH. However, WDOE recorded minor excursions at the RM 2.8 study site (upstream of the WWTP), although all values were higher than 6.0.

WDOE also recorded low pH values in the WWTP discharge itself in August 2005, with values between 2.8-4.3, i.e., very acidic (WDOE, 2008). However, the plant itself has undergone numerous upgrades in recent years and the measured values were believed to be an anomaly. For comparison, discharges from the Snoqualmie and Duvall WWTPs are typically near neutral values (i.e., pH 7.0).

[33] These calculations are approximate and are simply intended to illustrate the role of dilution in considering point-source pollution effects.

Tributary data collected by KCRMS in the sub-basin show that all tributary sites meet the standard for pH.

The minor excursions below 6.5 at RM 2.8, and the fact that the South Fork is listed as a Category 5 water for pH (i.e., a 303(d) listed water body) led to the rating of "Basin of concern" for the South Fork, but addressing pH is not a top tier priority for the sub-basin.

Nutrients: Basin of concern

WDOE sampled the WWTP discharge for ammonia-nitrogen, nitrate-nitrite nitrogen, as well as orthophosphates in 2003-05. While nitrogen compounds were elevated on a few occasions, they generally met the guidelines identified in the original TMDL. Orthophosphate, however, was significantly elevated. Mean concentration were roughly 10-times the recommended limit during the late summer months, though this result is based on only four samples. The City's own data from 2001-2003 reported concentrations of approximately 5-times the guideline concentration (WDOE, 2008). The plant has undergone additional upgrades in recent years that may have helped to alleviate the problem, but WDOE has not reported on the results of later improvements.

WDOE also sampled RM 2.0 and RM 2.8 for the same pollutants. While the upstream stations met the guidelines established in the TMDL, the downstream station did not. Orthophosphate concentrations were roughly 50% higher than the recommended TMDL guideline. Nitrogen values were generally low at the downstream location.

Benthic invertebrates

KCRMS has collected B-IBI data at three locations in the vicinity of North Bend, though all are in unincorporated areas south of I-90 (Table 19). Results are mixed; the site with the lowest scores over time (E1031) is located within the UGA on a very short tributary that flows out of rural residential areas with numerous road crossings. In contrast, the other sites are along tributaries that flow from forested headwater areas before passing through low-density residential areas.

Table 19. B-IBI Scores for selected sites in the South Fork Snoqualmie sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E1023	Clough Crk., LB Tributary at 415th Ave SE	32	34	26	44	38	40	30
E1031	LB Tributary at 437th Ave SE	16	18	20	32	30	26	30
E1045	Trib. to Boxley Creek at Edgewick Rd	28	28	24	36	40	30	36

Excellent	Good	Fair	Poor	Very Poor

Synthesis and recommendations

In late summer, the South Fork Snoqualmie is a fairly small river with an average flow of only 172 cfs in August (USGS Gage #12144000). This means that inputs from point sources and non-point sources alike are not as effectively diluted as they would be in a larger river. This highlights the importance of addressing sources of impairment along not only the mainstem South Fork but also along tributaries, particularly in the rural residential and incorporated areas downstream of Twin Falls State Park.

As part of its stormwater management program, North Bend has investigated drainage conditions in a variety of local tributaries, including Gardiner and Ribary Creeks (City of North Bend, 2001). We have not included water quality data from these locations for this report, but future updates to the South Fork Snoqualmie sub-basin discussion should include additional tributary information. Both Ribary and Gardiner Creeks originate in unincorporated areas south of the I-90 corridor, but the majority of each drainage is within the UGA and city limits. A significant portion of Ribary Creek flows through Tollgate Farm, and has been the focus of restoration projects in the past, including riparian plantings and installation of fencing to exclude animals from the immediate stream corridor. Similarly, Gardiner Creek borders Meadowbrook Farm and has also benefited from past riparian restoration projects. Further opportunities exist along both streams on both private and public property.

Though temperature conditions are better in the South Fork than in the neighboring Middle and North Forks, the impact of historic and current forestry practices on temperature should be evaluated and minimized to ensure high water quality in the long-term for both fish and for human uses.

Given the proximity of I-90 to the river corridor, WSDOT should also play a prominent role in protecting the South Fork from water quality degradation. For this report, we have not reviewed any data regarding metals or other pollutants primarily associated with road runoff. Future iterations of this report should fill that gap through discussions WSDOT and associated data acquisition.

North Bend's Comprehensive Stormwater Management Plan (City of North Bend, 2001) includes an excellent discussion of specific threats to water quality within city limits, including: non-point source pollution from impervious surfaces, nonexistent or inadequate stormwater treatment, erosion from land disturbance associated with development, pollutant inputs from agricultural and pasture lands, pollutant inputs from residences, WWTP discharges, aging or inadequate sewage conveyance systems, and other factors. The plan also includes numerous recommendations that include new policies and programs, enforcement of existing regulations, public outreach, and strategic upgrades to existing outdated infrastructure. Implementation of the plan, coupled with monitoring for its effectiveness are highly recommended.

Priority actions for the South Fork Snoqualmie River:

- Enhance riparian conditions along tributaries in rural residential and incorporated areas downstream of Twin Falls State Park. Couple riparian plantings with fencing to exclude livestock from streams wherever appropriate.
- Conduct public education and outreach efforts to homeowners to encourage reductions in the use of fertilizers, pesticides and other household chemicals.
- Encourage rapid expansion of municipal sewage treatment services to the entire incorporated area to reduce reliance on septic systems in existing neighborhoods. In the meantime, provide outreach and technical assistance to landowners (in both incorporated and unincorporated areas) regarding septic system operation and maintenance.
- In cooperation with WSDOT, assess contribution of I-90 runoff to water quality impairment in the South Fork.
- Implement the City of North Bend Comprehensive Stormwater Management Plan.

Snoqualmie Mainstem (64.1 mi^2)

A note about GIS and the Mainstem

As a unit of analysis, the Snoqualmie Mainstem is unlike any other sub-basin in the report. This is an artifact of our use of Geographic Information Systems (GIS) to divide the basin into discrete units. The Snoqualmie Mainstem is not a 'complete' basin per se in that it is simply the mainstem of the river from the mouth to the confluence of the North and Middle Forks, a distance of more than 43 river miles. While all other sub-basin delineations in this report are independent in the sense that they contain their entire drainage area, the Snoqualmie Mainstem does not since it is formed by the confluence of two other sub-basins. This is important to keep in mind when interpreting results.

Also, since all of the other sub-basins extend to their confluence with the Snoqualmie Mainstem, the sub-basin has an odd shape, with narrow pinch points where other sub-basins extend across the floodplain.

While the Mainstem sub-basin delineation is somewhat unusual, it allows us to make accurate calculations of other spatially delineated information (such as land use categories by sub-basin), and to assign relevant data (such as KCRMS water quality data) to the correct sub-basin.

Finally, in order to provide a desirable level of detail, the thematic maps have been divided into two sections "Mouth to Harris Creek" and "Harris Creek to Forks". This division coincides with the transition in applicable temperature and DO standards.

Sub-basin Description

Land Use (unincorporated areas) [34]	
Rural Res. 1 DU/2.5-10 acres	47.6%
Agriculture	31.4%
Rural Res. 1 DU/20 Acres	7.0%
Forestry	6.9%
Rural City UGA	2.9%
Urban Planned Dev.	2.4%
Rural Town	0.9%
Other	0.5%
Mining	0.4%
Incorporated	7.8%

The Snoqualmie Mainstem features diverse land uses in unincorporated areas as well as portions of the cities of Duvall, Carnation and Snoqualmie. Rural residential land use is most prevalent, though agriculture, small-scale forestry and other activities may take place in some of these areas.

Below Snoqualmie Falls, nearly the entire floodplain is designated for agricultural land use. The floodplain itself is very broad, measuring roughly one mile wide along much of the river and over two miles wide downstream of Duvall.

Along the western rim of the lower valley, one

[34] Includes both King County and Snohomish County land-use designations.

square mile of Urban Planned Development (UPD) encroaches into the sub-basin from the Redmond Ridge area. Runoff from the UPD reaches the Snoqualmie via several small west-to-east flowing tributaries including Adair Creek and others.

The agricultural floodplain is traversed by countless ditches and tributaries that flow directly into the Snoqualmie. KCRMS has collected water quality data along many of these drainage features.

Public lands are very limited in the Snoqualmie Mainstem when compared to sub-basins with extensive public forest ownership. King County owns and operates Tolt-MacDonald Park at the confluence of the Tolt River, the small Ring Hill Forest resource land in the vicinity of Tuck Creek, and several Natural Areas, including Chinook Bend, Carnation Marsh and Fall City. The county-owned Snoqualmie Valley Trail runs nearly the entire length of the sub-basin from Duvall to the City of Snoqualmie, and assorted city and county parks dot the landscape. The 456-acre WDFW Stillwater Wildlife Area is located at the confluence of Harris Creek.

As a mainstem area, the river naturally hosts all anadromous fish species that are known to reside in the basin, including four species of salmon, winter and summer run steelhead, as well as bull trout. Tributaries within the floodplain provide rearing habitat and high-water refuge areas for juveniles of many species. The Snohomish Basin Salmon Recovery Plan explicitly assumes that all tributaries within the river's 100-year floodplain are utilized by Chinook salmon.

Water Quality

The discussion of each water quality parameter includes a section that focuses on the mainstem river and a second that addresses conditions in the small independent tributaries that traverse the floodplain, not including those located within other named sub-basins.

In general, water quality in the mainstem is fairly good. High temperature is the most worrisome issue, and certain areas deviate slightly from dissolved oxygen and pH standards.

<u>Temperature: Impaired</u>

Mainstem:

The temperature standard changes from 17.5°C to 16°C at the Harris Creek confluence, with the cooler standard applied upstream. Seasonal 13°C standards apply to the mainstem from Chinook Bend to Patterson Creek from September 15 – May 15, and from Patterson Creek to the falls from September 15 – June 15.

WDOE (2008) collected grab samples in 2003-2005 from several locations along the mainstem, from RM 2.7 in Snohomish County to RM 42.3 near the City of Snoqualmie. All locations violated their respective standards on more than one occasion during summer months, though sampling did not occur prior to August in any year, potentially missing seasonal high temperatures in July.

WDOE's ongoing temperature TMDL study collected continuous data at fifteen locations on the mainstem from RM 0.8 to RM 42.3 in 2006. All locations violated the 7-DADMax for substantial periods. Near Monroe at RM 0.8, the temperature exceeded the 17.5°C standard continuously from late June until mid-September. All other stations followed a similar pattern, with the RM 42.3 station exceeding the 16°C standard from July 1 until the second week of September. In the lower river, maximum recorded 7-DADMax values surpassed 22°C while RM 42.3 reached a high of 20.8°C.

Tributaries:

KCRMS monitors water quality at five locations in the lower portion of the sub-basin where the 17.5°C 7-DADMax standard applies. Four of the sites have never exceeded the standard (based on grab samples), while the other two have had isolated excursions. The highest monthly average temperature at any of these sites is 16.2°C for August at site E2046, located near the mouth of a left-bank tributary just downstream of Duvall (See lower sub-basin map, Panel 3).

KCRMS also maintains several monitoring locations upstream of the Harris Creek confluence where the 16°C standard applies. None of the sites has recorded more than a few grab sample temperature readings above 16°C, and in each case a notation in the data refers to very low flow at the site.

King County maintains three temperature gages along tributaries that drain from the Redmond Ridge UPD. All three show consistently cool temperatures with very rare deviations above the 17.5°C standard during the period of record.

These data show that even in the lower portions of the watershed, many small tributaries remain cool year-round and are likely very important sources of cool water during the summer months, although flows may be very low at that time.

<u>Dissolved oxygen: Basin of concern (tributaries)</u>

Mainstem:

Dissolved oxygen conditions are generally good in the mainstem. WDOE (2008) reported only very minor, occasional excursions below the 9.5 mg/L standard at RM 42.3 and at stations below the falls. Downstream of Harris Creek, the 8.0 mg/L standard applies. This lower standard was met on all occasions at RM 2.7.

At RM 40.7 immediately downstream of the City of Snoqualmie's WWTP outfall, the TMDL established a location-specific DO standard of 7.9 mg/L . The site met this lower standard on all occasions, with a minimum recorded value of 8.6 in August 2004. As noted previously, the City of Snoqualmie WWTP has little to no discharge during the summer months due to the utilization of reclaimed water on local golf courses.

Tributaries:

The results from tributaries monitored by KCRMS are mixed, with extremely poor conditions at some locations. Tributary inputs are the primary basis for the Basin of Concern rating.

Most sites maintain high DO values through the winter, but experience seasonal lows during the summer months. A few sites experience lower DO values nearly year-round, with average values that fail to meet the 1-day minimum concentration on which the standard is based. The two poorest sites monitored by KCRMS in the lower portion of the sub-basin (Mouth to Harris Creek) are E2046 (left bank, downstream of Duvall) and E2072 (near the west end of NE 124th Street). The latter flows into an old oxbow that is also fed by Adair Creek. DO concentration averages less than 5.0 mg/L and 6.2 mg/L at these sites during the June-September period, respectively, while minimum concentrations have fallen to less than 1.0 mg/L at site E2046.

In contrast, at site E2052, located near the edge of the western floodplain just south of Tuck Creek, monthly mean concentrations exceed 10 mg/L year-round, and the lowest recorded concentration is 8.9 mg/L .

A similarly uneven set of D.O conditions is evident in tributaries that flow into the upper half of the Mainstem sub-basin (i.e., Harris Creek to the Forks). Two sites along Neal Road between Fall City and Carnation (E2095, E2096) and a third along West Snoqualmie Valley Rd. north of Patterson Creek (E2094) have especially poor DO conditions and fail to meet standards in any month. All are associated with agriculturally impacted drainage systems, and with slow-flowing, occasionally stagnant waters that cross extensive portions of the floodplain. However, the fact that low DO persists in the wetter, cooler winter months is alarming and is suggestive of excess nutrients in the system.

Fecal coliform: Basin of concern

Mainstem:

According to WDOE (2008), mean bacteria concentrations are generally low throughout the mainstem. All sites from RM 42.3 to RM 2.7 failed the second part of the FC standard during the month of August, primarily due to a single exceedance that coincided with a watershed-wide spike in bacteria. Below the falls, depending on the sampling location, the standard was also exceeded for September and/or October, again due to isolated high values during the period of the study. Importantly, none of the observed concentrations in the mainstem reached levels akin to those in the more impaired tributaries. The highest single value during the study was 840 CFU/100 ml at RM 40.3 near Snoqualmie.

WDOE's sampling site at RM 35.3, just downstream of Fall City, had the highest fecal coliform concentrations of any mainstem site. The stretch of the river from Snoqualmie Falls to Fall City is intensively used for rafting, swimming and other recreation in the summer months. WDOE (2008) notes that restroom facilities recently installed by Puget Sound Energy just below the falls and by WDFW near Fall City may lead to a reduction in human-caused bacterial loading during the recreation season. Both human and pet waste have been observed in this area along the shore and surrounding vegetation, particularly between the mouth of the Raging River and the beach below the SR 202 crossing (WDOE, 2008). Additional facilities may be required to reduce risks to the public.

Due to relatively high concentration of on-site sewage systems in the town of Fall City, the Snoqualmie River in the vicinity of Fall City has been a focal point for investigation of potential bacterial sources and concentrations. WDOE (2008) conducted a targeted study of the Fall City reach (i.e., the "Fall City Transect Study", Appendix H; WDOE, 2008). Sampling sites extended from upstream of the Raging River confluence to the downstream edge of Fall City, with sites located along both banks.

The study found that the highest concentrations of bacteria (and of nitrite-nitrate nitrogen and chloride) were seen along the left bank near the Raging River confluence immediately downstream of a campground that is known to have year round residents. In September 2003, the study recorded a concentration of 2000 CFU/100 ml along the left bank, far higher than the mid-channel sample. This could be explained by shore-based sources of contamination from Fall City or by inputs from the Raging River. Further downstream, differences in concentration between left bank and right bank sites decreased, possibly due to mixing.

WDOE recommends additional, detailed monitoring of bacteria and nutrient concentrations in this area to identify likely sources and potential solutions.

The Snoqualmie and Duvall WWTP discharge into the mainstem. These locations were monitored by WDOE during the TMDL effectiveness study. The Snoqualmie plant recorded the lowest concentrations of any plant during the study, with a maximum concentration of only 330 CFU/100 ml. In contrast, the Duvall WWTP recorded a maximum concentration of 90,000 CFU/100 ml, with 5 of 10 samples exceeding 800 CFU/100 ml (WDOE, 2008; Appendix E-7). The Duvall plant has undergone several upgrades in recent years - we have not reviewed more recent Discharge Monitoring Reports that are required as a condition of the NPDES permit.

Tributaries:

No data are available for bacteria concentrations in the many small tributaries that cross the floodplain of the mainstem sub-basin. Results from larger tributary sub-basins (such as Ames, Cherry and Patterson Creeks) suggest that fecal coliform concentrations may be fairly high, but that conditions likely vary substantially between streams.

pH: Basin of concern

Mainstem:

Data from WDOE (2008) shows that pH appears to meet standards in the mainstem at all locations, with the very minor exception of the lower river at RM 25.2 and 2.7 where a single value below 6.5 was recorded during the period of the study.

However, one point of concern is that pH seems to be substantially lower in general near the mouth of the river than at locations further upstream. This may be attributable in part to soil types or other natural conditions, in addition to anthropogenic factors. A comparison of same-day pH data at RM 35.3 near Fall City and at RM 2.7 near the County line show that the mean pH difference is 0.6 units, and that the pH at the downstream location was lower than the upstream site on every sampling date (based on a comparison of 25 data points from WDOE, 2008).

Tributary data cited throughout this report show that the pH in floodplain tributaries in agricultural areas tends to be fairly low, in some cases below standards. The density of tributaries, man-made channels and other drainage features in the lower river suggests that inputs from the floodplain may play a significant role in the pH condition of the mainstem.

Tributaries:

A review of KCRMS tributary reveals a familiar pattern. The same sites that feature low DO also tend to have lower pH, occasionally well below standards. In most cases, observed minima stay above 6.0, but some locations – including Site E2046 – have recorded values of 5.8 on occasion.

In contrast, many sites that are located at the edge of the floodplain and thus capture water quality conditions from upland areas generally appear to meet standards for pH year-round, with higher average values.

<u>Nutrients: Basin of concern</u>

Mainstem:

Nutrient conditions in the mainstem appear to meet the TMDL guidelines as well as standards for ammonia-nitrogen. Of the five mainstem sites monitored by WDOE (2008), only the site furthest downstream (RM 2.7) occasionally exceeded the orthophosphate guideline of 10 μg/l.

WDOE data shows that the Snoqualmie WWTP discharge was elevated for orthophosphate during the study. In general, the Snoqualmie WWTP appears to discharge the lowest levels of nutrients and bacteria of the three WWTPs. An important factor in reducing the impact of discharges from the WWTP on the receiving water is the use of reclaimed water by Snoqualmie Ridge golf course during summer months. In fact, discharge from the plan approaches zero during the driest months of the year.

WDOE only sampled the Duvall WWTP on one occasion for nutrients. The agency found that both orthophosphate and ammonia-nitrogen exceeded the TMDL control target for the plant's discharge. However, the Duvall WWTP benefits from a very large dilution factor due to the size of the river. Average discharge flow during the dry months is roughly 0.4 MGD (0.62 cfs) (WDOE, 2008), while river flow in August averages 1,090 at Carnation (USGS #12149000).

Tributaries:

No data are available on nutrient concentrations in mainstem tributaries outside of named sub-basins. However, the combination of low DO and low pH in many locations is indicative of excess nutrient loading.

Benthic invertebrates

B-IBI data collected by KCRMS reflects generally poor-to-fair water quality conditions in tributaries to the mainstem (Table 18). Not surprisingly, the worst scores are associated with a site that has many water quality challenges (E2072). However, the suitability of the site for the B-IBI protocol has not been evaluated for this report. Unfortunately, data are limited to a small number of locations.

Table 20. B-IBI Scores for selected sites in the Snoqualmie Mainstem sub-basin. Data from KCRMS.

Site	Location	2000	2001	2002	2003	2004	2005	2006
E2072	NE 124th Street, near Adair Creek			14	14	20	18	14
E2052	West Snoqualmie Valley Rd. near Tuck Creek	18	22	20	20	28	34	34
E2118	LB trib David Powell Rd. - RM 37	16	20	24	36	34	32	22
E2153	RB tributary above falls at Reinig Rd.	20	26	18	30	40	30	22

Excellent	Good	Fair	Poor	Very Poor

Synthesis and recommendations

Water quality in the mainstem integrates the effects of inputs from all tributaries and each of the forks of the Snoqualmie River. Thus, the recommendations in this section should be considered in the context of others made for specific sub-basins.

For the mainstem itself, the greatest concern is high water temperature. As WDOE's draft temperature TMDL data indicate, the water can be very warm during the peak summer months throughout the mainstem, but also in nearly all incoming tributaries. Actions to restore shading will be very important to mainstem water quality in the long-term.

Absent additional years of continuous data, it is difficult to say whether the patterns observed in WDOE's 2006 data are anomalous or par for the course. WDOE and USGS should be encouraged to install continuous temperature monitoring equipment at each of the USGS gage sites in the basin, much as they have in the Tolt River.

The data also show that many small tributaries are quite cool as they flow from the surrounding canyons and slopes, even during summer months. Unfortunately, many of these tributaries have been severely altered in floodplain areas, causing them to warm in some cases by several degrees before reaching the river. Moreover, river bank armoring disrupts the connectivity of the mainstem to its tributary inputs in some places, further downgrading the cooling potential of small tributaries. Efforts to maintain cool temperatures in tributaries across the floodplain should be strongly encouraged, and the connectivity of tributaries to the river should be enhanced or maintained, where possible.

The apparent longitudinal pattern in the pH data suggests that the lower river is more acidic than upper reaches, though it still appears to meet standards. Continuous data collection would help to characterize the magnitude of the effect and to quantify the range of daily and seasonal fluctuations. Low pH could be a function of tributary inputs, excess periphyton growth, or possibly natural conditions due to soil types, etc.

Priority actions for the Mainstem Snoqualmie River:

As noted above, the Mainstem sub-basin integrates the water quality conditions in all of the other sub-basins in addition to the effects of independent tributaries and surrounding land use. Thus, all of the actions prescribed above – particularly for floodplain tributaries – apply equally to the many streams that traverse the river's floodplain.

The commonalities observed across agricultural sub-basins suggest that other small tributaries with similar land uses would also benefit from similar actions:

- Investigate the role of soil types, floodplain hydrology, riparian conditions and agricultural practices as contributors to the low DO, low pH and high levels of nutrients observed in many agricultural tributaries.
- Install fencing in livestock areas to exclude animals from the stream.
- Restore riparian conditions in degraded areas to help reduce nutrient inputs and to provide shading.
- Conduct additional monitoring of fecal coliform and nutrient concentrations to identify areas where restoration actions can be most effective.

In rural residential areas both above and below the falls, fragmentation of intact forests, riparian areas and wetlands pose potential threats to water quality. The results of this report suggest that many small tributaries that pass through these areas are critical sources of cool water to the mainstem that should be protected:

- Protect and enhance forest cover, intact riparian corridors and wetlands through the use of incentives, restoration and enforcement of existing regulations.
- Conduct outreach and provide technical assistance to small livestock operations in rural residential areas to protect human health and water quality. Emphasize exclusion of animals from streams and the importance of intact riparian areas.
- In more densely developed residential areas (such as Fall City, Preston, Lake Marcel) provide incentives and education to promote responsible septic system operation and maintenance practices.

For the Snoqualmie River itself:

- Initiate long term restoration of the riparian corridor in as many locations as possible, with the recognition that temperature benefits will not accrue for many years.
- Install continuous temperature monitoring equipment at all flow gages in the mainstem.

7 CONCLUSIONS AND NEXT STEPS

Section 6 highlights the fact that sub-basins are unique, each with its own combination of history, physical context, land use patterns, development intensity and likely future trajectory. Nevertheless, the following conclusions highlight some of the common patterns and challenges observed across the watershed.

In the many sub-basins that feature agriculture in floodplain areas, we need to better understand the legacy effects of a century of farming in a formerly forested floodplain. Changes in soils and in drainage patterns may have as much to do with some of the observed impairments as agricultural practices themselves. There is still much room for improvement, especially in terms of restricting livestock access to streams, management of manure and other fertilizers, and the need to restore riparian areas. But meaningful improvements will only occur with the help of incentives and technical assistance that help farmers improve practices while maintaining economic viability.

Agriculture is not limited to areas with a designated agricultural land use. Rural residential areas contain a large fraction of total agricultural acreage, most of it in horse farms and other livestock operations, including many that might be considered 'hobby farms'. These areas must not be ignored as they may pose some of the more severe localized impacts in numerous small tributaries in the watershed.

Water quality in rural residential areas can suffer due to old and outdated septic systems. As density increases through the division of large parcels, cumulative deficiencies in septic systems may produce more noticeable impacts than we have seen to date. Moreover, even well-functioning systems often do little to reduce nitrogen and phosphorus. Monitoring programs in rural residential areas should be conducted in an effort to identify specific areas where additional steps, such as requirements for nitrogen reducing technologies, should be targeted.

Intact wetlands and forests are the best defense against water quality degradation. Local jurisdictions should place a premium on protecting these assets in perpetuity. They also reduce flooding and bank erosion while sustaining the aesthetic beauty of rural communities. In more densely developed areas, low impact development approaches should be emphasized in order to reduce stormwater quantity, enhance its quality and maintain groundwater recharge that supplies tributaries with cool water during late summer

Like agriculture, the legacy of more than a century of logging has likely altered many rivers and streams to a profound degree, causing channels to become wider and shallower while also altering the water-retention capacity of forest soils. Moreover, the relative lack of large wood in the rivers and the habitat complexity that wood creates have reduced the supply of thermal refugia for fish during the warm summer months. Recent research also provides compelling evidence that restoring habitat complexity in a manner that promotes hyporrheic flow may be more effective in lowering the temperature of a large river than riparian restoration. These approaches should be tested and developed in places like the Raging River, the North and Middle Forks of the Snoqualmie River, and in the Tolt River.

The greatest risk of forest conversion is likely at the fringe of rural residential areas. The ability to maintain these lands in a forested condition is dependent on the economic viability of small-scale private forestry in particular. Thus, while further improvements in forestry practices and enforcement of regulations are very important, the viability of forestry is a key ingredient for the long-term protection of the watershed.

As the cities in the Snoqualmie watershed expand, land use planning and regulations should emphasize retention of forest, wetland and riparian areas as a key component of stormwater management. As formerly low-density rural neighborhoods become more dense, cities will also need to invest in educating residents and businesses alike about stewardship and how everyday practices can help or hurt local waterways. Municipal sewer service will provide water quality benefits, but in many areas this is still many years away. In cities and in currently unincorporated neighborhoods, education, incentives and technical support should be provided to septic system owners to promote best management practices.

Finally, for all types of activities and land uses, enforcement of existing regulations and compliance with permit conditions are critical components of water quality protection. Without them, all of the voluntary efforts that are being undertaken by citizens throughout the watershed will do little more than slow the rate of decline in our quality of life and environmental health.

7.1 Next steps

This report should be applied by the Snoqualmie Watershed Forum and basin partners (such as King County, KCD and non-governmental organizations) to target restoration actions, incentives, outreach and enforcement into areas where they are most needed. For example, the Forum is encouraged to utilize the report's findings in an effort to solicit high-priority restoration project proposals for the grant programs that it manages in collaboration with KCD. Also, Forum member jurisdictions should consult the report to identify high-value projects in their local areas. The report can also be utilized by the Forum to develop new partnerships with other entities, such as Public Health – Seattle & King County to address septic system issues in targeted areas.

King County is strongly encouraged to utilize the report across many different program areas. For example:

- The County's Agriculture program can use the report to inform farmers about the water quality challenges in their local areas and to target restoration actions in a way that addresses the highest priority water quality issues.

- The Watershed Stewardship program can target potential property acquisitions and restoration opportunities in rural residential areas where such actions can help to protect high-quality tributaries.

- Similarly, the Public Benefit rating System and Timberland incentive programs can use the report to identify potential areas of focus and to communicate with potential program participants about the water quality challenges in their local areas.

- The Ecological Services Unit that is charged with implementing most large-scale capital projects on county lands can also apply the report's findings to project design in an effort to help address high priority water quality impairments in specific locations.
- As the manager of the County's parks and natural lands, the Parks Resource Section can utilize the information to better prioritize restoration actions on County lands.
- The report should also inform the Water and Land Resources Division's Scientific and Technical Support Section work program. Several important monitoring and research initiatives have been identified in the report, some with applicability to other areas in King County.

This list is not intended to represent a comprehensive suite of the report's relevance to County programs, but it can provide a common frame of reference for better understanding the nexus between County activities and improving water quality conditions in the watershed.

Finally, as a synthesis report, this document and any future revisions or supplements are dependent on having up-to-date knowledge of available data and any new data collection efforts. We have undoubtedly missed some existing data sources in the preparation of this report that could have improved the assessment of water quality in certain areas. Our hope is that the report will foster information sharing and collaboration within and across all organizations that have an interest in the health, beauty and ecological integrity of the Snoqualmie watershed.

8 REFERENCES

Bethel, J. 2004. An overview of the geology and geomorphology of the Snoqualmie River Watershed. King County Department of Natural Resources and Parks, Water and Land Resources Division. 88 p.

City of Duvall. 2006. Comprehensive Plan. Capital Facilities Element.

City of North Bend. 2001. Final Comprehensive Sewer Plan.

City of North Bend. 2001b. Comprehensive

City of Snoqualmie. 2001. Kimball Creek water quality inventory and assessment and habitat restoration project. Final report. December 28, 2001.

City of Snoqualmie. 2003. Snoqualmie Vicinity Comprehensive Plan. Element 7: Capital facilities and utilities.

Collins, B.D. and A.J. Sheikh. 2002. Mapping historical conditions in the Snoqualmie River valley (RM 0 – RM 40). Report to King County Department of Natural Resources. Department of Earth and Space Sciences, University of Washington.

Drapcho, C.M. and A.K.B. Hubbs. 2003. Fecal Coliform Concentration in Runoff from Fields with Applied Dairy Manure. Unpublished manuscript. Louisiana State University Agricultural Center. http://www.lwrri.lsu.edu/downloads/Drapcho_annual%20report01-02.pdf

DuFour, A.P. 1984. Health Effects Criteria for Fresh Recreational Waters. U.S. Environmental Protection Agency. EPA-600/1-84-004.

Faries, F.C. Jr, J.M Sweeten, and J. Reagor, 1998. Water Quality: Its relationship to livestock. Texas Agricultural Extension Service, Publication L-2374. From p2pays website at http://www.p2pays.org/ref/12/11608.pdf.

Haring, D. 2002. Salmonid habitat limiting factors analysis. Snohomish River Watershed. WRIA 7. Washington State Conservation Commission. 331 p.

Herrera Environmental Consultants. 2004. Kimball Creek Water Quality Monitoring and Microbial Source Tracking Study. Prepared for City of Snoqualmie. Available from City of Snoqualmie Public Works Department.

Joy, J., 1994. Snoqualmie River Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. 42 p. Publication No. 94-71. www.ecy.wa.gov/biblio/9471.html

King County. 2002. Snoqualmie watershed aquatic habitat conditions report: summary of 1999-2001 data. October 2002. Prepared by Fran Solomon and Melissa Boles.

King County. 2004. Patterson Creek Rapid Rural Reconnaissance Report. Department of Natural Resources and Parks. Land and Water Stewardship Section.

King County. 2004b. Snoqualmie watershed stream habitat reconnaissance report.

King County. 2005. Water quality near the Snoqualmie watershed agricultural production district (APD). Prepared by Fran Solomon, Ph.D. for King County Water and Land Resources Division, Agricultural Lands Program.

King County. 2005b. Existing Conditions in the Tolt and Snoqualmie Rivers Near Carnation: 2003-2004 Monitoring Results. Prepared by Dean Wilson, Water and Land Resources Division. Seattle, Washington.

King County. 2007. Snoqualmie Watershed Agricultural Assistance Team, Water Quality Monitoring. Prepared by Richard Jack, Kollin Higgins, Deb Lester, and Fran Solomon, Water and Land Resources Division. Seattle, Washington.

King County. 2007b. Mountains to Sound Greenway Biosolids Forestry program at Hancock Snoqualmie Forest - 2006 Project Summary. Department of Natural Resources and Parks. Wastewater Treatment Division.

King County. 2008. Raging River Basin Temperature Investigation Sampling and Analysis Plan. Water and Land Resources Division – Science Section.

McHugh, M. 1999. Preliminary Water Quality Findings, Cherry Valley Wildlife Unit. Tulalip Tribes. Marysville, WA.

Naiman, R.J., T.J. Beechie, L.E. Benda, D.R. Berg, P.A. Bisson, L.H. MacDonald, M.D. O'Connor, P.L. Olson, and E.A. Steel, 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion. In: Naiman, R.J. (ed.), Watershed Management: Balancing Sustainability and Environmental Change, Springer-Verlag, New York, NY, pp. 127-188.

Onwumere, G. and D. Batts. 2004. Quality Assurance Project Plan - Snoqualmie River Total Maximum Daily Load Effectiveness Evaluation. Washington State Department of Ecology. Environmental Assessment Program. Olympia, Washington. Publication No. 04-03-201. http://www.ecy.wa.gov/biblio/0403201.html

Pfost, D.L., C. Fulhage, and S. Casteel, 2006. Water Quality for Livestock Drinking. University of Missouri Extension. From website at http://muextension.missouri.edu/xplor/envqual/eq0381

Purser, M. and R. Simmonds. 2001. Snohomish County Land Cover Project: February 2001 Status Report. Snohomish County Department of Public Works, Surface Water Management Division. Everett, WA.

Seedang, S., A.G. Fernald, R.M. Adams and D.H. Landers. 2008. Economic analysis of water temperature reduction practices in a large river floodplain: An exploratory study of the Willamette River, Oregon. River Research and Applications 24: 941-959.

Snohomish Basin Salmon Recovery Forum. 2005. Snohomish River Basin Salmon Conservation Plan. Snohomish County Department of Public Works, Surface Water Management Division. Everett, WA.

Snohomish River Basin Salmonid Recovery Technical Committee. 2002. Snohomish River Basin Salmonid Habitat Conditions Review. Snohomish County Department of Public Works, Surface Water Management Division. Everett, WA.

Snohomish River Basin Salmonid Recovery Technical Committee. 2005. Snohomish River Basin Ecological Analysis for Salmonid Conservation (EASC). Prepared in cooperation with NOAA Fisheries. Snohomish County Department of Public Works, Surface Water Management Division. Everett, WA.

Thelin R., and G.F. Gifford. 1983. Fecal coliform release patterns from fecal material of cattle. J. Environ. Qual. 12(1):57-63.

Washington Department of Ecology, 2008. Snoqualmie River Basin Fecal Coliform Bacteria, Dissolved Oxygen, ammonia-Nitrogen, and pH Total Maximum Daily Load—Water Quality Effectiveness Monitoring Report. Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA. Publication No. 08-03-005. March 2008. http://www.ecy.wa.gov/biblio/0803005.html

Washington Department of Fish and Wildlife. 2002. Tokul Creek Winter Steelhead – Hatchery and Genetic Management Plan. Available from: http://wdfw.wa.gov/hat/hgmp/#pugetsound

Washington Trout. 2004. Land Use and Coho Prespawning Mortality in the Snohomish Watershed, Washington. EPA Agreement ID: MM97061201-0

Watershed Sciences, Inc. 2007. Airborne thermal infrared remote sensing – Snoqualmie River Basin, WA. Report prepared for Washington Department of Ecology and Tetratech.

Weyerhauser.1995. Griffin-Tokul Watershed Analysis.

APPENDIX – MAPS