Working Draft
Identification of Streams with Declines in Summer Low Flows

Revised April 2010

King County

Department of
Natural Resources and Parks
Wastewater Treatment Division

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Prepared for:

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Citation:

King County Department of Natural Resources and Parks. 2010. *Working Draft: Identification of Streams with Declines in Summer Low Flows.* Prepared by Curtis DeGasperi and Jeff Burkey, Water and Land Resources Division. Seattle, Washington.

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EXECUTIVE SUMMARY

King County conducted a preliminary assessment of water resource conditions to support the preparation of a reclaimed water comprehensive plan. The assessment focused on identifying streams and rivers with summer low flows that are lower than historical summer low flows, wetland areas that are not classified as bogs or forested coniferous wetlands and that are likely to have altered hydrology, and groundwater resources that are reported to have lower groundwater levels. The assessment is intended to provide preliminary information on water resources that might potentially benefit from additional water inputs, with an understanding that further investigation may be needed to understand if, or how, these water resources might benefit from additional water. The planning area includes the county's wastewater service area and areas immediately surrounding the service area.

The streams and rivers assessment, documented in this report, relied on available information and on statistical analysis of available data to produce a list of basins in the reclaimed water planning area that have declining summer low flows and that could possibly benefit ecologically from additional inputs of water. The assessment attempted to identify declines that have resulted from human activities rather than from natural climatic and flow cycles. The focus was on the summer low-flow period (July–October) because of the greater potential for natural flows to be reduced by human activities such as increased demand from surface water and groundwater sources for irrigation. The summer low-flow period is also the time of year when addition of water from supplemental sources might have the greatest effect on streamflow, water temperature, and thus on habitat and aquatic life. The assessment did not include analyses of high-flow conditions or of stream and river habitat conditions.

The assessment relied on the following methods to identify suitable streams and rivers:

- Information, approaches, and findings of previous streamflow studies were compiled and summarized. The studies had different goals, study areas, and level and type of analysis. They used a variety of techniques to identify regional stream basins that have declines in summer low flows as a result of development and export of water from the basin to other locations.
- Existing rules and habitat conservation plans directed at maintaining or improving low flow also were compiled and summarized. Information found in two completed habitat conservation plans and published instream flow rules indicates that all or portions of watersheds in the region are closed to further appropriation of new surface water rights.
- Using the guidance provided in previous studies, low-flow trends, precipitation trends, and continuous water temperature data were analyzed to confirm low-flow trends identified in other studies, to identify other streams that may be affected by human activities, and to determine the extent to which identified low-flow trends could be ascribed to changes in climate.

Flow in many stream basins has not been monitored long enough to establish whether long-term declines in low flow have occurred, and many other streams have little or no stream gauging information. Water temperature records are also limited. However, one or more sources reviewed for this assessment identified a number of other streams in or very near the reclaimed water planning area as having declining low flows.

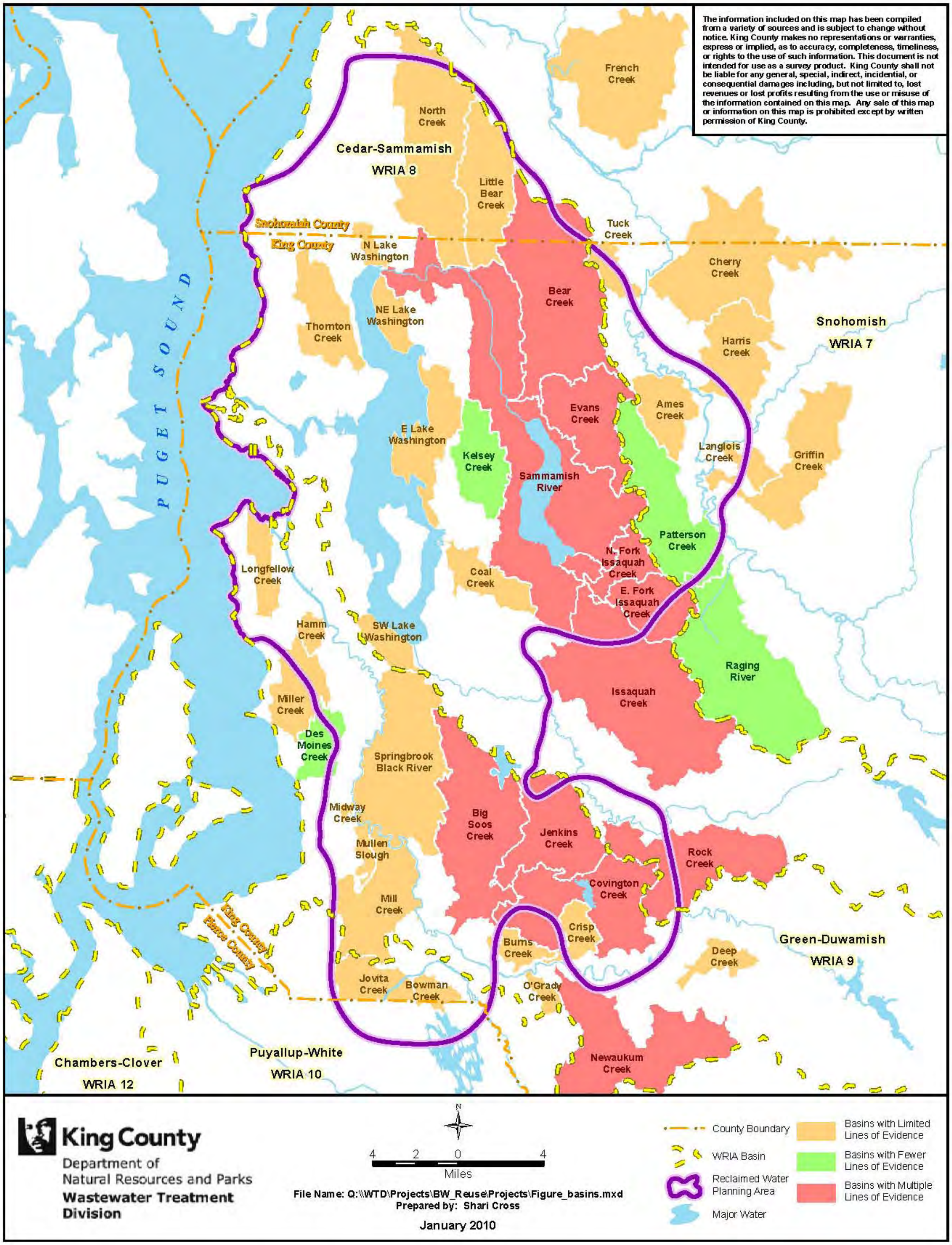
The assessment identified 11 basins with multiple lines of evidence that suggest that summer low flows have been reduced by a combination of withdrawals and development. These basins are Big Bear Creek; Evans Creek; mainstem, North Fork, and East Fork Issaquah Creeks; Rock Creek; and the Sammamish River in Water Resource Inventory Area (WRIA) 8 and Newaukum, Big Soos, Covington, and Jenkins Creeks in WRIA 9. Four basins show fewer lines of evidence. These basins are Patterson Creek and the Raging River (WRIA 7), Mercer (Kelsey) Creek (WRIA 8), and Des Moines Creek (WRIA 9). Several other basins have only limited evidence. The figure below shows the locations of these basins.

Over the long-term, it does not appear that regional trends in precipitation are responsible for the steady downward low-flow trends identified in this report. It is difficult to determine to what extent the generally dry period between 1977 and the mid-1990s or the warming trend over the same period has contributed to observed long-term low-flow trends.

Review of available continuous water temperature data indicates that summer daily maximum temperatures at the majority of stations evaluated were above state standards for protection of salmonid habitat. Although trend analysis of available stream temperature data was not performed for this assessment, trends in warmer air temperatures would suggest that regional water bodies, including streams and rivers, are also becoming warmer.

Data gaps make it difficult to identify specific causes of low-flow declines, to determine typical historical flow levels in pre-development conditions, and to relate changes in flow to biological benefits. Adding more water during low flow will not be the only restoration measure necessary if other aspects of the flow regime have been significantly altered. For example, in highly developed areas in and near cities, significant alteration of high flows may have occurred as a result of rapid runoff and transfer of rainfall from streets, rooftops, and parking lots to streams and rivers. Other critical aspects of the environment may also require restoration if the full biological benefit of stream restoration is to be realized. At a minimum, this restoration would include attention to riparian vegetation cover, sediment transport, water quality, and instream woody debris in any stream initially targeted for additional inputs of water.

Comprehensive follow-up studies to field verify conditions, address data gaps, or identify alternative approaches for providing additional water inputs would need to be done prior to developing any project to provide water that would benefit streams in need of more water.



Locations of Basins Identified in this Assessment with Declines in Summer Low Flows

1.0 INTRODUCTION

King County conducted a preliminary assessment of water resource conditions to support the preparation of a reclaimed water comprehensive plan. State law (Chapter 90.46 RCW—the Reclaimed Water Act) authorizes the use of reclaimed water for environmental purposes, including augmenting streamflows, creating or enhancing wetlands, and recharging groundwater aquifers.

The assessment focused on identifying streams and rivers with summer low flows that are lower than historical summer low flows, wetland areas that are not classified as bogs or forested coniferous wetlands and that are likely to have altered hydrology, and groundwater resources that are reported to have lower groundwater levels. The assessment is intended to provide preliminary information on water resources that might potentially benefit from additional water inputs, with an understanding that further investigation may be needed to understand if, or how, these water resources might benefit from additional water.

This report documents the streams and rivers portion of the assessment.[1] It describes the methods used to identify streams and rivers in the reclaimed water planning area with declining summer low flows and then presents and discusses the results. The reclaimed water planning area encompasses the county's wastewater service area and areas immediately surrounding the service area, including portions of Water Resource Inventory Areas (WRIAs) 7, 8, 9, and 10 (Figure 1).

The primary goal of this portion of the assessment is to produce a list of streams and rivers that have been affected (declines in summer low flow) by human activities. These streams are believed to be most likely to benefit ecologically from additional sources of water. Benefit was defined as improved habitat for aquatic life. Comprehensive follow-up studies to field verify conditions, address data gaps, or identify alternative approaches for providing additional water inputs would need to be done prior to developing any project to provide water that would benefit streams in need of more water.

[1] See King County, 2009a and 2009b, for the wetlands and groundwater reports.

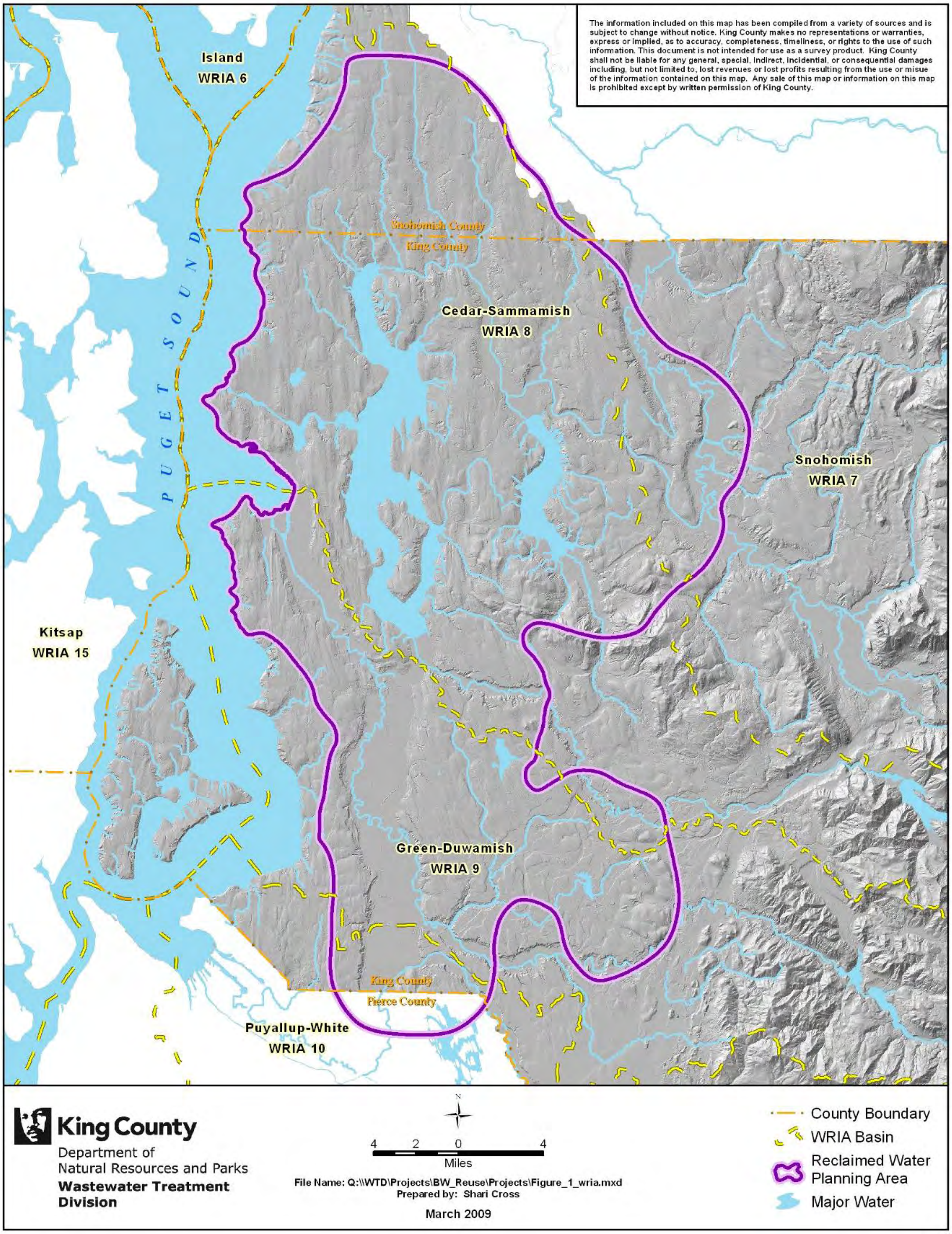


Figure 1. King County Reclaimed Water Planning Area

2.0 METHODS

The approach to the streams and rivers assessment assumed that increase in habitat from water added to a particular stream or river will depend on the existing amount of streamflow, the temperature and size of the receiving stream, and the amount and temperature of the water available for additional water inputs. The general approach to the assessment was as follows:

- Available information related to long-term declines in summer low flow of streams and rivers in the reclaimed water planning area was compiled and summarized.
- Existing rules and plans directed at maintaining or improving low flows in the planning area were compiled and summarized. These rules and plans include habitat conservation plans (including flow rules), watershed conservation plans, and instream resources protection programs for King County WRIAs codified under the Washington Administrative Code.
- Available stream and river flow data were evaluated for trends in low flow to confirm previous studies that identified streams with human-caused depletions in summer flow and to identify other streams that might be affected by human activity.
- Precipitation and air temperature data were evaluated for trends to assess whether natural variability and/or steady trends related to climate change may also play a role in streamflow trends.
- Available data on water temperature were evaluated to identify streams and rivers that might be too warm for native fish.[2]
- Streams and rivers and their associated drainage basins that have declines in summer low flows were identified based on the review and analyses.

The following two sections (1) summarize the information compiled from available literature and studies and (2) describe the methods and results of the streamflow and climate trend analyses and the review of water temperature data.

[2] There is an established correlation between low flows and higher water temperatures.

3.0 REVIEW OF AVAILABLE INFORMATION

This section summarizes available literature on the causes and effects of declining low flows and the possible benefits of adding more water to increase these flows. It then summarizes previous studies that attempted to identify streams in the region with human-induced declines in low flows.

3.1 Background on Low Flows

Lower streamflow has been implicated as one of several factors contributing to the overall decline of anadromous salmon in streams and rivers of King County and throughout the Puget Sound basin (Kerwin, 2001; Lombard and Somers, 2004). Lowest flows in local streams and rivers typically occur between July and October when precipitation is lowest and streamflow is dominated by groundwater inputs (Sinclair and Pitz, 1999).

As flows decrease in summer, the area of stream bottom available for laying eggs or that may provide a place for juvenile fish to hide is reduced. Lower flow also means water levels that could eventually fall low enough that connections to valuable side channel habitats may be lost. Fish eggs that were laid during periods of higher flows could be exposed to the air and sun if water levels fall too low. Lower flow and the associated reduction in stream bottom area can translate into fewer bottom dwelling stream animals that provide food for fish and other animals. Lower amounts of water can also result in poorer water quality, including higher temperature and lower concentrations of dissolved oxygen, that may be harmful to fish and other aquatic life.

This naturally stressful period for stream biota can be exacerbated by human-caused reductions in summer low flow (Lombard and Somers, 2004). Human-caused changes in streamflow are suspected to be a major cause of biological degradation in streams and rivers (Poff et al., 1997). It is generally believed that native fish and other native aquatic life have adapted to the natural flow regime—the flow regime typical of the many thousands of years prior to significant human alteration of the landscape. This regime includes many aspects of flow that historically have varied over time, including the magnitude, frequency, duration, timing, and rate of change. Significant changes beyond the natural range in any or all of these flow characteristics are expected to result in adverse biological responses.

3.1.1 Causes of Lower than Historical Flows

There are four main reasons why flows may be lower now than in the past:

- More people pump water from wells or directly from rivers and streams, leaving less flow for fish or other aquatic life (Hutson et al., 2004).
- More and more development has forced winter rainwater to flow away during the winter instead of being absorbed by the ground. Clearing of trees and other vegetation that divert water back into the air may offset some of this loss (Cuo et al., 2008). Historically,

evapotranspiration of water from undisturbed forest cover may have returned about 40 percent of the total annual precipitation back into the air (Vaccaro et al., 1998).[3]

- More houses are now hooked up to the regional wastewater system, which discharges treated wastewater to Puget Sound, instead of using onsite treatment systems, which allow the wastewater to be reabsorbed by the ground and infiltrated into the basin.
- Changes in climate may be causing warmer and drier summers than several decades ago (Climate Change Technical Committee, 2006). Some of these changes could be part of natural cycles, while steady increases or declines over long periods could be caused by human activities.

Residential, agricultural, and industrial activities rely on water extracted from surface or groundwater sources. Water is used for a variety of purposes, including crop irrigation, livestock watering, industrial cooling and other industrial and commercial needs, landscape and lawn watering, drinking water supply, and various domestic needs. The U.S. Geological Survey (USGS) estimated that in 2005, a total of 227.88 million gallons per day (mgd), or 350 cubic feet per second (cfs), was withdrawn from King County groundwater and surface water sources (USGS, 2005).

Water demand and extraction and the character of demands and extractions (surface vs. groundwater or domestic vs. irrigation supply) vary seasonally and geographically. In more urbanized areas, water is used for domestic, industrial, and agricultural needs and wastewater is channeled into a wastewater collection and treatment system. The water is typically supplied from sources outside of the local area for domestic and industrial uses. In less urbanized areas, water is used for domestic and agricultural needs. It may be supplied from a number of local sources, including surface extractions, individual wells, and public water supplies (most often from groundwater), and from outside the local area. Wastewater collection and treatment in these less developed areas occur onsite via septic systems, and the wastewater is released onto drain fields below ground. Regardless of the water source, water demand generally peaks during the summer months because of the increased use of water for irrigation.

Future climate change impacts on streamflow and temperature should also be considered when planning for stream habitat restoration (Battin et al., 2007). In addition to more or less direct effects of humans on local streamflow, climate variability resulting from natural 10-year cycles and long upward or downward trends related to human activities can impact streamflow. Local attention has focused primarily on the effects of reduced mountain snowpack and related shifts to earlier timing of runoff in snowmelt-supplied rivers of the Pacific Northwest (Barnett et al., 2008); less attention has been paid to effects of climate change on flows of precipitation-dominated streams of the Puget Lowland. However, a number of expected changes in the climate of the Puget Sound region are relevant to summer streamflow. These changes include increased surface air temperatures and related increases in evaporation and evapotranspiration; increased temperatures of rivers, streams, and lakes; and greater frequency of droughts (Climate Change

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[3] Evapotranspiration in this context refers primarily to the sum total of loss of water primarily from wet plants through evaporation and from plants in general through transpiration.

Technical Committee, 2006).[4] Although the direction and magnitude of precipitation changes are somewhat uncertain, most of the evidence points toward an increase in winter precipitation and a decrease in summer precipitation. These projections are more uncertain than those for temperature, and the expected magnitude of change will likely remain within historical variability in the near future (Climate Impacts Group, 2004).

3.1.2 Adding Water as a Part of Stream Restoration

The *Puget Sound Salmon Recovery Plan* identifies flow as a limiting factor for salmon recovery in many of the 14 Puget Sound watershed planning areas (Shared Strategy for Puget Sound, 2007).[5] The plan includes a regional strategy on instream flow to address issues that are common to multiple watersheds or that have not been adequately addressed in an individual watershed plan. The regional flow strategy, to be implemented at the watershed level, consists of three parts:

- Establish fish-protective instream flows to prevent future degradation
- Advance the science to better define instream flow limits for recovery
- Implement programs over the next 10 years to achieve the flows necessary for recovery

Lombard and Somers (2004) noted the difficulty of extrapolating improvement in flow conditions to changes in fish populations and of evaluating tradeoffs between different forms of flow restoration and management. One generalization that can be made with confidence is that the potential biological benefit of water added to a particular stream or river will depend primarily on the existing amount and temperature of the water in the receiving stream and the amount and temperature of the water being added. Also, because the size of the stream or river generally determines the total amount of biological resources that might benefit from additional water, there is likely some range of optimal stream size that would benefit most from a given quantity and temperature of additional water.

Adding water to low flows under a natural flow regime approach may not be the only restoration measure necessary if other aspects of the flow regime have been significantly altered. For example, in highly developed areas in and near cities, significant alteration of high flows may have occurred as a result of rapid runoff and transfer of rainfall from streets, rooftops, and parking lots to streams and rivers (DeGasperi et al., 2009). Other critical aspects of the environment may also require restoration if the full biological benefit of flow restoration is to be realized. At a minimum, this would include attention to riparian vegetation cover, sediment transport, water quality, and instream woody debris in any stream initially targeted for inputs of additional water (Lombard and Somers, 2004; Tributary Streamflow Technical Committee, 2006).

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[4] Evapotranspiration = the sum total of loss of water primarily from water bodies, wet soil, and wet plants (evaporation) and their respective vegetation (transpiration).

[5] The salmon recovery plan can be found at http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/PS-Recovery-Plan.cfm.

3.2 Previous Streamflow Studies

In the last 25 years, several flow studies have been conducted that include all or part of the reclaimed water planning area and that focus exclusively or in part on summer low flows and the potential influence of human activities on identified low-flow problems.[6] The studies have taken a number of approaches:

- Trend analyses, relying primarily on historical streamflow records (Ecology, 1995b; Ecology, 1995d; Konrad and Booth, 2002)
- Combination of simple empirical models and data on water extractions, consumptive and non-consumptive uses, and inter-basin transfers (King County, 2001)[7]
- Compilation, summarization, and evaluation of information from other studies (Lombard and Somers, 2004)
- Data-driven water balance approach using a combination of streamflow observations and data on water extractions, consumptive and non-consumptive uses, and inter-basin transfers (Northwest Hydraulic Consultants, 2005)
- Combination of expert opinion, review of previous reports and studies, and observed data for flow and water extractions (Tributary Streamflow Technical Committee, 2006)
- Water quality topic forum, which discusses where human activities have most significantly altered streamflows in the Puget Sound region (Puget Sound Partnership, 2008)

The Tributary Streamflow Technical Committee's report (2006) most closely aligns with the goals and areal extent of this streamflow assessment. The committee identified and prioritized regional streams that would potentially benefit from a temporary or permanent replacement of a set volume of water taken from the stream.

3.2.1 Trend Analysis of Streamflow Records

Two trend analysis approaches were reviewed: initial watershed assessment studies conducted by the Washington State Department of Ecology (Ecology) on the Cedar-Sammamish and Green-Duwamish watersheds (Ecology, 1995b; Ecology, 1995d) and a study of streams in the Puget Sound basin (Konrad and Booth, 2002).

Ecology Initial Watershed Assessments

In the early 1990s, Ecology partnered with teams of consultants to conduct initial watershed assessments for 16 of the state's 62 WRIAs to expedite decisions on pending water rights. The assessments generally compiled information on existing water rights, streamflow, precipitation,

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[6] The word "problems" is used in this text to indicate streams with declining low flows. The word is taken from the Lombard and Somers (2004) report in which data from previous studies on low flows in the region are reviewed and evaluated.

[7] Consumptive use refers to the amount of water consumed during use that is no longer available to the stream system, including water that is not immediately available for reuse because it has been evaporated, transpired, or incorporated into products, plant tissue, or animal tissue.

geology, hydrology, water quality, fisheries resources, and land use patterns. In 1995, initial watershed assessment reports were produced for WRIAs in King County (WRIAs 7, 8, 9, and 10) (Ecology, 1995a; Ecology, 1995b; Ecology, 1995c; Ecology, 1995d). The initial watershed assessments for WRIA 8 (Cedar-Sammamish) and WRIA 9 (Green-Duwamish) used statistical trend analysis approaches and included data from rivers and streams in the reclaimed water planning area. The assessments conducted for WRIA 7 (Snohomish) and WRIA 10 (Puyallup-White), on the other hand, used a more graphical trend analysis approach and focused on data from larger mainstem river systems that are outside of the reclaimed water planning area. For these reasons, only the WRIA 8 and 9 assessments are discussed below.

The *Watershed Assessment: Water Resources Inventory Area 8, Cedar-Sammamish Watershed* (Ecology, 1995b) and the *Watershed Assessment: Water Resources Inventory Area 9, Green-Duwamish Watershed* (Ecology, 1995d) reports describe the relationships between streamflow and water use in these watersheds. They are comprehensive in scope and include background information on hydrogeology, water demand, the effect of operations of the Chester Morse Dam and the Seattle Public Utilities surface withdrawal from the Cedar River, and the effect of the Howard Hanson Dam and Tacoma Public Utilities surface withdrawal from the Green River.

The emphasis of these assessments was on explaining downward trends in mean annual flow and/or summer low flow (defined as the annual minimum of the 7-day moving average flow) observed in long-term records collected by USGS on the Sammamish River near Woodinville, Issaquah Creek near the mouth, at the outlet of Big Soos and Newaukum Creeks, and at the Auburn gauge on the mainstem Green River. To do this, Ecology used a parametric linear regression approach.[8]

Significant downward trends in 7-day low flow were observed in all of these locations, except for the Sammamish River near Woodinville. Although it did not show a downward trend in 7-day low flow, the Sammamish River location did show a significant downward trend in mean annual flow. Ecology (1995b) suggested the reason for this discrepancy is that changes in low flow on the Sammamish River were buffered by the storage capacity of Lake Sammamish upstream of the station.

Downward trends in annual precipitation were also observed over the period of flow observations for the Sammamish River (1965–1991), Issaquah Creek (1965–1992), Big Soos Creek (1967–1991), Newaukum Creek (1953–1992), and the mainstem Green River near Auburn (1963–1993). A comparison of the percent of long-term decline in precipitation and flow led Ecology to conclude that not all of the decline in flow could be attributed to precipitation changes and that a combination of effective impervious cover development and extractions had contributed to the decline.[9] The human-related causes in declines in low flow in Newaukum

[8] Parametric statistics are the most well-known statistical tests (such as the classical t-test), but require a number of assumptions regarding the statistical distribution of the data and their variance to be met. Primary among these assumptions is that the data are normally distributed (similar to a “bell-curve”) or can be transformed to fit a normal distribution. When the assumptions of parametric statistics are met, these methods can have more statistical power. If these assumptions are incorrect, results can be misleading.

[9] Effective impervious area is the portion of total impervious area that conveys runoff directly into receiving waters. This concept recognizes that some forms of impervious land cover direct runoff to adjacent forested or grassed areas that would permit some infiltration and attenuation of direct runoff to receiving waters

Creek were less significant than those in Issaquah and Big Soos Creeks and were ascribed primarily to consumptive extractions because impervious cover development in the Newaukum basin was relatively minor.

Ecology (1995d) also compared total instantaneous water rights in the Green-Duwamish watershed (through the mid-1960s) and annual average and summer average (July–September) flow rates measured at the Auburn gauge on the mainstem Green River. Combined surface water and groundwater instantaneous water rights totaled 545 cfs, which was 40 percent of the average annual flow and greater than the average summer flow of the Green River at the gauge. This finding suggests that some portion of the downward low-flow trend might be due to water use.

Ecology (1995d) explains why a water budget analysis was not done as a part of these assessments:

> *Water-budget analyses can be a valuable tool for gaining a conceptual understanding of watershed hydrology. However, all of the elements of water budgets, such as evapotranspiration, recharge, discharge, and water use, are difficult to ascertain and often derived through the use of assumptions. As a proper water budget analysis requires a great deal of effort and the results are of limited use, a water budget analysis was not performed during this initial watershed analysis.*

Konrad and Booth Study of Puget Sound Basin Streams

In 2002, Konrad and Booth published a report titled *Hydrologic Trends Associated with Urban Development for Selected Streams in the Puget Sound Basin, Western Washington* (Konrad and Booth, 2002). Seven of the streams selected for analysis lie in the reclaimed water planning area: Juanita, Mercer (Kelsey), Swamp, May, Big Soos, Newaukum, and Issaquah Creeks.

Similar to the Ecology studies, Konrad and Booth used long-term USGS gauging records to evaluate hydrologic trends associated with urban development. They analyzed the effects of urbanization on both high (storm) and summer low flow and calculated correlations between flow statistics and population trends in each basin to evaluate potential relationships between flow and urbanization. They focused on four streamflow statistics: annual mean flow, annual maximum flow, annual minimum 7-day moving average flow (7-day low flow), and the annual fraction of the year the annual mean discharge in a particular basin was exceeded (T_{Qmean}). To limit the likelihood of errors that result from using relatively short periods of record, only stations with at least 30 years of data were analyzed and both parametric (Pearson) and non-parametric (Mann-Kendall) trend analysis techniques were used.[10]

With respect to low flow, the study did not identify any consistent trends between 7-day low flow and the level of urbanization. The study found that trends in 7-day low flow were not consistent with streams classified as urban, suburban, or rural based on current (around 1995) road densities in each basin. Results for streams in the reclaimed water planning area illustrate this finding:

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[10] The Pearson trend test is a parametric trend detection method and the Mann-Kendall is a non-parametric trend test. Non-parametric methods often rely on ranking the data rather than on absolute values and assumptions about their distribution (as in parametric statistics). These methods are considered less powerful than parametric methods if parametric assumptions are met, but they are considered more robust in situations where the distribution of the data cannot be determined with confidence.

- Newaukum and Issaquah Creeks (classified as a rural basins) indicated significant downward trends in low flow over their periods of record (using a statistical significance threshold of $p < 0.05$). These low-flow trends were also significantly correlated with time trends in basin population density.
- Mercer (Kelsey) Creek (an urban basin) had a consistently significant upward trend in low flow over the period of record.
- Less consistent trends were also observed in Swamp Creek. The analysis found a significant upward trend in low flow but no significant relationship with basin population.
- Although a significant downward trend in summer low flow was not detected in Soos Creek, it appears that the analysis included data prior to October 1966 that were affected by withdrawals by a local fish hatchery (USGS 2008 water-data report).[11] When these data are excluded (Ecology, 1995d; Konrad and Booth, 2005; and the trend analysis done for this report), evidence for a significant downward trend emerges, which is consistent with Konrad and Booth's (2002) finding of a significant negative correlation between the trend in low flow in Soos Creek and population density.

Konrad and Booth conclude that upward trends in Mercer (Kelsey) and Swamp Creeks could have resulted from importation of water supplies from sources outside the basins. They also suggest that declines in Issaquah and Newaukum Creeks could have resulted from shallow groundwater extractions. The effect of the extractions from Issaquah Creek could have been exacerbated by wastewater disposal to the regional collection system, which would diminish the potential for recharge through onsite wastewater disposal more typical of the Newaukum Creek basin. In general, the authors state that urban development does not appear to have a predictable influence on summer low flow. An earlier study (Konrad, 2000) found that the development of impervious cover had a negative effect on wet-season baseflow in local streams.

The detection of trends in 7-day low flow was also particularly sensitive to the period of analysis. Increasing and decreasing trends were detected in a number of 10-year subsets of the period of record for some streams. Konrad and Booth, therefore, recommended that streamflow trend analyses rely on more than 10 years of continuous streamflow data to avoid erroneously identifying trends in the effects of urbanization when the effects may have been caused by background decadal variation in streamflow:

> *Analysis of 10-year periods are likely to show trends in a streamflow statistic even if there is no significant trend over a long period of record for the stream (Type I error). Conversely, a 10-year period may be insufficient for identifying a trend for a longer period (Type II error).…any conclusions about hydrologic trends based on periods of 10 years or less should be tentative and may not apply to periods before or after the period analyzed.*

[11] The 2008 water data report for Soos Creek can be found at http://waterdata.usgs.gov/nwis/nwisman/?site_no=12112600&agency_cd=USGS.

3.2.2 Combination of Simple Models and Data-Based Approaches

In 2001, King County produced a report titled *Screening Level Analysis of 3rd Order and Higher WRIA 8 Streams for Change in Hydrologic Regime* (King County, 2001).[12] The study examines hydrologic change in streams in the Cedar-Sammamish watershed. As in the Konrad and Booth (2002) study, King County was concerned with the response of high and low flows from historical to current conditions. Three indices were developed that were simple empirical models or a combination of simple models and available data: (1) Peak Flow/Duration Index (PFDI), (2) Storm Volume Change Index (SVCI), and (3) Base Flow Change Index (BFCI).

The BFCI was based on (1) regional estimates of contribution to summer low flow from various land use/land cover types (till forest, outwash forest, till grass, outwash grass, saturated soils, open water, and effective impervious area) and (2) basin estimates of pumping, export, import, and consumptive use of water and of wastewater management activities. The final BFCI value for each basin represented the estimated change in July–October flow from pre-development to current conditions. Because the reduction in recharge from effective impervious cover was explicit in the calculation, the respective contributions of effective impervious cover and net consumptive water use could be estimated.

Figure 2 shows the basin BFCI results categorized as low (0–10 percent), medium (11–25 percent), high (26–50 percent), and extreme (>50 percent) low-flow reduction. In general, extreme levels of low-flow change were identified in the urban area surrounding Lake Washington, primarily the result of effective impervious cover. Extreme change levels, primarily the result of water extractions, were also identified in an area to the east of Lake Sammamish, including Evans Creek, East Lake Sammamish Plateau, and North Fork Issaquah Creek, and in Rock Creek (Lower Cedar River). High levels of low-flow change were identified primarily in the relatively urbanized area between Lakes Washington and Sammamish and the Redmond area to the north of Lake Sammamish, including Big Bear and Mercer (Kelsey) Creeks.

Figure 2 illustrates the potential of the BFCI approach for estimating low-flow reductions at a scale and extent that is useful for planning purposes. The approach also has the potential for use in examining the tradeoffs between the effect of impervious cover on both low flows and high flows and the relative impacts of effective impervious cover and water extraction/export. King County (2001) justified its empirical approach, including BFCI, because long-term gauge records are generally inadequate for identifying pre- and post-development flows:

> *In general, watershed streamflow records are not of sufficient length, nor do they fall into distinct, homogeneous, pre- and post-disturbance samples that would allow a direct determination of the level of flow regime change.*

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[12] The King County 2001 report can be found at http://www.scc.wa.gov/index.php/239-WRIA-8-Cedar-and-Sammamish-Basin/View-category.html and in the *Salmon and Steelhead Habitat Limiting Factors Report for the Cedar-Sammamish Basin* (Kerwin, 2001).

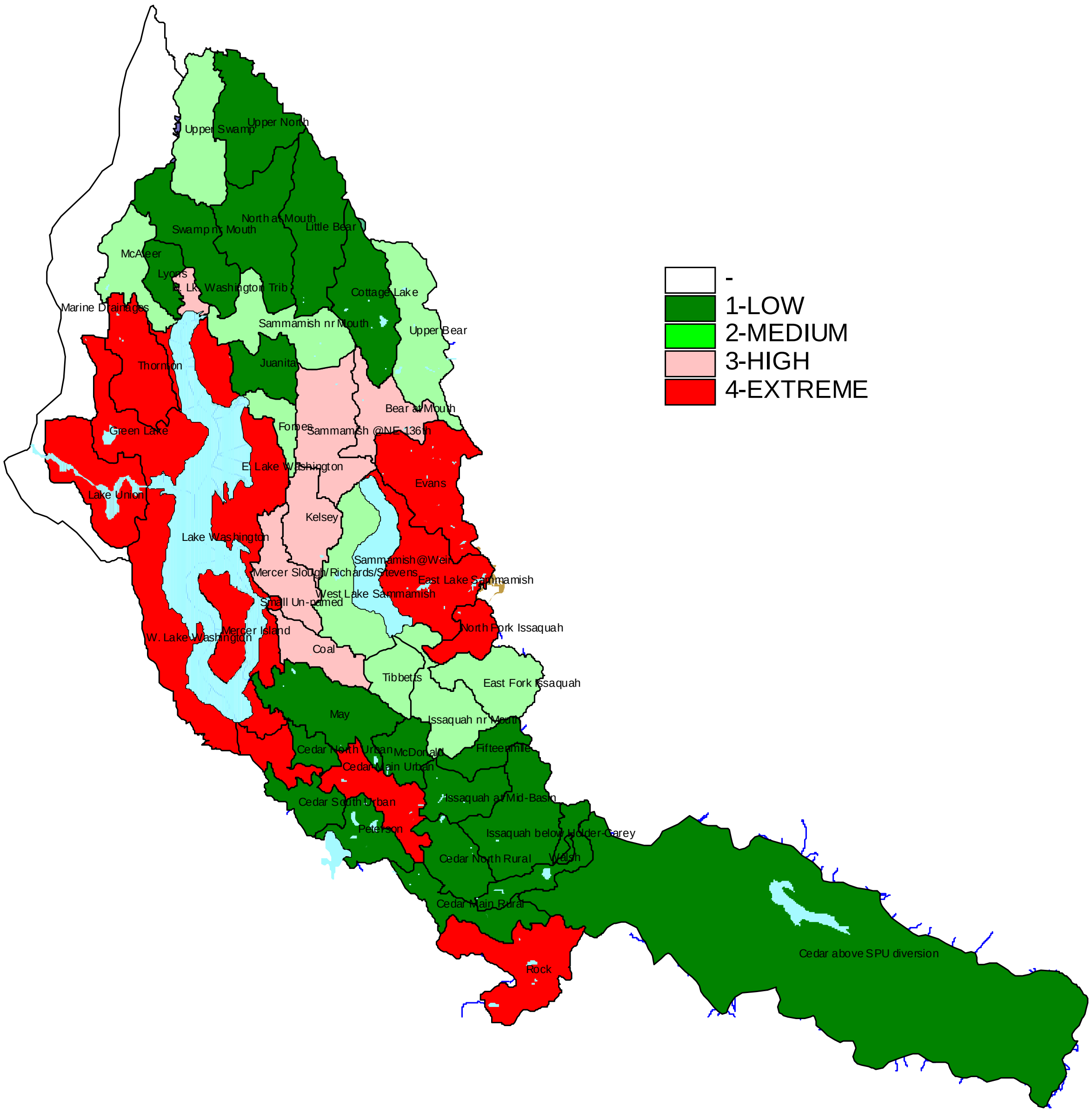

Figure 2. Estimated Decrease in Low Flow from Effective Impervious Cover and Net Basin Water Extraction in Cedar-Sammamish Watershed—
Low (0-10 %), Medium (11-25 %), High (26-50 %), Extreme (> 50 %)
(Source: King County, 2001)

3.2.3 Compilation and Review of Other Information Sources

A 2004 report by Lombard and Somers—*Central Puget Sound Low Flow Survey*—summarizes existing information regarding human-induced streamflow reductions in the Central Puget Sound region, including the reclaimed water planning area, and their effects on salmon populations. Study conclusions were based primarily on reports produced as part of the limiting factors analyses conducted by the Washington State Conservation Commission for salmon recovery planning under the Endangered Species Act. The report identifies streams with low-flow problems but does not rank the streams. It also provides background on instream flow rules in WRIAs 7, 8, 9, 10, and 12; on climate change impacts on low flow and temperature; and on methods historically used to establish instream flow needs.

The streams identified with low-flow problems are shown in Figure 3. The authors suggest that their approach likely identified only the most obvious and serious flow problems. They highlight the difficulty in identifying what constitutes a "low flow problem" and the difficulty in determining whether and how the effects of flow changes on habitat affect the health and abundance of fish populations. Consistent with King County (2001) summarized above, Lombard and Somers (2004) state that data are insufficient for comparison of historical and current flows:

> *Relatively few streams have flow gages; far fewer have good records for both current and historical flows. Even if this information were widely available, more analysis would be needed to estimate the relative contribution of different factors to changes in flows, the relative contribution of flow changes to changes in fish populations, and the likely benefits of different forms of flow restoration for fish.*

In addition to these cautionary statements, the authors also identify the complexity of flow changes (changes in timing, duration, frequency, and rate of change in addition to magnitude) that have occurred and invoke natural flow regime concepts to suggest that there is no simple solution to evaluating and correcting low-flow problems.

Using information from interviews conducted as part of the study, Lombard and Somers suggest the following approach to low-flow evaluation:

1. An initial screening to identify impervious surface cover, forest and wetland cover, and water withdrawal based on water rights, available data, or water withdrawal estimates including estimates of exempt well withdrawals.
2. A second phase to identify where the highest degree of human impact intersects with relatively abundant, or potential for abundant, fish populations.
3. Targeted studies of basin groundwater–surface water interactions, flow habitat relationships, fish responses to flows, and appropriate actions to address identified problems.

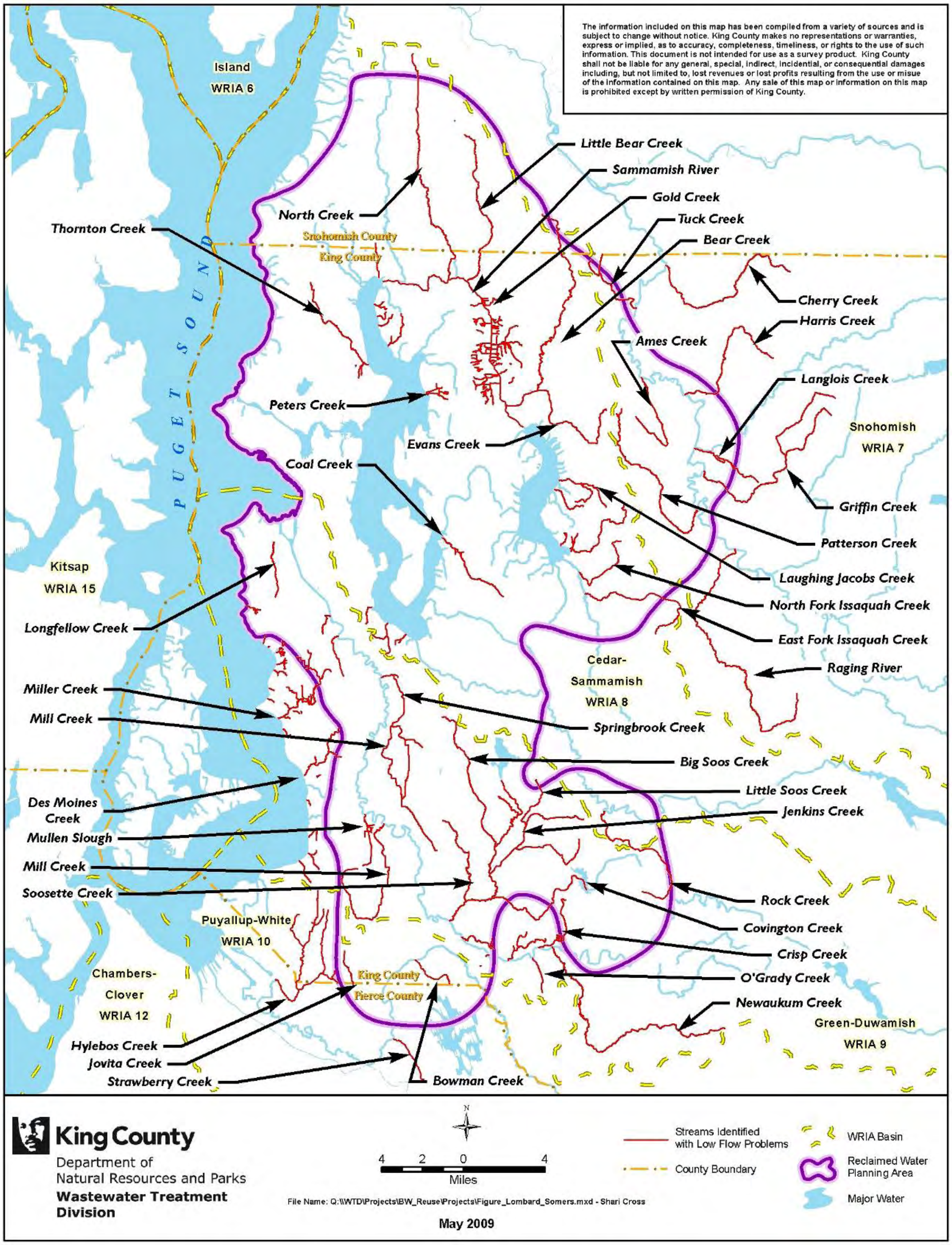

Figure 3. Streams in the Central Puget Sound with Low-Flow Problems
(Source: Lombard and Somers, 2004)

3.2.4 Data Driven Analysis of Streamflow and Water Management Information

One of the most comprehensive and well-documented efforts in the region to develop a water balance at a basin scale was performed for the Green-Duwamish watershed by Northwest Hydraulic Consultants, Inc., for the WRIA 9 Steering Committee (Northwest Hydraulic Consultants, 2005). The study—*Assessment of Current Water Quantity Conditions in the Green River Basin*—relied on prior studies that characterized water resources in WRIA 9, including the Ecology (1995d) assessment of WRIA 9 summarized above.

The focus of the study was on characterizing streamflow at various well-gauged points in the watershed, mainstem Green River, and major tributary inputs and on comparing observed streamflow statistics (50 percent and 90 percent exceedance values for 7-day low flow and monthly mean flow) to the estimated net export (or import) of water in the basin represented by the gauging location.[13] The amount of net exported or imported water was based on reported and estimated amounts of surface water and groundwater extractions, consumptive use, water exported for external water supply, and water discharged via the regional wastewater collection system.

The results of the comparison indicated that extraction of water for human use (managed water) affected streamflows in all of the study basins. The greatest impacts were estimated for Covington and Jenkins Creeks in the Big Soos Creek basin; August median monthly flow and 7-day low flows in these creeks may have been depleted by as much as 70 and 90 percent, respectively. The entire Big Soos Creek basin also ranked high in relative flow impacts from managed water. Further, Northwest Hydraulic Consultant's land use change analysis highlighted that over half of the projected future urban level of development in the Green-Duwamish watershed was planned to occur in the Big Soos Creek basin. Newaukum Creek was found to be the least impacted stream basin studied. Total extractions and exports represented about 20 percent of the 7-day low flow.

3.2.5 Combination of Expert Opinion and Observed Data

The Tributary Streamflow Technical Committee produced a report in 2006 as part of a regional water supply planning process.[14] The objective of the study was to identify streams where the substitution (temporary or permanent) of up to 2 cfs of basin water supply sources with other sources of water had the greatest potential to improve flow and water temperature and to increase the abundance and distribution of salmon and steelhead populations. The committee used 2 cfs as a common reference for ranking and did not intend to limit potential flow restoration to this amount. The committee ranked selected streams in WRIAs 8 and 9 that might benefit during

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[13] The percentage values refer to ranked percentiles of the annual 7-day low flow. If there were 100 ranked records (lowest to highest), the 50th record would represent the 50 percent exceedance value and the 10th value would represent the 90 percent exceedance value (90 percent of the 7-day low flow values would be greater than this value).

[14] The Tributary Streamflow Technical Committee's report and information on the regional water supply planning effort can be found at http://www.govlink.org/regional-water-planning/.

summer low flow from such a substitution. To do this, the committee relied on previous studies and summary reports, expert opinion, reported and estimated water extractions, and observed streamflow at gauging locations.

The committee's initial list of 20 candidate streams came from the Lombard and Somers (2004) report summarized above. Some initial candidate streams were dropped and others added. The final list included 13 basins in the Cedar-Sammamish (WRIA 8) watershed and 7 basins in the Green-Duwamish (WRIA 9) watershed. Twelve criteria distributed under three categories were scored by committee members and participants:

- Category 1—Relative biological importance under current conditions
    1. Pre-spawn mortality
    2. Adult migration delay
    3. Percent of Chinook population in WRIA present in stream
    4. Total number of listed anadromous species present
    5. Total number of other anadromous fish species present
    6. Juvenile rearing capacity or survival limitations due to low flows
- Category 2—Hydrologic need
    7. Potential flow depletion indicator: ratio of estimated withdrawals to current summer-fall (July–October) flow rates
- Category 3—Probability of measurable benefit/bang for buck
    8. Predicted hydrologic response based on up to 2 cfs of water available for source exchange
    9. Predicted thermal response
    10. Channel condition
    11. Added benefits to downstream reaches
    12. Multiple problems (fish passage, temperature, water quantity) addressed

The scoring results were combined into Low (L), Medium (M), and High (H) for each category. The ranked list was based on the following combinations for the three categories:

- Highest Likelihood of Benefit = H,H,H or H,H,M
- Moderately High Likelihood of Benefit = H,H,L or H,M,M
- Moderate Likelihood of Benefit = H,M,L or M,M,M
- Low Likelihood of Benefit = H,L,L or M,L,L or M,M,L
- Poor Likelihood of Benefit = L,L,L

The rankings were used as the starting point for additional discussion. The final list of streams and their rankings are shown in Table 1. Five basins were ranked as having the highest likelihood of benefit from source exchange: Big Bear Creek, East Fork Issaquah Creek, Covington Creek, Jenkins Creek, and Big Soos Creek. Four basins were ranked as having a moderately high likelihood of benefit: Issaquah Creek, Rock Creek (Lower Cedar), North Fork Green River, and Newaukum Creek.

Table 1. Tributary Streamflow Technical Committee (2006) Ranking of Streams for the Likelihood of Benefit from Source Exchange

Basin	Likelihood of Benefit
Cedar-Sammamish Watershed (WRIA 8)	
Big Bear Creek	Highest
East Fork Issaquah Creek	Highest
Issaquah Creek	Moderately High
Rock Creek	Moderately High
Sammamish River	Moderate
North Fork Issaquah Creek	Moderate
Cottage Lake Creek	Moderate
Cedar River	Low
Taylor Creek	Low
Little Bear Creek	Low
North Creek	Low
Evans Creek	Low
Lake Washington Ship Canal	Low
Green-Duwamish Watershed (WRIA 9)	
Covington Creek	Highest
Jenkins Creek	Highest
Big Soos Creek	Highest
North Fork Green River	Moderately High
Newaukum Creek	Moderately High
Lower Green River	Moderate
Upper Green River	Poor

3.2.6 Puget Sound Partnership Water Quantity Topic Forum

Although much broader in scope, a recent publication produced as part of Washington State's Puget Sound Partnership initiative explores the fundamental themes of assessing where human activities have most significantly altered streamflows in the Puget Sound region (Puget Sound Partnership, 2008). The discussion of the status of freshwater in the region focused on several key questions:

- Where in the Puget Sound region are the amount, timing, and distribution of freshwater flows adequate? Where are they impaired?
- Where do we know that freshwater supply is not adequate to protect habitat function?
- What are the major threats to freshwater supply and availability?

The discussion paper identified knowledge gaps with respect to issues of water quantity. Gaps that are relevant to this streamflow assessment are as follows:

- Data that indicate groundwater use, levels, trends, and depletion on a regional scale
- Localized hydraulic continuity between surface water and groundwater
- Hydrologic impacts of climate change, particularly how climate change may alter rainfall patterns
- Understanding of the relative impact of land development and water withdrawals on seasonal flow levels
- A quantitative correlation between streamflow and fish productivity
- Full understanding of the ecological impact of flow alteration on riparian vegetation, instream primary production, invertebrates, reptiles, amphibians, and birds
- Identification of flow impairments (both high- and low-flow problems) in Puget Sound watersheds similar to the work of the Tributary Streamflow Technical Committee (2006)
- Regional understanding of water system plans and watershed plans to inform where current water supply is inadequate to meet projected demand between now and 2020
- The quantity of water used to meet consumptive demand

3.3 Review of Rules and Plans

This section describes habitat conservation plans (HCPs) and instream flow rules that have been developed to address low-flow issues in basins in the reclaimed water planning area.

3.3.1 Habitat Conservation Plans

Two HCPs are in place: the Cedar River watershed HCP (Seattle Public Utilities) and the Green River HCP (Tacoma Public Utilities).[15] Table 2 lists characteristics of each HCP. A third HCP is under way for the City of Kent's Clark Springs withdrawal on Rock Creek—a tributary of the Cedar River—but appears to be a few years from approval.

Both existing HCPs were developed in response to actual and potential listings under the Endangered Species Act (ESA) that had a high likelihood of affecting water supply and water supply planning. Other motivations included strong public support for conservation values, opportunities for collaboration and efficiency in planning, agreements with other entities, and a stewardship ethic in the respective agencies.

Each HCP includes strategies for mitigating the effects of the utility's activities on both listed and unlisted species and their habitats. The strategies employed often depend on the availability of sufficient water, either through enhanced storage (in the case of Tacoma) or through normal rainfall patterns (in the case of the Seattle).

Table 2. Characteristics of the Seattle and Tacoma Habitat Conservation Plans

Permit Holder	Area Covered	Activities Covered	Motivations	Species Covered
Cedar River Watershed HCP				
City of Seattle	The municipal watershed and the Cedar River upstream and downstream of the diversion	Water supply; hydroelectric power; land management activities	Certainty for water supply and planning; Listing of species; Public conservation values	83 species including 4 salmon species
Green River HCP				
City of Tacoma	Upper Green River Watershed and the mainstem Green River downstream of Howard Hanson Dam	Water supply and land management activities	Certainty for water supply; listing of species; Collaboration and efficiency in planning; stewardship	32 species including 3 salmon and 2 trout species

Note: The Seattle HCP was approved in 2000; the Tacoma HCP was approved in 2001. Both HCPs were approved for a 50-year period.

[15] Cedar River watershed HCP: http://www.seattle.gov/util/About_SPU/Water_System/Habitat_Conservation_Plan--HCP/index.asp.
Green River HCP: http://www.ci.tacoma.wa.us/water/WaterSystem/habitat.htm.

Cedar River Watershed HCP

Approved in April 2000, the Cedar River watershed HCP has three components:

- **Landsburg Mitigation and Cedar River Sockeye Hatchery—**includes projects that address blockage to salmon and steelhead trout at the Landsburg Diversion Dam
- **Instream Flow Management (IFM)—**a flow regime to improve habitat and survival for salmon and steelhead in the mainstream Cedar River
- **Watershed Management—**forest and land management activities throughout the watershed related to habitat for a wide variety of fish and wildlife species

The IFM strategy, the HCP's only potential nexus for additional water inputs, includes multiple components. The flow regime establishes improved habitat conditions for the four species of anadromous fish found in the Cedar River: Chinook, coho, and sockeye salmon, and steelhead trout. The regime is managed to mimic natural fluctuations in river flow, although it guarantees a minimum flow to the river and limits the rate at which river levels can drop. It includes a plan for supplementing flows to the river during periods of low seasonal flow.

Green River HCP

Tacoma Water's Green River HCP was approved in 2001. Although terrestrial species and habitats are included, streamflow issues are the most significant aspect of this HCP. The flow prescriptions apply only to the mainstem Green River downstream from the Howard Hanson Dam and include the reach between the main dam and the diversion dam.

The City of Tacoma worked for more than 15 years with federal, state, and local resource agencies and with the Muckleshoot Indian Tribe to determine how its operations on the Green River could best be carried out with minimal adverse impact on Green River fisheries. The resulting HCP employs several mitigation strategies:

- Voluntarily reducing the city's First Diversion Water Right claim from 400 cfs (established in 1912) to 113 cfs
- Amending the city's water rights to incorporate higher instream flows in accord with a 1995 settlement agreement with the Muckleshoot Indian Tribe
- Funding a project at Howard Hanson Dam that will store 5,000 acre-feet of water for enhancing streamflow during summer months
- Contracting with the U.S. Army Corps of Engineers to support augmented flow releases from Howard Hanson Dam during low-flow periods by reducing Tacoma's use of surface water during years when autumn rains do not arrive when expected

3.3.2 Instream Flow Rules

The four WRIAs (7, 8, 9, and 10) located in whole or in part in the reclaimed water planning area have instream flow rules established in the Washington Administrative Code (WAC). Some basins carry additional flow rules as part of HCPs. Under state law, those with surface water rights that predate instream rules hold senior rights to the water and cannot be required to withdraw less water to meet target instream flow levels. Surface water rights issued after an instream rule can be curtailed when flow falls below the rule threshold. In general, all four WRIAs have been identified as over-appropriated (Washington State Joint Natural Resources Cabinet, 1999).

The following sections describe instream flow rules established for each WRIA.

Snohomish Watershed (WRIA 7)

In 1979, instream flow rules were established for WRIA 7 (Chapter 173-507 WAC):

- Instream flow rules were set for major rivers, including the Skykomish, Pilchuck, Sultan, Tolt, North Fork Snoqualmie, mainstem Snoqualmie, and mainstem Snohomish Rivers.
- Low-flow limitations (diversion is halted when flow drops below a certain level) were set for a number of creeks, including Evans, Foye, French, Langlois, Tate, Tulalip, Wood, and Woods Creeks, and for several unnamed streams tributary to creeks or rivers.
- Closures (no further surface water rights available) were set for several named and unnamed streams. Named streams include the Raging River and Griffin, Harris, Little Pilchuck, May (tributary to the Wallace River), Quilceda, and Patterson Creeks.

Cedar-Sammamish Watershed (WRIA 8)

In 1979, regulatory instream flow rules were established for the USGS gauge on the Cedar River near Renton in WRIA 8 (Chapter 173-508 WAC). The rules, along with subsequent case law, essentially closed the basin to further appropriation of new surface water rights. They are junior to the water rights held by the City of Seattle for Cedar River water.

As described earlier, the HCP for the Cedar River watershed developed by the City of Seattle includes flow rules that provide for minimum flows and a plan for supplementing flows in spring and fall to aid juvenile and adult salmon migration.

Green-Duwamish Watershed (WRIA 9)

In 1980, regulatory instream flow rules were established for WRIA 9 (Chapter 173-509 WAC):

- Instream flow rules were set for the USGS gauge on the mainstem Green River near Auburn and another gauge near Palmer below the Tacoma Public Utilities water diversion.
- Surface water closures were set for several unnamed tributaries to the Green River and for Deep, Des Moines, Garrison (tributary to the Black River), Miller (tributary to Maybrook Creek), and Springbrook Creeks.
- Maximum lake levels were set for Angle Lake, Star Lake, and Lake Sawyer.

The rule is junior to a water right claim held by the City of Tacoma, the major water right holder in the basin. Tacoma’s HCP includes additional flow rules for managing flow in the Green River and for maintaining minimum flows at the USGS gauge on the Green River near Auburn to honor its 1995 agreement with the Muckleshoot Indian Tribe.

For more information on instream flow rules and additional HCP flow agreements in WRIA 9, see *Assessment of Current Water Quantity Conditions in the Green River Basin* (Northwest Hydraulic Consultants, 2005).

Puyallup-White Watershed (WRIA 10)

In 1980, minimum instream flow rules were established for WRIA 10 (Chapter 173-510 WAC):

- Instream rules were set for the mainstem Puyallup River and the Carbon River.
- Low-flow limitations were set for a few unnamed tributaries to the Puyallup and Carbon Rivers.
- Closures were set for South Prairie, Clarks, Kapowsin, Ohop, Clear, Fiske, Canyon Falls, Hylebos, Le Dout, Niesson, Wapato, and Kellogg Creeks, Kapowsin Lake, the White River, their tributaries, and an unnamed stream.

4.0 ANALYSIS OF FLOW, CLIMATE, AND WATER TEMPERATURE DATA

Two types of analyses were conducted for this streamflow assessment: (1) statistical analysis of trends in flow and climate (precipitation and air temperature) and (2) review of patterns in stream temperature records.

Using the work of Konrad and Booth (2002) and Ecology (1995b and 1995d) as a basis, the trend analysis focused on analyzing relatively long-term and complete records of mean annual flow, 7-day low flow, total annual precipitation, and annual average air temperature for long-term (monotonic) upward or downward trends. The stream temperature review looked at the maximum 7-day moving average of daily maximum water temperature. These metrics are described below:

- **Minimum 7-day moving average of daily flow.** The low-flow condition is assumed to be the condition most likely to be improved with additional water sources. The low-flow condition typically occurs between July and October in the Puget Sound region's streams and rivers. The minimum 7-day moving average of the daily average flow rate (7-day low flow) was used to assess the low-flow condition at selected gauging stations during each calendar year.
- **Mean annual flow.** The mean annual flow was calculated as the average of the daily flow at each station for the period between October 1 of one year and September 30 of the following year. This period is known as the water year and is chosen to best represent the annual onset of high flows (typically beginning in October or September) and the transition to summer low-flow conditions. Changes in mean annual flow could indicate basins with the most significant reductions in flow.
- **Total annual precipitation.** Total annual precipitation is the sum of all hourly precipitation records for the water year. The relatively high variability in annual precipitation has a direct influence on the variability of annual streamflow. Total annual precipitation was used to evaluate whether any observed trends in streamflow are due at least in part to trends in precipitation.
- **Mean annual temperature.** Mean annual temperature is the average of all hourly temperature records for the water year. Upward trends in regional temperature have already been identified and described (Mote, 2003). Upward trends in local air temperature have implications for stream temperature and flow. Higher air temperatures will generally translate into higher water temperatures, as has already been observed in Lake Washington (Arhonditsis et al., 2004). Increasing air temperature may also translate into higher potential rates of evaporation, although higher rates of evaporation or evapotranspiration will also depend on factors such as soil moisture and vegetation.
- **Maximum 7-day moving average of daily maximum water temperature.** The maximum 7-day moving average of the daily maximum water temperature (7-day maximum temperature) is calculated by finding the maximum temperature recorded during each day from continuous water temperature recorders. A 7-day moving average

is then calculated, and the maximum value for each calendar year is found. Warmer streams generally would benefit ecologically from the addition of cooler water.

4.1 Flow Trends

This section describes the data sources, methods, and results of the trend analysis of low flows in selected streams in the reclaimed water planning area.

4.1.1 Flow Records Used

All available daily average streamflow data through 2007 were compiled from USGS and King County databases for stations located in King County.[16] Streamflow data for the portions of Snohomish and Pierce Counties in the planning area were compiled from the USGS database. In all, data were obtained from 433 USGS and 260 King County stations (Figure 4).

To select a set of stations for statistical trend analysis, compiled flow records were reviewed for completeness and for the period and length of record. The selection criteria were as follows:

- The station should have a minimum of 15 years of usable data collected between 1990 and 2007 (with an allowance of 3 missing years over this period).[17,18]
- Usable data were defined as no missing data between July and October for minimum 7-day moving average flow and an allowance for up to 30 missing days in any water year for mean annual flow.
- Streams or rivers with an average 7-day low flow of over 100 cfs (65 mgd) were excluded as less likely to benefit ecologically from available additional water.
- Only streams or rivers in or near (within about 2 miles) the reclaimed water planning area were included.

Long-term records from 22 stations were selected for analysis—15 King County gauging stations and 7 USGS gauging stations (Table 3 and Figure 5). Records from an additional nine stations, representing five locations, were visually inspected for apparent trends (Table 4 and shown as "additional gauges" on Figure 5). Records for these stations were relatively long but did not pass the selection criteria for statistical trend analysis because of large gaps between earlier long-term records and fewer more recent observations. The additional stations are as follows:

- Two USGS gauging stations: Thornton Creek (USGS Gauge 12128000) and Rock Creek (USGS Gauge 12118500). King County has monitored flow on Rock Creek since the mid-1990s at Gauge 30L (near the USGS gauge), but this record was considered too short for statistical trend analysis.

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[16] USGS data were downloaded from the National Water Information System's Web server (http://waterdata.usgs.gov/wa/nwis/), accessed June 2008. King County data were downloaded from the Hydrologic Information Center Web site (http://green.kingcounty.gov/wlr/waterres/hydrology/), accessed May 2008.

[17] King County records generally spanned the period 1990 to 2007; the complete USGS records were typically longer, sometimes spanning several decades. The length of record varies from station to station.

[18] As recommended by Konrad and Booth (2002), this trend analysis uses more than 10 years of data.

- Three locations with earlier USGS data and more recent King County data from the same (or very nearly the same) location: Big Bear Creek near the mouth (USGS Gauge 12124500 and King County Gauge 02a), Juanita Creek near the mouth (USGS Gauge 12120500 and King County Gauge 27a), and Swamp Creek near the mouth (USGS Gauge 12127100 and King County Gauge 56b). (King County Gauge 02a on Big Bear Creek was also included in the statistical trend analysis.)

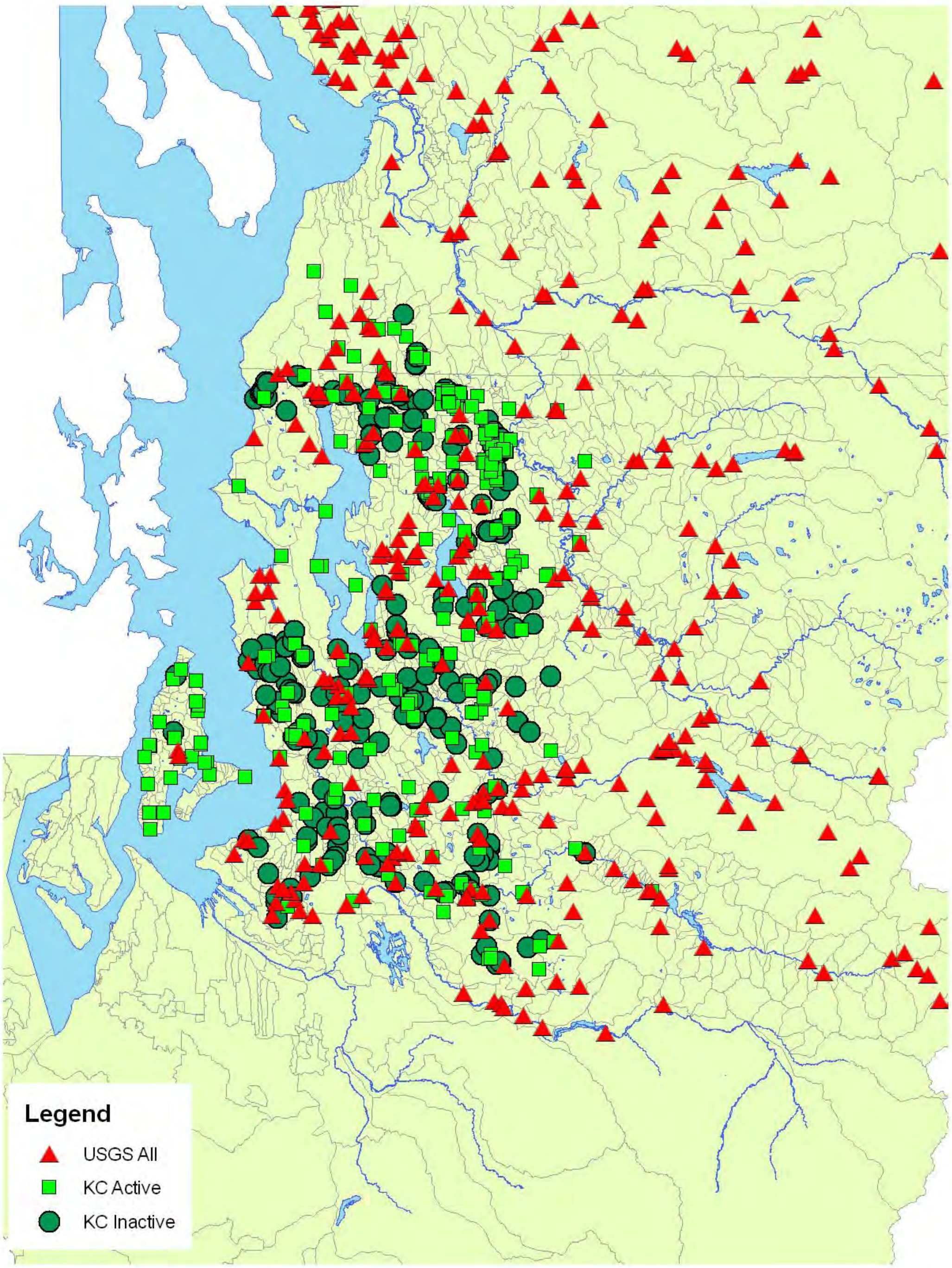

Figure 4. Locations of all USGS and King County Streamflow Gauges Screened for Use in Statistical Trend Analysis

Table 3. List of USGS and King County Stream Gauges Selected for Streamflow Trend Analysis

Gauge	Description	Period of Record	
	USGS		
12112600	Big Soos Creek above hatchery near Auburn	1967[a]	2007
12120600	Issaquah Creek near Hobart	1987	2007
12121600	Issaquah Creek near mouth near Issaquah	1964	2007
12120000	Mercer (Kelsey) Creek near Bellevue	1956	2007
12108500	Newaukum Creek near Black Diamond	1953	2007
12145500	Raging River near Fall City	1965	2007
12125200	Sammamish River near Woodinville	1966	2007
	King County		
02a	Big Bear Creek at Union Hill Road	1988	2007
48b	Canyon Creek at Aldera Farms	1990	2007
09a	Covington Creek near mouth at 168th Way SE – Big Soos Creek basin	1988	2007
11c	Des Moines Creek above Tyee Regional Pond	1990	2007
11d	Des Moines Creek below SR 509, Des Moines (near mouth)	1992	2007
18a	Evans Creek at Union Hill Road	1988	2007
46a	Issaquah Creek, North Fork	1988	2007
26a	Jenkins Creek near mouth – Big Soos Creek basin	1988	2007
15c	Laughing Jacobs Creek at E. Lake Sammamish Parkway	1992	2007
37a	May Creek at mouth	1989	2007
37b	May Creek at Coal Creek Parkway	1991	2007
42b	Miller Creek Detention Facility	1990	2007
42a	Miller Creek near mouth	1988	2007
48a	Patterson Creek at Aldera Farms	1990	2007
31h	Taylor Creek at mouth	1991	2007

[a] Although the period of record at the gauge began in August 1960, data prior to October 1966 was excluded from the analysis because a fish hatchery upstream of the station diverted up to 19 cfs and returned the flow downstream.

Table 4. List of USGS and King County Stream Gauges Selected for Visual Inspection of Streamflow Trends

Gauge	Description	Period of Record
USGS 12118500	Rock Creek near Maple Valley	1945–1973; 2001–2007
King County 31L	Rock Creek at 244th	2001–2006
USGS 12128000	Thornton Creek near Seattle	1945–1946; 1961–1968; 1996–2007
USGS 12127100	Swamp Creek at Kenmore	1964–1989
King County 56b	Swamp Creek	2000–2004
USGS 12120500	Juanita Creek near Kirkland	1945; 1963–1989
King County 27a[a]	Juanita Creek at mouth	1988–2007
USGS 12124500	Bear Creek at Redmond	1945–1950; 1955–1958; 1984–1986
King County 02a[b]	Bear Creek at Union Hill Road	1988–2007

[a] Not included in the statistical trend analysis because of the large number of missing records in some years.
[b] Also evaluated in the statistical trend analysis.

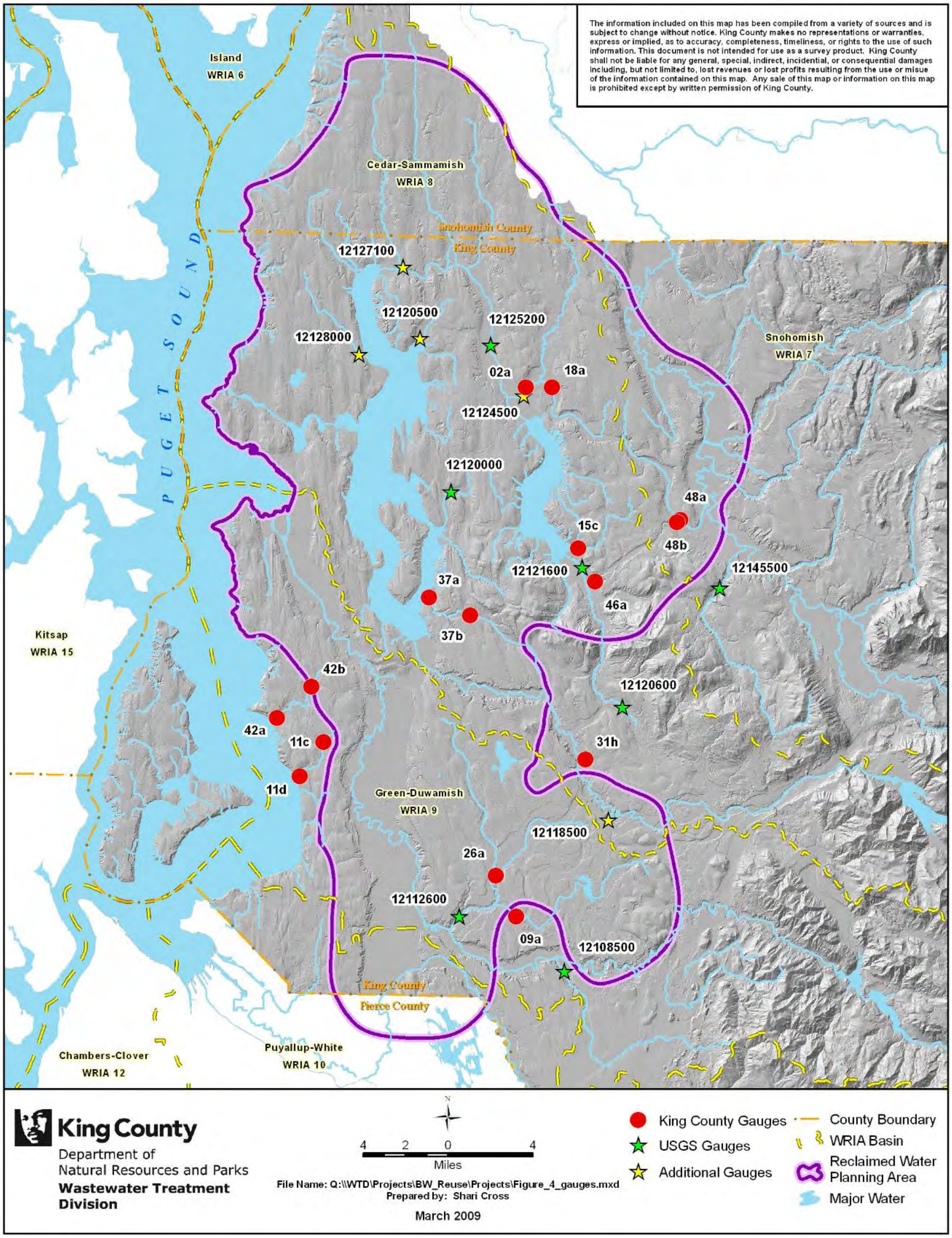

Figure 5. Locations of USGS and King County Stream Gauges Selected for Trend Analysis

4.1.2 Evaluation Methods

Following the recommendation of Konrad and Booth (2002), the non-parametric Mann-Kendall trend test was used to statistically evaluate trends in each data time series. The Mann-Kendall test is a relatively powerful and widely used trend testing method in hydrological science (Hirsch et al., 1991). The trend tests were performed using a FORTRAN program available from USGS (Helsel et al., 2006). The strength and direction of the Mann-Kendall trend are indicated by the tau regression coefficient, which can range between -1 and +1 with absolute values closer to 1 indicating the strongest trends. The statistical significance *p*-value is also reported by the program.

Of particular concern in any statistical analysis is the avoidance of Type I and Type II errors. These errors are illustrated in Table 5. A Type I error occurs when the test fails to identify a real trend in the data, either because of the weakness of the trend, the methodology, or the shortness of the record. Type I errors can be controlled by the selection of the statistical significance level (*p*). In general, the lower the value of *p* used to determine statistical significance, the less likely that Type I errors will occur. Typically, a significance level of less than 0.05 is selected to identify “statistically significant” trends. However, many researchers have argued against the use of rather arbitrary definitions of statistical significance (Newman, 2008). In this assessment, the following definitions are used to qualify the evidence for the presence of a trend:

- $p \geq 0.10$ — no reliable statistical evidence against the null hypothesis that a trend exists
- $0.05 \leq p < 0.10$ — weak evidence against the null hypothesis that a trend exists
- $0.01 \leq p < 0.05$ — strong evidence against the null hypothesis that a trend exists
- $p < 0.01$ — very strong evidence against the null hypothesis that a trend exists

Type II errors are more difficult to avoid. Such errors occur when the statistical trend test suggests a trend, but a trend really exists. Type II errors are also difficult to quantify because they require prior knowledge that a trend in the data exists. Nonetheless, one approach to minimizing Type II errors is to use relatively long records for analysis.

Table 5. Description of Statistical Trend-Testing Errors

		Does a trend exist?	
		Yes	No
Has a trend been detected?	Yes	+	Type I error: false trend detected when none exists
	No	Type II error: failure to detect an existing trend due to weakness of the trend, the methodology, or the shortness of the record	+

In addition to the Mann-Kendall tau regression coefficient and significance level, the following analyses were done:

- The non-parametric regression slope and intercept, which can be used to plot the estimated regression line indicating the slope of the measured trend, were calculated using the USGS program.
- Time series plots with estimated regression lines and regression statistics tau and *p*-value were prepared and visually inspected for patterns in the data that might be inconsistent with the statistically estimated long-term trend.
- The regression slope was divided by the long-term mean of the annual average flow or minimum 7-day flow (and multiplied by 100) to estimate the percent increase or decrease relative to the long-term baseline as an indication of the relative magnitude of the estimated trend. These percentages served as another indicator of the significance of a flow trend.

4.1.3 Trends in 7-Day Low Flow

Appendix A contains 7-day low-flow trend results for all 22 stations tested for trends over the available continuous low-flow period of record; Appendix B contains plots of the time series for the stations. Of the 22 stations tested, 15 stations indicated negative (downward) trends and seven showed positive (upward) trends.

Of the seven stations with upward trends, only one (Mercer/Kelsey Creek) showed statistical evidence of an upward trend. The *p*-value for this station was between 0.01 and 0.05, indicating strong evidence for a real trend. A positive upward trend at this station was previously reported by Konrad and Booth (2002). Nine of the fifteen stations with negative trends had *p*-values of less than 0.10, indicating at least weak evidence for a real trend:

- Two of the nine stations (Des Moines Creek at Gauge 11c and Raging River) had *p*-values ranging between 0.10 and 0.05, indicating weak evidence of a downward trend.
- Four stations (Des Moines Creek at Gauge 11d, Evans Creek, North Fork Issaquah Creek, and Patterson Creek) had *p*-values between 0.01 and 0.05, indicating strong evidence of a downward trend.
- Three stations (Newaukum Creek, Issaquah Creek, and Big Soos Creek) had *p*-values of less than 0.01, indicating very strong evidence for a downward trend. The long-term low-flow time series and estimated trends for these three locations are shown in Figure 6, Figure 7, and Figure 8.

Table 6 shows the results of the low-flow trend analysis, including annual percentage of increase or decline, for the ten stations that showed statistical evidence of a trend. Figure 9 shows the locations of the eight stations with strong evidence of a trend and their percentage of increase or decrease. The North Fork Issaquah Creek (King County Gauge 46a) and Des Moines Creek (King County Gauges 11c and 11d) locations showed the largest estimated relative declines (greater than an average of 4 percent decline per year).

Visual inspection of the time series plots generally confirmed the identified trends, with the exception of records for Mercer (Kelsey) Creek (USGS Gauge 12120000) (Figure 10). It appears that over the period of continuous data collection at the Mercer (Kelsey) Creek gauge, low flows have trended upward from 1956 through the mid-1980s and have since begun to decline. The upward and then downward trends, which occurred over a period of intense urbanization of the Bellevue area in the Mercer (Kelsey) Creek basin, highlights the difficulty of attributing cause and effect in flow trends based on gauging records alone. It is likely that some combination of imported water use along with more efficient summer landscape watering explains the overall increasing and then decreasing trend, but confirmation would require construction of a time-varying water balance that includes amounts of imported and exported water and water use statistics.

Although the trend in Big Soos Creek (USGS Gauge 12112600) is consistently downward over the long-term (1967–2007), it appears that since 1990, the trend toward lower flows has leveled off or has begun to increase (Figure 8). To evaluate the strength and direction of more recent trends for Big Soos Creek and other streams, the longer data sets from the seven USGS stations used in this analysis were trimmed so that only the available records collected since 1990 were analyzed for trends. The results are shown in Table 7. Five of the seven estimated trends are downward, but the *p*-values for only two stations (Mercer/Kelsey Creek and Issaquah Creek) suggest enough evidence ($p < 0.1$) of a real trend. The trends at both of these stations are downward, with declines in flow on the order of 1.7 percent per year.

The more recent downward trend in Mercer (Kelsey) Creek is consistent with the visual evaluation of the long-term low-flow records for that gauge, and the previous long-term downward trend in Issaquah Creek near the mouth appears to continue into the present. However, previous trends suggested by the long-term analysis of records from Big Soos Creek, Newaukum Creek, and the Raging River were not confirmed in the analysis of more recent records collected since 1990. This does not necessarily mean that the downward trends at these stations are no longer continuing. It is possible that Type II errors (failure to detect a real trend) are occurring as the result of some combination of weakness in the trend and shorter length of record tested.

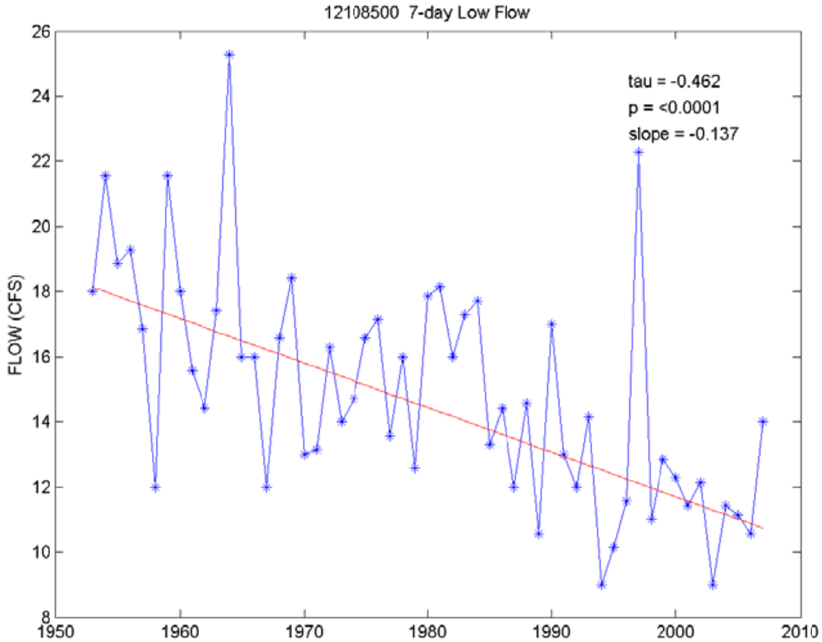

Figure 6. Time Series Plot Showing Long-Term 7-Day Low Flow at USGS Gauge 12108500 on Newaukum Creek near Black Diamond, 1953–2007

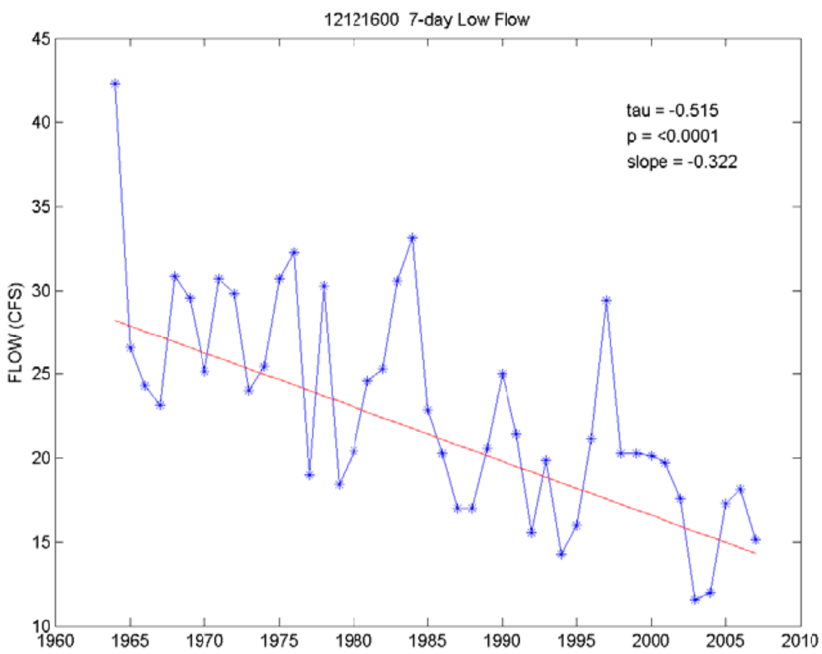

Figure 7. Time Series Plot Showing Long-Term 7-Day Low Flow at USGS Gauge 12121600 on Issaquah Creek near Mouth near Issaquah, 1964–2007

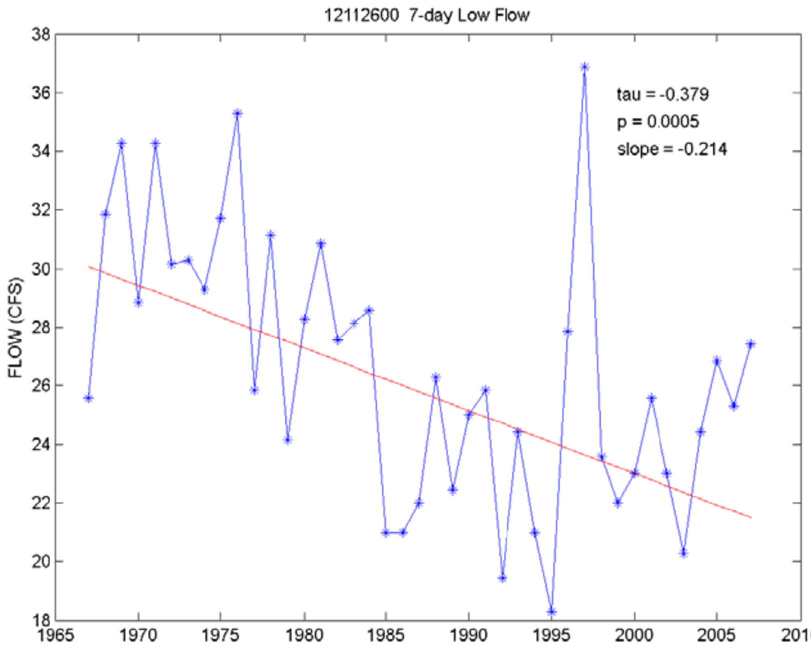

Figure 8. Time series Plot Showing Long-Term 7-Day Low Flow at USGS Gauge 12112600 on Big Soos Creek above Hatchery near Auburn, 1967–2007

Table 6. Trend Analysis Results for the 10 Streamflow Gauges with Weak to Very Strong Evidence (*p* < 0.10) of a Real Long-Term Trend in 7-Day Low-Flow

Gauge	tau	*p*	Years of Record	Intercept (cfs)	Slope (cfs/yr)	Avg. Annual Minimum 7-Day Low flow (cfs)	Annual Percent Increase or Decline
USGS 12112600—Big Soos Creek above Hatchery Near Auburn	-0.379	0.0005	41	451.6	-0.21	26.6	-0.8
King County 11c—Des Moines Creek above Tyee Regional Pond	-0.314	0.0748	18	19.8	-0.01	0.2	-4.9
King County 11d—Des Moines Creek below SR 509, Des Moines (near mouth)	-0.483	0.0103	16	92.9	-0.05	1.0	-4.5
King County 18a—Evans Creek at Union Hill Road	-0.346	0.0489	18	167.8	-0.08	3.5	-2.3
USGS 1212160—Issaquah Creek near mouth near Issaquah	-0.515	<0.0001	44	661.4	-0.32	22.9	-1.4
King County 46a—Issaquah Creek, North Fork	-0.326	0.0478	20	61.3	-0.03	0.6	-5.0
USGS 12120000—Mercer (Kelsey) Creek near Bellevue	0.226	0.0183	52	-62.4	0.03	5.5	0.6
USGS 12108500—Newaukum Creek near Black Diamond	-0.462	<0.0001	55	285.5	-0.14	14.9	-0.9
King County 48a—Patterson Creek at Aldera Farms	-0.431	0.0137	18	198.3	-0.10	5.1	-1.9
USGS 12145500—Raging River near Fall City	-0.198	0.0702	41	142.3	-0.07	11.4	-0.6

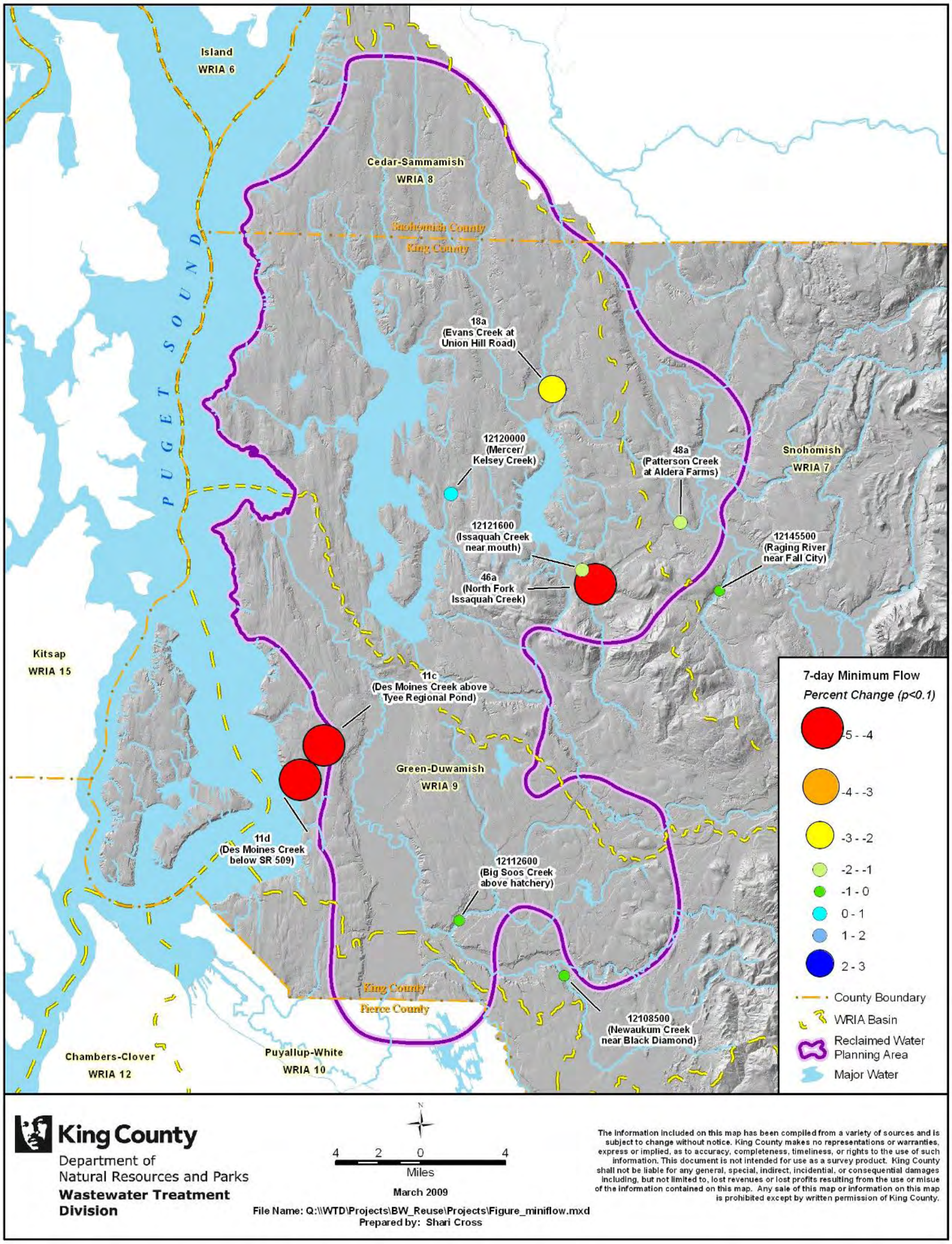

Figure 9. Map Showing the Relative Percent Annual Average Increase or Decline at the Eight Gauging Stations with Strong to Very Strong ($p < 0.05$) Evidence of Long-Term Low-Flow Trends

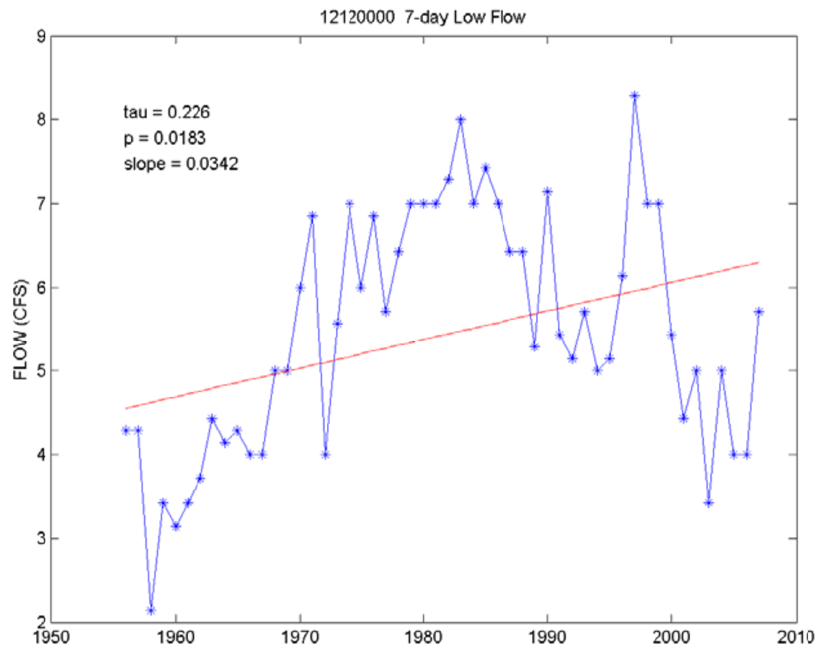

Figure 10. Time series Plot Showing Long-Term 7-Day Low Flow at USGS Gauge12120000 on Mercer (Kelsey) Creek near Bellevue, 1956–2007

Table 7. Trend Analysis Results for the Seven USGS Streamflow Gauges Analyzed for Trends in 7-Day Low Flow, 1990–2007

USGS Gauge	tau	*p*	Years of Record	Intercept (cfs)	Slope (cfs/yr)	Average Annual Minimum 7-Day Low flow (cfs)	Annual Percent Increase or Decline
12112600—Big Soos Creek above hatchery near Auburn	0.150	0.404	18	-375.3	0.20	24.5	0.8
12120600—Issaquah Creek near Hobart	0.039	0.8493	18	-19.7	0.01	8.9	0.2
12121600—Issaquah Creek near mouth near Issaquah	-0.366	0.0371	18	646.9	-0.31	18.6	-1.7
12120000—Mercer (Kelsey) Creek near Bellevue	-0.346	0.0475	18	195.7	-0.10	5.5	-1.7
12108500—Newaukum Creek near Black Diamond	-0.229	0.1972	18	253.3	-0.12	12.5	-1.0
12145500—Raging River near Fall City	-0.046	0.8196	18	62.8	-0.03	10.5	-0.2
12125200—Sammamish River near Woodinville	-0.083	0.6853	16	888.7	-0.42	52.4	-0.8

Visual inspection of the long-term flow records at the nine stations (at five locations) where gaps in the records precluded statistical evaluation yielded the following results:

- **Rock Creek.** The Rock Creek location near Maple Valley (USGS Gauge 12118500) that discharges to the lower Cedar River was the only location with a distinct downward shift in flow (Figure 11). Beginning in 1965, minimum 7-day flow dropped from an average of 5 cfs (1945–1964) to an average of 1.5 cfs (1965–1972; 2001–2007). The shift to lower flow appears to be associated with the City of Kent's development of a system of water supply wells. The decline in summer low flow in Rock Creek was recognized in the *Lower Cedar River Basin and Nonpoint Pollution Action Plan* (King County, 1998), which recommended that the city develop a plan for adding water to increase low flow.
- **Thornton Creek.** The summer flow records for Thornton Creek (USGS Gauge 12128000) are not complete enough to draw any firm conclusions (Figure 12).
- **Swamp Creek.** The low-flow time series for Swamp Creek suggests an increase in flow between 1964 and 1989 (Figure 13). This upward trend in 7-day low flow was also noted by Konrad and Booth (2002). Changes that occurred in low flow during the data gap between 1990 and 1999 cannot be known with certainty, but measurements made by King County (Gauge 56b, 2000–2004) about a mile upstream indicate that more recent low flows are probably similar to those observed by USGS at Gauge 12127100 in the late 1980s.[19]
- **Juanita Creek.** USGS records for Juanita Creek suggest an increase in 7-day low flow since 1945; King County gauge (27a) records indicate that variability increased beginning in 1992 (with a few data gaps), which makes it difficult to visually identify any recent trends (Figure 14).
- **Big Bear Creek.** Statistical trend analysis of the 7-day low flow for Big Bear Creek near the mouth, based on recent King County data (Gauge 02a), did not provide reliable evidence of a trend. However, placing the data in the context of earlier USGS data from the same location (Gauge 12124500) suggests that summer low flows have declined over the period of record beginning around 1990 (Figure 15).

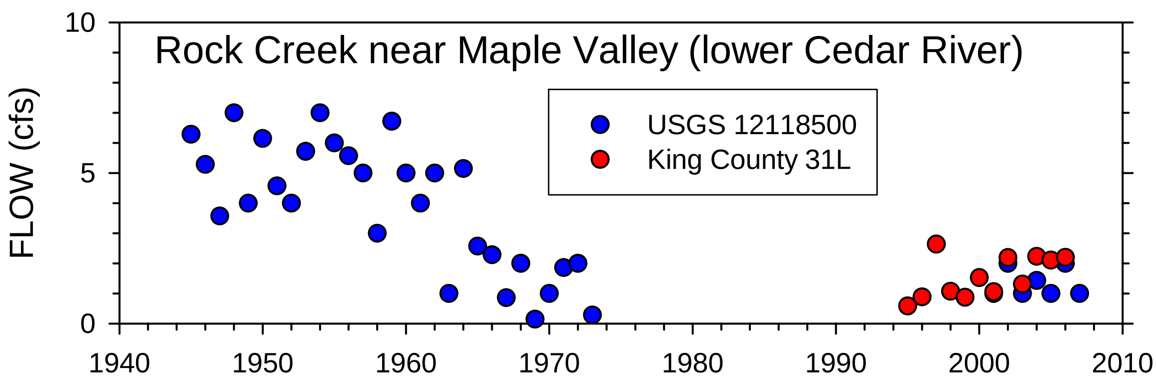

Figure 11. Time Series Plot Showing Long-Term 7-Day Low Flow at USGS Gauge 12118500 on Rock Creek near Maple Valley (discharges to Lower Cedar River)[20]

[19] The King County gauge (56b) was discontinued in 2004.

[20] King County Gauge 31L was discontinued after 2007.

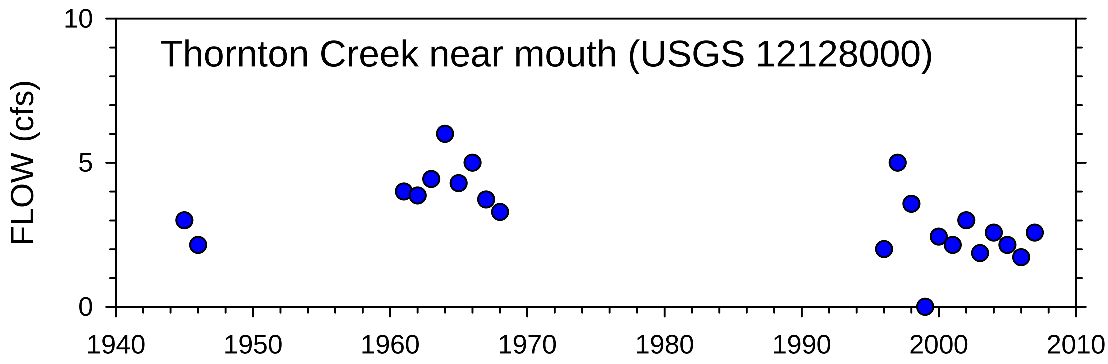

Figure 12. Time Series Plot Showing Long-Term 7-Day Low Flow at USGS Gauge 12128000 near the Mouth of Thornton Creek

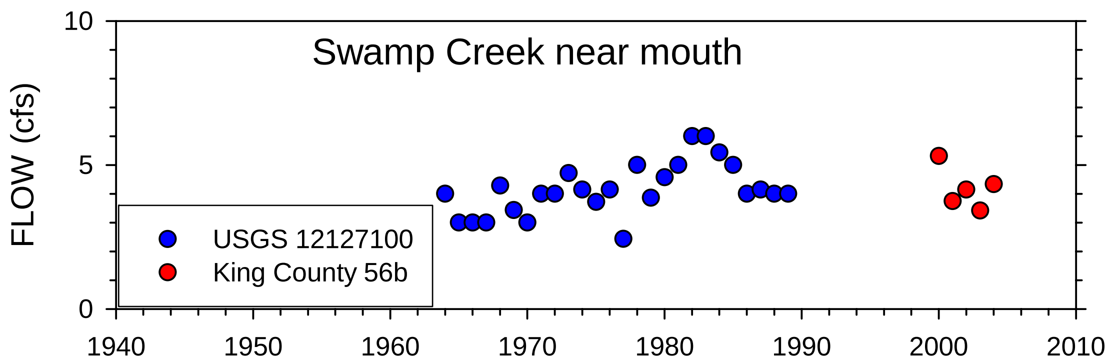

Figure 13. Time Series Plot Showing Long-Term 7-Day Low Flow at USGS Gauge 12127100 and King County Gauge 56b near the Mouth of Swamp Creek

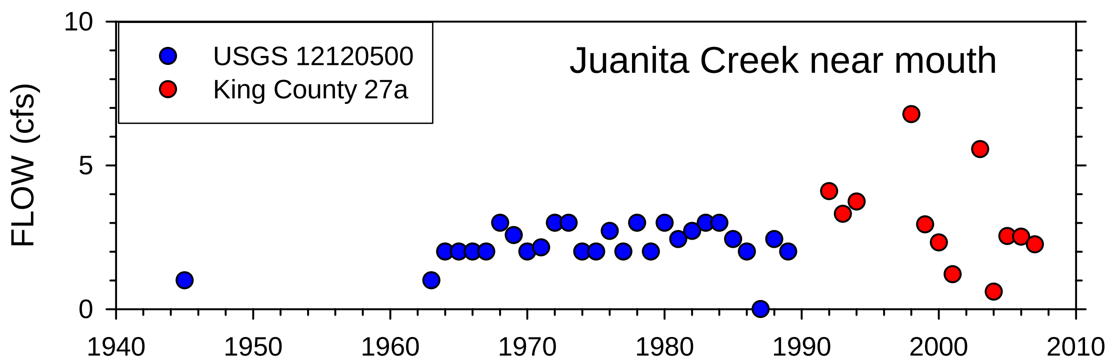

Figure 14. Time Series Plot Showing Long-Term 7-day Low Flow at USGS Gauge 12120500 and King County Gauge 27a Near the Mouth of Juanita Creek

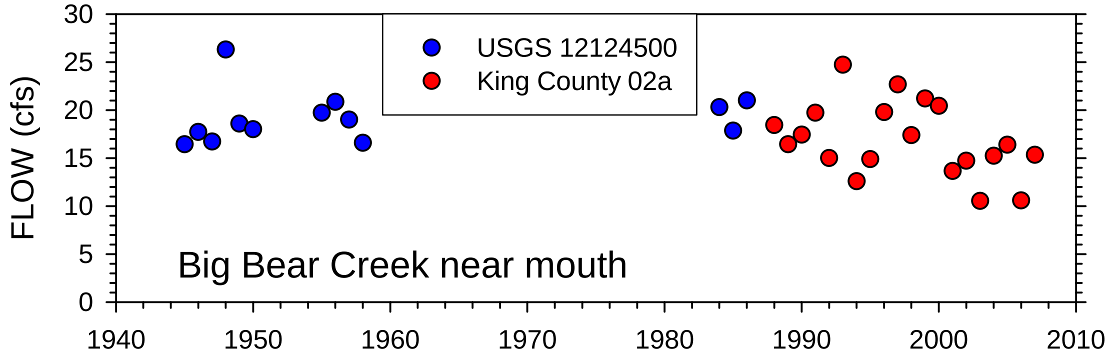

Figure 15. Time Series Plot Showing Long-Term 7-Day Low Flow at USGS Gauge 12124500 and King County Gauge 02a Near the Mouth of Big Bear Creek

4.1.4 Trends in Mean Annual Flow

Results for all 22 stations analyzed for trends in mean annual flow over the available period of record are provided in Appendix A; plots of the time series are provided in Appendix B.

Of the 22 stations tested, 11 showed negative (downward) and 11 showed positive (upward) trends. Only 3 of the 22 station trends had *p*-values of less than 0.10, indicating at least weak evidence for a trend (Table 8). All three trends were downward and ranged from 0.4 to 0.7 percent per year declines in mean annual flow. The three stations were Issaquah Creek near the mouth near Issaquah (USGS Gauge 12121600), Newaukum Creek near Black Diamond (USGS 1210850), and the Sammamish River near Woodinville (USGS Gauge 12125200). The long-term mean annual flow time series and estimated trends for these three locations are shown in Figure 16, Figure 17, and Figure 18.

The trends in mean annual flow in Issaquah Creek and Newaukum Creek are consistent with the very strong evidence ($p < 0.0001$) for long-term trends in 7-day low flow at the same locations.

Although evidence suggests a downward trend in mean annual flow in the Sammamish River, no reliable evidence exists for a downward trend in 7-day low flow. This discrepancy may stem from the fact that much of the flow at the Sammamish River gauge comes from the Issaquah and Evans Creek basins, which have statistical evidence for long-term downward trends in 7-day low flow, while the presence of Lake Sammamish (a natural storage reservoir) at the headwaters of the river likely helps maintain summer low flows. Ecology (1995b) identified similar patterns in long-term flow trends in Issaquah Creek and the Sammamish River and offered the same explanation—that the storage capacity of the lake moderates changes in low flow in the Sammamish River.[21]

[21] Ecology (1995b) found statistically significant trends in mean annual flow in Issaquah Creek and the Sammamish River and a significant trend in low flow in Issaquah Creek only.

Table 8. Trend Analysis Results for the Three Streamflow Gauges with Weak to Strong Evidence (*p* < 0.10) of a Real Long-Term Trend in Mean Annual Flow

Gauge	tau	*p*	Years of Record	Intercept (cfs)	Slope (cfs/yr)	Average Annual Mean Flow (cfs)	Annual Percent Increase or Decline
USGS 12121600—Issaquah Creek near mouth near Issaquah	-0.214	0.0421	44	1881	-0.88	130	-0.7
USGS 12108500—Newaukum Creek near Black Diamond	-0.170	0.0673	55	550.8	-0.25	58	-0.4
USGS 12125200—Sammamish River near Woodinville	-0.223	0.0438	40	4775	-2.3	304	-0.7

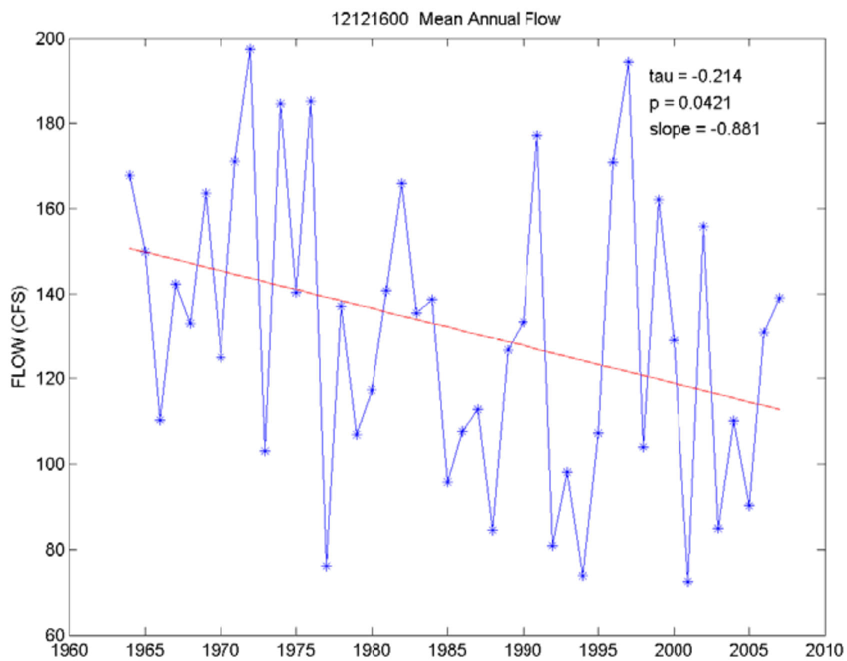

Figure 16. Time Series Plot Showing Long-Term Annual Mean Flow at USGS Gauge 12121600 on Issaquah Creek near Mouth near Issaquah, 1964–2007

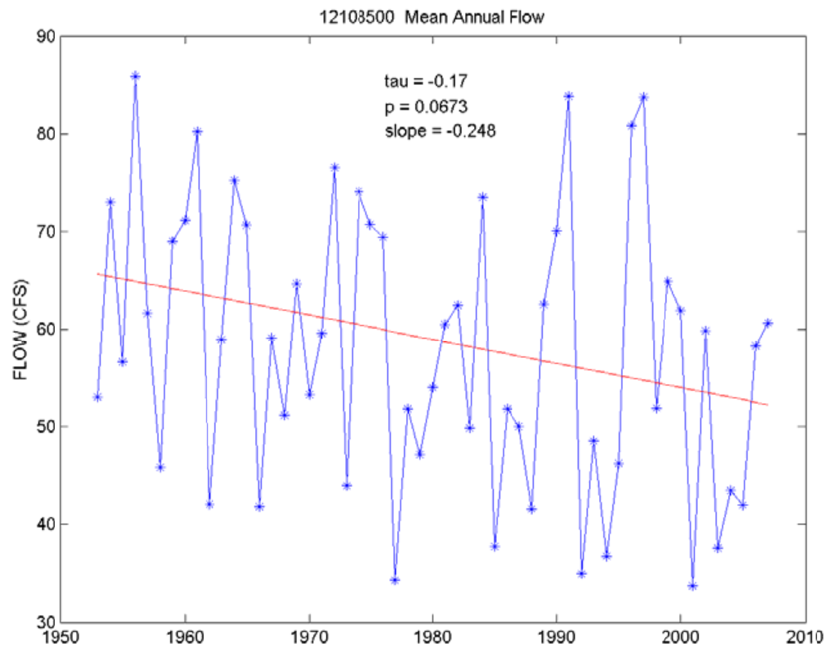

Figure 17. Time Series Plot Showing Long-Term Annual Mean Flow at USGS Gauge 12108500 on Newaukum Creek near Black Diamond, 1953–2007

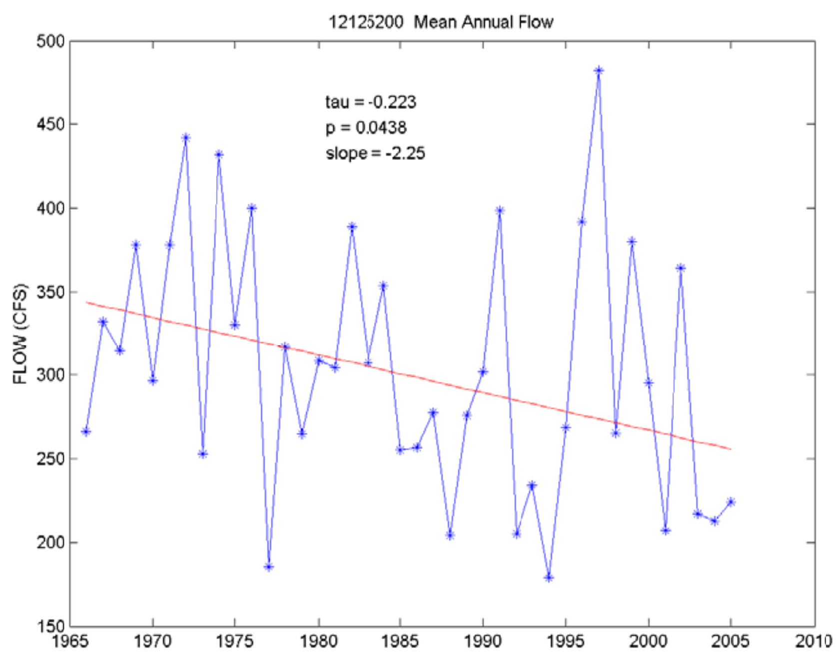

Figure 18. Time Series Plot Showing Long-Term Annual Mean Flow at USGS Gauge 12125200 on the Sammamish River near Woodinville, 1966–2007

4.2 Climate Trends

Hourly precipitation and air temperature data were obtained from the National Climatic Data Center (NCDC) for a station located at Seattle-Tacoma International Airport (SeaTac). This location provides the longest and most complete hourly records for the region and is assumed to be a reasonable surrogate for regional climate conditions on an annual basis. The hourly precipitation data were modified to match NCDC's reported daily total precipitation, which includes corrections not reflected in the original data.

4.2.1 Trends in Total Annual Precipitation

Trend analysis of total annual precipitation over the available period of record at SeaTac (1949–2007) does not show reliable evidence for a trend (tau = -0.109; $p = 0.224$). Visual inspection of the time series suggests shifts between long periods of wet and dry years, with increasing variability since the mid-1970s (Figure 19). These shifts generally follow variations in the Pacific Decadal Oscillation (PDO)—an index of Pacific climate variability (Mantua et al., 1997). Between 1947 and 1976, the PDO was dominantly in a "cool" phase, which generally means below-average temperatures and above-average precipitation in the Pacific Northwest between October and March. Between 1977 and at least the mid-1990s, the PDO was typically in the opposite "warm" phase, which generally means warmer and drier conditions between October and March. Since the late 1990s, the PDO has oscillated between warm and cool phases with more frequency.

Trend results and visual inspection of the total annual precipitation time series indicate that long-term trends detected in streamflow records collected through 2007 are not completely due to similar steady shifts in precipitation. The downward trend in SeaTac precipitation between 1967 and 1991 was noted by Ecology (1995d) and used to explain a portion of the declines in Big Soos and Newaukum Creeks. However, while the decline in Newaukum Creek (and Issaquah Creek) has continued since 1991, the total annual precipitation since the mid-1990s has not continued to decline. It is possible that some of the leveling off or possible increase in 7-day low flow in Big Soos Creek since the mid-1990s may be due to recent higher than normal precipitation. Precipitation has been variable, with two years of exceptionally high precipitation in 1996 and 1997 and a year (2001) with relatively low precipitation.

4.2.2 Trends in Annual Average Air Temperature

Analysis of annual average air temperatures for the period 1949 through 2007 provides very strong evidence ($p < 0.0001$) for a long-term trend (Figure 20). The rate of increase in temperature is about 0.27^{o}C per decade, which translates to about a 2.5 percent increase per decade relative to the long-term average air temperature.

This trend is consistent with temperature trends observed throughout the Pacific Northwest (Mote, 2003; Figure 21) and has implications for water temperature and rates of evaporation and evapotranspiration. In general, it implies steady warming of streams, rivers, lakes, wetlands, and even groundwater. Increasing trends in water temperature have already been documented for Lake Washington (Arhonditsis et al., 2004). Higher rates of evaporation and evapotranspiration would translate into decreasing streamflows. Assessment of the potential loss of streamflow through increasing evapotranspiration will require further studies that include long-term modeling of the potential and actual basin-scale evapotranspiration with and without the observed air temperature trend.

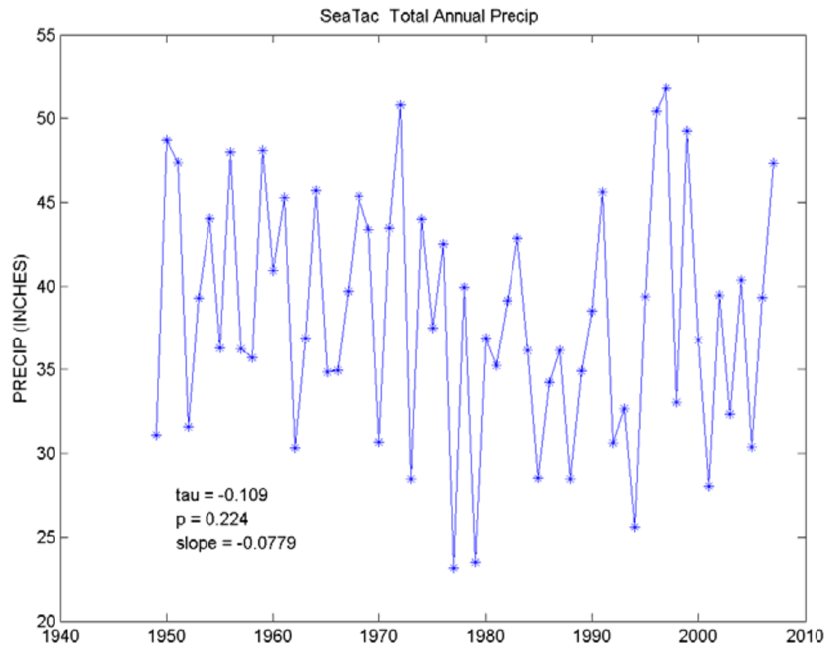

Figure 19. Time Series Plot of Long-Term Total Annual Precipitation (Oct–Sept) Recorded at Seattle-Tacoma International Airport, 1949–2007

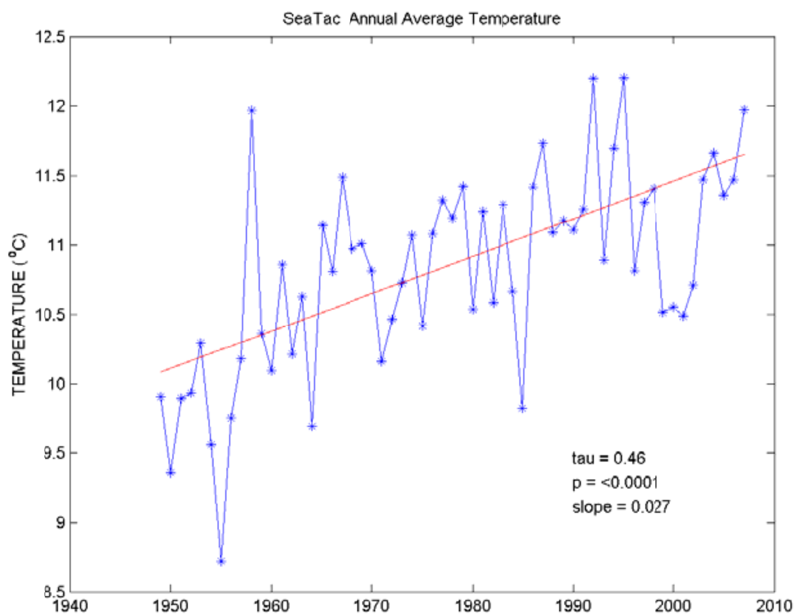

Figure 20. Time Series Plot of Long-Term Annual Average Air Temperature (Oct–Sept) Recorded at Seattle-Tacoma International Airport, 1949–2007

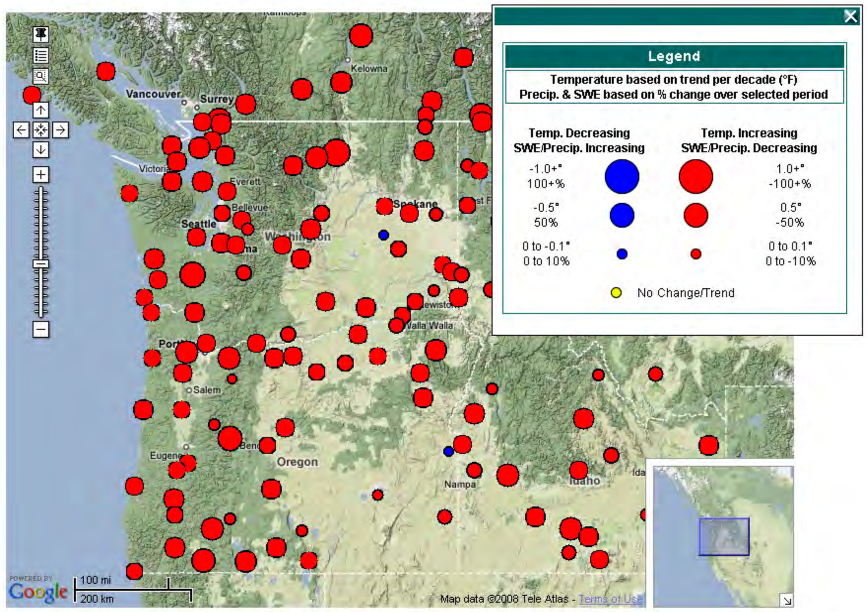

Figure 21. Map Showing a Predominantly Increasing Trend in Annual Average Air Temperature Based on Data from U.S. and Canadian Climate Stations, 1949–2006[22]

4.3 Water Temperature

Data for the water temperature analysis were compiled from continuous stream temperature records in and surrounding the reclaimed water planning area. Continuous records included all available 15-minute and hourly stream and river temperature data through 2007 in the King County monitoring program database and 15-minute data collected between 2000 and 2002 by the University of Washington (UW) for stations in the Green River and the Big Soos Creek basin (Cherkauer et al., 2005; Kay et al., 2005). In all, data from 161 King County stations and 20 UW stations were compiled. Much of the King County water temperature data were collected at the same locations as the streamflow gauges. King County continuous stream temperature records, however, are not as long as the longest streamflow records; the earliest continuous summer temperature records are from 1994.

Stream temperature data were analyzed to find the 7-day maximum temperature recorded over the period of record at each monitoring location. Data were not evaluated for data gaps. Annual maximum 7-day maximums and the average of the annual 7-day maximums were calculated. The analysis indicated that warm stream temperatures occur in streams and rivers throughout the reclaimed water planning area (Figure 22 and Figure 23). The mean 7-day maximum temperature is 19.6^{o}C (± 3.5). A maximum temperature of 29.4^{o}C was recorded in Springbrook Creek near the mouth. Most of these locations would be considered “core summer salmonid habitat” with a 7-day maximum Washington State temperature standard of 16^{o}C. Approximately 80 percent of the stations analyzed have exceeded this standard, and 60 percent of the stations have exceeded

[22] The map was created using the Northwest Temperature, Precipitation, and Snow Water Equivalent trend analysis tool provided by the Office of the Washington State Climatologist (http://www.climate.washington.edu/trendanalysis/).

the 17.5°C standard for the protection of salmonid spawning, rearing, and migration. For state water quality assessment purposes, the 7-day maximum temperature would have to exceed a standard only once to cause that stream reach to be listed on the 303(d) list—a list of state water bodies considered as not supporting designated beneficial uses.

The maximum recorded 7-day moving average of the maximum temperature and the average 7-day maximum temperature for all of the stations analyzed are summarized in Appendix C.

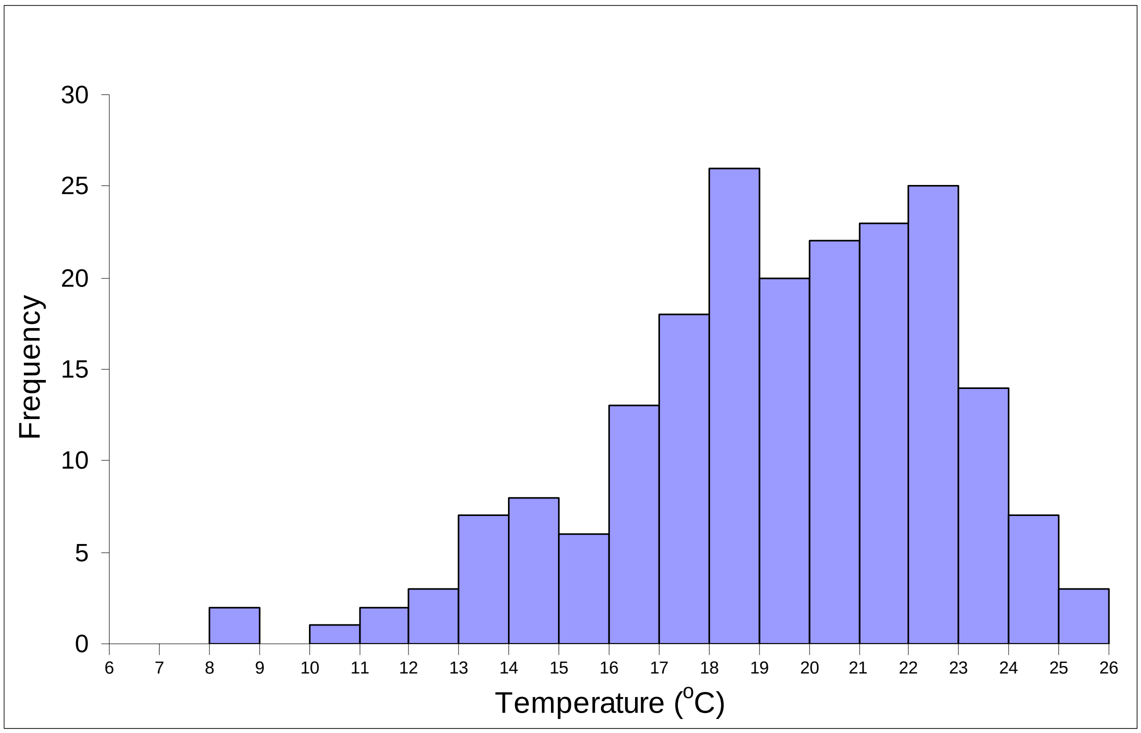

Figure 22. Frequency Distribution of Maximum 7-Day Average of Daily Maximum Water Temperatures (°C) in Reclaimed Water Planning Area

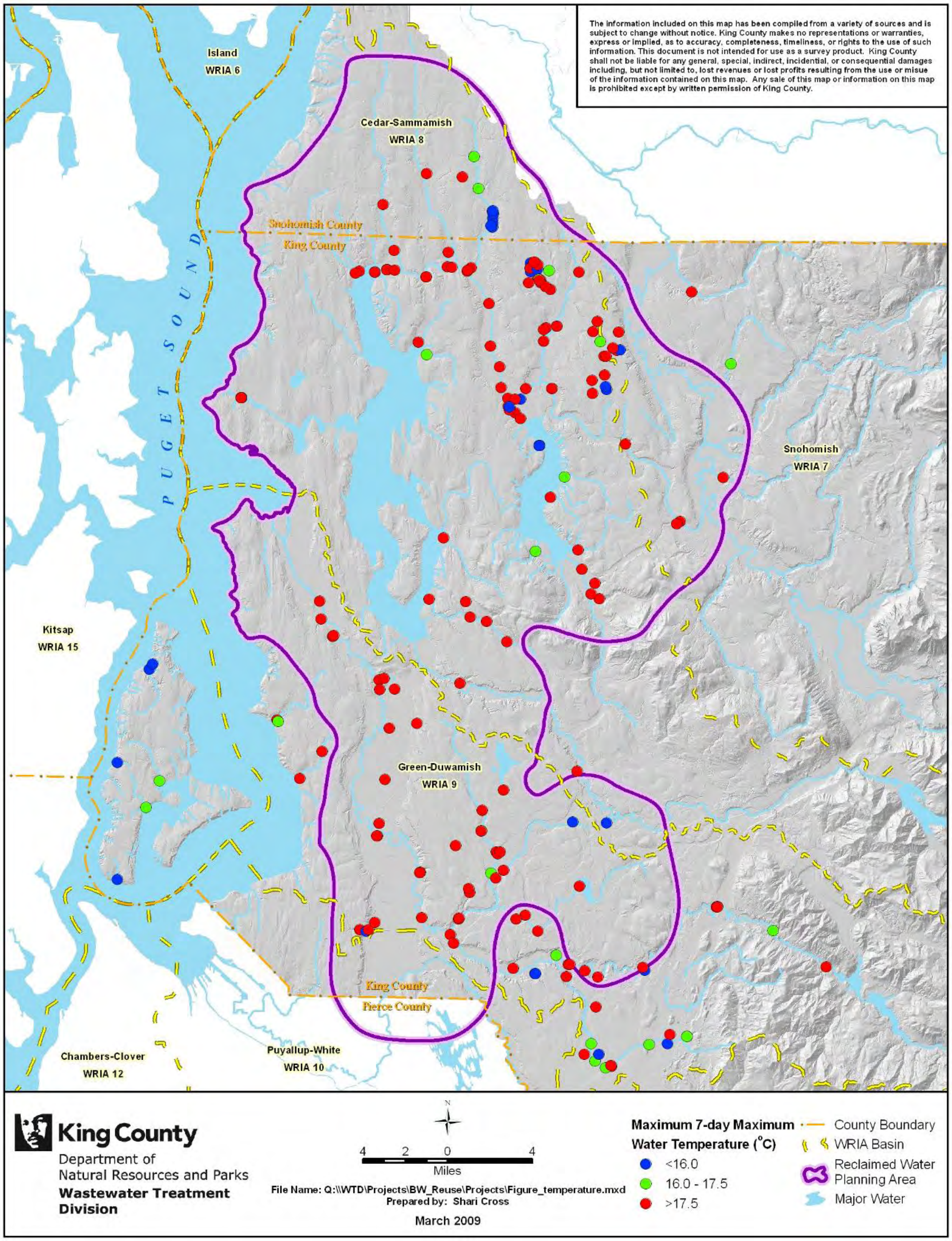

Figure 23. Map Showing the Distribution of the Maximum 7-Day Average of the Daily Maximum Water Temperature in the Reclaimed Water Planning Area

5.0 FINDINGS AND RECOMMENDATIONS

This section presents the findings and recommendations of the streams and rivers assessment.

5.1 Findings

The summary of findings of other studies and of the analyses conducted for this assessment is organized in three categories:

- Basins with multiple lines of evidence suggesting declines in summer low flows
- Basins with fewer lines of evidence suggesting declines in summer low flows
- Basins with limited evidence of declines in summer low flows

The location of each basin is shown in Figure 24; the sources for their identification are given in the text below and in Table 9 at the end of this section. The evidence includes consideration of instream flow rules. The WRIA 8 Instream Flow Rule essentially closes the entire WRIA to appropriation of any new surface water rights. Portions of other WRIAs are also closed to further surface water appropriations and to withdrawals if flows fall below specified levels.

Despite the gaps in flow and temperature data and the differences in the goals, study areas, and level and type of analysis of the studies used to identify streams with low-flow problems, the list presented in section is sound enough to use as a foundation for further studies.

5.1.1 Basins with Multiple Lines of Evidence Suggesting Declines in Summer Low Flows

Multiple lines of evidence suggest that summer low flows in 11 basins in the reclaimed water planning area have decreased as the result of a combination of withdrawals and development of effective impervious surface cover. Seven of the basins are in WRIA 8: Big Bear, Evans, mainstem Issaquah, East Fork Issaquah, North Fork Issaquah, and Rock Creeks, and the Sammamish River. The remaining four are in WRIA 9: Newaukum, Big Soos, Jenkins, and Covington Creeks.

Big Bear Creek Basin (WRIA 8)

Low-Flow Problems

- The Tributary Streamflow Technical Committee (2006) identified the Big Bear Creek basin as having the highest likelihood of benefit from flow restoration. The ranking was based on the basin’s high relative biological importance, hydrologic need (based on qualitative estimate of the ratio of potential groundwater withdrawals to summer low flow), and high probability of measurable benefit.
- Lombard and Somers (2004) identified summer-fall low-flow problems in the basin and suspected both withdrawals and development of effective impervious cover as the causes.

- Hartley and Funke (2001) observed decreases in summer low flow and concluded that the lower flows could not be completely accounted for by development of effective impervious surfaces and that water withdrawals were likely causes as well.

Low-Flow Trends

Data for gauges on Big Bear Creek did not meet the selection criteria for trend analysis for this report. Comparison of earlier flow data collected near the King County gauge near the mouth of Big Bear Creek (1940s and 1950s) with current summer low flows suggests a downward trend in the last decade.

Water Temperature

- Temperature data reviewed for this assessment confirm previous analyses that identified the Big Bear Creek basin as impaired for coldwater fish.
- Roberts and Jack (2006a) generally considered temperatures to be too high in basin streams to adequately support salmon spawning, rearing, and migration or to provide core summer salmon habitat.
- Ecology completed a water quality improvement study that focused on temperature and dissolved oxygen concentrations (Mohamedali and Lee, 2008). The study identified loss of streamside vegetation (which historically has provided shade) and reduced groundwater inflows (which tend to provide cooler water) as the primary causes of elevated water temperatures in the basin. Withdrawals for irrigation and drinking water and the development of effective impervious cover were cited as the primary causes of reduced groundwater inflows.

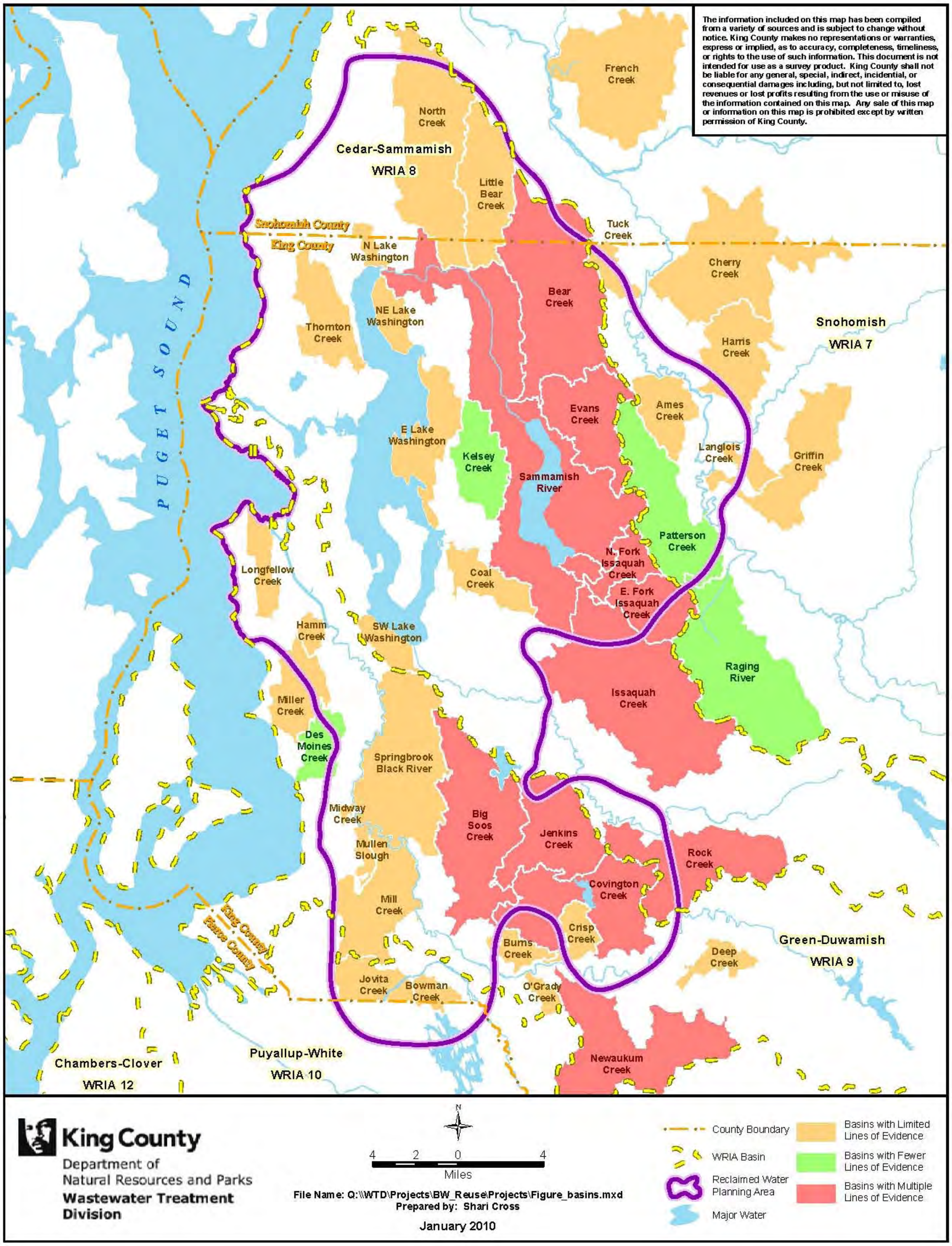

Figure 24. Locations of Basins Identified in this Assessment with Declines in Summer Low Flows

Evans Creek Basin (WRIA 8)

Low-Flow Problems

- The Tributary Streamflow Technical Committee (2006) identified the Evans Creek basin as having a low likelihood of benefit from additional water. Even though it was determined to have a high estimated hydrologic need, the basin was considered to be of relatively low biological importance.
- Lombard and Somers (2004) identified summer-fall low-flow problems in the basin and suspected both withdrawals and development of effective impervious cover as the causes.
- Hartley and Funke (2001) observed decreases in summer low flow and concluded that the lower flows could not be completely accounted for by development of effective impervious surfaces and that water withdrawals were likely causes as well.

Low-Flow Trends

The trend analysis for this report found strong evidence for a significant downward trend in summer low flow for Evans Creek.

Water Temperature

- Temperature data reviewed for this assessment confirm previous analyses that identified the Evans Creek basin as impaired for coldwater fish.
- Roberts and Jack (2006a) generally considered stream temperatures to be too high to adequately support salmon spawning, rearing, and migration or for providing core summer salmon habitat.
- Ecology completed a water quality improvement study that focused on temperature and dissolved oxygen concentrations (Mohamedali and Lee, 2008). The study identified loss of streamside vegetation (which historically has provided shade) and reduced groundwater inflows (which tend to provide cooler water) as the primary causes of elevated water temperatures in the basin. Withdrawals for irrigation and drinking water and the development of effective impervious cover were cited as the primary causes of reduced groundwater inflows.

Mainstem Issaquah Creek Basin (WRIA 8)

Low-Flow Problems

- The mainstem Issaquah Creek basin was ranked by the Tributary Streamflow Technical Committee (2006) as having a moderately high likelihood to benefit from flow restoration, primarily because of the large number of salmon using the creek.

Low-Flow Trends

- The trend analysis done for this report found very strong evidence of a downward trend (1964–2007) near the mouth of mainstem Issaquah Creek.[23]
- Ecology (1995b) identified a downward trend (1965–1992), which they attributed, in part, to precipitation declines over the same period and to declining groundwater levels from withdrawals and loss of infiltration from urbanization.
- Konrad and Booth (2002) found consistent evidence of a downward trend (1964–2000) and suggested that the decline was due to local groundwater withdrawals and export via the regional wastewater system.

Water Temperature

- Temperature data near the mouth of the creek indicate that the use of the creek as core summer salmon habitat is impaired.
- Ecology has listed mainstem Issaquah Creek as a “water of concern” for temperature (2004 final Clean Water Act 303(d) list).[24]

East Fork Issaquah Creek Basin (WRIA 8)

Low-Flow Problems

- The Tributary Streamflow Technical Committee (2006) ranked East Fork Issaquah Creek as having the highest likelihood of benefit from additional water because of its high estimated level of flow depletion, importance as Chinook and sockeye spawning habitat, and high probability of benefiting from additional water.
- Lombard and Somers (2004) identified summer-fall low-flow problems, most likely stemming from withdrawals, development of effective impervious cover, and changes to channel morphology.

Water Temperature

- Analysis of temperature data near the mouth of East Fork Issaquah Creek indicate that use of the creek as core summer salmon habitat is impaired.

North Fork Issaquah Creek Basin (WRIA 8)

Low-Flow Problems

- The Tributary Streamflow Technical Committee (2006) ranked North Fork Issaquah Creek as moderately likely to benefit from additional water. Members considered this creek to be depleted based on the magnitude of local well withdrawals relative to typical flow levels. However, it was considered to be of low biological importance because

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[23] Trend analysis was also done on data collected from a gauge in the upper reach of mainstem Issaquah Creek near Hobart. No significant evidence for a trend was found.

[24] King County continuous temperature data indicate warmer temperatures than those used by Ecology to make its determination.

spawning surveys indicated that low numbers of salmon used the creek and because there is a natural barrier that prevents upstream migration at River Mile 1.3.

- Lombard and Somers (2004) identified summer-fall low-flow problems, most likely stemming from withdrawals, development of effective impervious cover, and changes to channel morphology.

Low-Flow Trends

- The analysis done for this report found strong evidence of a downward trend (1988–2007) in low flow in North Fork Issaquah Creek.

Water Temperature

- Analysis of temperature data near the mouth of North Fork Issaquah Creek indicate that use of the creek as core summer salmon habitat is impaired.

Rock Creek Basin (WRIA 8)

Low-Flow Problems

- The Tributary Streamflow Technical Committee (2006) ranked Rock Creek as having a moderately high likelihood of benefit from additional water. The committee estimated that the basin had a high level of hydrologic need because of water withdrawals and that it had good-to-excellent habitat conditions.
- Lombard and Somers (2004) identified low-flow problems in the creek and attributed them to withdrawals and land use development.
- Adding water to Rock Creek was recommended in the *Lower Cedar River Basin and Nonpoint Pollution Action Plan* (King County, 1998), and low-flow issues will likely be addressed in the City of Kent's planned HCP.

Low-Flow Trends

In the analysis for this report, visual inspection of long-term flow records with several years of missing data suggests that 7-day low flow in Rock Creek has declined from historical levels.

Water Temperature

Temperature data for a location near the mouth of Rock Creek suggest that summer maximum water temperatures are adequate for use by salmon.

Sammamish River Basin (WRIA 8)

Low-Flow Problems

- The Tributary Streamflow Technical Committee (2006) gave the Sammamish River an overall ranking of moderate likelihood of benefit from flow restoration. The committee commented that the river might have ranked higher if the amount of flow to be added had been greater. The river was considered to be of high biological importance and to have a moderate level of hydrologic need.

- Lombard and Somers (2004) identified the Upper Sammamish River as having low-flow problems. The problems were attributed to withdrawals, development, and channel changes.

Low-Flow Trends

The trend analysis conducted for this report confirmed the trend pattern seen in the previous study conducted by Ecology (1995b). The analyses found strong evidence of a significant downward trend in mean annual flow but no significant trend in summer low flow. Ecology suggested that this trend may be due to summer storage and release of water from Lake Sammamish that mask the effect of low-flow decreases noted in the two largest tributaries to the Sammamish River—Big Bear Creek and Issaquah Creek.

Water Temperature

Temperature data analyzed at locations along the Sammamish River confirm statements made by the Tributary Streamflow Technical Committee (2006) that summer maximum water temperatures are high enough to impair the use of the river as core summer salmon habitat.

Newaukum Creek Basin (WRIA 9)

Low-Flow Problems

Although Northwest Hydraulic Consultants (2005) found Newaukum Creek to be the least impacted basin in the Green-Duwamish watershed in terms of water extracted for human use, other studies have identified low-flow problems in the basin:

- The Tributary Streamflow Technical Committee (2006) identified Newaukum Creek as having a moderately high likelihood of benefit from additional water. This ranking was based on the creek's importance for natural reproduction of coho, steelhead, and Chinook and on the magnitude of water withdrawals relative to typical summer low flows.
- Lombard and Somers (2004) also identified a low-flow problem and suspected withdrawals, land use development, and channel changes as the primary causes.

Low-Flow Trends

- The analysis done for this assessment identified very strong evidence for a downward trend (1953–2007) in summer low flow at the mouth of Newaukum Creek.
- Ecology (1995d) also found evidence for a downward trend (1953–1992) in the creek and attributed it, in part, to long-term declines in total annual precipitation. Groundwater extraction was identified as the primary contributor to the overall decline.
- Konrad and Booth (2002) identified a consistent downward trend (parametric and non-parametric), which they thought might be due to shallow groundwater extraction.

Water Temperature

- Temperature data confirm previous analyses (Roberts and Jack, 2006b) that identified Newaukum Creek basin streams as impaired for coldwater fish.

- Ecology is currently conducting a water quality improvement study that focuses on temperature and dissolved oxygen concentrations in the basin.

Big Soos Creek Basin (WRIA 9)

Low-Flow Problems

- The Tributary Streamflow Technical Committee (2006) identified the Big Soos Creek basin as having the highest likelihood of benefit from flow restoration, mainly because of its overall biological importance and hydrologic need and the probability of benefit for mainstem Big Soos Creek.
- Lombard and Somers (2004) identified summer-fall low-flow in the Big Soos Creek basin as a problem for fish and attributed the problem to withdrawals and land use development.
- Northwest Hydraulic Consultants (2005) ranked the Big Soos Creek basin high in terms of relative flow impacts from water extracted for human use, and highlighted that over half of the projected future urban level of development in the Green-Duwamish watershed was planned to occur in the basin.

Low-Flow Trends

- The analysis for this report identified very strong evidence for a downward trend (1967–2007) in summer low flow at the mouth of Big Soos Creek.[25]
- Ecology (1995d) also found such a downward trend in the creek (1967–1991) and attributed the trend to long-term declines in total annual precipitation and a combination of groundwater extractions and development of effective impervious cover.
- Konrad and Booth (2002) noted that in parts of the Big Soos Creek basin, water is supplied by groundwater pumping and that wastewater is collected, treated, and discharged out of the basin—a combination that might deplete streamflow in the basin. It appears that they did not identify a significant downward trend in low flow because the data used in the analysis included data from years when some flow in the creek was diverted by a nearby fish hatchery.

Water Temperature

- Temperature data confirm the findings of a previous analysis (Timm et al., 2008) that identified the creek as impaired for coldwater fish.
- Ecology is currently conducting a water quality improvement study that focuses on temperature and dissolved oxygen concentrations in the basin.

[25] Covington and Jenkins Creeks were the only other two creeks in the Big Soos Creek basin that were considered to have sufficient flow data for trend analysis. Statistical analysis suggested no significant evidence of a trend (1988–2007) in low flow in these creeks.

Jenkins Creek Basin (WRIA 9)

Low-Flow Problems

- The Tributary Streamflow Technical Committee (2006) identified the Jenkins Creek basin as having the highest likelihood of benefit from flow restoration, mainly because of its overall biological importance and hydrologic need and the probability of benefit for mainstem Big Soos Creek.
- Northwest Hydraulic Consultants (2005) estimated that Jenkins Creek had the greatest low-flow impact relative to other streams in the Green-Duwamish watershed.

Water Temperature

- Temperature data confirm the findings of a previous analysis (Timm et al., 2008) that identified the creek as impaired for coldwater fish.
- Ecology is currently conducting a water quality improvement study that focuses on temperature and dissolved oxygen concentrations in the basin.

Covington Creek Basin (WRIA 9)

Low-Flow Problems

- The Tributary Streamflow Technical Committee (2006) identified the Covington Creek basin as having the highest likelihood of benefit from flow restoration, mainly because of its overall biological importance and hydrologic need and the probability of benefit for mainstem Big Soos Creek.
- Northwest Hydraulic Consultants (2005) estimated that Covington Creek had the greatest low-flow impact relative to other streams in the Green-Duwamish watershed.

Water Temperature

- Temperature data confirm the findings of a previous analysis (Timm et al., 2008) that identified the creek as impaired for coldwater fish.
- Ecology is currently conducting a water quality improvement study that focuses on temperature and dissolved oxygen concentrations in the basin.

5.1.2 Basins with Fewer Lines of Evidence Suggesting Declines in Summer Low Flows

Four basins in or very near the reclaimed water planning area show fewer lines of evidence than the basins described above that suggest that summer low flows have been reduced by a combination of withdrawals and development of effective impervious surface cover. These basins are Patterson Creek and the Raging River in WRIA 7, Mercer (Kelsey) Creek in WRIA 8, and Des Moines Creek in WRIA 9.

Patterson Creek Basin (WRIA 7)

Low-Flow Problems

- Lombard and Somers (2004) identified Patterson Creek as having summer-fall low-flow problems and suspected that withdrawals and land use development were the causes.

- The WRIA 7 Instream Flow Rule specifically closed the Patterson Creek basin to further appropriation of new surface water rights.

Low-Flow Trends

The analysis done for this report found strong evidence of a downward trend (1990–2007) in summer low flow for one streamflow gauge on Patterson Creek.

Water Temperature

Temperature data for two locations on Patterson Creek suggest that summer maximum water temperatures are high enough to consider the creek to be impaired for use by salmon.

Raging River Basin (WRIA 7)

Low-Flow Problems

- Lombard and Somers (2004) identified the Raging River as having summer-fall low-flow problems.
- The WRIA 7 Instream Flow Rule specifically closed the Raging River to further appropriation of new surface water rights.

Low-Flow Trends

Weak evidence for a downward trend (1965–2007) in summer low flow was found in the analysis for this report.

Water Temperature

Although no continuous temperature data were available for analysis, elevated summer water temperature in the Raging River was noted in a temperature total maximum daily load (TMDL) study conducted by Ecology (Sargeant and Svrjcek, 2008). King County is conducting a follow-up study of the Raging River.

Mercer (Kelsey) Creek Basin (WRIA 8)

Low-Flow Trends

- The analysis done for this report found strong evidence of an overall upward trend (1956–2007) for summer low flow in Mercer (Kelsey) Creek, although visual inspection of the time series data indicated an apparent upward and then downward trend in the data. Analysis of the trend in low flow over the period 1990–2007 indicated strong evidence for a downward trend in recent years.
- Konrad and Booth (2002) also found a consistent upward low-flow trend in Mercer (Kelsey) Creek (1956–2000). The authors suggested that the trend might be due to importation of water for domestic use, while also indicating that much of the wastewater in the basin is routed out of the basin through delivery to the regional wastewater system. Konrad and Booth did not note the apparent upward and then downward trend, but did say that the summer low-flow metric was the most sensitive to the moving 10-year period of record used to test the effect of record length on trend testing results.

Water Temperature

Although no continuous temperature data were available for analysis, Ecology has listed Mercer (Kelsey) Creek as temperature impaired based on instantaneous monthly observations.

Des Moines Creek Basin (WRIA 9)

Low-Flow Problems

- Although Lombard and Somers (2004) did not specifically identify Des Moines Creek as having low-flow problems, they did say that Puget Sound drainages in general were experiencing low-flow problems as the result of development.
- The WRIA 9 Instream Flow Rule established the Des Moines Creek basin as closed to further appropriation of new surface water rights.
- The *Des Moines Creek Basin Plan* includes a recommendation for adding water to increase summer creek flows (Des Moines Creek Basin Committee, 1997).

Low-Flow Trends

The analysis done for this report found strong evidence for a downward trend (1990–2007) in summer low flow for Des Moines Creek.

Water Temperature

Temperature data (two stations) indicate that Des Moines Creek is impaired for use by salmon during the summer.

5.1.3 Basins with Limited Evidence of Declines in Summer Low Flows

Several streams in or very near the reclaimed water planning area were identified in one or more sources reviewed for this assessment as having streamflow problems.

WRIA 7

- **Cherry, Tuck, and Ames Creeks—**identified by Lombard and Somers (2004) as having low-flow problems.
- **Harris and Griffin Creek**s**—**identified by Lombard and Somers (2004) as having low-flow problems; year-round surface water closures as part of WRIA 7 Instream Flow Rule.
- **Langlois Creek—**identified by Lombard and Somers (2004) as having low-flow problems; surface water closures as part of WRIA 7 Instream Flow Rule when flows drop below 3.0 cfs.
- **French Creek—**surface water closures as part of WRIA 7 Instream Flow Rule when flows drop below 0.75 cfs.

WRIA 8

- **North and Little Bear Creeks—**identified by Lombard and Somers (2004) as having low-flow problems, while considered by the Tributary Streamflow Technical Committee

(2006) as having a low hydrologic need and overall low likelihood of benefit from flow restoration.

- **Thornton and Coal Creeks—**identified by Lombard and Somers (2004) as having low-flow problems.
- **Unnamed tributary at the north end of Lake Washington and tributaries northeast, east, southwest of Lake Washington—**identified by Lombard and Somers (2004) as having low-flow problems, presumed to be the result of development in these areas.

WRIA 9

- **Mullen Slough and Longfellow, Hamm, Midway, Mill, Burns, Crisp, and O'Grady Creeks (and unnamed creek between Burns and Big Soos Creeks)—**identified by Lombard and Somers (2004) as having low-flow problems presumably from development in these areas and from withdrawals from Hamm, Burns, and O'Grady Creeks.
- **Springbrook/Black River system—**identified by Lombard and Somers (2004) as having low-flow problems; several established closures as part of WRIA 9 Instream Flow Rule.
- **Miller Creek and basins north and south of Miller Creek:**
  - The creeks are part of Puget Sound drainages, which were identified by Lombard and Somers (2004) as having low-flow problems caused by development.
  - The WRIA 9 Instream Flow Rule established Miller Creek closures and closed the creek to further appropriation of new surface water rights.
  - Data reviewed for this assessment indicate that water temperature in Miller Creek may be too high for use by salmon.
- **Deep Creek—**surface water closures as part of WRIA 9 Instream Flow Rule.

WRIA 10

- **Bowman and Jovita Creeks—**identified by Lombard and Somers (2004) as having low-flow problems.
- **Hylebos Creek—**identified by Lombard and Somers (2004) as having low-flow problems and is subject to surface water closures as part of the WRIA 10 Instream Flow Rule.
- **Wapato Creek—**subject to surface water closures as part of the WRIA 10 Instream Flow Rule.

5.2 Recommendations for Further Technical Work

In general, the weight of evidence from previous studies reviewed and from additional analyses conducted provides sufficient support for the assertion that summer low flows have declined in several King County streams as a result of the natural hydrologic cycle and of human alteration of the landscape. However, a number of limitations hampered the flow trend analyses performed in this assessment:

- No flow records predate significant human development, which makes it difficult to establish pre-development low-flow conditions for comparison to current conditions.

- Few flow gauging records are of sufficient length or quality to allow for meaningful statistical trend analysis.
- Flow gauges have not been established in every basin.
- Although a trend may be evident through the present, it is difficult to extrapolate these trends into the future.
- It is difficult to distinguish changes in low flow caused by climate (precipitation and temperature) from those caused by land cover change and/or water management activities.

Depending on the strength of the statistical relationship between annual precipitation and flow, especially 7-day low flow, future assessments could include the precipitation time series in the flow trend analysis in order to better distinguish the effects of climate variability from the effects of development and water demand. However, trends cannot be extrapolated to other locations in a basin or to ungauged basins.

It may also be possible to (1) develop models using the compilation of statewide baseflow information provided in Sinclair and Pitz (1999) to estimate pre-development seasonal low flow and (2) perform mechanistic hydrologic modeling to evaluate the importance of increasing air temperature on evaporation/evapotranspiration to observed streamflow declines.

To better understand the overall water balance in each basin, it is recommended that the methods used in the analysis developed by King County (2001) for WRIA 8 be refined and extended to cover both WRIA 8 and WRIA 9. This type of analysis has the potential to illustrate and contrast the negative effects of land development caused by effective impervious area and consumptive withdrawals. Estimates of net water export (or import) needed for the analysis allows for more explicit consideration of various water management activities. A full accounting method such as this would help provide better spatial data suitable for evaluating the potential benefit of additional water for streams throughout the region.

Although these recommendations would improve the understanding of historical low-flow conditions and the causes of observed or estimated declines in flow, the challenge remains to connect changes (or improvements) in low flow to measurable aquatic ecosystem benefits. Relatively long-term flow data exist for some locations, but biological resource data such as numbers and types of fish or benthic invertebrates are limited in spatial and temporal extent.

There may be some limitations to restoring only low flow in streams in basins with higher levels of effective impervious cover. Comparisons of biological data to various components of the flow regime (using the Benthic Index of Biological Integrity) indicate that high flows may be more important than low flows in determining stream biological integrity (DeGasperi et al., 2009). This finding is consistent with the natural flow regime concept introduced earlier in this report. Although effective impervious cover reduces infiltration and low flow, it also results in more frequent high flows, which may offset benefits of adding water during summer low flow.

Finally, connecting improvements in the streamflow regime to improvements in the health of the aquatic ecosystem would provide exceptionally useful information for assessing tradeoffs between various water resource management decisions. Coupled hydrologic-ecosystem models have been developed and used in this region in recent years to evaluate restoration questions related to flow and water temperature (for example, Bartz et al., 2006). These types of models developed at the local and/or regional scale might be useful management tools.

Table 9. Preliminary List of Basins in the Reclaimed Water Planning Area with Declines in Summer Low Flows

Stream Basin	Tributary Streamflow Technical Committee (TSTC) (WRIAs 8 & 9)[a]	Ecology (1995b; 1995d) (WRIA 8 & 9)[b]	Konrad & Booth (2002) (Puget Sound Basin)[c]	King County (2001) (WRIA 8)[d]	Lombard & Somers (2004) (Central Puget Sound)[e]	NHC (2005) (WRIA 9)[f]	Instream Flow Rule: Low-Flow Limits	Instream Flow Rule: Closed to Further Surface Water Rights	King County (2009): Downward Trend in Low Flow (planning area)[g]	King County (2009): Elevated Water Temp. (planning area)[h]	Comments
WRIA 7—Snohomish Watershed											
Patterson Creek					X			X	X	X	
Raging River								X	X	X	Elevated summer water temperature noted during Ecology temperature TMDL study. Follow-up study in progress.
Cherry Creek					X						
Tuck Creek					X						
Ames Creek					X						
Harris Creek					X		X				
Griffin Creek					X		X				
Langlois Creek							X				
French Creek							X				
WRIA 8—Cedar-Sammamish Watershed											
Big Bear Creek	X			X	X			X		X	• TSTC considered creek to be an important contributor to natural salmon production and to have a high ratio of potential groundwater withdrawals to summer low flow. • Reductions in summer low flow noted in paired basin study published by Hartley and Funke (2001). • Mohamedali and Lee (2008) and Roberts and Jack (2006a) identified elevated water temperatures.
Evans Creek				X	X		X	X	X	X	• Ranked lower by TSTC primarily because relative biological importance was considered to be low. • Reductions in summer low flow noted in paired basin study published by Hartley and Funke (2001). • Mohamedali and Lee (2008) and Roberts and Jack (2006a) identified elevated water temperatures.
Mainstem Issaquah Creek	X	X	X					X	X	X	• Ranked moderately high by TSTC because of support of large numbers of salmon, migration delays due to low flow, and observed pre-spawn mortality. • Listed by Ecology as a “water of concern” based on temperature.
East Fork Issaquah Creek	X				X			X		X	TSTC considered creek to be an important contributor to high numbers of Chinook and sockeye and to have a high estimated level of flow depletion.
North Fork Issaquah Creek				X	X			X	X	X	Ranked lower by TSTC primarily because relative biological importance was considered to be low.
Mercer (Kelsey) Creek				X				X	X	X	Visual inspection of the long-term record indicates that low flow initially increased and has declined since the mid-1980s.
Rock Creek (tributary of the Cedar River)	X			X	X			X	X		• Additional water inputs recommended in the *Lower Cedar River Basin and Nonpoint Pollution Plan* (King County, 1998). • City of Kent is preparing an HCP for its Clark Springs withdrawal. • City of Seattle HCP establishes flow rules for maintenance of minimum flows on the Cedar River and for supplementing flows to aid salmon migration. • Instream flow rules apply to the Cedar River at the USGS gauge near Renton.
Sammamish River					X (upper river)			X		X	• Ranked moderate by TSTC, which noted that the river might have ranked higher if the amount of flow to be added had been greater.
North Creek					X						
Little Bear Creek					X						
Thornton Creek					X						

Stream Basin	Tributary Streamflow Technical Committee (TSTC) (WRIAs 8 & 9)[a]	Ecology (1995b; 1995d) (WRIA 8 & 9)[b]	Konrad & Booth (2002) (Puget Sound Basin)[c]	King County (2001) (WRIA 8)[d]	Lombard & Somers (2004) (Central Puget Sound)[e]	NHC (2005) (WRIA 9)[f]	Instream Flow Rule: Low-Flow Limits	Instream Flow Rule: Closed to Further Surface Water Rights	King County (2009): Downward Trend in Low Flow (planning area)[g]	King County (2009): Elevated Water Temp. (planning area)[h]	Comments
Coal Creek					X						
Lake Washington tributaries					X						
WRIA 9—Green-Duwamish Watershed											
Big Soos Creek	X	X			X	X			X	X	• NHC (2005) estimated that total net export of water was equivalent to 33 percent of the August median 7-day low flow. • Over half of projected future urban development in the Green-Duwamish watershed is planned to occur in the Big Soos Creek basin (NHC, 2005). • TSTC ranked Big Soos Creek basin as having the highest likelihood of biological benefit. • Ecology temperature TMDL in progress.
Covington Creek	X				X	X				X	• NHC (2005) estimated that total net export of water was equivalent to 69 percent of the August median 7-day low flow • TSTC ranked Covington Creek basin as having the highest likelihood of biological benefit. • Ecology temperature TMDL in progress.
Jenkins Creek	X				X	X				X	• NHC (2005) estimated that total net export of water was equivalent to 41 percent of the August median 7-day low flow. • TSTC ranked Jenkins Creek basin as having the highest likelihood of biological benefit. • Ecology temperature TMDL in progress.
Des Moines Creek					X			X	X	X	Additional water inputs recommended in1997 *Des Moines Creek Basin Plan,* but not yet fully implemented.
Newaukum Creek	X	X	X		X				X	X	• NHC (2005) estimated that total net export of water was equivalent to 11 percent of the August median 7-day low flow. • TSTC ranked as moderately high likelihood of biological benefit due to high numbers of spawning Chinook and steelhead and migration delays caused by low flow. • Ecology is conducting a water quality improvement study that focuses on temperature and dissolved oxygen. • Ecology temperature TMDL in progress.
Mullen Slough					X						
Longfellow Creek					X						
Hamm Creek					X						
Midway Creek					X						
Mill Creek					X						
Burns Creek					X						
Crisp Creek					X						
O'Grady Creek					X						
Unnamed creek between Burns and Big Soos Creeks					X						
Springbrook/Black River system					X		X				
Miller Creek (and basins north and south)					X			X			
Deep Creek							X				
WRIA 10—Puyallup-White											
Bowman Creek					X						

							Instream Flow Rule		King County (2009)		
Stream Basin	**Tributary Streamflow Technical Committee (TSTC) (WRIAs 8 & 9)[a]**	**Ecology (1995b; 1995d) (WRIA 8 & 9)[b]**	**Konrad & Booth (2002) (Puget Sound Basin)[c]**	**King County (2001) (WRIA 8)[d]**	**Lombard & Somers (2004) (Central Puget Sound)[e]**	**NHC (2005) (WRIA 9)[f]**	**Low-Flow Limits**	**Closed to Further Surface Water Rights**	**Downward Trend in Low Flow (planning area)[g]**	**Elevated Water Temp. (planning area)[h]**	**Comments**
Jovita Creek					X						
Hylebos Creek					X		X				
Wapato Creek							X				

Ecology = Washington State Department of Ecology.
HCP = habitat conservation plan.
NHC = Northwest Hydraulic Consultants.
TMDL = total maximum daily load.
TSTC = Tributary Streamflow Technical Committee.
USGS = U.S. Geological Survey.
WRIA = water resource inventory area.

[a] Ranked 20 streams in WRIAs 8 and 9 for likely benefit from substitution of 2 cfs of water supply with other water sources. Streams ranked as highest or moderately high likelihood of benefit are listed here.
[b] Examined (1) long-term USGS flow records at Big Soos Creek, Newaukum Creek, and the Auburn gauge on the mainstem Green River; (2) precipitation records; and (3) instantaneous water rights to determine reasons for downward trends in low flow at these locations.
[c] Examined long-term (at least 30 years) of flow data for streams in Puget Sound basin and 1995 road densities to analyze connection between urban development and downward trends in low flow.
[d] Determined a Base Flow Change Index (BCFI) for streams in WRIA 8. Streams with an extreme (>50 %) or high (26–50 %) low-flow reduction from pre-development to current conditions are listed here.
[e] Reviewed existing information on human-induced streamflow reductions to identify streams in the Central Puget Sound region with the most obvious and serious low-flow problems (did not rank the streams).
[f] Northwest Hydraulic Consultants examined how water extracted for human use affected streamflows in basins in WRIA 9 (Green-Duwamish watershed).
[g] Streams in the reclaimed water planning area with statistically significant ($p < 0.1$) decreasing trend in observed summer low flow since 1990 (trend analysis conducted for the assessment documented in this report).
[h] Streams in the reclaimed water planning area where the 7-day moving average of the daily maximum temperature has exceeded summer stream temperature standards (temperature analysis conducted for the assessment documented in this report).

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Appendix A
Statistical Trend Test Tables

Table 1. Trend analysis results for the 22 stream flow gauges selected for analysis of long-term trends in annual minimum 7-day average flow

Table 2. Trend analysis results for the 22 stream flow gauges selected for analysis of long-term trends in mean annual flow

Table 1. Trend analysis results for the 22 stream flow gauges selected for analysis of long-term trends in annual minimum 7-day average flow

Gauge	Description	tau	p	Years	Intercept (cfs)	Slope (cfs/yr)	Average Annual Min 7-Day Low Flow	Annual Percent Increase or Decline
02a	Bear Creek @ Union Hill RD	-0.242	0.1443	20	485.7	-0.235	16.8	-1.4
12112600	BIG SOOS CREEK ABOVE HATCHERY NEAR AUBURN	-0.379	0.0005	41	451.6	-0.214	26.6	-0.8
48b	Canyon Creek at Aldera Farms	0.092	0.6222	18	-25.6	0.014	1.8	0.8
09a	Covington Creek near Mouth, at 168th WY SE - Soos	0.032	0.8711	20	-7.8	0.005	2.1	0.2
11c	Des Moines Creek above Tyee Regional Pond	-0.314	0.0748	18	19.8	-0.010	0.2	-4.9
11d	Des Moines Creek below SR 509, Des Moines (near mo	-0.483	0.0103	16	92.9	-0.046	1.0	-4.5
18a	Evans Creek @ Union Hill Road	-0.346	0.0489	18	167.8	-0.082	3.5	-2.3
12120600	ISSAQUAH CREEK NEAR HOBART	0.133	0.4122	21	-107.2	0.058	8.8	0.7
12121600	ISSAQUAH CREEK NEAR MOUTH NEAR ISSAQUAH	-0.515	<0.0001	44	661.4	-0.322	22.9	-1.4
46a	Issaquah Creek, North Fork	-0.326	0.0478	20	61.3	-0.030	0.6	-5.0
26a	Jenkins Creek near Mouth - Soos Creek Watershed	0.095	0.5813	20	-101.6	0.056	9.5	0.6
15c	Laughing Jacobs Creek at E Lake Sammamish Pkwy	0.233	0.2241	16	-9.0	0.005	0.2	2.6
37a	May Creek @ Mouth	-0.228	0.1837	19	84.0	-0.040	3.3	-1.2
37b	May Creek at Coal Creek PKWY	-0.221	0.2322	17	35.7	-0.018	0.7	-2.7
12120000	MERCER CREEK NEAR BELLEVUE	0.226	0.0183	52	-62.4	0.034	5.5	0.6
42b	Miller Creek Detention Facility	-0.190	0.2889	18	11.2	-0.006	0.2	-2.5
42a	Miller Creek near Mouth	0.263	0.1237	19	-25.7	0.014	1.5	0.9
12108500	NEWAUKUM CREEK NEAR BLACK DIAMOND	-0.462	<0.0001	55	285.5	-0.137	14.9	-0.9
48a	Patterson Creek at Aldera Farms	-0.431	0.0137	18	198.3	-0.097	5.1	-1.9
12145500	RAGING RIVER NEAR FALL CITY	-0.198	0.0702	41	142.3	-0.066	11.4	-0.6
12125200	SAMMAMISH RIVER NEAR WOODINVILLE	-0.149	0.1802	40	436.1	-0.193	53.6	-0.4
31h	Taylor Creek at Mouth	-0.287	0.1172	17	62.9	-0.031	1.8	-1.7

Table 2. Trend analysis results for the 22 stream flow gauges selected for analysis of long-term trends in mean annual flow

Gauge	Description	tau	p	Years	Intercept (cfs)	Slope (cfs/yr)	Average Annual Min 7-Day Low Flow	Annual Percent Increase or Decline
02a	Bear Creek @ Union Hill RD	0.147	0.3810	20	-1099.0	0.586	76.7	0.8
12112600	BIG SOOS CREEK ABOVE HATCHERY NEAR AUBURN	-0.090	0.4123	41	933.1	-0.407	123.6	-0.3
48b	Canyon Creek at Aldera Farms	-0.029	0.9016	17	43.1	-0.018	7.1	-0.3
09a	Covington Creek near Mouth, at 168th WY SE - Soos	-0.029	0.8887	19	401.0	-0.184	30.8	-0.6
11c	Des Moines Creek above Tyee Regional Pond	0.088	0.6505	17	-38.1	0.020	2.2	0.9
11d	Des Moines Creek below SR 509, Des Moines (near mo	0.150	0.4440	16	-191.2	0.099	7.1	1.4
18a	Evans Creek @ Union Hill Road	0.133	0.4149	21	-267.9	0.144	19.7	0.7
12120600	ISSAQUAH CREEK NEAR HOBART	<0.0001	1.0000	21	41.4	0.001	46.4	0.0
12121600	ISSAQUAH CREEK NEAR MOUTH NEAR ISSAQUAH	-0.214	0.0421	44	1881.0	-0.881	130.3	-0.7
46a	Issaquah Creek, North Fork	-0.042	0.8203	20	42.3	-0.018	6.6	-0.3
26a	Jenkins Creek near Mouth - Soos Creek Watershed	-0.011	0.9741	20	90.4	-0.027	38.0	-0.1
15c	Laughing Jacobs Creek at E Lake Sammamish Pkwy	0.100	0.6204	16	-165.1	0.085	5.7	1.5
37a	May Creek @ Mouth	-0.059	0.7619	18	264.5	-0.122	22.6	-0.5
37b	May Creek at Coal Creek PKWY	0.029	0.9016	17	-99.2	0.055	12.6	0.4
12120000	MERCER CREEK NEAR BELLEVUE	0.071	0.4630	52	-38.8	0.031	22.4	0.1
42b	Miller Creek Detention Facility	-0.072	0.7049	18	31.9	-0.015	2.7	-0.5
42a	Miller Creek near Mouth	0.029	0.9016	17	-9.1	0.008	8.0	0.1
12108500	NEWAUKUM CREEK NEAR BLACK DIAMOND	-0.170	0.0673	55	550.8	-0.248	57.9	-0.4
48a	Patterson Creek at Aldera Farms	0.029	0.9016	17	-146.9	0.083	19.9	0.4
12145500	RAGING RIVER NEAR FALL CITY	-0.110	0.3175	41	782.7	-0.327	126.8	-0.3
12125200	SAMMAMISH RIVER NEAR WOODINVILLE	-0.223	0.0438	40	4775.0	-2.254	303.8	-0.7
31h	Taylor Creek at Mouth	0.133	0.4995	16	-268.6	0.139	10.8	1.3

Appendix B
Statistical Trend Test Figures

Time Series Plot Showing		
Long-term 7-day low flow	**Long-term mean annual flow**	**Near/on**
Figure 1	Figure 23	Big Bear Creek
Figure 2	Figure 24	Big Soos Creek
Figure 3	Figure 25	Canyon Creek
Figure 4	Figure 26	Covington Creek
Figure 5 Figure 6	Figure 27 Figure 28	Des Moines Creek
Figure 7	Figure 29	Evans Creek
Figure 8 Figure 9 Figure 10	Figure 30 Figure 31 Figure 32	Issaquah Creek
Figure 11	Figure 33	Jenkins Creek
Figure 12	Figure 34	Laughing Jacobs Creek
Figure 13 Figure 14	Figure 35 Figure 36	May Creek
Figure 15	Figure 37	Mercer (Kelsey) Creek
Figure 16 Figure 17	Figure 38 Figure 39	Miller Creek
Figure 18	Figure 40	Newaukum Creek
Figure 19	Figure 41	Patterson Creek
Figure 20	Figure 42	Raging River
Figure 21	Figure 43	Sammamish River
Figure 22	Figure 44	Taylor Creek

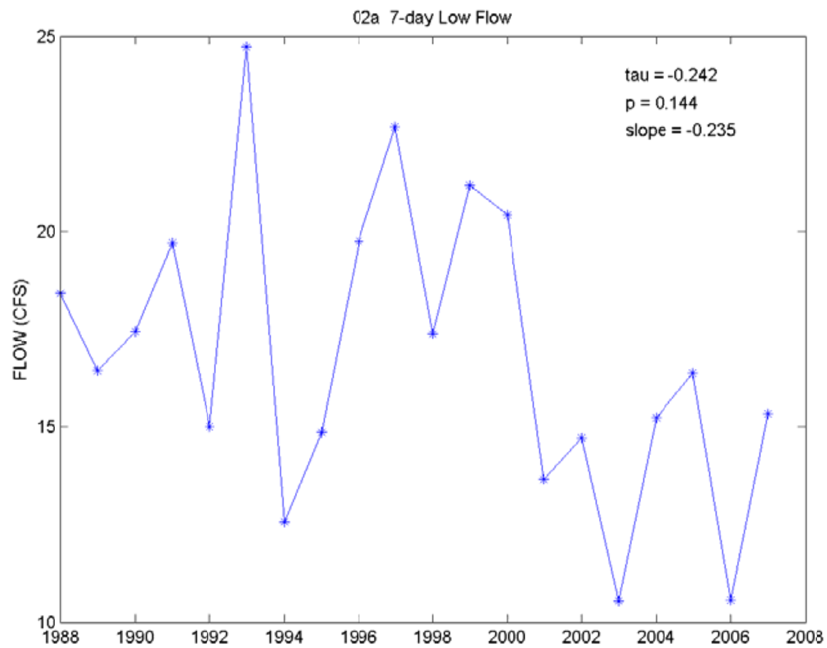

Figure 1. Time series plot showing long-term 7-day low flow at King County gauge 02a near the mouth of Big Bear Creek.

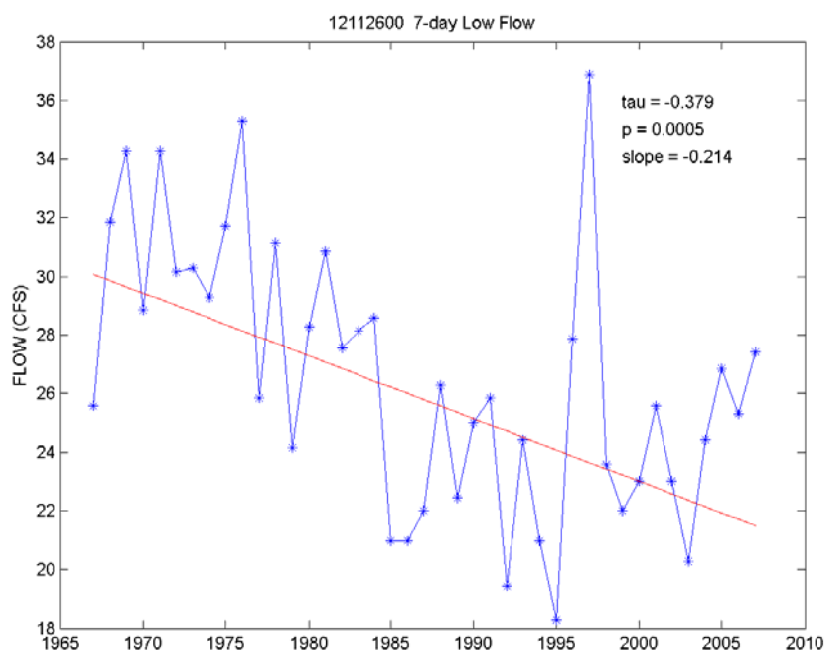

Figure 2. Time series plot showing long-term 7-day low flow at USGS gauge 12112600 near the mouth of Big Soos Creek.

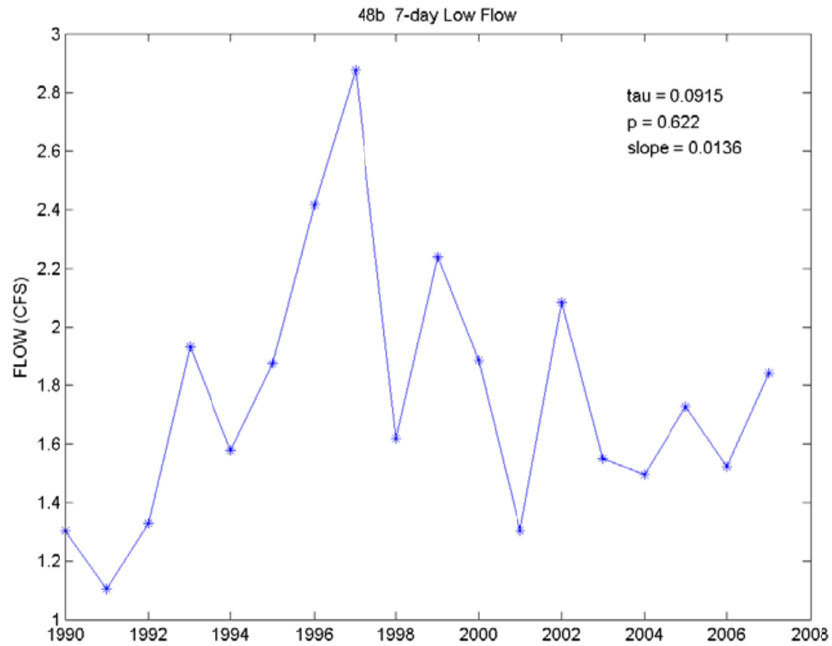

Figure 3. Time series plot showing long-term 7-day low flow at King County gauge 48b on Canyon Creek near Aldera Farms.

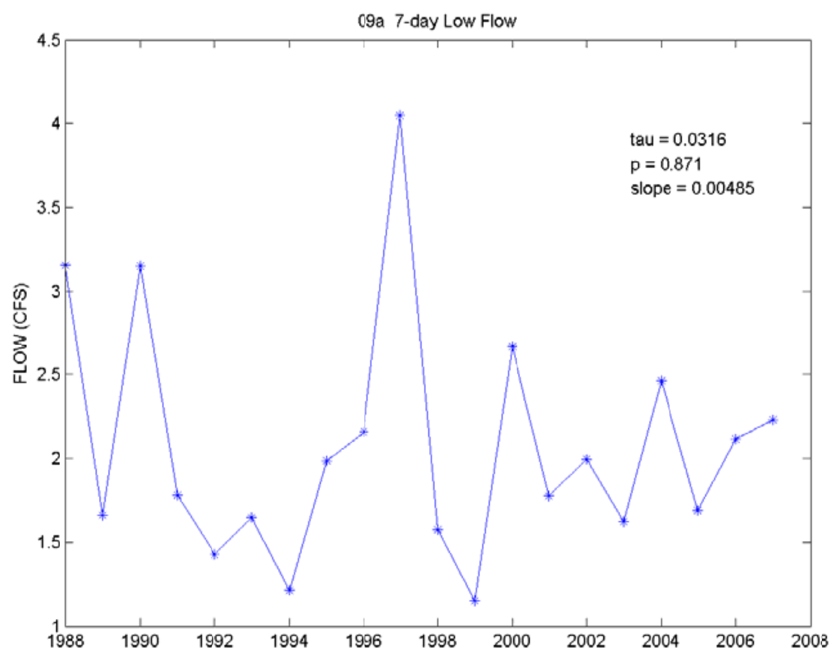

Figure 4. Time series plot showing long-term 7-day low flow at King County gauge 09a near the mouth of Covington Creek.

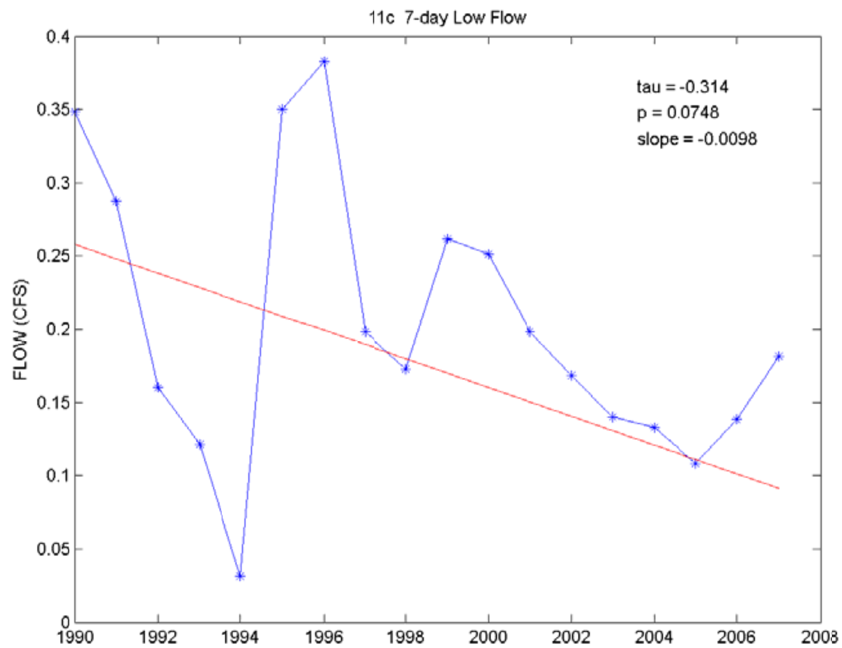

Figure 5. Time series plot showing long-term 7-day low flow at King County gauge 11c on Des Moines Creek above Tyee Regional Pond.

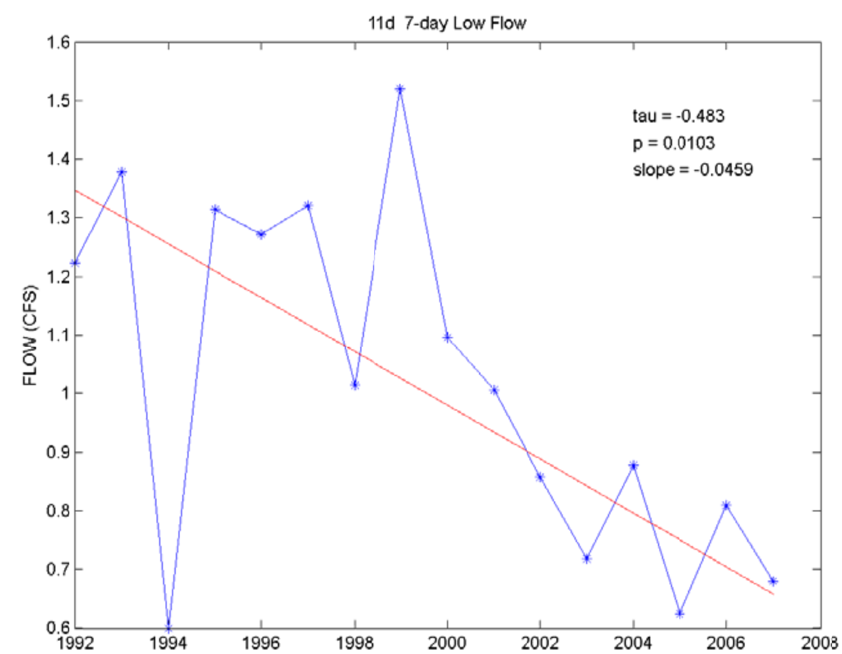

Figure 6. Time series plot showing long-term 7-day low flow at King County gauge 11d near the mouth of Des Moines Creek.

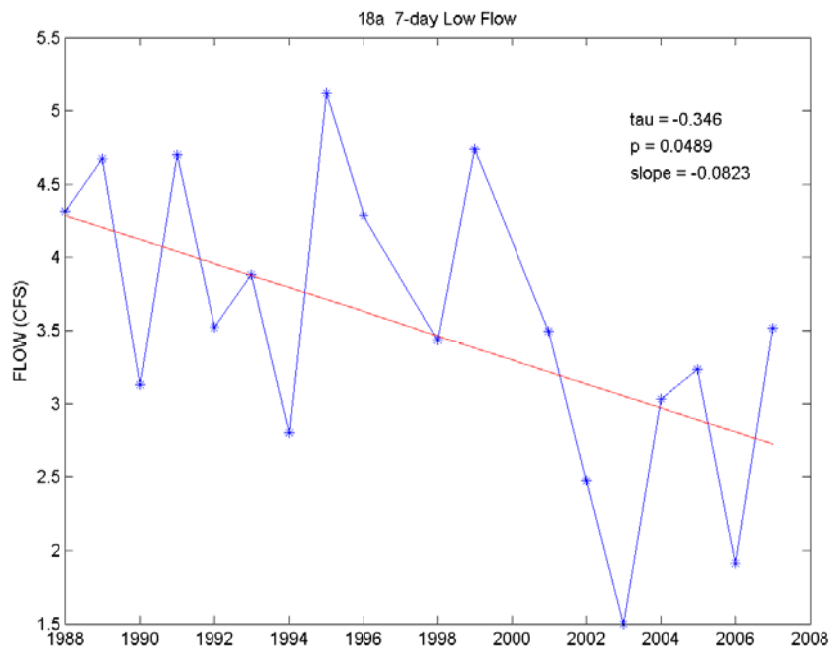

Figure 7. Time series plot showing long-term 7-day low flow at King County gauge 18a near the mouth of Evans Creek.

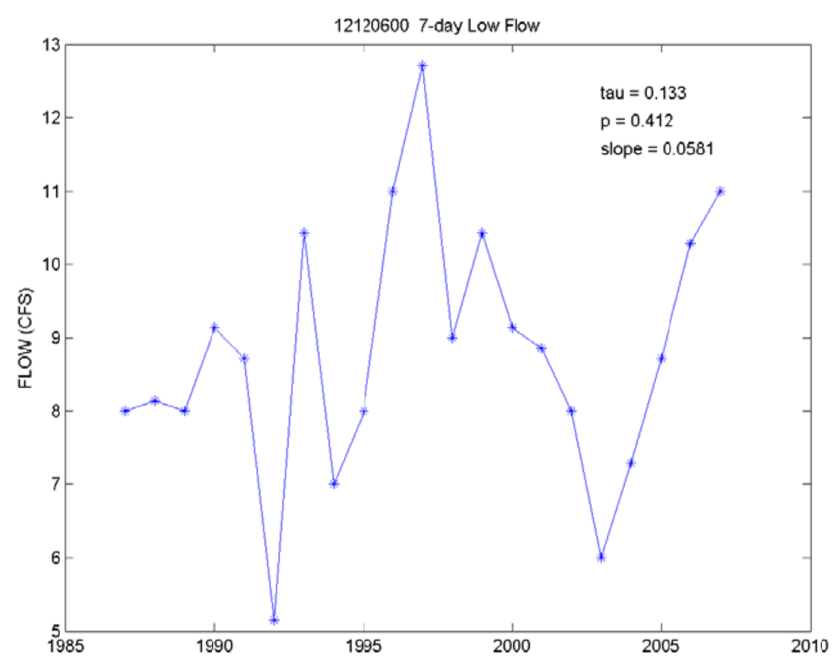

Figure 8. Time series plot showing long-term 7-day low flow at USGS gauge 12120600 on Issaquah Creek near Hobart.

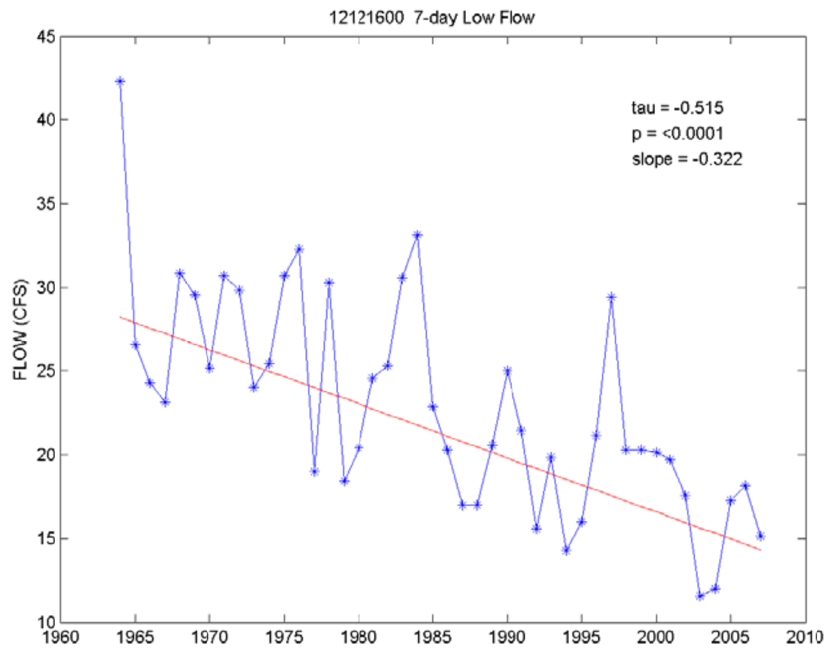

Figure 9. Time series plot showing long-term 7-day low flow at USGS gauge 12121600 near the mouth of Issaquah Creek.

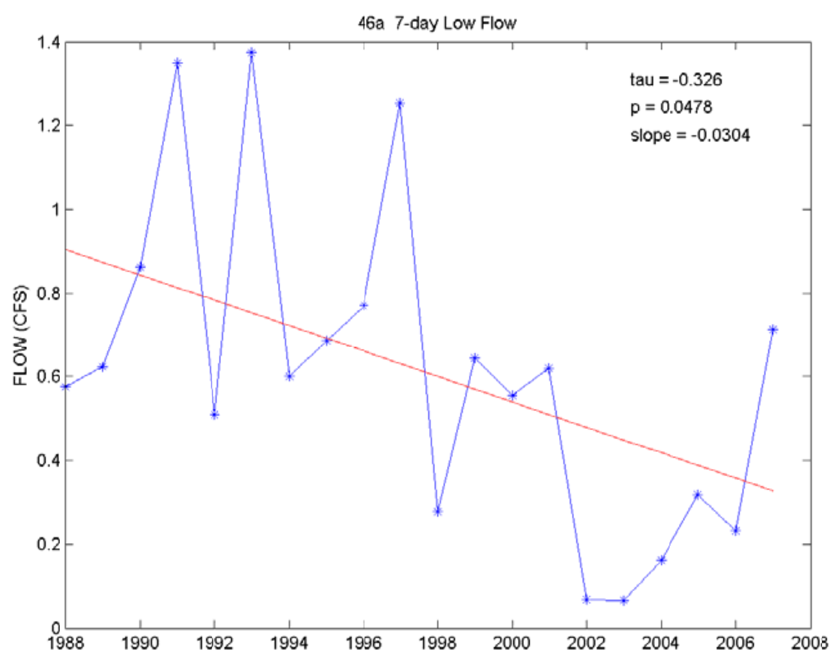

Figure 10. Time series plot showing long-term 7-day low flow at King County gauge 46a on North Fork Issaquah Creek.

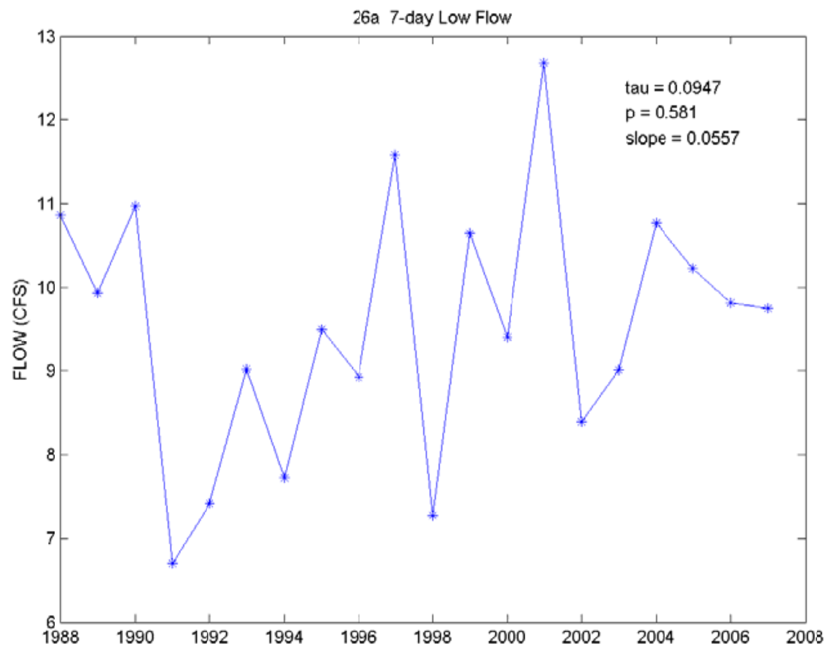

Figure 11. Time series plot showing long-term 7-day low flow at King County gauge 26a near the mouth of Jenkins Creek.

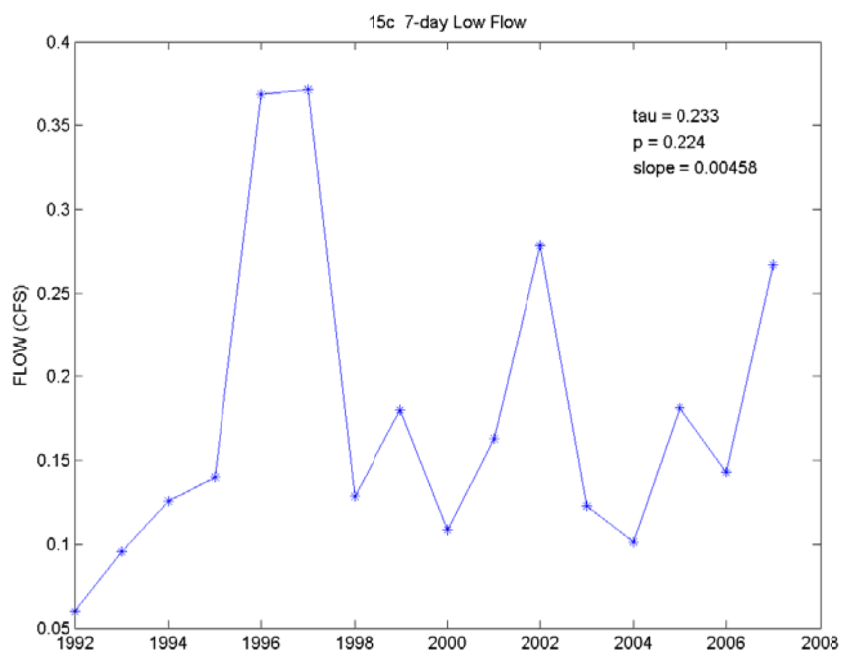

Figure 12. Time series plot showing long-term 7-day low flow at King County gauge 15c near the mouth of Laughing Jacobs Creek.

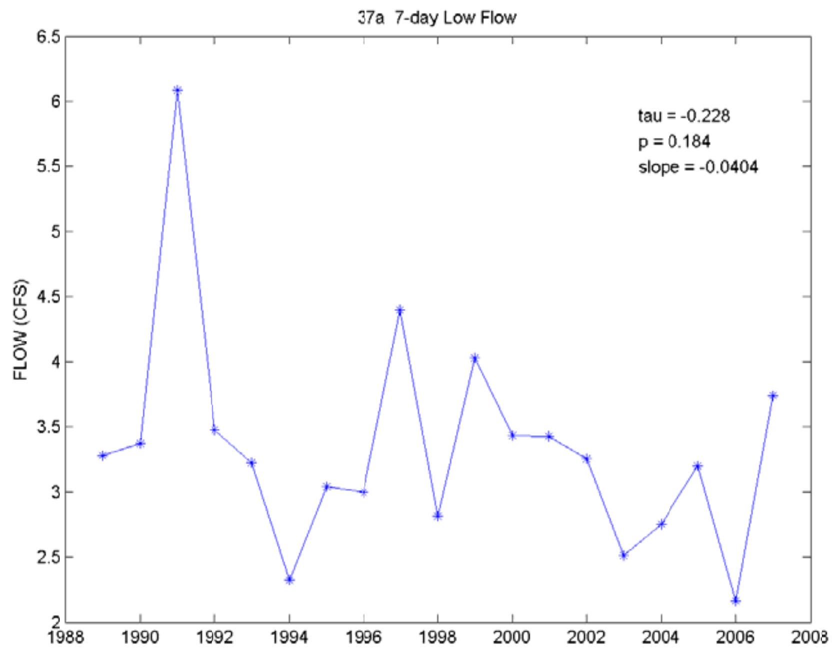

Figure 13. Time series plot showing long-term 7-day low flow at King County gauge 37a near the mouth of May Creek.

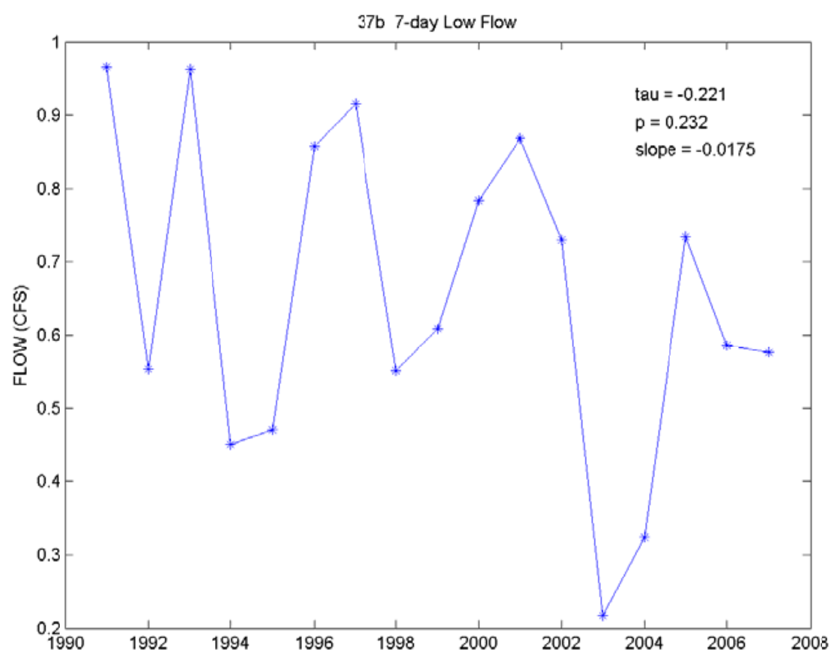

Figure 14. Time series plot showing long-term 7-day low flow at King County gauge 37b on May Creek near Coal Creek Parkway.

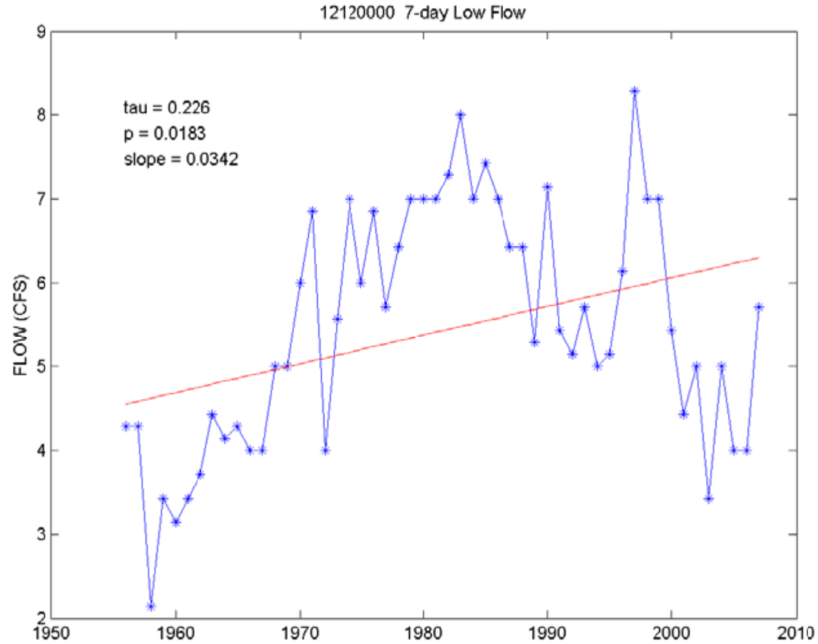

Figure 15. Time series plot showing long-term 7-day low flow at USGS gauge 12120000 on Mercer (Kelsey) Creek.

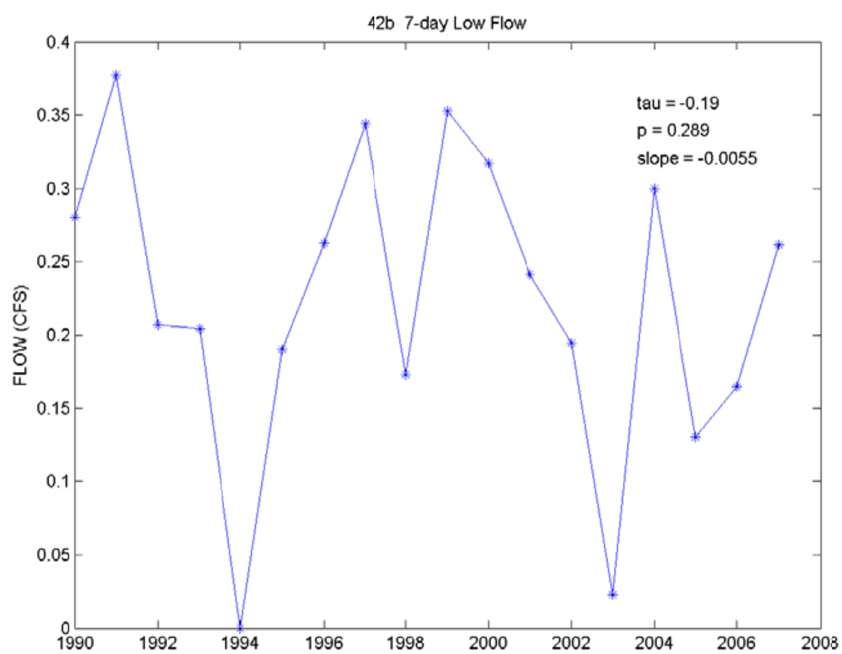

Figure 16. Time series plot showing long-term 7-day low flow at King County gauge 42b at the Miller Creek detention facility.

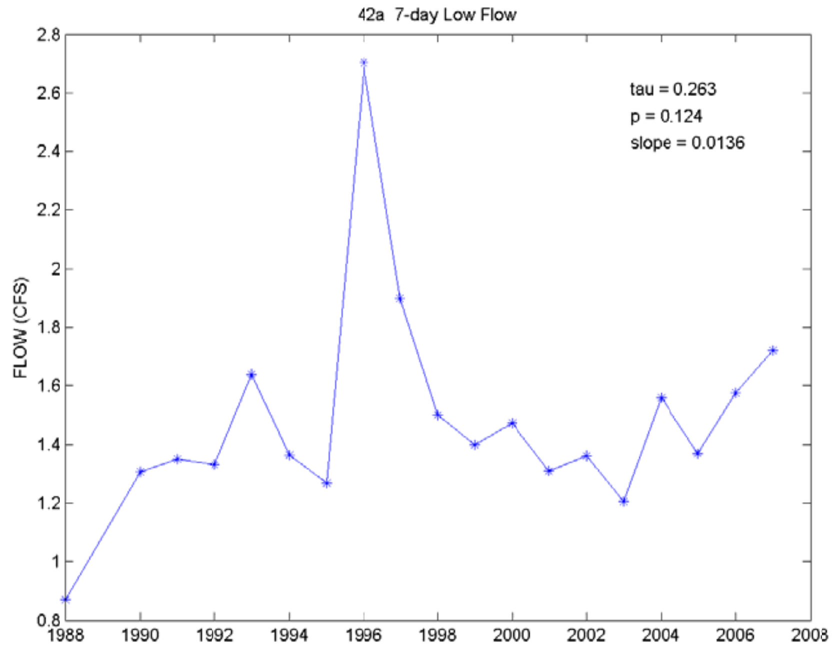

Figure 17. Time series plot showing long-term 7-day low flow at King County gauge 42a near the mouth of Miller Creek.

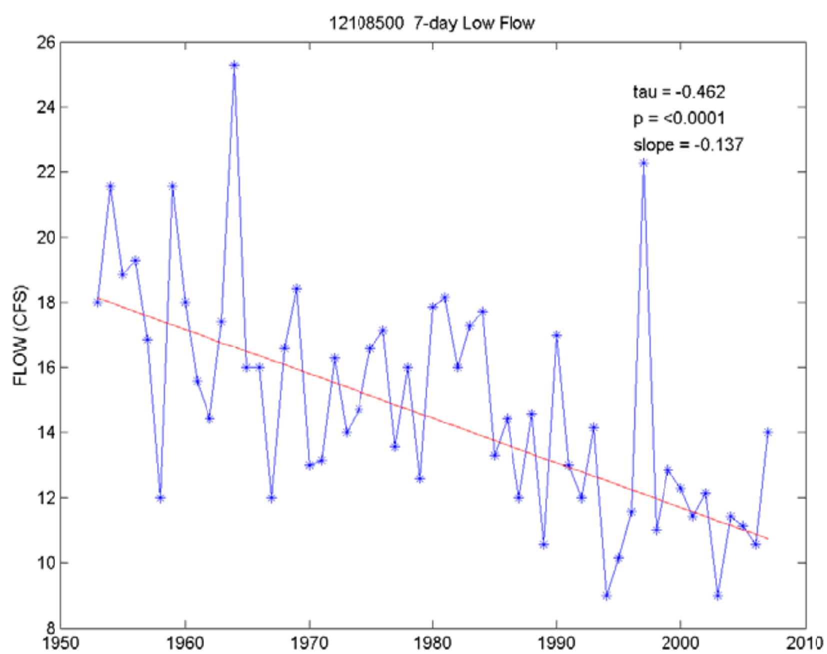

Figure 18. Time series plot showing long-term 7-day low flow at USGS gauge 12108500 on Newaukum Creek near Black Diamond.

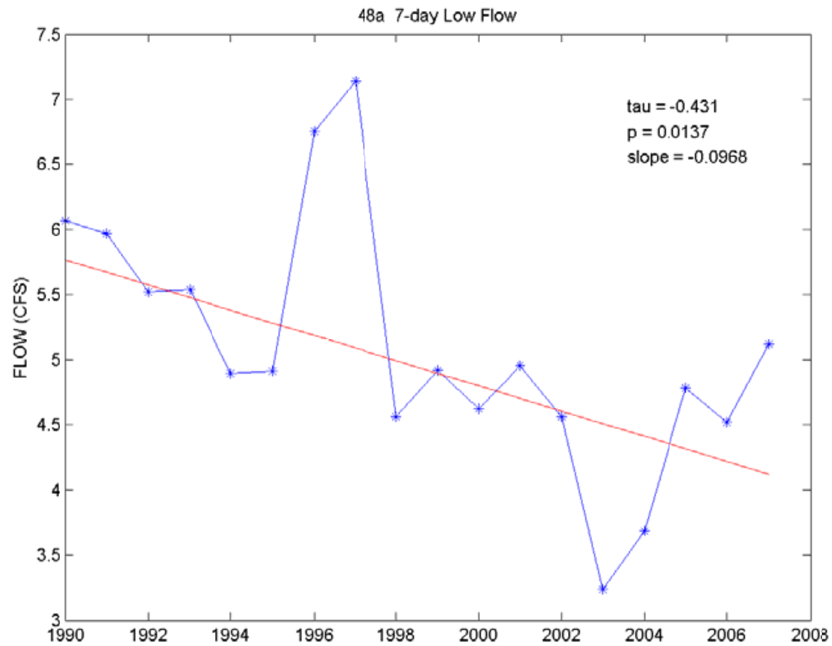

Figure 19. Time series plot showing long-term 7-day low flow at King County gauge 48a on Patterson Creek near Aldera Farms.

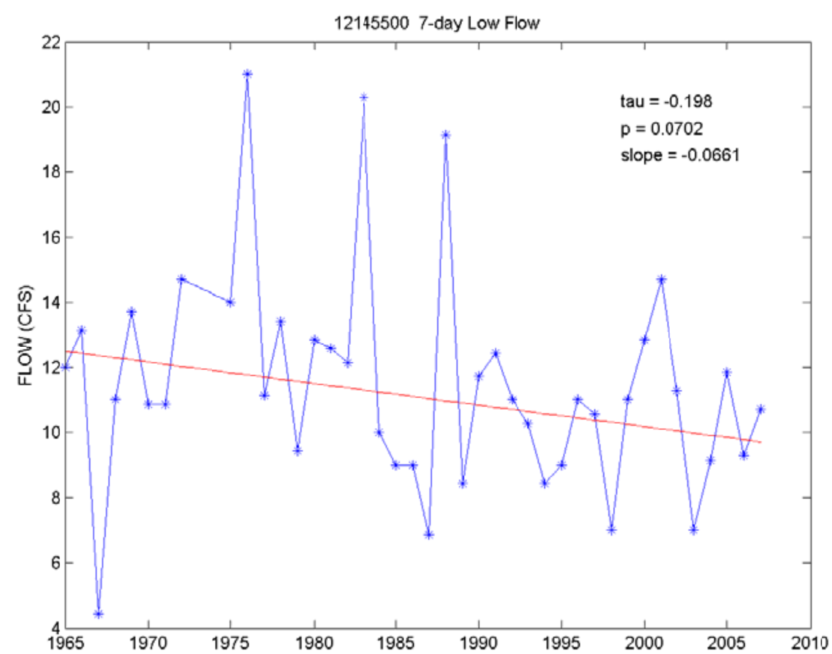

Figure 20. Time series plot showing long-term 7-day low flow at USGS gauge 12145500 on the Raging River near Fall City.

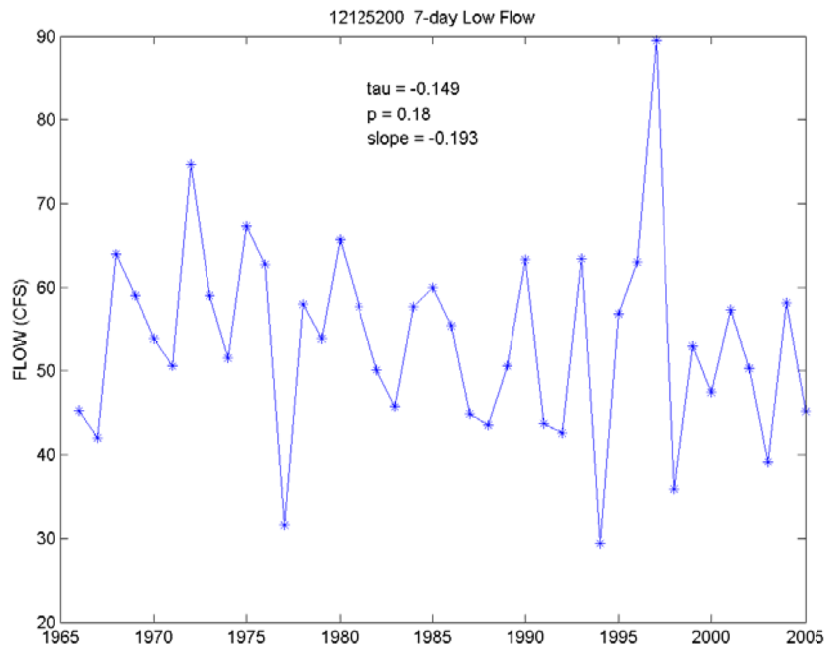

Figure 21. **Time series plot showing long-term 7-day low flow at USGS gauge 12125200 on the Sammamish River near Woodinville.**

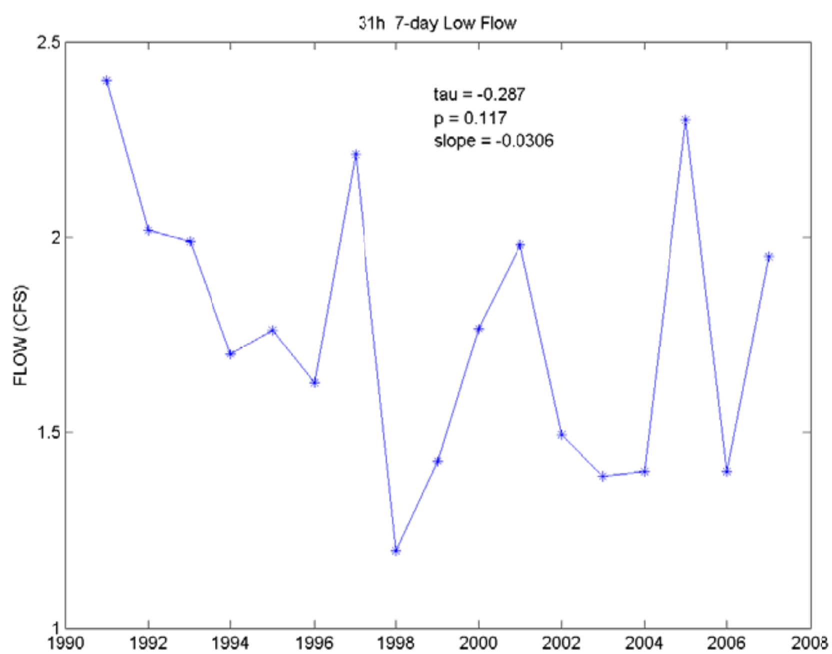

Figure 22. **Time series plot showing long-term 7-day low flow at King County gauge 31h near the mouth of Taylor Creek.**

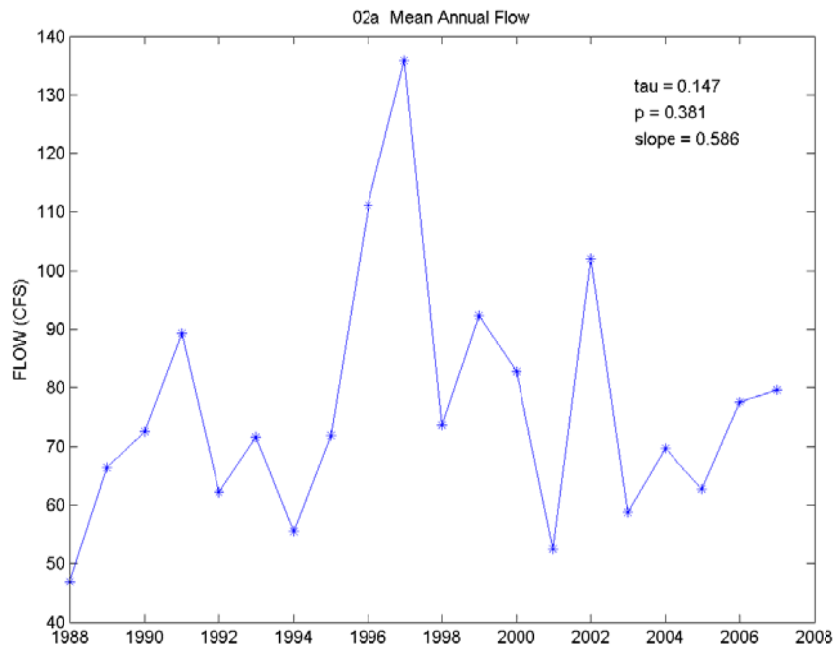

Figure 23. Time series plot showing long-term mean annual flow at King County gauge 02a near the mouth of Big Bear Creek.

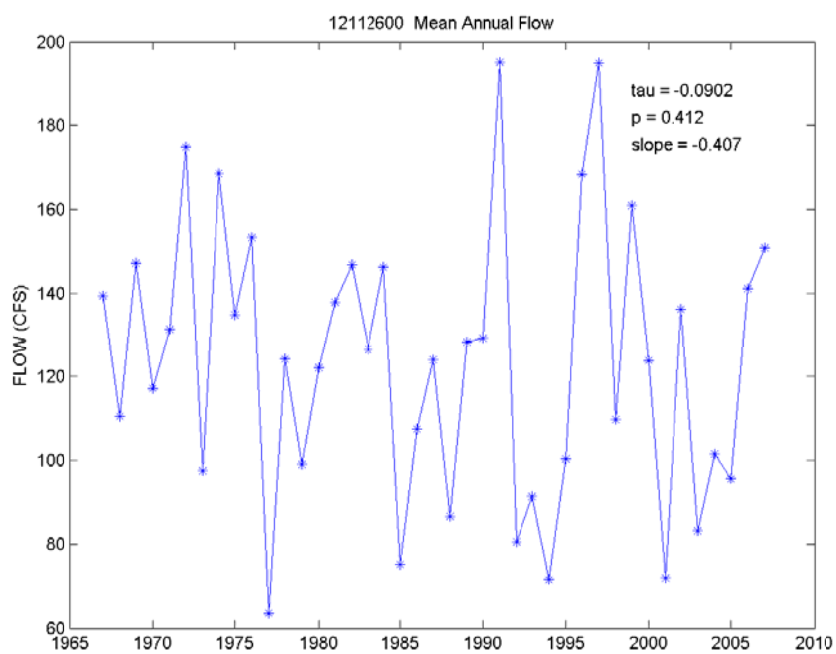

Figure 24. Time series plot showing long-term mean annual flow at USGS gauge 12112600 near the mouth of Big Soos Creek.

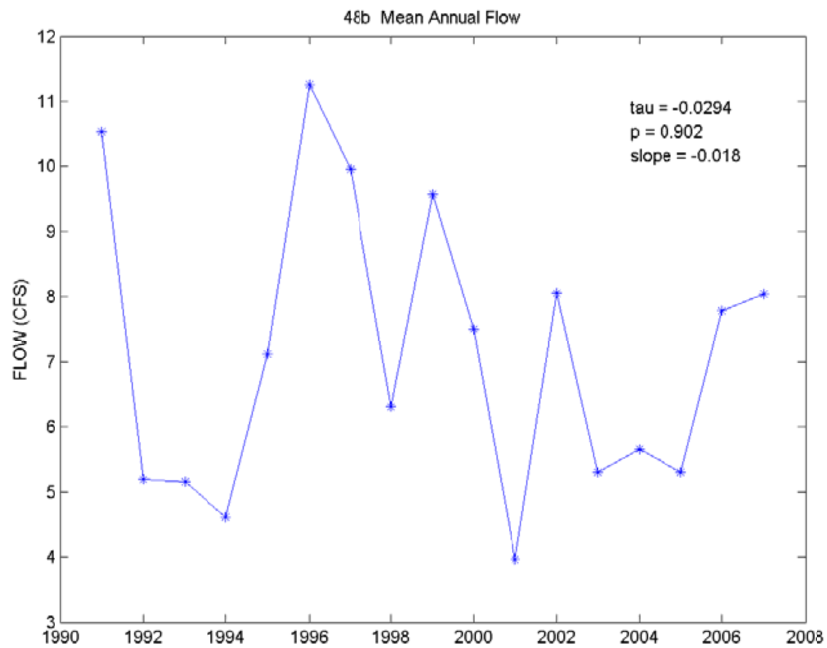

Figure 25. Time series plot showing long-term mean annual flow at King County gauge 48b on Canyon Creek near Aldera Farms.

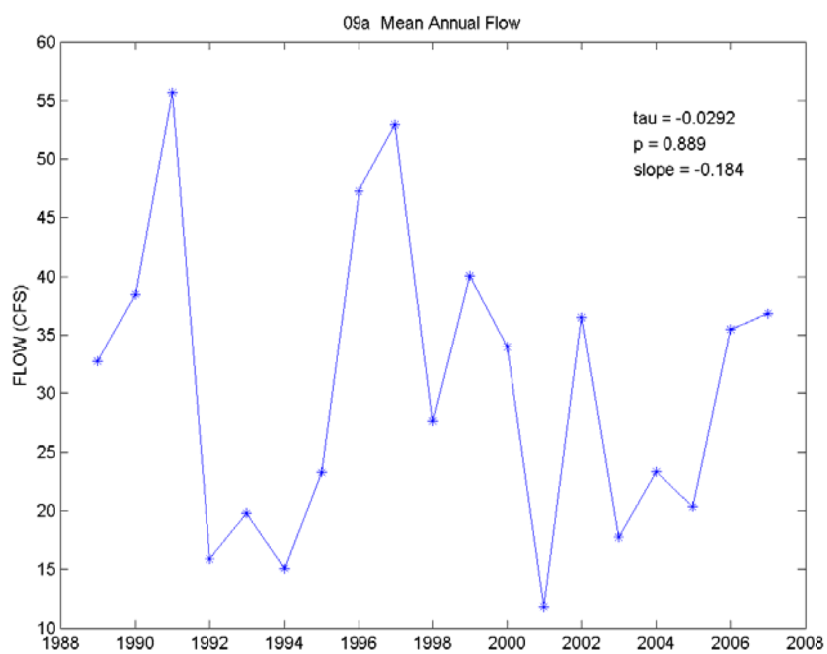

Figure 26. Time series plot showing long-term mean annual flow at King County gauge 09a near the mouth of Covington Creek.

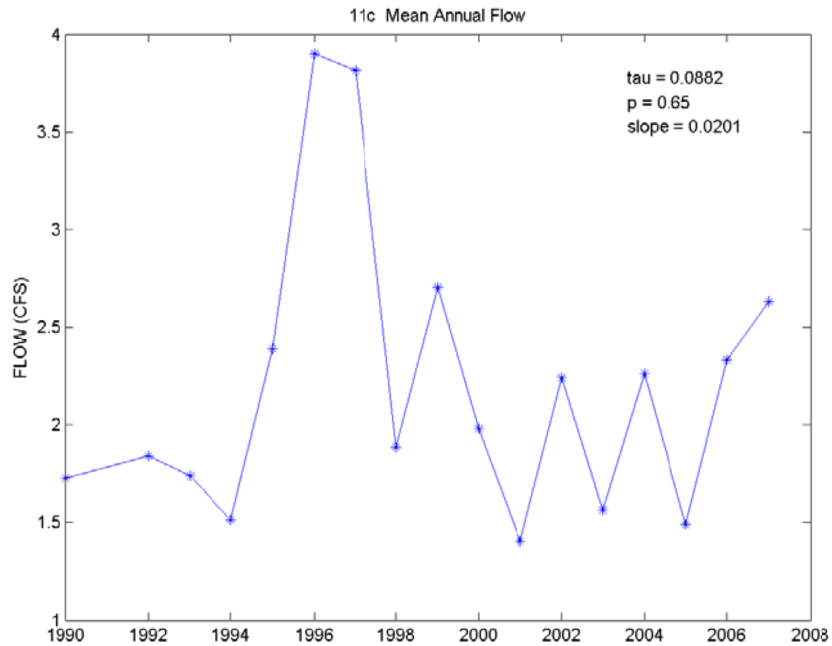

Figure 27. Time series plot showing long-term mean annual flow at King County gauge 11c on Des Moines Creek above Tyee Regional Pond.

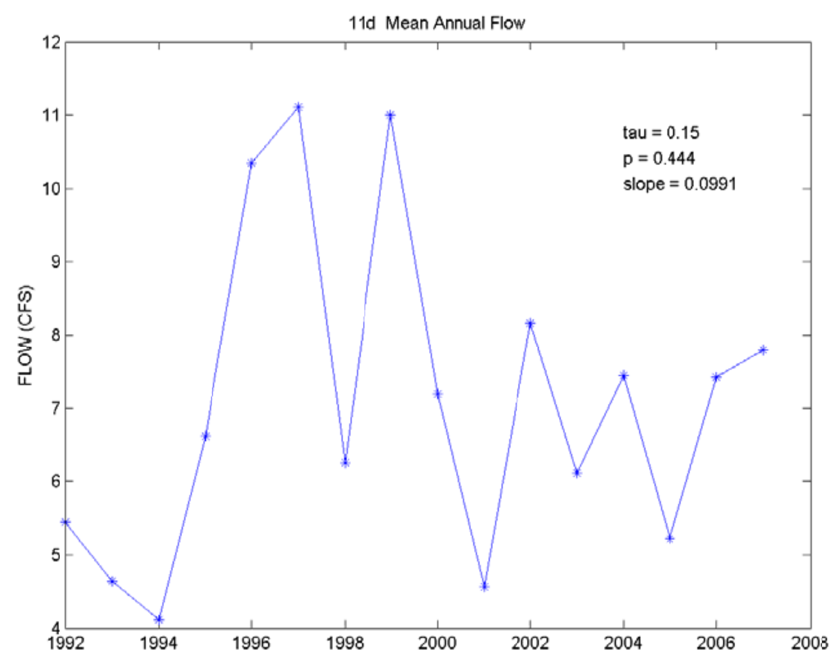

Figure 28. Time series plot showing long-term mean annual flow at King County gauge 11d near the mouth of Des Moines Creek.

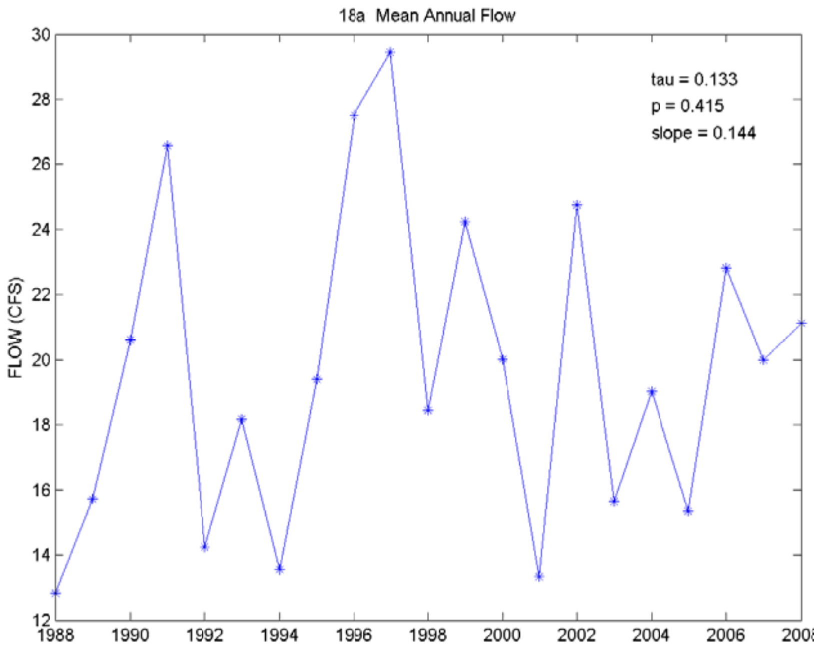

Figure 29. Time series plot showing long-term mean annual flow at King County gauge 18a near the mouth of Evans Creek.

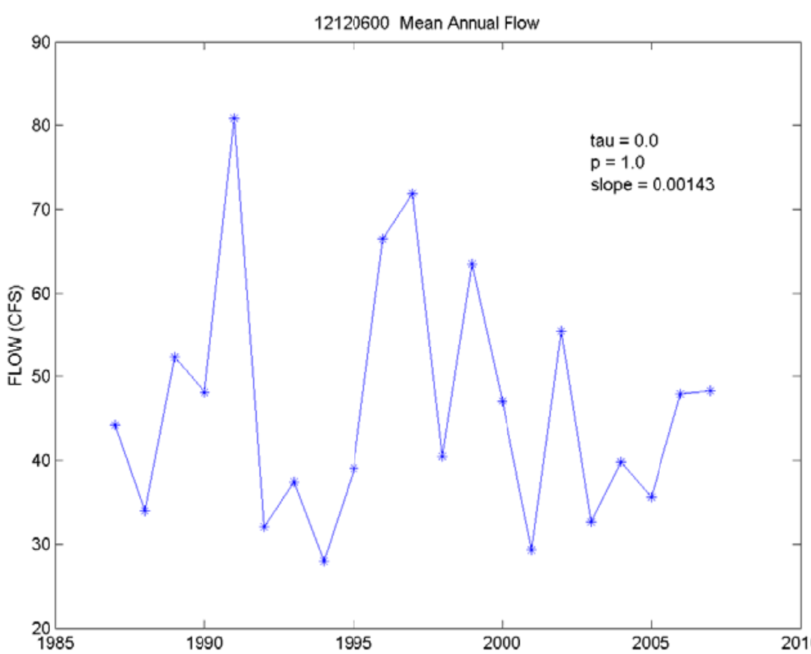

Figure 30. Time series plot showing long-term mean annual flow at USGS gauge 12120600 on Issaquah Creek near Hobart.

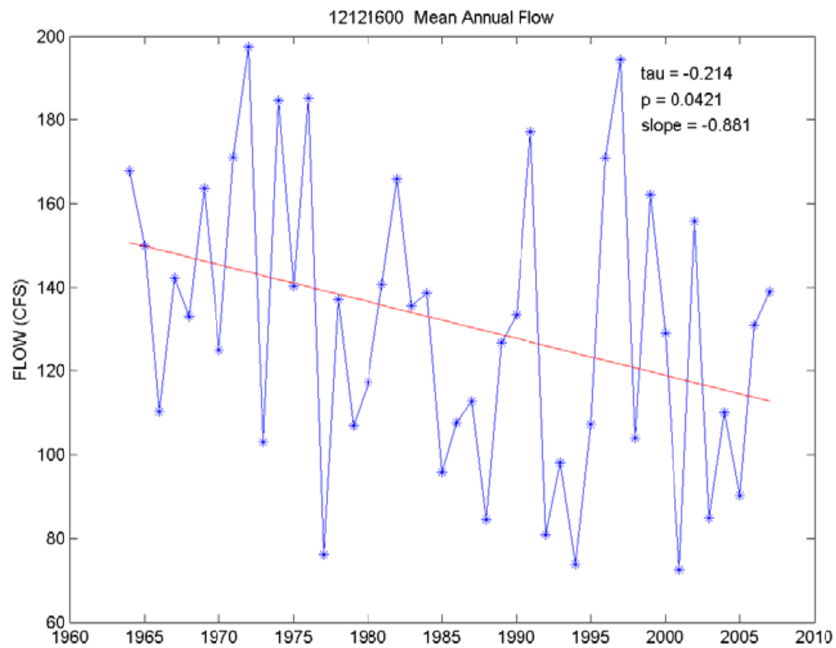

Figure 31. Time series plot showing long-term mean annual flow at USGS gauge 12121600 near the mouth of Issaquah Creek.

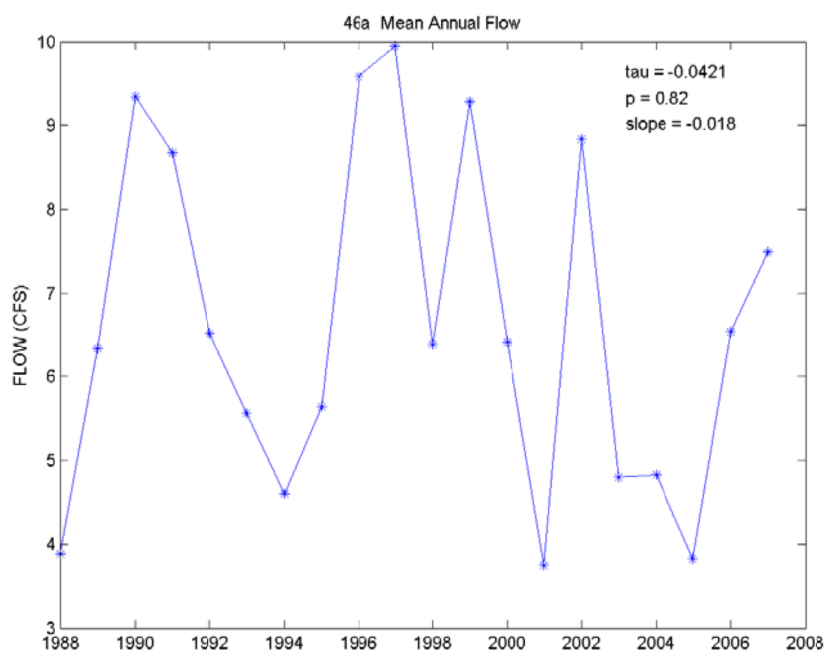

Figure 32. Time series plot showing long-term mean annual flow at King County gauge 46a on North Fork Issaquah Creek.

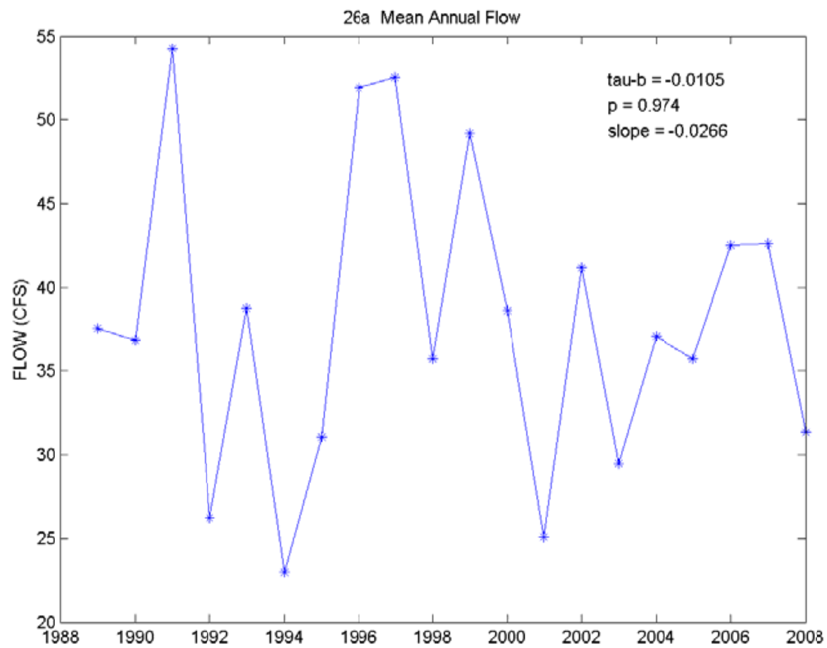

Figure 33. Time series plot showing long-term mean annual flow at King County gauge 26a near the mouth of Jenkins Creek.

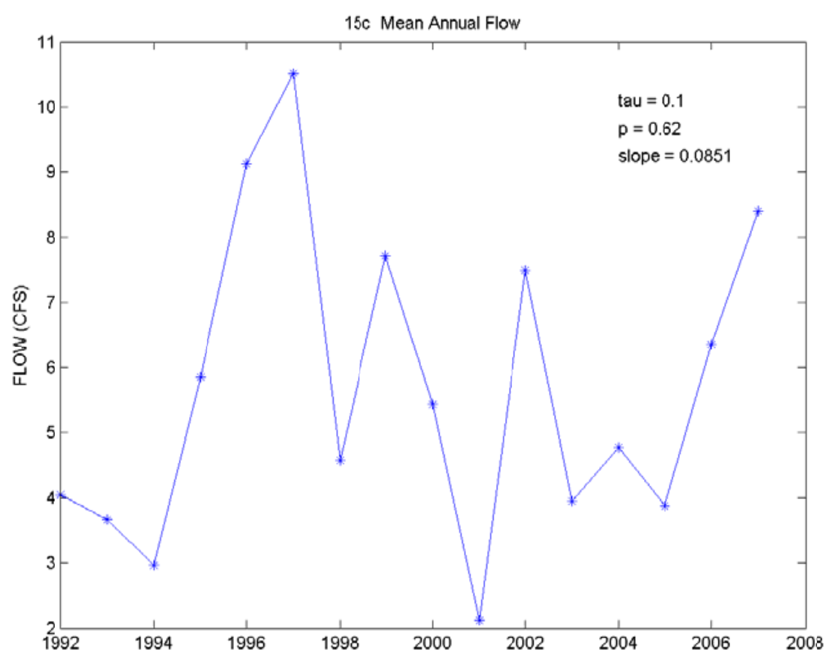

Figure 34. Time series plot showing long-term mean annual flow at King County gauge 15c near the mouth of Laughing Jacobs Creek.

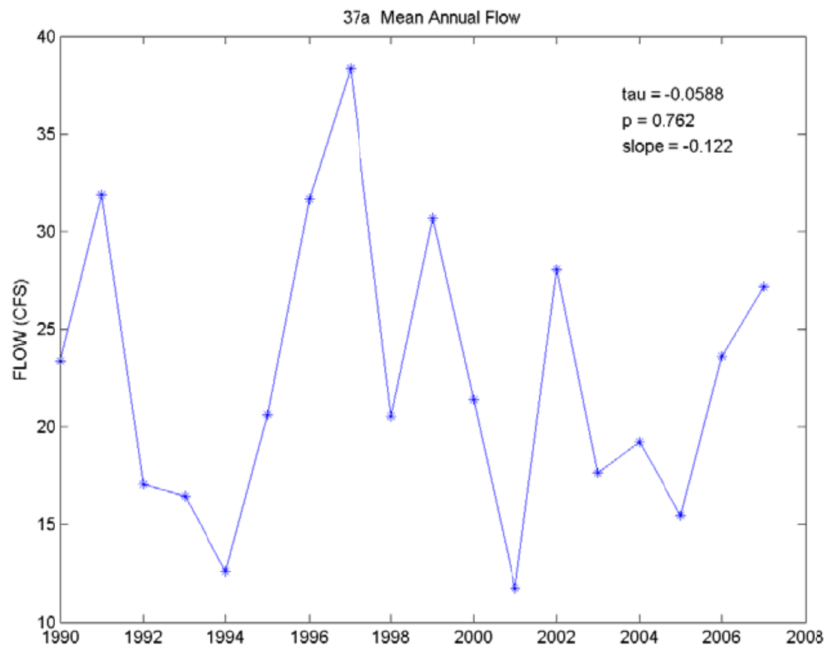

Figure 35. Time series plot showing long-term mean annual flow at King County gauge 37a near the mouth of May Creek.

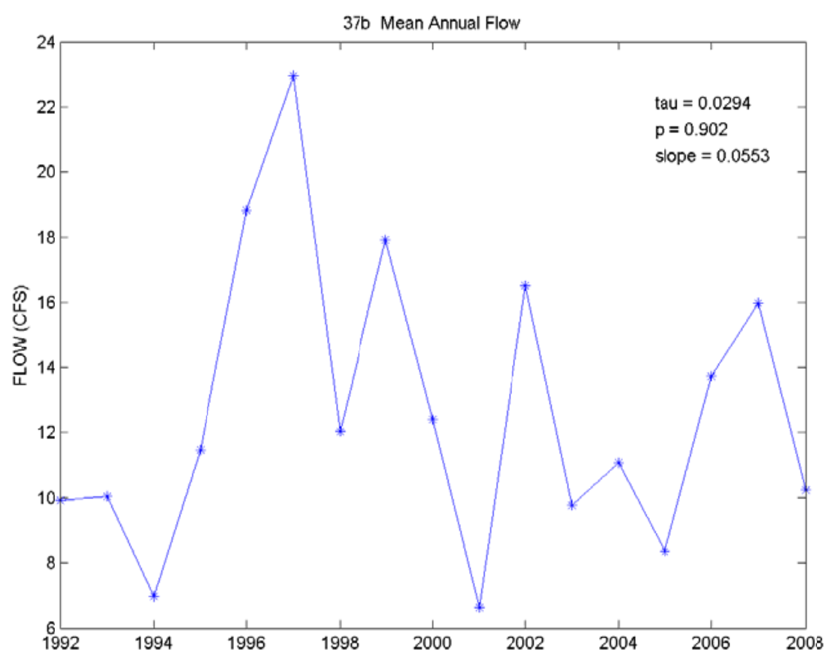

Figure 36. Time series plot showing long-term mean annual flow at King County gauge 37b on May Creek near Coal Creek Parkway.

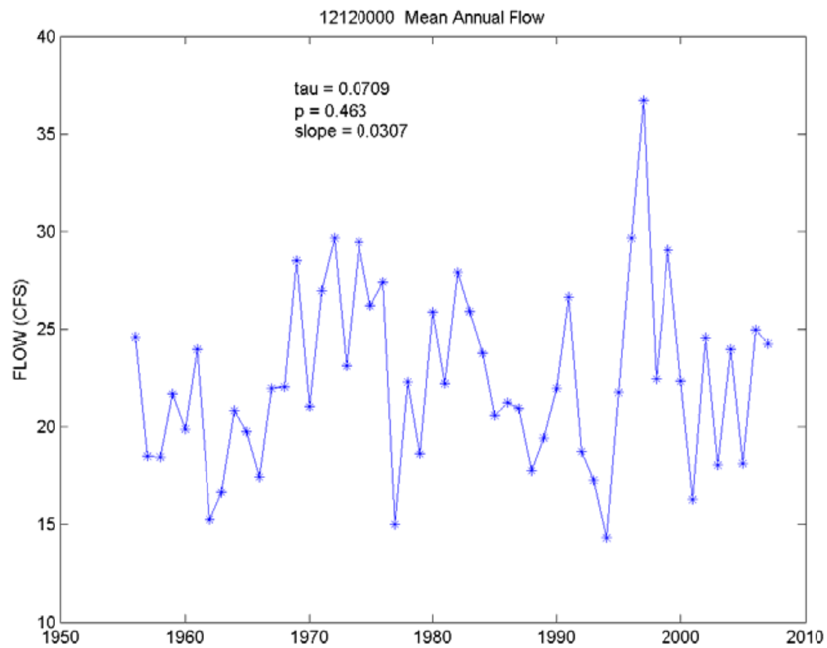

Figure 37. Time series plot showing long-term mean annual flow at USGS gauge 12120000 on Mercer (Kelsey) Creek.

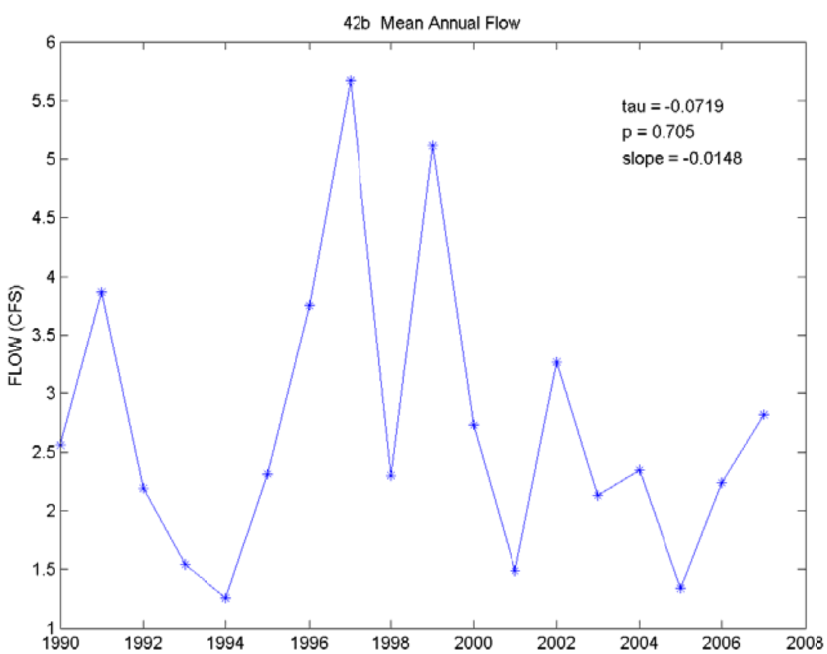

Figure 38. Time series plot showing long-term mean annual flow at King County gauge 42b at the Miller Creek detention facility.

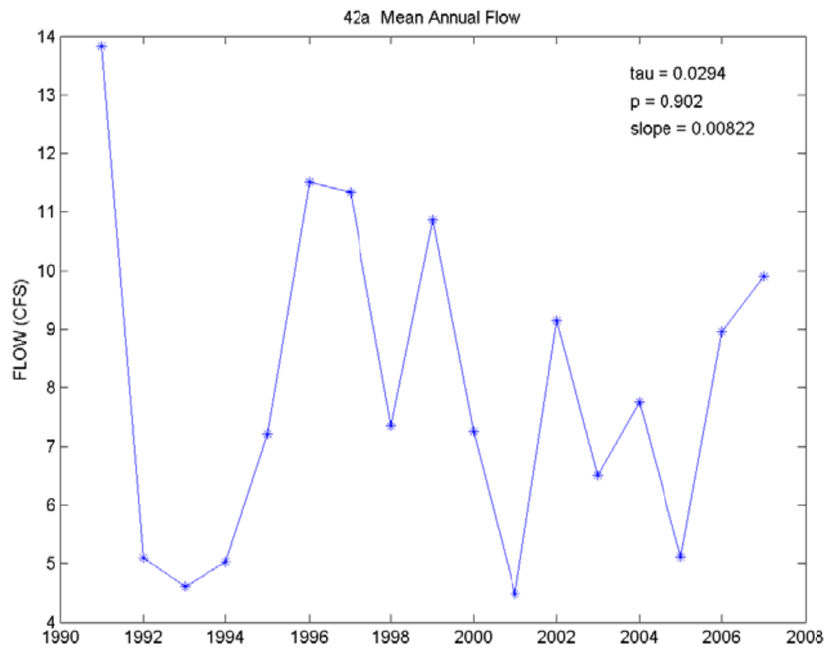

Figure 39. Time series plot showing long-term mean annual flow at King County gauge 42a near the mouth of Miller Creek.

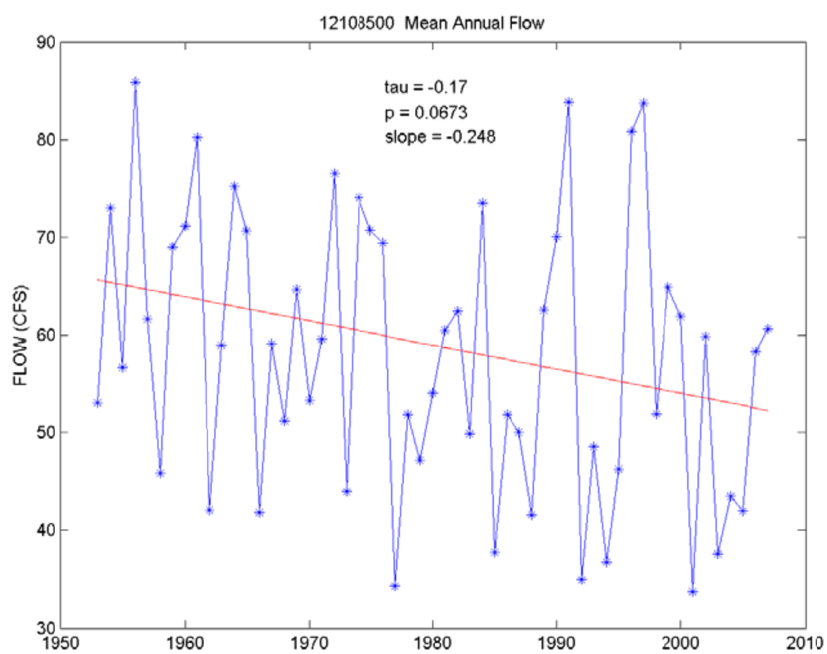

Figure 40. Time series plot showing long-term mean annual flow at USGS gauge 12108500 on Newaukum Creek near Black Diamond.

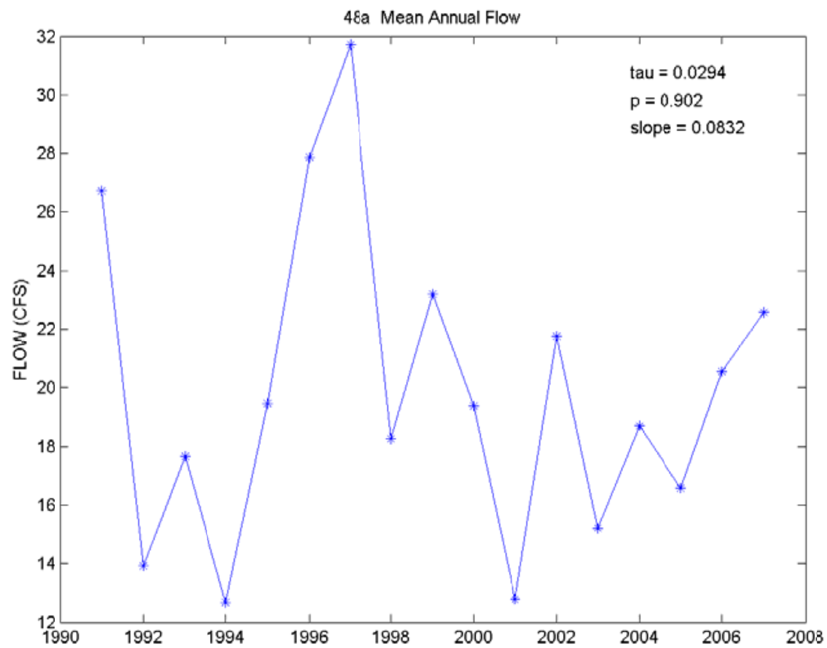

Figure 41. Time series plot showing long-term mean annual flow at King County gauge 48a on Patterson Creek near Aldera Farms.

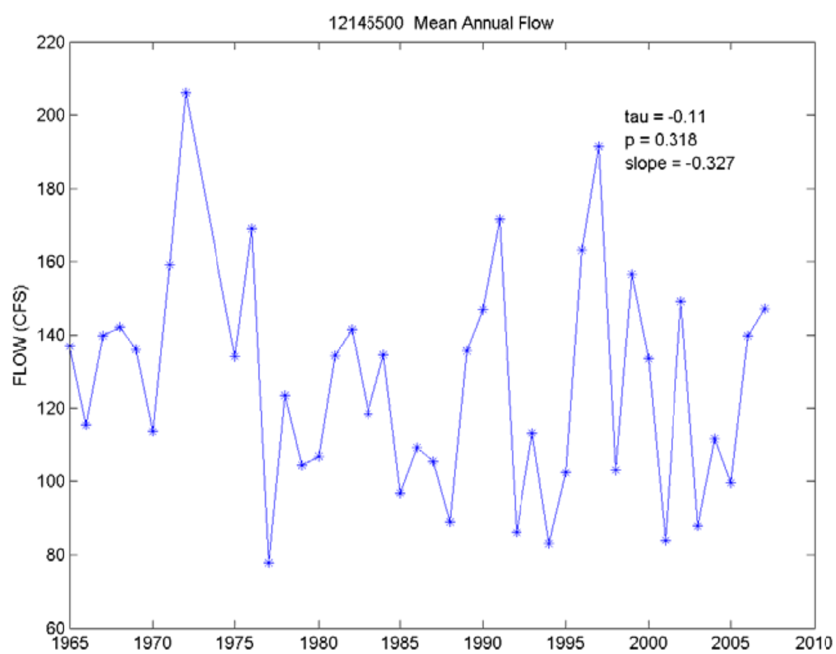

Figure 42. Time series plot showing long-term mean annual flow at USGS gauge 12145500 on the Raging River near Fall City.

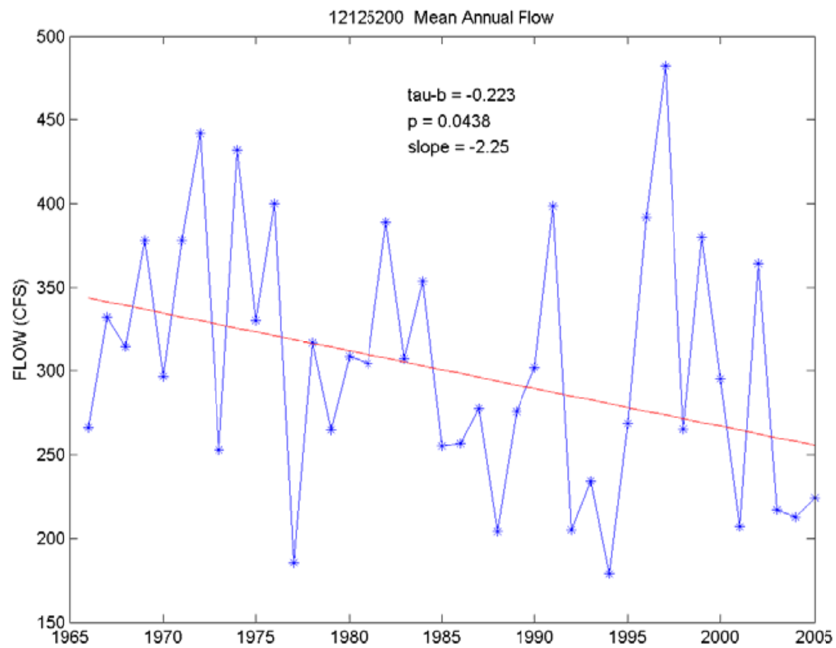

Figure 43. Time series plot showing long-term mean annual flow at USGS gauge 12125200 on the Sammamish River near Woodinville.

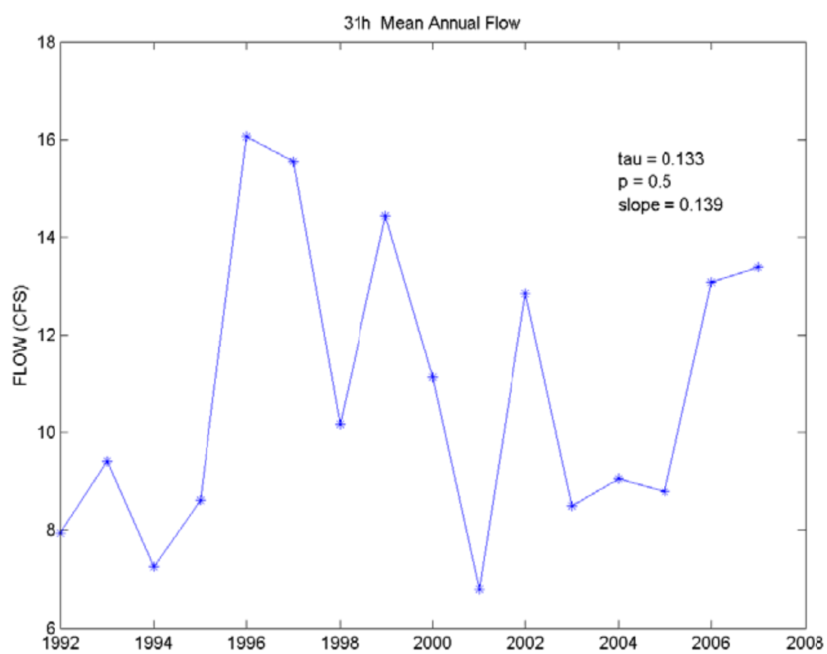

Figure 44. Time series plot showing long-term mean annual flow at King County gauge 31h near the mouth of Taylor Creek.

Appendix C
Water Temperature Data Summary

Table 1. Water temperatures in NE Lake Washington

Table 2. Water temperatures in North Green River

Table 3. Water temperatures in North Lake Sammamish

Table 4. Water temperatures in North Lake Washington

Table 5. Water temperatures in SE Lake Washington

Table 6. Water temperatures in South Green River Kent Planning Zone

Table 7. Water temperatures in South Green River Auburn Planning Zone

Table 8. Water temperatures in South Green River Soos Planning Zone

Table 9. Water temperatures in South Lake Sammamish

Table 10. Water temperatures in South Lake Washington

Table 11. Water temperatures in other areas

The following tables summarize water temperatures by Planning Basin. Rivers are included for these data. (KC = King County; UW = University of Washington.)

Table 1. Water temperatures in NE Lake Washington

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
20a	KC	2000	2003	4	230	17.00	16.64
27a	KC	1999	2008	10	208	20.18	16.84

Table 2. Water temperatures in North Green River

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
GRT34	KC	2002	2004	3	208	19.11	18.01
GRT33	KC	2002	2005	4	175	19.54	17.56

Table 3. Water temperatures in North Lake Sammamish

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
BBR0038000	KC	1999	1999	1	265	15.68	15.68
MMT0001000	KC	1999	1999	1	218	15.33	15.33
SMR1275000	KC	2000	2000	1	228	21.48	21.48
53c	KC	2002	2004	3	150	14.18	12.54
51T	KC	2005	2008	4	187	24.77	22.23
EC4	KC	2002	2005	4	201	16.00	14.64
EC61	KC	2002	2005	4	172	20.71	16.32
BBC44	KC	2001	2005	5	219	16.57	15.60
BBC45	KC	2000	2004	5	243	23.43	19.00

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
BBR0040000	KC	2000	2004	5	209	22.16	20.29
18b	KC	2002	2008	7	214	12.78	10.60
SMR1344000	KC	1999	2005	7	185	25.88	21.71
53b	KC	2001	2008	8	174	18.93	14.82
53a	KC	2000	2008	9	201	18.57	16.22
BBC52	KC	2000	2008	9	214	24.43	18.05
SR24B	KC	2000	2008	9	231	23.43	18.50
02a	KC	1995	2008	14	200	22.19	20.05
51m	KC	1995	2008	14	204	26.31	24.12

Table 4. Water temperatures in North Lake Washington

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
LB5	KC	2004	2004	1	150	14.03	14.03
SMR0074000	KC	2000	2000	1	219	21.38	21.38
LB2	KC	2003	2004	2	183	8.67	8.53
LB3	KC	2003	2004	2	223	14.87	12.69
NCK0080000	KC	1999	2002	4	201	20.01	13.33
SMR0458000	KC	2001	2004	4	226	23.30	19.63
LBR0003000	KC	2001	2005	5	217	18.94	13.12
30A	KC	1999	2007	9	226	18.04	16.25
56b	KC	1998	2008	11	189	21.33	17.52

Table 5. Water temperatures in SE Lake Washington

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
06a	KC	2002	2005	4	208	18.63	17.95
37g	KC	2002	2005	4	218	22.35	18.68
37f	KC	2002	2007	6	196	23.16	21.48
37b	KC	1997	2008	12	199	20.57	17.05

Table 6. Water temperatures in South Green River Kent Planning Zone

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
GRT21	KC	2002	2003	2	182	21.44	21.06
03F	KC	2003	2007	5	201	23.98	22.23
54c	KC	2001	2005	5	193	23.41	19.57
41a	KC	1999	2008	10	194	22.82	20.10

Table 7. Water temperatures in South Green River Auburn Planning Zone

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
41c	KC	2004	2008	5	187	18.22	15.80
GRT05	KC	2001	2005	5	188	19.54	16.73
mf1	KC	1999	2006	8	171	17.87	14.92

Table 8. Water temperatures in South Green River Soos Planning Zone

Gauge	Source	Start	Stop	Duration	Avg Julian	Max7DADM	avg7DADM
31L	KC	1997	2008	12	212	14.56	13.06
54i	KC	1995	2008	14	205	22.47	20.00
54h	KC	1994	2008	15	203	19.66	16.43

Table 9. Water temperatures in South Lake Sammamish

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
14b	KC	2004	2008	5	190	17.82	15.89
14a	KC	1997	2003	7	225	19.76	17.52
15b	KC	2000	2008	9	196	17.74	15.62
63a	KC	2000	2008	9	212	17.36	15.55
15g	KC	1999	2008	10	205	16.26	14.39
46a	KC	1999	2008	10	204	26.75	19.72
48a	KC	1998	2008	11	173	18.80	16.77
15c	KC	1996	2008	13	200	20.23	17.63
48b	KC	1996	2008	13	190	27.33	14.86

Table 10. Water temperatures in South Lake Washington

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
GRT02	KC	2001	2003	3	223	29.41	27.47
GRT18	KC	2002	2005	4	192	22.68	19.72
GRT19	KC	2002	2005	4	178	22.18	18.62
03G	KC	2002	2008	7	186	19.16	17.82
31p	KC	1999	2008	10	198	21.06	16.76
37a	KC	1998	2008	11	185	20.00	16.76

Table 11. Water temperatures in other areas

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
CL20	KC	2007	2007	1	154	17.28	17.28
CL21	KC	2007	2007	1	153	17.71	17.71
GR5	UW	2001	2001	1	222	19.18	19.18
SD1	UW	2001	2001	1	191	22.61	22.61
30B	KC	2003	2004	2	196	8.16	7.67
44I	KC	2007	2008	2	146	13.21	10.97
BS1.5	UW	2001	2002	2	154	17.21	16.91
CL16	KC	2005	2006	2	231	20.92	17.86
GR2	UW	2000	2001	2	109	19.82	13.03
GR3-4	UW	2001	2002	2	224	20.14	20.02
GR6	UW	2001	2002	2	225	18.63	18.52
GR7	UW	2001	2002	2	232	17.11	17.11
GRT04b	KC	2001	2002	2	187	15.94	15.04
GRT24	KC	2002	2003	2	218	16.41	16.00
GRT27	KC	2002	2003	2	200	23.75	18.74
JE1	UW	2000	2001	2	218	17.73	16.94
LB1	KC	2003	2004	2	231	11.85	10.22
LB7	KC	2003	2004	2	242	13.86	10.54
LS2	UW	2001	2002	2	215	21.06	20.40
ST1	UW	2000	2001	2	218	18.78	17.97
02L	KC	2005	2007	3	215	20.76	18.83
17A	KC	2005	2007	3	186	12.55	12.47
44H	KC	2002	2004	3	186	17.23	15.57
70c	KC	2006	2008	3	168	28.15	20.52
BS1	UW	2000	2002	3	173	18.69	18.26
BS2	UW	2000	2002	3	167	21.46	18.52
BS3	UW	2000	2002	3	213	17.20	17.02
BS4	UW	2000	2002	3	212	18.77	18.28
CL_MW1	KC	2005	2007	3	132	11.21	11.17
CL12	KC	2005	2007	3	252	17.70	13.69
CL13	KC	2005	2007	3	185	19.58	15.72

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
CL14	KC	2005	2007	3	154	18.05	13.01
CO1	UW	2000	2002	3	194	25.14	24.75
CO2	UW	2000	2002	3	184	18.18	17.67
CT1	UW	2000	2002	3	213	22.73	20.33
EC3	KC	2002	2004	3	179	19.14	14.88
GR1	UW	2000	2002	3	228	19.92	19.40
GRT07	KC	2001	2003	3	212	13.91	13.52
GRT26	KC	2002	2004	3	231	16.14	15.24
JE2	UW	2000	2002	3	241	13.86	13.69
LS1	UW	2000	2002	3	186	21.69	20.39
30D	KC	2005	2008	4	182	17.62	15.45
40c	KC	2005	2008	4	182	14.36	13.16
70a	KC	2005	2008	4	174	17.06	12.67
70b	KC	2005	2008	4	172	19.67	13.72
70D	KC	2005	2008	4	166	22.79	15.66
CL10	KC	2005	2008	4	169	13.36	11.28
CL11	KC	2005	2008	4	169	14.58	11.98
CL15	KC	2005	2008	4	182	21.10	17.08
GRT01	KC	2001	2004	4	217	22.41	21.33
GRT28	KC	2002	2005	4	178	21.15	18.41
GRT29	KC	2002	2005	4	172	16.04	14.66
SMR0735000	KC	2001	2004	4	229	24.50	20.70
25A	KC	2004	2008	5	198	20.41	16.64
44F	KC	2001	2005	5	204	21.31	17.69
44G	KC	2001	2005	5	156	18.63	15.86
65A	KC	2004	2008	5	184	15.61	14.05
65B	KC	2004	2008	5	186	16.11	14.12
65C	KC	2004	2008	5	194	12.56	11.34
GRT11	KC	2001	2005	5	186	20.76	16.57
GRT35	KC	2002	2006	5	212	20.90	20.11
02d	KC	2000	2005	6	223	17.82	16.52
30C	KC	2003	2008	6	209	18.23	14.53

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
37E	KC	2001	2006	6	211	24.33	21.25
EVS0073000	KC	1999	2004	6	200	19.65	17.79
GRT14	KC	2002	2007	6	208	19.18	17.67
GRT25	KC	2002	2007	6	197	16.06	15.07
GRT36	KC	2003	2008	6	181	21.88	17.83
02c	KC	2001	2007	7	205	19.44	17.11
02K	KC	2001	2007	7	237	14.71	11.49
BBR0493000	KC	1999	2005	7	188	20.24	17.04
BBR0601000	KC	1999	2005	7	182	20.34	17.35
GRT20	KC	2002	2008	7	192	21.57	17.98
GRT23	KC	2002	2008	7	221	13.26	11.51
GRT31	KC	2002	2008	7	176	22.86	18.69
GRT32	KC	2002	2008	7	186	18.10	15.45
LBR0658000	KC	1999	2005	7	177	16.85	14.42
05A	KC	2001	2008	8	212	20.24	18.38
21A	KC	2001	2008	8	206	19.27	15.56
51L	KC	2001	2008	8	203	23.74	19.32
51R	KC	2001	2008	8	189	24.33	18.42
GRT03	KC	2001	2008	8	206	18.51	15.79
GRT04	KC	2001	2008	8	193	21.46	18.88
GRT06	KC	2001	2008	8	202	18.05	15.94
GRT09	KC	2001	2008	8	201	18.64	17.16
GRT10	KC	2001	2008	8	186	22.63	19.42
GRT12	KC	2001	2008	8	197	13.84	13.26
GRT13	KC	2001	2008	8	219	10.54	9.89
GRT16	KC	2001	2008	8	201	20.63	17.49
GRT17	KC	2001	2008	8	201	17.89	15.24
11d	KC	2000	2008	9	203	19.38	17.79
11f	KC	2000	2008	9	198	20.85	18.02
18f	KC	2000	2008	9	194	21.75	19.12
22A	KC	2000	2008	9	197	16.50	15.72
42a	KC	2000	2008	9	199	18.93	16.81

Gauge	Source	Starting Year	Ending Year	Duration (years)	Average Julian Day	Average Maximum 7-Day Maximum Temperature	Average Annual Maximum 7-Day Maximum Temperature
42e	KC	2000	2008	9	206	17.21	15.94
45A	KC	2000	2008	9	199	21.49	16.33
51p	KC	2000	2008	9	202	24.90	22.20
28a	KC	1999	2008	10	202	16.40	14.53
30E	KC	1999	2008	10	190	16.18	13.82
31g	KC	1998	2007	10	196	19.54	17.39
45B	KC	1999	2008	10	184	18.25	15.58
56C	KC	1999	2008	10	179	18.47	16.47
CLK0500	KC	1999	2008	10	187	20.20	17.44
43a	KC	1998	2008	11	205	14.56	13.75
02h	KC	1996	2007	12	164	18.09	15.31
02i	KC	1996	2007	12	194	20.86	19.00
40d	KC	1997	2008	12	202	16.85	14.52
48c	KC	1997	2008	12	227	21.37	15.81
02f	KC	1994	2007	14	211	22.94	19.92
02j	KC	1995	2008	14	203	22.34	19.67
51n	KC	1995	2008	14	205	25.27	21.93
02e	KC	1994	2008	15	207	22.83	18.32
09a	KC	1994	2008	15	183	18.73	15.25
18a	KC	1994	2008	15	189	20.99	18.53
26a	KC	1994	2008	15	207	18.57	16.57
54a	KC	1994	2008	15	200	19.97	17.68