Green River
Temperature
Total Maximum Daily Load

Water Quality Improvement Report

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Cover photo: Green River (station 09A190), upstream of Kanaskat Palmer Recreation Area.

Project Codes

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Green River Temperature Total Maximum Daily Load

Water Quality Improvement Report

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Abstract

In 2006, Washington Department of Ecology (Ecology), King County Department of Natural Resources and Parks, the Muckleshoot Indian Tribe and others initiated a cooperative effort to conduct TMDL studies for temperature and dissolved oxygen in the Green River and Newaukum Creek basins (Roberts and Jack, 2006). King County is supporting the development of the TMDL studies through in-kind laboratory analyses, field activities, and model development.

This water quality improvement report documents the temperature TMDL study and proposes an implementation strategy for improving temperature in the Middle and Lower Green River below Howard Hanson Dam. Located in Water Resource Inventory Area (WRIA) 09, this stretch of the Green River flows approximately 54 miles from Howard Hanson Dam to the confluence with the Duwamish Waterway at river mile 11 in the city of Tukwila.

Modeling and data analysis determined that portions of the Green River exhibit unhealthy and sometimes lethal temperatures for salmonids and fail to consistently meet state water quality standards. The Green River serves as an important migration corridor and spawning and rearing habitat for several salmon species, including Puget Sound Chinook, bull trout, coho, chum, pink, sockeye, Kokanee, steelhead/rainbow, and cutthroat trout. These species all need cold waters for optimum health during various life stages.

Stream temperature data from the field monitoring effort supported the development of QUAL2Kw, a water quality model. The temperature model helped to answer some management questions by predicting how different hypothetical meteorological, shade, and flow conditions would affect the temperature of the river. The QUAL2Kw model assisted Ecology in setting thermal load reduction targets for the Middle and Lower Green River.

Newaukum Creek and Soos Creek, two major sub-basins of the Green River, are targeted for their own TMDL studies on temperature and dissolved oxygen and will be documented in separate reports.

Acknowledgements

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Teizeen Mohamedali, Mindy Roberts, Trevor Swanson, Craig Homan, and Richard Jack participated in the data collection and helped author the Green River and Newaukum Creek Temperature and Dissolved Oxygen Total Maximum Daily Load Study Data Summary Report in 2007.

Greg Pelletier of Ecology's Environmental Assessment Program provided technical advice throughout the development of the TMDL.

Lynette Loyden with Ecology's Northwest Regional Office assisted in the organization of the document.

Ecology's publishing team in the Water Quality Program, Diane Dent, Ann Kahler, Kelsey Highfill and Becky Powell, put in many hours editing and formatting the document for final publication and printing.

DouGlas Palenshus with Ecology's Water Quality Program directed public outreach and education for the Green River TMDL process.

Executive Summary

Introduction

Portions of the Green River and its major tributaries, including Newaukum Creek, Soos Creek, Hill (Mill) Creek and Mullen Slough exhibit unhealthy stream temperature and oxygen conditions that do not meet Washington State water quality standards (Figure ES-1). This water quality improvement report documents the studies and the implementation strategy that outlines the approaches for improving temperature in the Lower and Middle Green River. Separate Ecology reports will document the dissolved oxygen TMDL study for the Green River and the temperature and dissolved oxygen TMDLs for Newaukum and Soos Creeks.

What is a total maximum daily load (TMDL)?

The federal Clean Water Act (CWA) requires that a total maximum daily load (TMDL) be developed for each of the water bodies on the 303(d) list. The 303(d) list is a list of water bodies, which the CWA requires states to prepare, that do not meet state water quality standards. A TMDL study identifies pollution problems in a watershed, and then specifies how much pollution needs to be reduced or eliminated to achieve clean water and meet standards. Then Ecology, with the assistance of local governments, agencies, and the community develops a plan that describes actions to control the pollution and a monitoring plan to assess the effectiveness of the water quality improvement activities. This *Middle and Lower Green River Temperature TMDL: Water Quality Improvement Report* (WQIR) consists of the TMDL study and an implementation strategy.

Watershed description

Located in western Washington State in Water Resource Inventory Area (WRIA) 09, the Green River basin drains about 484 square miles of land area and includes portions of King County and the cities of Auburn; Black Diamond; Covington; Enumclaw; Kent; Maple Valley; Renton; Sea-Tac; and Tukwila. The Green River flows for over 93 miles from the Cascade Mountains to Elliott Bay.

The study area for this TMDL focuses on the Middle and Lower Green River[1], which flows about 54 miles from the outlet of the Howard Hanson Dam to the confluence with the Duwamish Waterway at river mile 11 in the city of Tukwila. Land use in the study area varies considerably, from a mix of residential, commercial forestry and agricultural land uses along the Middle Green River, to agricultural, residential, industrial, and commercial land uses near the Lower Green River.

[1] The Middle Green River is defined as the reach between the outlet of Howard Hanson Dam and Auburn Narrows below Soos Creek. The Lower Green River is defined as the reach between Auburn Narrows and the confluence with the Black River in Tukwila.

The major tributaries to the lower and middle reaches of the Green River are Mill Creek (RM 23.8), Soos Creek (RM 33.8), and Newaukum Creek (RM 40.7). These three tributaries drain a combined basin of 106 square miles (NHC, 2005). Newaukum Creek runs about 14 miles from its headwaters in the Cascade foothills (3,000 ft above sea level) east of the city of Enumclaw through the Enumclaw valley and then into the Green River.

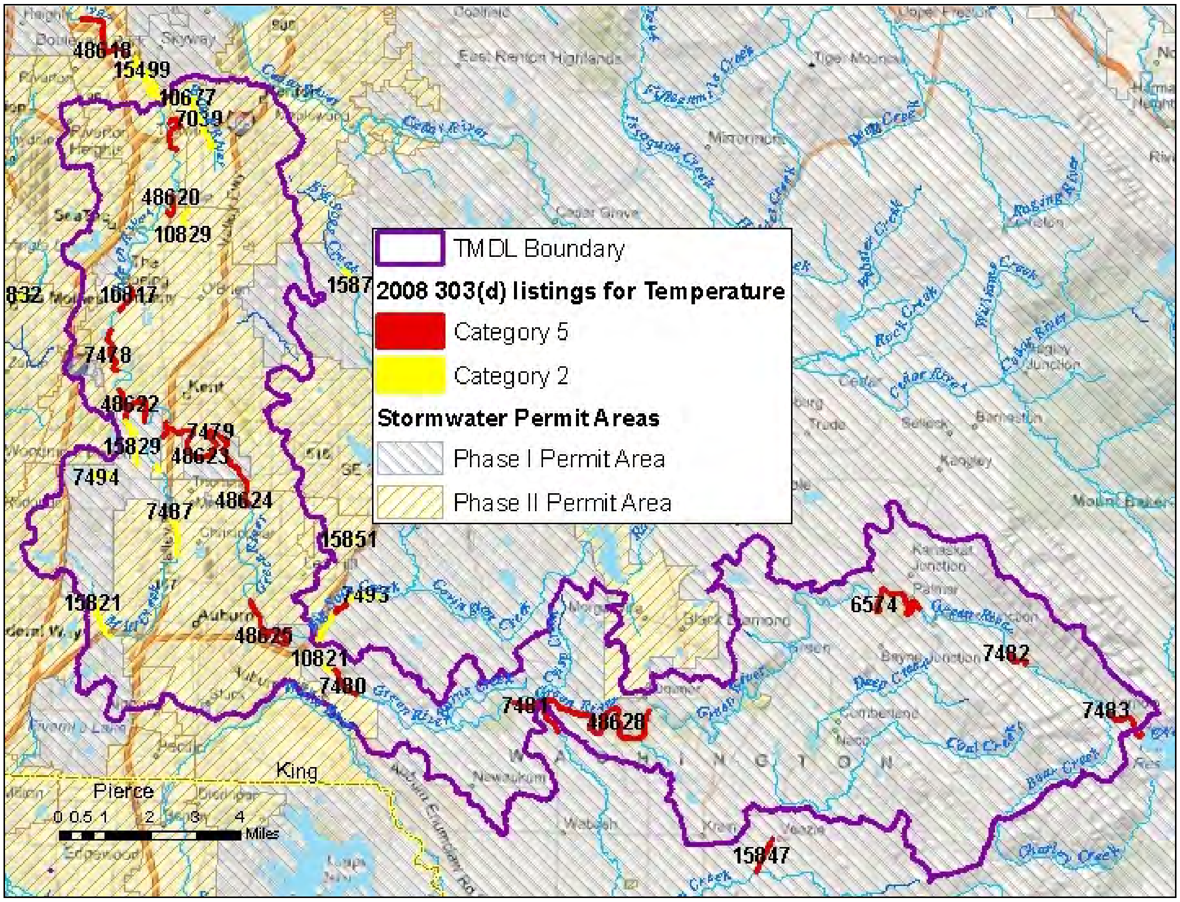

Figure ES-1. Temperature listings in the Middle and Lower Green River watershed.

The middle portion of the Newaukum Creek watershed is primarily agricultural and rural development, with increasing urban development near the city of Enumclaw. The lower and upper reaches of Newaukum Creek are more forested. Soos Creek is partially forested but has been developing rapidly with residential tracts, and Mill Creek drains an area that has several wetland areas but is heavily commercial/industrial and is crossed by several roads and highways.

What needs to be done in this watershed?

Summer water temperatures in the Middle and Lower Green River are too warm to support proper habitat for the fish that use these waters for migration, spawning and rearing. Modeling and monitoring for this TMDL, as well as data from prior monitoring demonstrated that temperatures in the lower reaches of the Green River approach and sometimes exceed lethal conditions for salmonids. High temperatures can have many detrimental effects on the health of salmonids, including blocking or delaying migration; causing a decrease in dissolved oxygen;

increasing susceptibility to disease; hindering or stopping the development of egg; fry and smolt; reducing the natural food supply; and killing both mature and immature fish. To increase survivability and rebuild the habitat, it will be necessary to reduce and then maintain lower temperatures in the river below Howard Hanson Dam.

Late August temperatures of water flowing into the middle Green River from Howard Hanson Dam are occasionally above state water quality standards. Water quality standards require temperatures of 16°C or less in this area of the watershed, but monitoring demonstrated temperatures of a degree or more higher just below the dam. This may be due to a combination of the river running through the lakebed just upstream of the dam, and the increased residence time of the water impounded behind the dam. Because the withdrawal from the reservoir is at a fixed elevation, the temperature of the water released from the dam may also be affected by the interaction of changing reservoir water levels and thermal stratification, which can tend to alter the seasonal timing of the reservoir outlet temperature. It may also be due to natural conditions in the upper watershed.

The Corps of Engineers reports that temperatures of the water flowing into the reservoir behind Howard Hanson Dam are often several degrees warmer than the water exiting the reservoir at the dam. Lake depth behind the dam can be greater than 100 ft. during July and August, and the dam withdraws water from the reservoir near the elevation of the lakebottom. Stratification of water in the reservoir may tend to cause the cooler water to pool at the bottom of the reservoir when the reservoir is full and be passed downstream, through the dam into the river. Drawdown of the reservoir typically occurs from late August through October to augment flows in the mainstem river.

Trees growing along a river will shade the waterway from solar radiation, the primary source of heat to the river. The effectiveness of shade provided by trees is dependent upon several variables, including the height of the trees and the width and density of the planted riparian area (buffer).

Monitoring and modeling show that a shade deficit exists throughout the Middle and Lower Green River riparian corridor, with the exception of the reach through the Green River gorge. The effective shade deficit is especially prevalent below the city of Auburn (Figure ES-1). Much of the existing forested riparian area downstream of Howard Hanson Dam to the head of the Green River gorge and just downstream of the gorge to Auburn is often fragmented, un-vegetated, or covered in low or immature vegetation, offering poor shade qualities and allowing solar radiation to heat the river. Downstream of Auburn the river is channeled between a series of revetments, levees and steep banks, mostly devoid of trees and any significant riparian cover. This area is heavily urbanized with residential, commercial and industrial development, roads, highways, railroads, and some agricultural enterprises.

Shade in itself does not cool the river water, but rather protects cool water from being heated by the sun as it moves downstream. Increasing and improving the riparian buffer below Howard Hanson Dam will help maintain the cool water that is delivered to the Middle Green River from the forested upper watershed.

Tributaries to the Middle and Lower Green River must also supply an adequate flow of cool clean water. These sub-watersheds are in the spotlight for ongoing and future urban and residential development. Special care must be practiced in these watersheds to improve and protect cool water temperatures. Riparian corridors need to be reestablished where they are inadequate to provide shade and precipitation must be allowed to infiltrate into soils contribute cool, consistent baseflow to the streams.

Human development and building have brought with them impervious surfaces such as roofs, driveways, roads, and parking lots that catch precipitation and divert much of the stormwater runoff directly into stormwater drainage systems and, ultimately, either through direct discharge or through discharge to ground, into the tributary channels. The direct surface discharges from stormwater drainage systems can contribute to a fast, and sometime furious, flush of stormwater that ebbs as soon as the storm events subside. Under predeveloped, forested conditions, the precipitation would be caught by the trees and vegetation and evaporate or transpire into the atmosphere (evapotranspiration); be trapped by the organic duff layer to be released back into the atmosphere or to the ground; or infiltrate into the soils, and slowly be released to the streams, providing a more prolonged and consistent release of cool groundwater to the stream and river.

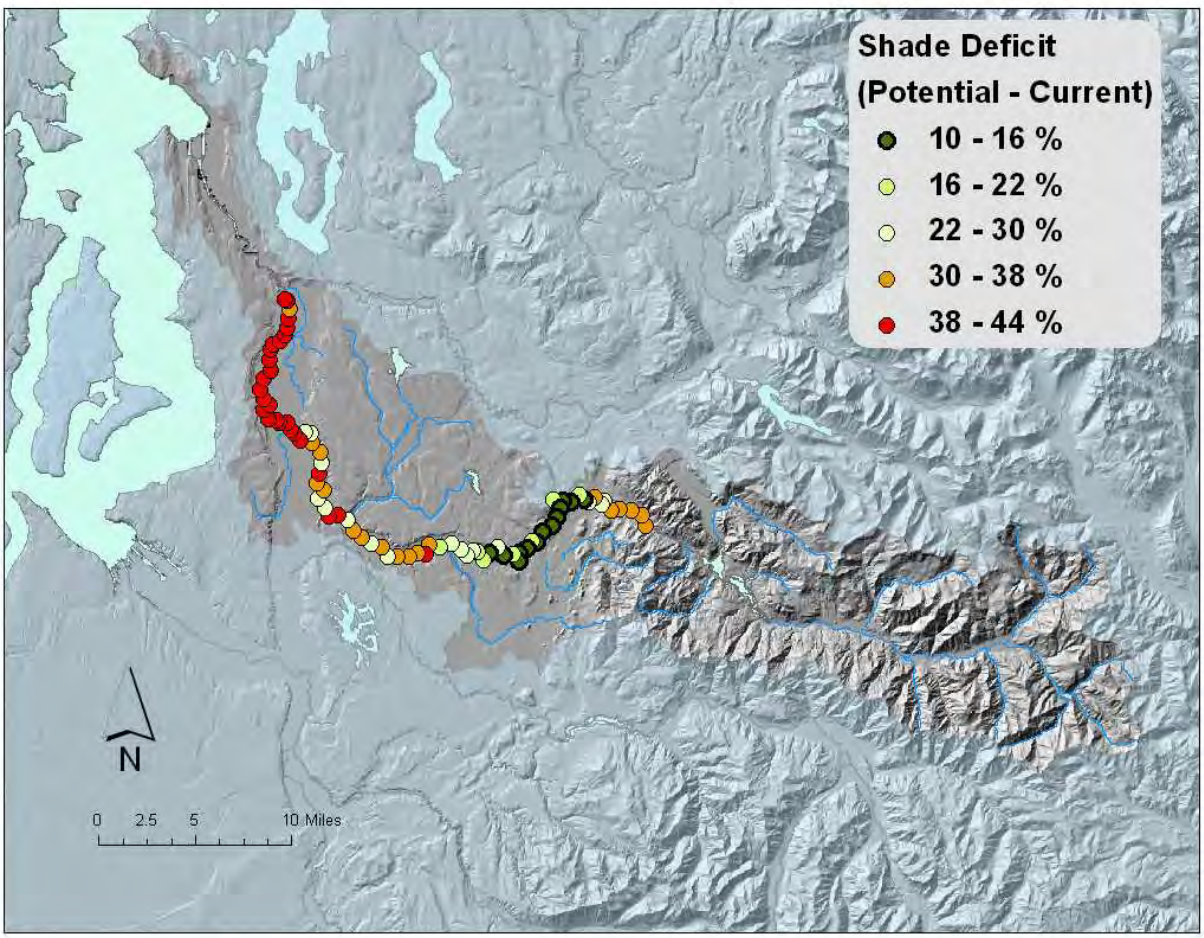

Figure ES-2. Effective shade deficit by 1,000 m increments. The deficit is the difference between the mature riparian shade condition and the current riparian shade condition.

Low impact development (LID) employs behavioral, planning, and building methods whose intent is to minimize impervious surfaces, reduce pollutant loading and stormwater surface runoff, and promote stormwater controls at the site level which include retention of native vegetation and promoting infiltration into the soils. Through the 2012 Municipal NPDES permits the LID paradigm is anticipated become the required approach for all new construction and building retrofits in the watershed. All stormwater management tools and policies including programs such and pollutant source control should always be considered in management of stormwater and the protection of the receiving waters.

The model used in the Green River temperature TMDL analysis shows that under current conditions lethal temperatures can be expected in the Lower Green River during high summer temperatures and low flow conditions (Figure ES-2). It goes on to demonstrate that even when all riparian areas along the Middle and Lower Green River, except the levees, are vegetated with full site potential shade, lethal temperatures will still occur in the lower ten kilometers of the Lower Green River. Until the Corps of Engineers levee maintenance policy can be changed to allow the growth of a full riparian corridor, or levees set back to allow for planting, or until another mitigation approach can be successfully employed, temperatures will not meet state standards in the lower Green River.

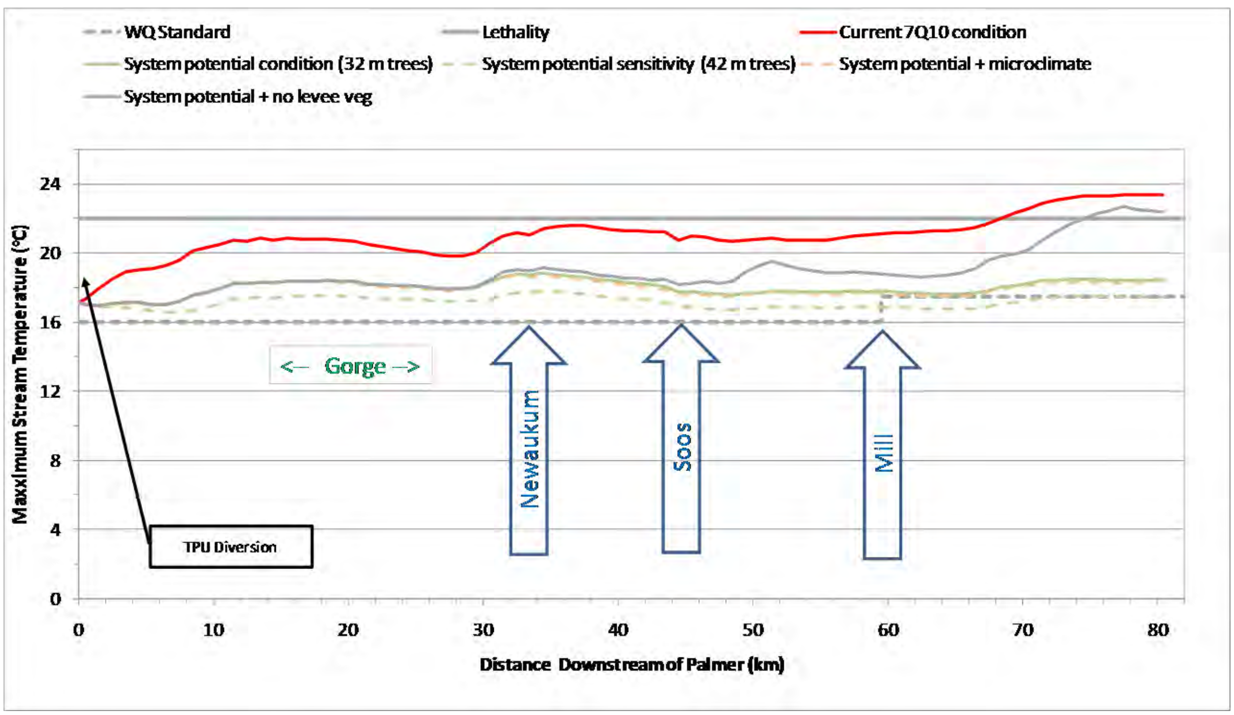

Figure ES-3. **Temperature modeling results under several scenarios. Of note is that when system potential shade exists everywhere along the river** *except on the levees below Auburn, there can still be lethal temperatures in the lower 6 km of the river.*

As much of a challenge as it may seem to move levees and change federal policy, it will be equally daunting to push back and plant the areas now covered by roads, residences, businesses, agriculture, and industry that line much of the banks on the Lower Green River. Several projects that address some of these issues were proposed in the 2005 report *Salmon Habitat Plan –*

Making Our Watershed Fit for a King. Some of the projects have been funded and are now being implemented.

Implementation strategy

Table ES-1 is a list of implementation strategies that apply to the Green River and its tributaries. Specific actions will be developed to address the strategies and will be described in a *water quality implementation plan* that will be developed within a year of the approval and adoption of this TMDL.

Table ES-1. Summary of implementation strategies to improve temperature in the Middle and Lower Green River.

Implementation Strategies
Provide more shade and improve riparian areas
Assess potential planting sites along the Middle and Lower Green River and along tributaries.
Encourage riparian planting projects
Locate available funding for watershed restoration projects
Complete the necessary negotiations with USCOE and other agencies and/or municipalities that own or control levees and the adjacent properties to allow an adequate riparian buffer to be developed along the length of the lower Green River.
Incorporate TMDL actions into local regulatory programs and policies.
Protect cool groundwater and enhance current summer baseflows
Promote Low Impact Development (LID) practices that are demonstrated to be environmentally sound.
Consider TMDLs during SEPA and other land use planning reviews.
Minimize stormwater runoff to the maximum extent feasible using techniques that do not put groundwater or surface water quality at risk.
Restore and/or create beneficial wetlands.
Increase water conservation
Consider economically-feasible alternative water sources such as community water systems.
Reduce unauthorized water withdrawals through enforcement.
Monitoring
Conduct in-stream water quality & flow monitoring.
Effectiveness monitoring

What is a Total Maximum Daily Load (TMDL)

Federal Clean Water Act requirements

The Clean Water Act (CWA) established a process to identify and clean up polluted waters. The CWA requires each state to have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of (1) designated uses for protection, such as cold water biota and drinking water supply, and (2) criteria, usually numeric criteria, to achieve those uses.

The Water Quality Assessment and the 303(d) List

Every two years, states are required to prepare a list of water bodies that do not meet water quality standards. This list is called the CWA 303(d) list. In Washington State, this list is part of the Water Quality Assessment (WQA).

To develop the WQA, the Washington State Department of Ecology (Ecology) compiles its own water quality data along with data from local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the assessment. The list of waters that do not meet standards [the 303(d) list] is the Category 5 part of the larger assessment.

Category 1 – Meets standards for parameter(s) for which it has been tested.

Category 2 – Waters of concern.

Category 3 – Waters with no data or insufficient data available.

Category 4 – Polluted waters that do not require a TMDL because:
- 4a. – Have an approved TMDL being implemented.
- 4b. – Have a pollution control program in place that should solve the problem.
- 4c. – Are impaired by a non-pollutant such as low water flow, dams, culverts.

Category 5 – Polluted waters that require a TMDL – the 303(d) list.

Further information is available at Ecology's Water Quality Assessment website.

The CWA requires that a total maximum daily load (TMDL) be developed for each of the water bodies on the 303(d) list. A TMDL is a numeric value representing the highest pollutant load a surface water can receive and still meet water quality standards. Any amount of pollution above the TMDL level needs to be reduced or eliminated to achieve clean water.

TMDL process overview

Ecology uses the 303(d) list to prioritize and initiate TMDL studies across the state. The TMDL identifies pollution problems in the watershed, and specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology, with the assistance of local governments, tribes, agencies, and the community then develops a strategy to control and reduce pollution sources and a monitoring plan to assess effectiveness of the water quality improvement activities. Together, the study and implementation strategy comprise the *water quality improvement report* (WQIR).

Within a year after approval of the WQIR by the U.S. Environmental Protection Agency (EPA) Ecology will develop a Water *quality implementation plan* (WQIP). The WQIP identifies specific tasks, responsible parties, and timelines for reducing or eliminating pollution sources and achieving clean water.

Who should participate in this TMDL?

Many government agencies, citizen groups, and tribes in the watershed have regulatory authority, influence, information, resources, or other involvement activities to protect and restore the stream health of the Green River and its tributaries.

Nonpoint source pollutant load targets have been set in this TMDL and are described in Table 13. Because nonpoint pollution comes from diffuse sources, all upstream watershed areas have the potential to affect downstream water quality. Therefore, all potential nonpoint sources in the watershed must use the appropriate best management practices to reduce impacts to water quality. The area subject to the TMDL is shown in Figure 4. The TMDL is focused on the mainstem Green River from river mile (RM) 64.5 below Howard Hanson Dam to the confluence with the Black River in Tukwila at RM 11.0. Several of the major tributaries to the Green River have also been shown to exceed water quality criteria and are not meeting state standards. These smaller basins will be addressed separately through the TMDL process, but must also be considered while developing the Green River TMDL.

Elements the Clean Water Act requires in a TMDL

Loading capacity, allocations, seasonal variation, margin of safety, and reserve capacity

A water body's *loading capacity* is the amount of a given pollutant that a water body can receive and still meet water quality standards. The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a water body into compliance with the standards.

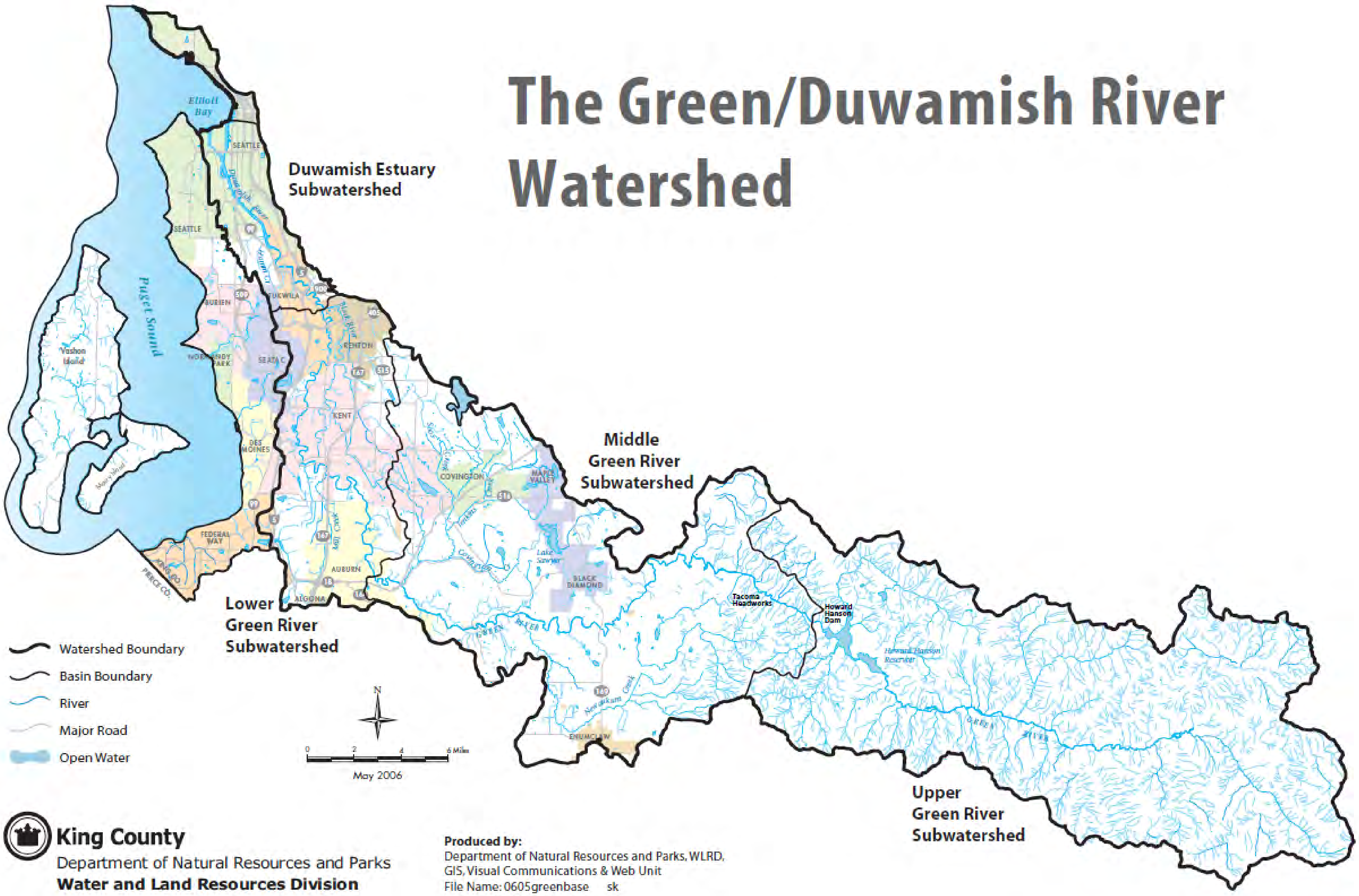

Figure 4. Green/Duwamish Watershed.

The portion of the receiving water's loading capacity assigned to a particular source is a *wasteload* or *load* allocation. If the pollutant comes from a discrete (point) source subject to a National Pollutant Discharge Elimination System (NPDES) permit, such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation*. If the pollutant comes from diffuse (nonpoint) sources not subject to an NPDES permit, such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation*.

The TMDL must also consider *seasonal variations*, and include a *margin of safety* that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A *reserve capacity* for future pollutant sources is sometimes included as well.

Therefore, a TMDL is the sum of the wasteload and load allocations, any margin of safety, and any reserve capacity. The TMDL must be equal to or less than the loading capacity.

Surrogate measures

To provide more meaningful and measurable pollutant loading targets, this TMDL uses shade as a *surrogate measure* for temperature. EPA regulations [40 CFR 130.2(i)] allow other appropriate measures in a TMDL. See the Glossary section of this document for more information.

Potential surrogate measures for use in this TMDL are in the following discussion. The ultimate need for, and the selection of a surrogate measure for use in setting allocations depends on how well the proposed surrogate measure matches the selected implementation strategy.

Temperature

Temperature represents the equivalent of heat concentration within a water body, and water temperatures increase as a result of increased heat loads. Therefore, when temperature standards are violated, heat is considered the pollutant. Processes that affect the heat load in the Green River basin include:

- Riparian vegetation disturbance that affects stream surface shading and microclimate.
- Reduced exchange of cool groundwater.
- Reduced summer baseflows (reducing the volume of water available to absorb heat).
- Tributaries discharging warm water into the mainstem.

Heat loads (from incoming solar radiation) to the stream are calculated in this TMDL in units of watts per square meter (W/m^2). However, heat loads are of limited value in guiding management activities needed to solve identified water quality problems.

Therefore, appropriate "surrogate measures" were used in this TMDL to fulfill the requirements of Section 303(d) as provided under EPA regulations [40 CFR 130.2(i)]. The "Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program" (EPA, 1998) includes the following guidance on the use of surrogate measures for TMDL development: *"When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional "pollutant," the state should try to identify another (surrogate) environmental indicator that can be used to* *develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not."*

The technical assessment in this TMDL uses effective shade as a surrogate measure of heat flux from solar radiation. Effective shade is defined as the fraction of potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. The definition of effective shade allows direct translation of the solar radiation loading capacity. Other factors influencing heat loads and water temperature were also considered, including microclimate, channel geometry, groundwater recharge, and instream flow.

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Why Ecology Conducted a TMDL Study in this Watershed

Ecology conducted a TMDL study in this watershed because the federal Clean Water Act requires that impaired water bodies on the 303(d) list be restored to meet water quality standards through a TMDL process. Ecology's Northwest Regional Office prioritized the watersheds needing TMDLs in northwest Washington. Producing a TMDL for the Green River is in accordance with that prioritization.

In the summer of 2006, Ecology, King County, Muckleshoot Indian Tribe, and others initiated a cooperative effort to develop a temperature and dissolved oxygen TMDL in this basin. The effort included water quality monitoring in the Green River. The monitoring supplemented existing data collection programs and provided input data for the water quality model used in this study as well as data to compare to the model.

Data collected were used to develop a temperature model for the mainstem Green River. The model was used to understand factors contributing to elevated temperatures in the system and to develop heat load reduction targets necessary to meet the water quality standards throughout the system. Ecology has on-going work to finalize the dissolved oxygen model for the Green River.

Newaukum Creek and Soos Creek are the two major sub-basins targeted for their own TMDL studies on temperature and dissolved oxygen.

Impairments addressed by this TMDL

The main uses to be protected by this TMDL are aquatic life uses for core summer salmonid habitat and salmonid spawning, rearing, and migration. Washington State established water quality standards to protect these beneficial uses. The uses will be protected by reducing heat and nutrient loadings to the water body. Table 2 includes 303(d) listings for temperature impairments along the Middle and Lower Green River that are addressed by this TMDL.

Table 2. Study area water bodies in the Green River basin on the 2008 303(d) list for temperature.

Water body	Parameter	Listing ID	Township	Range	Section	River reach
Green River	Temperature	7482	21N	08E	18	Middle
Green River	Temperature	7480	21N	05E	22	Middle
Green River	Temperature	7478	22N	04E	15	Lower
Green River	Temperature	7479	22N	05E	30	Lower
Green River	Temperature	7037	23N	04E	24	Lower
Green River	Temperature	7043	21N	06E	28	Middle
Green River	Temperature	7481	21N	06E	29	Middle
Green River	Temperature	6574	21N	07E	10	Middle
Green River	Temperature	7483	21N	08E	28	Middle
Green River	Temperature	10817	22N	04E	11	Lower
Green River	Temperature	48620	23N	04E	36	Lower
Green River	Temperature	48622	22N	04E	23	Lower
Green River	Temperature	48623	22N	04E	25	Lower
Green River	Temperature	48624	22N	05E	31	Lower
Green River	Temperature	48625	21N	05E	17	Lower
Green River	Temperature	48628	21N	06E	27	Middle

This watershed has other water quality issues that are not addressed in this Green River Temperature TMDL. In particular, Table 3 lists additional 303(d) listings for water quality impairments in the Green River and its major tributaries, including Newaukum and Soos Creeks. A separate and concurrent TMDL is being developed to address temperature listings in Newaukum Creek.

Table 3. Additional 2008 303(d) listings not addressed by this Green River Temperature TMDL.

Water body	Parameter	Listing ID	Township	Range	Section
Newaukum Creek	Temperature	48233	21N	06E	29
Hill (Mill) Creek	Temperature	7041	22N	04E	25
Mullen Slough	Temperature	15828	22N	04E	23
Green River	DO	12708	21N	06E	28
Green River	DO	10812	23N	04E	24
Green River	DO	10824	21N	07E	10
Green River	DO	47547	22N	04E	25
Green River	DO	47551	21N	05E	22
Green River	DO	48004	21N	08E	18
Newaukum Creek	DO	12700	21N	06E	33
Newaukum Creek	DO	47454	20N	06E	15
Newaukum Creek	DO	47455	20N	06E	14
Mullen Slough	DO	15825	22N	04E	26
Mullen Slough	DO	15826	22N	04E	23
Hill (Mill) Creek	DO	7488	21N	04E	01
Hill (Mill) Creek	DO	12707	22N	04E	25
Hill (Mill) Creek	DO	15811	22N	04E	26
Hill (Mill) Creek	DO	15814	22N	04E	35
Big Soos Creek	DO	15866	22N	05E	03
Big Soos Creek	DO	15867	22N	05E	10
Green River	Fecal coliform	12569	23N	04E	24
Green River	Fecal coliform	13159	21N	05E	21
Green River	Fecal coliform	16703	22N	04E	11
Hill (Mill) Creek	Fecal coliform	7485	22N	04E	25
Hill (Mill) Creek	Fecal coliform	7486	21N	04E	01
Hill (Mill) Creek	Fecal coliform	15815	22N	04E	26
Hill (Mill) Creek	Fecal coliform	15817	22N	04E	15
Hill (Mill) Creek	Fecal coliform	15820	22N	04E	35
Newaukum Creek	Fecal coliform	13157	21N	06E	28

Water body	Parameter	Listing ID	Township	Range	Section
Newaukum Creek	Fecal coliform	13165	21N	06E	33
Newaukum Creek	Fecal coliform	13166	20N	06E	10
Newaukum Creek	Fecal coliform	13971	20N	06E	12
Newaukum Creek	Fecal coliform	13972	20N	07E	07
Newaukum Creek	Fecal coliform	13981	20N	07E	07
Mullen Slough	Fecal coliform	15767	22N	04E	23
Mullen Slough	Fecal coliform	15827	22N	04E	26
Big Soos Creek	Fecal coliform	13160	22N	05E	16
Big Soos Creek	Fecal coliform	15870	22N	05E	03
Big Soos Creek	Fecal coliform	15971	22N	05E	23
Hill (Mill) Creek	Copper	13815	22N	04E	25
Newaukum Creek	Copper	13765	21N	06E	28
Newaukum Creek	Copper	13839	21N	06E	33

Water Quality Standards

Temperature and dissolved oxygen affect the physiology and behavior of fish and other aquatic life. Temperature may be the most influential factor limiting the distribution and health of aquatic life. The health of fish and other aquatic species also depends on maintaining an adequate supply of oxygen dissolved in the water. Oxygen levels affect growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants. While direct mortality due to inadequate oxygen can occur, the state designed the criteria to maintain conditions that support healthy populations of fish and other aquatic life.

Washington State Water Quality Standards, set forth in Chapter 173-201A of the Washington Administrative Code (Ecology, 2006), include designated beneficial uses, waterbody classifications, and numeric and narrative water quality criteria for surface waters of the state.

Designated aquatic life uses

In the state water quality standards, aquatic life use categories are described using key species (salmon versus warm-water species) and life-stage conditions (spawning versus rearing) [WAC 173-201A-200]. The beneficial uses to be protected within the Green River basin include (1) Core Summer Salmonid Habitat and (2) Salmonid Spawning, Rearing, and Migration Figure 5.

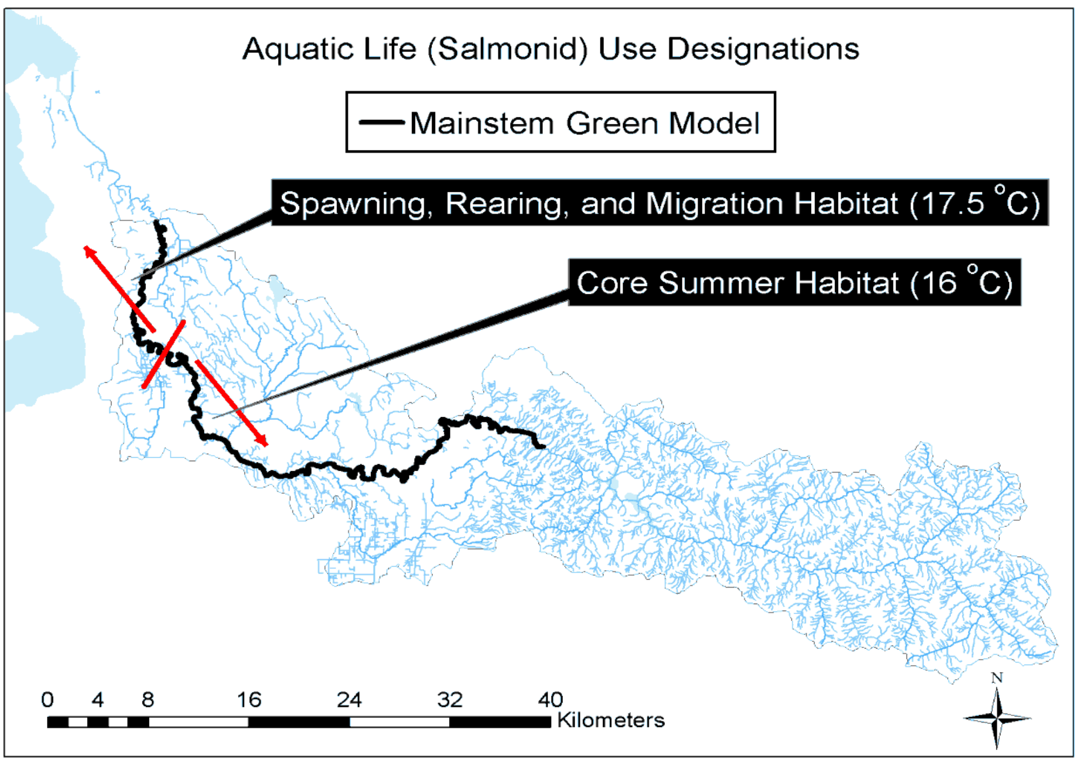

Figure 5. Aquatic life use designations and associated temperature criteria applied along the Green River.

These designated aquatic life uses are defined in WAC 173-201A-200 as:

- *Core summer salmonid habitat* - this use protects summer season, defined as June 15 through September 15, salmonid spawning or emergence, or adult holding; summer rearing habitat by one or more salmonids; or foraging by adult and sub-adult native char. Other protected uses include spawning outside of the summer season, rearing, and migration by salmonids.
- *Salmonid spawning, rearing, and migration* - this use protects salmon or trout spawning and emergence that only occur outside of the summer season (September 16 – June 14). Other uses include rearing and migration by salmonids.

Other non-aquatic life uses include water supply (domestic, industrial, and agricultural), stock watering, fish and shellfish (salmonid and other fish migration, rearing, spawning, and harvesting), wildlife habitat, recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment), and commerce and navigation.

Each beneficial use designation has associated water quality criteria. The relevant temperature criteria that apply to the Green River are summarized below.

Temperature criteria

Temperature levels fluctuate over the day and night in response to changes in climatic conditions and river flows. Since the health of aquatic species is tied predominantly to the pattern of maximum temperatures, the criteria are expressed as the highest seven-day average of the daily maximum temperatures (7-DADMax) occurring in a water body.

The applicable temperature criteria [WAC 173-201A-200(c) and 173-201A-602] for the designated uses are:

1. To protect the designated aquatic life uses of "Core Summer Salmonid Habitat," the highest 7-DADMax temperature must not exceed 16°C (60.8°F) at a probability frequency of more than once every ten years on average.

2. To protect the designated aquatic life uses of "Salmonid Spawning, Rearing, and Migration, and Salmonid Rearing and Migration Only," the highest 7-DADMax temperature must not exceed 17.5°C (63.5°F) at a probability frequency of more than once every ten years on average.

Washington State uses the criteria described above to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. When a water body is naturally warmer than the above-described criteria, the state provides an allowance for additional warming due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.3°C (0.54°F) increase above the naturally higher (inferior) temperature condition.

The 16°C criterion applies to the Green River above approximately river mile 23.8, at the river's confluence with Mill Creek. Downstream of that location the 17.5°C criterion applies.

Supplemental temperature standards

Special consideration is also required to protect spawning and incubation of salmonid species. In addition, the Green River from Black River (near Kent) to Howard Hanson Dam, including Newaukum Creek, Soos Creek System, and Crisp Creek, must not exceed 13°C between September 15 and July 1 (Figure 6). This study was designed to evaluate summer peak temperatures; other conditions are not evaluated explicitly.

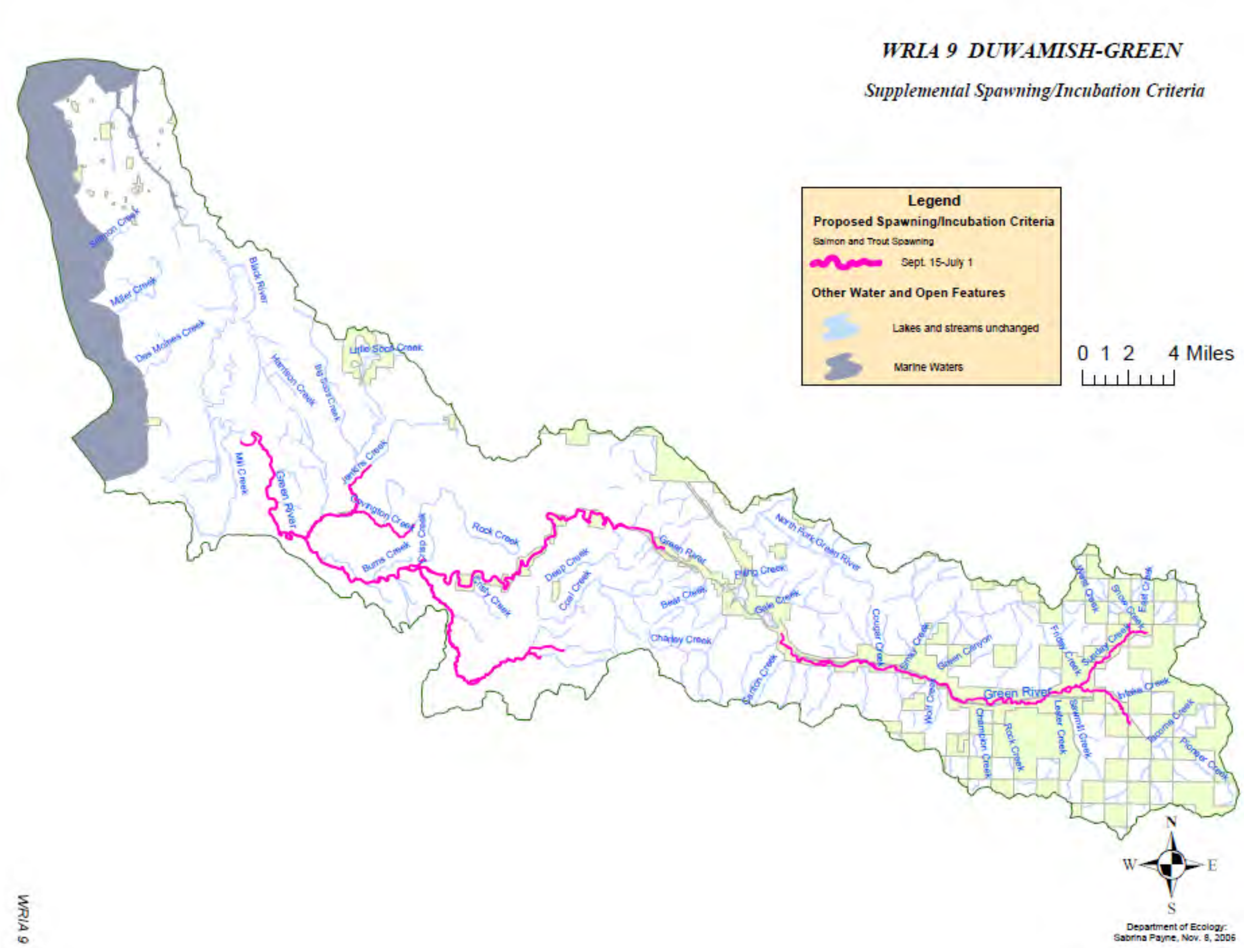

Figure 6. Application of supplemental spawning and incubation criteria in WRIA 9 Green-Duwamish Watershed.

The salmonid populations targeted for the additional protection are those that have eggs and embryos developing in the stream bed in late spring to early fall. Salmonid populations which begin spawning in late fall or whose young have emerged from the stream gravels before late spring do not require added protection.

A spawning temperature of 13°C (as a 7-day average of daily maximum temperatures) is used to protect summer reproduction areas for salmon and trout. Figure 6 shows the reaches along the Green River where these criteria are to be applied during September 15 to July 1.

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Watershed Description

Green River

Located in Western Washington State, the Green River basin drains about 484 square miles of land area within King County and includes the cities of Covington; Maple Valley; Kent; Black Diamond; Renton; Tukwila; Sea-Tac; Federal Way; Enumclaw; and Algona (Figure 4). The Green River extends from the crest of the Cascade Mountains near Stampede Pass north of Mt Rainier about 5,750 ft above sea level and flows about 54 miles from the outlet of Howard Hanson Dam to the Duwamish Waterway before empting into Elliot Bay in Puget Sound.

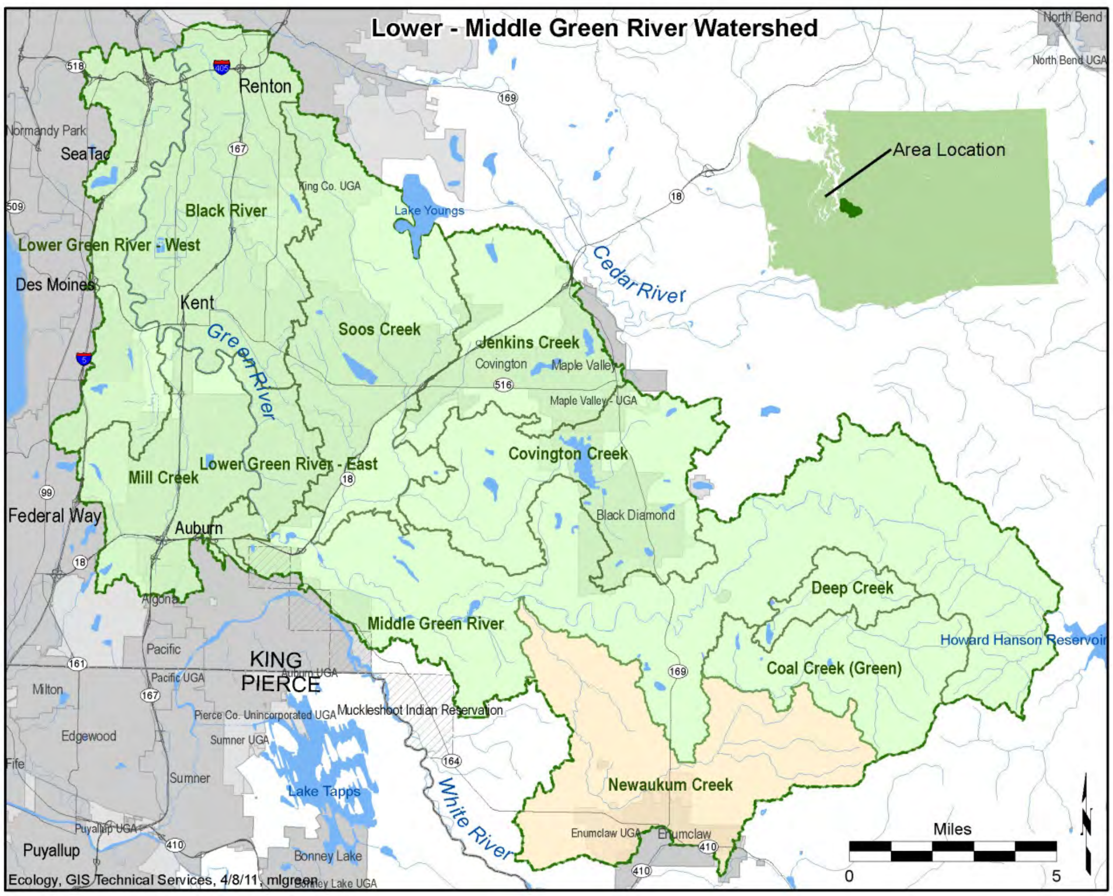

Figure 7. Middle and Lower Green River sub-watersheds.

The Green River can be divided into the Upper Green River above Howard Hanson Dam, Middle Green River between Howard Hanson Dam and the Auburn Narrows below Soos Creek, and Lower Green River sub-basin between the Auburn Narrows and Tukwila.

Public access to the Upper Green River is limited to protect the water supply for the city of Tacoma. The TMDL study does not include the Upper Green sub-basin.

The Green River Gorge, a steep-walled canyon with a bed of boulders and rock, is a unique feature of this Puget Sound river. The gorge is a relatively recent (post-glacial) feature approximately 13 miles long, cutting a steep, deep (approximately 300 ft from the rim), sinuous, and narrow path through glacial and bedrock deposits. Coal seams extend from both sides of the gorge in some places, and cinnabar was mined historically at two locations in the Gorge – one on the east wall and another on the south wall (Dunne and Dietrich, 1979).

A number of tributaries and springs enter the Middle Green River between the Tacoma Public Utilities diversion and the downstream end of the gorge. These springs include Palmer Pond Springs (RM 56.3), Resort Springs (RM 51.3), Palmer Springs (RM 49.7), Black Diamond Springs (RM 49.5), and Icy Creek Springs (RM 48.3) (Luzier, 1969; NHC, 2005). Water from Palmer Pond and Icy Creek springs supply water for Washington Department of Fish and Wildlife rearing ponds. It is suspected that the recharge areas for the springs emanating from the southern wall of the gorge (Resort, Black Diamond, and Icy Creek) are the closed (i.e., no surface outlet) Deep and Coal Creek basins to the south that are within the Green River watershed.

Below the gorge, beginning at Flaming Geyser State Park, the river again becomes a coarse gravel-bedded meandering and braided channel with limited flood and bank protection, that actively shifts across the floodplain. The river then descends a rapidly-decreasing gradient and emerges at the city of Auburn on the broad and low gradient Lower Green River valley (formerly the White River valley; Collins and Sheikh, 2005) which is extensively developed and protected by riprap and raised levees.

Between Flaming Geyser State Park and Auburn, the two major tributaries Newaukum Creek and Soos Creek enter the Green River. A number of smaller tributaries enter the river along this reach, including Crisp Creek, which is largely spring fed and also provides water for the Keta Creek Hatchery run by the Muckleshoot Indian Tribe. A Washington State Department of Fish and Wildlife hatchery, constructed in 1901, is also located near the mouth of Soos Creek.

Below Auburn, the river meanders across the floodplain through the city of Kent until it reaches the Duwamish at the confluence with the Black River in Tukwila at RM 11.0. Bed material becomes increasingly dominated by sand. Below Auburn the width of the river has decreased and channel migration has become almost non-existent, following diversion of the White River and construction of bank protection measures (Perkins, 1993). The largest tributaries are Mill Creek and Mullen Slough that drain most of the remaining agricultural areas in the Lower Green River basin. This TMDL does not include the lower Duwamish estuary.

Basin characteristics

Physical features and climate

A combination of tectonic processes, glaciations, and volcanic activity shaped the major drainage systems of Puget Sound, including that of the Green River (Dunne and Dietrich, 1979; Booth *et al.*, 2003). Perhaps the most dramatic event in recent geologic history was the Osceola mudflow, the catastrophic collapse of the northeast side of Mt. Rainier about 5,700 years ago, which along with subsequent lahars produced enough volcanic debris delivered by the White River to eventually fill much of the previously marine extent of the Duwamish from Auburn to Elliott Bay in Seattle (Dunne and Dietrich, 1979; Dragovich *et al.*, 1994; Booth *et al.*, 2003; Collins and Sheikh, 2005).

Overall, the area experiences relatively moderate temperatures and substantial rainfall due to the northerly location (47.5^{o} N), proximity to the Pacific Ocean and Puget Sound, and mountain effects. Annual precipitation ranges from about 40 inches in the Lower Green to over 90 inches at the headwaters near Stampede Pass. Most precipitation (~75 percent) falls between October and March. The driest months are typically June, July, and August.

Winter temperatures can drop below freezing, but snow at lower elevations is not common. Winter snow becomes more common at higher elevations and above 3,280 ft snow accumulates over the winter and then melts in spring. Due to the relatively lower elevations of the Upper Green River, winter rain-on-snow runoff typically generates the highest flows, although melting snow from the highest elevations does generate secondary peaks in the spring. Summer lowland temperatures typically range between 10 and 26 ^{o}C (50 and 78^{o}F), although temperatures exceeding 38 ^{o}C (100^{o}F) occur on average 3 to 5 days a year. Air temperature tends to decrease with increasing elevation.

Consistent with seasonal patterns in rainfall and temperature, cloud cover and percent possible sunshine is lowest in winter and highest in summer. The combination of high temperatures, relatively high solar intensity, reduced cloud cover, and declining river and stream flows typically result in maximum water temperatures near the first of August (Booth, 2002).

See Appendix C for information on projected climate change in the region and its impact on aquatic life.

Streamflows and groundwater use

Historically, the Green River was a tributary to the White River with their confluence located near the city of Auburn. The Green/White Rivers joined downstream with Cedar/Black Rivers to form the Duwamish River. In 1906, the White River was diverted into the Puyallup River for flood control, which reduced the Green River basin area above the confluence with the Black River by about 50 percent. The Black River originally drained Lake Washington, but a flood in 1911 on the Cedar River (then a tributary to the Black River at the southern end of Lake Washington) prompted the city of Renton to divert the Cedar River to Lake Washington. The diversion of the White and Cedar Rivers effectively reduced the original drainage basin to the

Duwamish River to a third of its historic extent. Diversion of the White River, which is fed by glaciers on the flanks of Mt. Rainier, and actively working the debris from the Osceola mudflow and subsequent lahars also significantly reduced the input of sediment to the Lower Green River and Duwamish River.

In 1913, the city of Tacoma began diverting water from the Green River near the town of Palmer to supply the domestic and industrial demands of Tacoma and Pierce County to the south. The construction of the diversion structure began in 1911, which effectively blocked upstream migration of anadromous salmonids (Dunne and Dietrich, 1979; Kerwin and Nelson, 2000; NHC, 2005).

The Howard Hanson Dam was completed in 1962 above Tacoma's water diversion structure for flood control and summer flow augmentation purposes. High flows from the project are currently managed so flow measured at USGS gage 12113000 in Auburn does not exceed 339.8 cubic meters per second (cms) or 12,000 cubic feet per second (cfs). The project also provides for additional storage in summer for low flow augmentation.

The largest single extraction of water from the mainstem Green River is by the city of Tacoma, with a First Diversion Water Right of 3.20 cubic meters per second (113 cubic feet per second) granted in 1913. In 1995 it was estimated that there were surface water rights to an additional 2.33 cubic meters per second (82.2 cubic feet per second), which were primarily municipal (57 percent) and irrigation (28 percent) water rights (Culhane *et al*., 1995; Kerwin and Nelson, 2000). Culhane *et al*. (1995) estimated total groundwater rights to 9.9 cubic meters per second (350 cubic feet per second), which are primarily for municipal (76 percent) and domestic (17 percent) uses. The total amount of water rights that are claimed, but that have not been adjudicated are even greater (Culhane *et al*., 1995).

Tacoma was granted a Second Diversion Water Right in 1985 to an additional 2.83 cms (100 cfs). An agreement with the Muckleshoot Indian Tribe and Instream Flow Rules (WAC 173-509-030) provide for additional conservation storage to meet minimum flow targets at the USGS gages near Palmer (gage 12106700) and in Auburn (gage 12113000) (NHC, 2005). The Army Corps of Engineers coordinates operations through the Green River Flow Management Committee – composed of federal, state, and local fisheries agencies, and the Muckleshoot Indian Tribe – during spring through fall each year to manage instream flows; balancing needs for flood control, water supply, and aquatic biota.

In addition to effects on low flow, the dam has eliminated historical high flows above 339.8 cms (12,000 cfs) at the Auburn gage and reduced the input of coarse sediment to the river (Dunne and Dietrich, 1979; Perkins, 1993). The response to these changes in the Lower and Middle Green River has been the narrowing of the channel and a reduction in the rate of migration of the river across the floodplain in spite of an increase in the duration of moderately high flows as a result of storing and releasing the highest flows. These changes, combined with changes in land use and management practices have significant implications for streamside vegetation.

Land uses and vegetation cover

The Green River watershed is significantly different than it was over 150 years ago (Kerwin and Nelson, 2000; NHC, 2005). Changes that have occurred include timber harvest, land clearing for agriculture, urban and suburban development, major water diversions, consumptive water withdrawals, and flood control activities. Initially, the lowlands were cleared of timber for agricultural uses and upland areas became the focus of mining (primarily coal, but also cinnabar – a source of mercury) and timber operations. Flooding of agricultural lands was a chronic problem in the lowland areas, and initial efforts to protect farmland focused on removal of wood debris and channeling and diking the Green River mainstem.

During the middle of the 20th century, economic development fostered further construction of levees and dams to reduce flooding, construction of roads and other transportation infrastructure, and industrial, commercial, and residential development.

Historically, streamside tree cover along the Lower and Middle Green River included red alder, black cottonwood, big leaf maple, vine maple, red alder, and willow were most common, while black cottonwood represented the greatest basal area (Collins and Sheikh, 2005). Limited information exists on the historical riparian conditions in the Green River above Flaming Geyser State Park.

An assessment conducted as part of the *WRIA 9 Habitat Limiting Factors and Reconnaissance Assessment for Salmon Habitat* (Kerwin and Nelson, 2000) suggests that the confined and relatively stable reaches in the gorge and between the dam and the Tacoma diversion likely supported stands of coniferous trees, including Douglas fir, western red cedar, and western hemlock. Riparian vegetation in less-confined reaches above the gorge and below the Tacoma diversion may have been similar to the vegetation present historically just below the gorge. The Upper Green River riparian vegetation may have been comprised of large coniferous trees (primarily western hemlock and western red cedar).

While over half of the Upper Green River riparian vegetation was similar to the natural potential vegetation, much of the vegetation was composed of small trees and shrubs, which were insufficient to provide good shade conditions (Kerwin and Nelson, 2000). Although over 80 percent of the Middle Green River supported native deciduous and coniferous riparian cover, only about half of the riparian zone was intact, resulting in an assessment that 30 percent of the channel had inadequate shade. In the Lower Green River very little intact riparian cover remained – mostly narrow deciduous stands with small, scattered trees mixed with patches of grass, pavement, or bare ground. Over 80 percent of the Lower Green River was considered to have poor shade.

Historically, the Green River has been prone to regular flooding and inundation of surrounding lands. Many of the levees in existence today were constructed in the late 1800s and early 1900s by local landowners using any materials available. In 1961, the Howard Hanson Dam went into operation and, accompanied by an extensive and continuous system of levees, major flooding in the area was moderated.

Age, poor construction, high peak flows from rain events, and urbanization all contributed to a weakening of the existing levee system and the need for levee repair efforts. As part of the U.S. Corps of Engineers levee maintenance policy, only trees and bushes with a trunk that is less than four inches in diameter are permitted on the levee face. Any vegetation with a larger stalk is removed.

Aquatic life resources

Protection and enhancement of coldwater habitat for salmon and trout species is the primary driver behind the need for this temperature TMDL for the Green River. Historically, runs of Chinook (spring and summer/fall stocks), pink, coho, chum salmon, winter steelhead, and cutthroat trout were present – summer steelhead was also likely present in low numbers (Kerwin and Nelson, 2000). Recent studies in the Green/Duwamish Basin determined the spring run of Chinook to be extinct, chum at high risk of extinction, and coho presence to be depressed (Nehlsen et al., 1991).

There is limited evidence of historical sockeye spawning and rearing. Sockeye adults have been reported in the vicinity of the Tacoma Public Utility (TPU) diversion but successful sockeye reproduction has not been confirmed. Limited access to lakes suitable for rearing makes it unlikely that sockeye will reproduce in large numbers (Kerwin and Nelson, 2000). Native char (either bull trout or Dolly Varden) were reported historically in the river below the TPU diversion, but none have been observed above Howard Hanson Dam (Kerwin and Nelson, 2000; Berge and Mavros, 2001).

Puget Sound Chinook salmon (including the Green River population) are currently listed as threatened by NOAA Fisheries under the federal Endangered Species Act (ESA). Although the early-run (spring) population of Green River Chinook is considered extinct, the late-run (summer/fall) population has generally been one of the larger runs in Puget Sound (Shared Strategy for Puget Sound, 2007), with spawning escapement ranging from 688-21,402 between 1968 and 2010 (Hans Berge, King County Ecologist, personal communication). The lowest and second lowest (1,840) escapement was recorded in 2009 and 2010. Along with Chinook salmon Puget Sound bull trout and steelhead have also been listed as ESA Threatened species.

Potential pollutant sources and factors

Many human activities can have an adverse effect on the natural environment. Recognized water quality problems in the basin are high water temperatures and low dissolved oxygen. Following is a discussion of possible sources of pollution that affect stream temperature and dissolved oxygen.

Loss of riparian habitat

Riparian habitat plays a valuable role in protecting stream water quality. The Puget Sound lowland study (May et al., 1997) found that a key determinant of the biological integrity of a stream appears to be the quality and quantity of the riparian zone available to buffer the stream ecosystem from negative influences in the watershed. Adequately-sized and healthy riparian buffers help filter out a variety of pollutants, including substances that can lead to the depletion of oxygen in streams.

Direct shading from trees is a critical component affecting stream temperatures. When wooded stream buffers are removed to create lawns, establish pasture or cropland, or make room for development, water temperatures increase. This is because greater portions of the stream are exposed to warm air and sunlight. Solar radiation, in the form of heat, is considered a pollutant. Increases in heat loads can result in increases in summer water temperatures and the loss of cold water fish habitat. In addition, temperature plays an important role in determining how much oxygen water can hold.

Other human actions, such as adding riprap or inadequate culverts, can alter channel morphology, particularly stream width and depth. These can make some areas of the watershed more vulnerable to the effects of riparian vegetation removal.

Lakes and wetlands can also be sources of heat to the receiving stream or river. The stream is cooled in the downstream direction via groundwater inflow and input from cooler spring-fed tributaries. The amount of downstream cooling depends on groundwater and tributary inflow temperatures and volume, and the amount of riparian vegetation available to reduce solar radiation and prevent additional heating.

The distinction between reduced heating of streams and actual cooling is important. Shade can significantly reduce the amount of heat flux that enters a stream. Whether there is a reduction in the amount of warming of the stream, maintenance of inflowing temperatures, or cooling of a stream as it flows downstream depends on the balance of all of the heat exchange and mass transfer processes in the stream.

Urban stormwater

Several kinds of stormwater runoff are regulated as point source discharges. Many of the contaminants found in stormwater runoff come from everyday human activities, such as yard maintenance or the use of cars or fireplaces which often release pollutants in an uncontrolled and dispersed manner. Stormwater may not be a pollutant in itself, but is often a conveyor of pollutants from the landscape to local waters, both surface and ground. Stormwater starts as rainwater, fog condensate, or snowfall, and evapotransporates back into the atmosphere; is stored on site; infiltrates into the ground; or, accumulates and flows over impervious surfaces and saturated pervious areas. Land uses and activities in urban and rural areas, coupled with an increase in impervious area and accumulation of contaminants, results in pollutant-loaded stormwater.

Rain events can wash contaminants off of impervious surfaces, including rooftops; driveways; sidewalks; parking lots; and roads; into stormwater drainage systems or across vegetated areas. Some pollutant removal and infiltration occurs in these pervious vegetated areas. Further, much of the existing stormwater drainage systems in outlying areas transport stormwater in grass-lined ditches, which also infiltrate some stormwater. Most of the county was built before any stormwater regulations, but many newer developments have flow control and water quality treatment facilities that moderate the discharges that flow directly into streams.

During storm events, pollutants mix with stormwater and can reach streams quickly and in highly variable and often elevated concentrations. Stormwater runoff from parking lots and other impervious surfaces can also be a transient source of warm water to streams. Some drainage systems are made up of underground pipes that can cool and moderate the discharge temperature, and some other drainage is through grass-lined ditches where some infiltration may occur. Stormwater flows are erratic and may not exhibit distinct seasonal trends. Since this TMDL is focused on summer critical conditions for temperature, when rain events are infrequent, stormwater is generally not considered a significant source that impacts temperature during dry summer months. However, because there is a potential for stormwater to have an effect on localized stream temperatures on rare occasions, stormwater must be mentioned in this TMDL as a potential source of thermal pollution.

Ecology regulates municipal separate storm sewer systems (MS4s) as point sources under the National Pollutant Discharge Elimination System (NPDES) Municipal Phase I and II Stormwater Management Program. The entire Green River watershed is covered by municipal stormwater Phase I and Phase II permit jurisdictions (Table 4). The Washington State Department of Transportation was issued a separate Municipal Stormwater Permit in 2009. This permit regulates stormwater discharges from state highways and related facilities contributing to discharges from MS4s owned or operated by WSDOT within areas covered by Phase I and Phase II Municipal Permits. Several local sites are covered by general permits for sand, gravel, and construction stormwater.

A review of facilities in the watershed under Ecology's General Stormwater Industrial and General Industrial permits on Ecology's GIS Facility Site/Atlas (http://www.ecy.wa.gov/fs/) show none that are likely to contribute to temperature impairments.

Table 4. Facilities covered under permits within the Green River basin.

Type of Permit	Permit Holder	Ecology Permit Number
Individual		
Phase I stormwater	King County	WAR04-4501
Phase II stormwater	City of Algona	WAR04-5500
Phase II stormwater	City of Auburn	WAR04-5502
Phase II stormwater	City of Black Diamond	WAR04-5505
Phase II stormwater	City of Covington	WAR04-5510
Phase II stormwater	City of Enumclaw	WAR04-5514
Phase II stormwater	City of Federal Way	WAR04-5516
Phase II stormwater	City of Kent	WAR04-5520
Phase II stormwater	City of Maple Valley	WAR04-5525
Phase II stormwater	City of Renton	WAR04-5559
Phase II stormwater	City of SeaTac	WAR04-5541
Phase II stormwater	City of Tukwila	WAR04-5544
Stormwater	Department of Transportation	WAR043000A
General		
Sand and Gravel	(Varies over time)	--
Construction Stormwater	(Varies over time)	--

Altered hydrology/loss of baseflows

Changes in hydrology can influence water quality of rivers and streams. Under natural conditions, rain water is captured by plants, infiltrated, evapotranspired, or stored in wetlands. When water is stored within the system, as in the ground or wetlands, it can feed local streams and rivers during dry summer periods. The natural environment also provides opportunities to filter out pollutants through natural processes wherever adequate soils and vegetation are retained. Figure 8 illustrates how changes in land use and increases in development can alter the natural hydrologic regime.

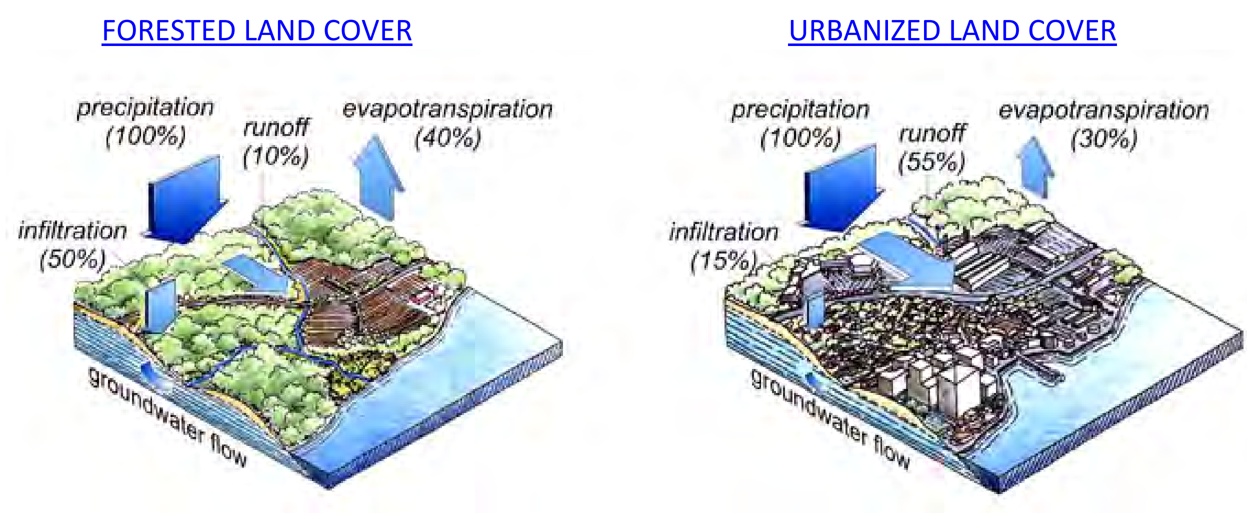

Figure 8. Altered hydrology due to urbanized land cover: roads, rooftops, and sidewalks change the percentage of water transported in different processes of the hydrologic cycle (EOEA, 2004).

Increasing amounts of impervious surface can limit groundwater infiltration and subsequent recharge into streams during summer low-flow conditions. Stormwater management facilities that allow infiltration of stormwater runoff help offset the reduced recharge due to impervious surfaces.

In addition to the effects of impervious surface cover on groundwater recharge, surface and groundwater withdrawals for consumptive uses or for export for uses outside of the basin can affect stream and river flows (King County, 2010a; also see streamflows and groundwater use in the previous section).

A report on the effect of groundwater withdrawals on discharge to Puget Sound lowland streams concluded that “groundwater development will, in most cases, affect the baseflow to streams” (Morgan and Jones, 1999).

Goals and Objectives

Project goals

The project goals are (1) to conduct TMDL studies on temperature impairments in the Green River basin during critical low-flow conditions and (2) to outline an implementation strategy for meeting water quality standards in these basins. Separate Ecology reports will document the Green River DO TMDL and the Newaukum Creek Temperature and DO TMDLs.

Study objectives

The objectives are to:

- Characterize stream temperatures and processes governing the thermal regime in the Green River during critical conditions.
- Develop a predictive temperature model of the Green River basin under critical conditions. Apply the model to determine load allocations for effective shade and other surrogate measures, as appropriate, to meet temperature water quality standards. Identify the areas influenced by lakes and wetlands and, if necessary, estimate the natural temperature regime.

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Analytical Approach

Study area

The Green River flows about 53.5 miles from the outlet of Howard Hanson Dam to the confluence with Duwamish Waterway. The Green-Duwamish watershed is composed of the following sub-basins:

1. Upper Green River sub-basin covering 219.7 square miles above RM 64.5 at Howard Hanson Dam.
2. Middle Green River sub-basin covering 177.5 square miles from RM 64.5 to RM 32.0 at Auburn Narrows.
3. Lower Green River sub-basin covering 63.8 square miles from RM 32.0 to RM 11.0 at Tukwila.
4. Green-Duwamish Estuary sub-basin covering 22.2 square miles from RM 11.0 to RM 0.0 at Elliott Bay.

The Green River TMDL focuses on the Lower to Middle Green River (Figure 4). Not included are the Upper Green River sub-basin above Howard Hanson Dam and the lower Green-Duwamish estuary reach which has a salt wedge influence. A separate TMDL focuses on the Newaukum Creek, which runs about 14.4 miles from its headwater to the confluence with the Middle Green River. A temperature and dissolved oxygen TMDL for the Soos Creek system will be developed at a later date.

Modeling framework

Three models were used to evaluate the Green River temperature loading capacity and to determine the allocations necessary to meet the water quality standards. Temperature models TTools, Shade, and QUAL2Kw were used. Data collection, compilation, and assessment were based on the data requirements of the three models, whose description follows.

TTools

TTools is an ArcView extension developed by the Oregon Department of Environmental Quality (ODEQ, 2001) to develop GIS-based data from polygon coverages and grids. The tool develops vegetation and topography perpendicular to the stream channel, and samples longitudinal stream channel characteristics such as the near-stream disturbance zone and elevation.

Shade model

Shade.xls (Ecology 2003a) was used to calculate effective shade along the Green River. The Shade.xls model requires physical and vegetation parameters, some of which were assembled from the field monitoring surveys. Effective shade was calculated at 50-meter intervals along the Green River.

QUAL2Kw model

The QUAL2Kw is a one-dimensional river and stream water quality model used to calculate the components of the heat budget and simulate water temperatures. It simulates diurnal variations in stream temperature for a steady flow condition. QUAL2Kw was applied by assuming that flow remains constant for a given condition such as a seven-day or one-day period, but key variables are allowed to vary with time over the course of a day.

Field monitoring methods

A variety of data are needed to develop and test water quality models. The primary source of water quality, stream flow, and meteorological data for establishing model inputs and model testing are from the field monitoring conducted during summer low-flow conditions in 2006. Data collection, compilation, and assessment were governed by the data requirements of the temperature model as described in the *Sampling and Analysis Plan/Quality Assurance Project Plan* (QAPP) for these TMDL studies (Roberts and Jack, 2006).

During summer low-flow and high temperature conditions from July to October 2006, the following types of field surveys were conducted:

1. Continuous monitoring of water and air temperatures and relative humidity.
2. Deployment of YSI® multi-probes to generate continuous pH, DO, and conductivity measurements.
3. A synoptic productivity survey which included grab nutrient samples for laboratory analysis and periphyton sampling.
4. Synoptic flow measurements in the stream.
5. HemiView photographs of riparian canopy at select locations.

Appendix D describes the monitoring locations and the data collected at each station.

Field Monitoring

From July through October 2006, Ecology, King County, and others participated in a cooperative effort to conduct a series of short-term water quality monitoring surveys (Roberts and Jack, 2006; and Swanson et al., 2007). Field data included pH, conductivity, dissolved oxygen, temperature, relative humidity, flow, periphyton biomass, and riparian shade. Laboratory data included total nitrogen, total phosphorus, dissolved nutrients, chlorophyll a, total organic carbon, dissolved organic carbon, and alkalinity. The data supplemented the routine ambient monitoring done by Ecology, King County, U.S. Army Corps of Engineer, city of Kent, and others.

Details on the sampling and measurement procedures and quality assurance evaluation can be found in the *Data Summary Report* (Swanson et al., 2007). Monitoring locations along the Green River for the different sampling programs are in Appendix D. Additional data used in the development of the temperature model are summarized in Appendix E.

Field monitoring results

All data that passed quality control checks are available in Ecology's EIM database under User Study ID MROB003. All collected data are presented in the form of plots and tables in the *Data Summary Report* (Swanson, et al., 2007). Since field monitoring of Green River and Newaukum Creek was coordinated together, the results for both basins are summarized in the following section.

Continuous temperature

Continuous temperature data were recorded throughout the summer. Except for Ecology's water temperature logger at its mouth, temperature loggers in Newaukum Creek were not deployed during the hottest period of the summer. Table 5 provides a summary of the temperature data in terms of the highest seven-day average of daily maximum temperatures recorded during summer 2006. All thirteen of the stations monitored by Ecology on the Green River mainstem exceeded the relevant temperature standards.

One obvious trend in the temperature data is downstream warming along the Green River. The upper Green River stations starting below the Tacoma Water Headworks Diversion Dam were less warm than the rest of the mainstem Green River. Water temperatures in the Green River and its major tributaries were relatively cool in late June at the start of monitoring. Hottest air and water temperatures, representative of the summer's critical conditions, were recorded between July 25 and 31.

Mullen Slough and Mill Creek, both in the lower Green River sub-basin, were the warmest tributaries to the Green River. Soos Creek and Newaukum Creek provided less warm water into the Green River. Crisp Creek in the middle Green River sub-basin is a source of cooler water to the Green River with water temperatures below standards throughout the summer.

Again, temperature loggers in Newaukum Creek were not deployed during the hottest period of the summer. Results for Newaukum Creek and its tributaries in Table 5 captured the highest 7-DADMax after the critical condition period.

Table 5. Highest 7-day of daily maximum temperature recorded in the Green River and Newaukum Creek basins during summer 2006.

Station ID	Station Description	Temperature (^{o}C)	
		Highest 7-DADMax	WQ Standard
Middle Green River			
09-GRE-DAM	Below Tacoma Water Headworks Diversion Dam	17.76	16.0
09-GRE-KAN	At Cumberland-Kanaskat Rd.	19.22	16.0
09-GRE-FLA	At Flaming Geyser Park, near end of SE Flaming Geyser Rd.	19.74	16.0
09-GRE-WHI	At 212th Way SE (Whitney Bridge)	21.83	16.0
09-GRE-GRE	At Green Valley Rd.	21.58	16.0
09-GRE-8TH	At 8th St. NE in Auburn	20.98	16.0
09-GRE-277	Off Green River Rd. under 277th St. bridge	20.94	16.0
09-GRE-167	Upstream of Mill Ck. Under Hwy 167 bridge	21.42	16.0
Lower Green River			
09-GRE-OLD	At Meeker St. near the “Old Fishin’ Hole”	21.59	16.0
09-GRE-212	At S. 212th St.	22.16	16.0
09-GRE-180	At SE 180th St. (SW 43rd St.)	22.61	16.0
09-GRE-FOR	Under Interurban Ave. bridge near Fort Dent	22.84	16.0
09-GRE-COM	Under 42nd Ave. S bridge at Tukwila Community Center	23.14	16.0
Green River Tributaries			
09-NEW-MOU	At mouth of Newaukum Creek	18.45	16.0
09-CRI-GRE	Crisp Ck at Green Valley Rd.	15.68	16.0
09-SOO-USG	Soos Ck at USGS gauging station upstream of hatchery	19.14	16.0
09-MIL-WAS	Mill Ck at Washington Ave.	21.97	16.0
09-FRA-FRA	Mullen Slough at Frager Rd	23.50	16.0
Newaukum Creek and Tributaries			
09-X322	Newaukum Ck near the mouth off of 358th SE	15.30	16.0
09-E322	Newaukum Ck at SE 400 St bridge	14.81	16.0
09-AC322	Trib upstream of confluence with Newaukum Ck at 236th St SE	13.25	16.0
09-AN322	Newaukum Ck just upstream of confluence with trib at 236th St	13.86	16.0
09-G322	Newaukum Ck at bridge on SE 424th St	13.55	16.0
09-R322	Newaukum Ck off 416th St down pipeline trail	15.77	16.0
09-N322	Newaukum Ck at Veazie Cumberland Rd crossing	13.72	16.0
09-Q322	Newaukum trib off Veazie Cumberland Rd, ditch north of TPU trail	17.91	16.0

Streamflows

Ecology measured instantaneous streamflows at all wadable sites during the synoptic sampling event. Discharge was calculated by measuring velocities and depths in 20 or more divisions of a cross-section (Ecology, 1993). Fewer divisions were measured if necessary on small streams. Ecology also collected USGS flow data. During the productivity and synoptic flow studies, discharge at the USGS gage in Auburn was 310 cubic feet per second (cfs).

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TMDL Analysis Framework

QUAL2Kw Water Quality model

Data collected during the field monitoring studies were used to continuously simulate temperature along the Green River using the QUAL2Kw stream and river water quality model. QUAL2Kw is a one-dimensional, steady-flow numeric model capable of simulating a variety of conservative and non-conservative water quality parameters (Chapra and Pelletier, 2003).

QUAL2Kw assumes steady-state flow and hydraulics; however, the heat budget and temperature are simulated on a daily time scale with diel variations in all water quality variables. QUAL2Kw was applied by assuming that flow remains constant for a given condition such as a 7-day or 1-day period, but key variables are allowed to vary with time over the course of a day in response to changes in the heat budget and biological processes such as photosynthesis. QUAL2Kw uses the kinetic formulations for the components of the surface water heat budget that are described in Chapra (1997).

Hydrology parameters

Manning's equation was used to express the relationship between flow and depth as:

$$Q = \frac{S_o^{1/2}}{n}\frac{A_c^{5/3}}{P^{2/3}}$$

where Q = flow [m^3/s], S_o = bottom slope [m/m], n = the Manning's roughness coefficient, A_c = the cross-sectional area [m^2], and P = the wetted perimeter [m]. The Manning's roughness coefficient represents the resistance of the stream channel to the flow of water, where smaller values represent less resistance (smooth, uniform channel) and higher values represent greater resistance (rough, rocky, irregular channel).

Temperature parameters

In addition to hydrology parameters, other parameters that affect stream temperature include effective shade, solar radiation, air temperature, cloud cover, relative humidity, and headwater temperature, as well as tributary point source and diffuse inflow temperatures. These were all specified or simulated as time-varying functions (changing over the course of a day) in QUAL2Kw using a finite difference numerical method at 1000-meter intervals along the Green River. In addition, QUAL2Kw uses light and heat parameters and surface heat transfer models that govern the temperature regime of the system being modeled.

Effective shade analysis

Link between effective shade and temperature

Effective shade is defined as the fraction of incoming shortwave solar radiation that is blocked by vegetation and topography before it reaches the stream surface. Shade is an important parameter that controls stream heating derived from solar radiation. Stream temperature represents the concentration of heat. If heat loads gained by a stream reach exceed heat losses, the temperature increases.

The rate of warming of water temperatures as a stream flows downstream can be dramatically reduced when high levels of shade exist and heat flux from solar radiation is minimized. Solar radiation has the potential to be one of the largest heat-transfer mechanisms in a stream system. The overriding justification for increases in shade from riparian vegetation is to minimize the contribution of solar heat flux in stream heating. Trees in riparian areas provide shade to streams and minimize undesirable water temperature changes (Brazier and Brown 1973; Steinblums et al., 1984).

Human activities can degrade riparian vegetation and channel morphology, and in turn, reduce shade. Loss of shade to the stream surface can significantly add more heat to the water. Effective shade generated from riparian vegetation is therefore an important factor in describing the heat budget for this analysis.

Effective shade is a function of several landscape and stream geometric relationships. Some of the factors that influence effective shade include the following:

- Latitude and longitude.
- Time of year.
- Stream aspect and width.
- Vegetation buffer height, width, overhang, and canopy density.
- Topographic shade angles.

Percent effective shade is a straightforward stream parameter to monitor and calculate, and it is easily translated into quantifiable water quality management and restoration objectives.

The effective shade analysis involves three steps:

1. Digitizing and sampling current stream channel and riparian vegetation.
2. Deriving vegetation heights using LiDAR, and
3. Generating effective shade from current riparian vegetation and topography.

System potential effective shade

System potential effective shade is the natural maximum level of shade that a given stream is capable of attaining with the growth of "system potential mature riparian vegetation," defined as *that vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.* System Effective Potential Shade occurs when:

1. Near stream vegetation is at a mature life stage
   - Vegetation community is mature and undisturbed from anthropogenic sources;
   - Vegetation height and density is at or near the potential expected for the given plant community;
   - Vegetation is sufficiently wide to maximize solar attenuation; and
   - Vegetation width should accommodate channel migrations.

2. Channel width reflects a suitable range for hydrologic process given that near stream vegetation is at a mature life stage
   - Stream banks reflect appropriate ranges of stability via vegetation rooting strength and floodplain roughness;
   - Sedimentation reflects appropriate levels of sediment input and transport;
   - Substrate is appropriate to channel type; and
   - Local high flow shear velocities are within appropriate ranges based on watershed hydrology and climate.

The Puget Sound River History Project has attempted to study and recreate historical vegetation in the Puget Sound lowlands using archival studies and field investigations documented in the form of General Land Office survey notes. Historically (mid-19th century), mixed hardwood-conifer riverine forests in the Puget Sound lowlands were heavily weighted toward hardwoods. Though less abundant, evergreen conifers accounted for the majority of biomass, and several species grew quite large (Collins et al., 2003). Common hardwoods included maples, cottonwoods, willows and red alders; common conifers included the western red cedar, Douglas fir, Sitka spruce and western hemlock (Collins and Montgomery, 2002). The General Land Office surveys noted vegetation species and tree diameters, but did not include tree heights. Mature stands of these different species are known to grow from 50 meters to over 70 meters tall.

Tree heights are specific to an area and dependent on several variables including soils, climate, elevation, and hydrologic processes. GIS soils datasets are often linked to an index with values of 100-year tree heights which the soils in the area can support. Both the Natural Resources Conservation Service Soil Survey Geographic Database and the Washington State Department of Natural Resources provide soils coverage for the state of Washington (Figure 9 and Figure 10).

There are four sources of determining system potential tree height for the Green River:

1. Refer to historical accounts of vegetation in the area
2. Analyze soils data: GIS Soil data layers often have a database with “SITE INDEX” values representing the 100-year old tree heights that the soil can support
3. Look at tallest existing vegetation in non-degraded areas
4. Evaluate LiDAR data from nearby Puget Sound watersheds

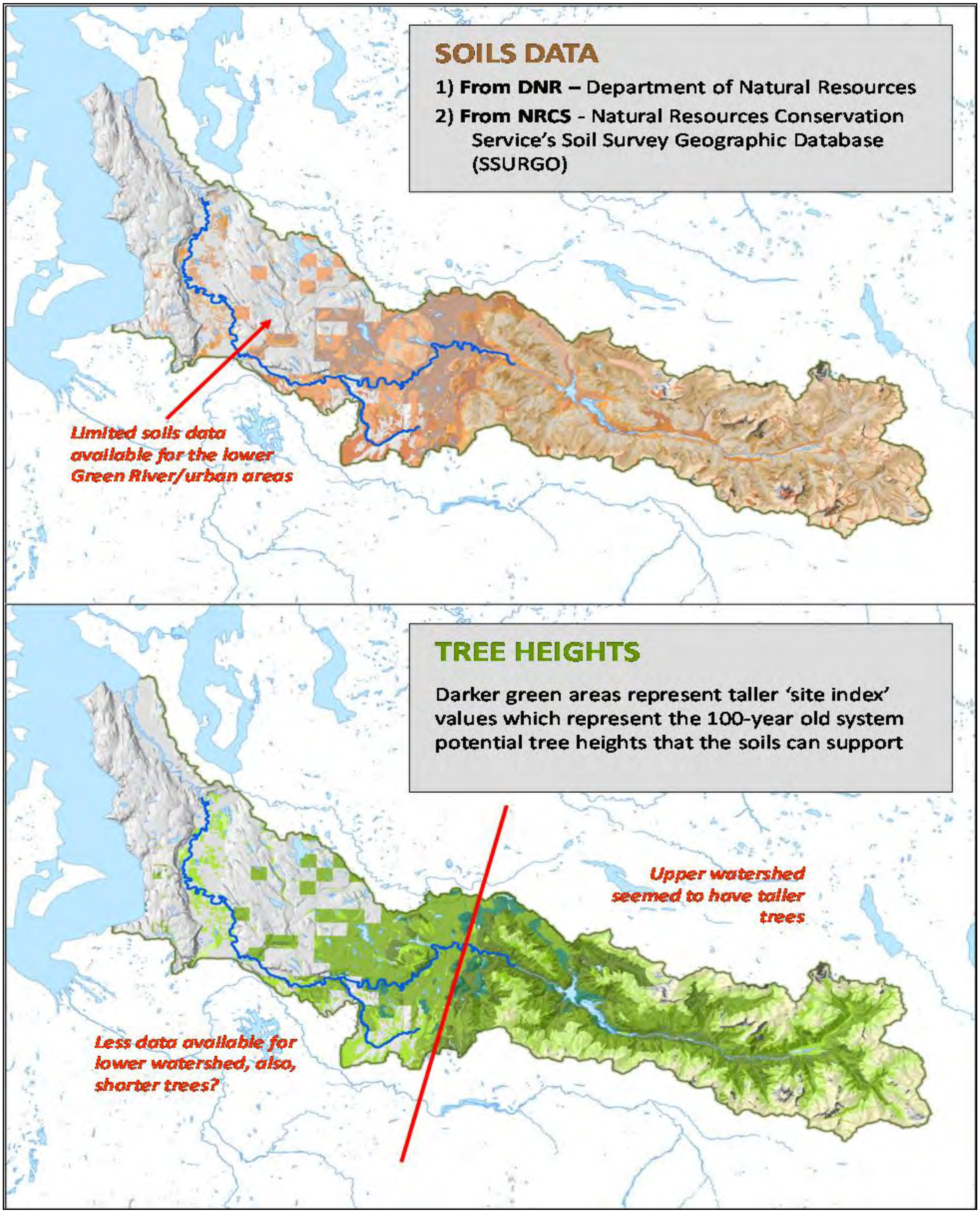

Figure 9. Soils data and tree height estimates in the Green-Duwamish Watershed.

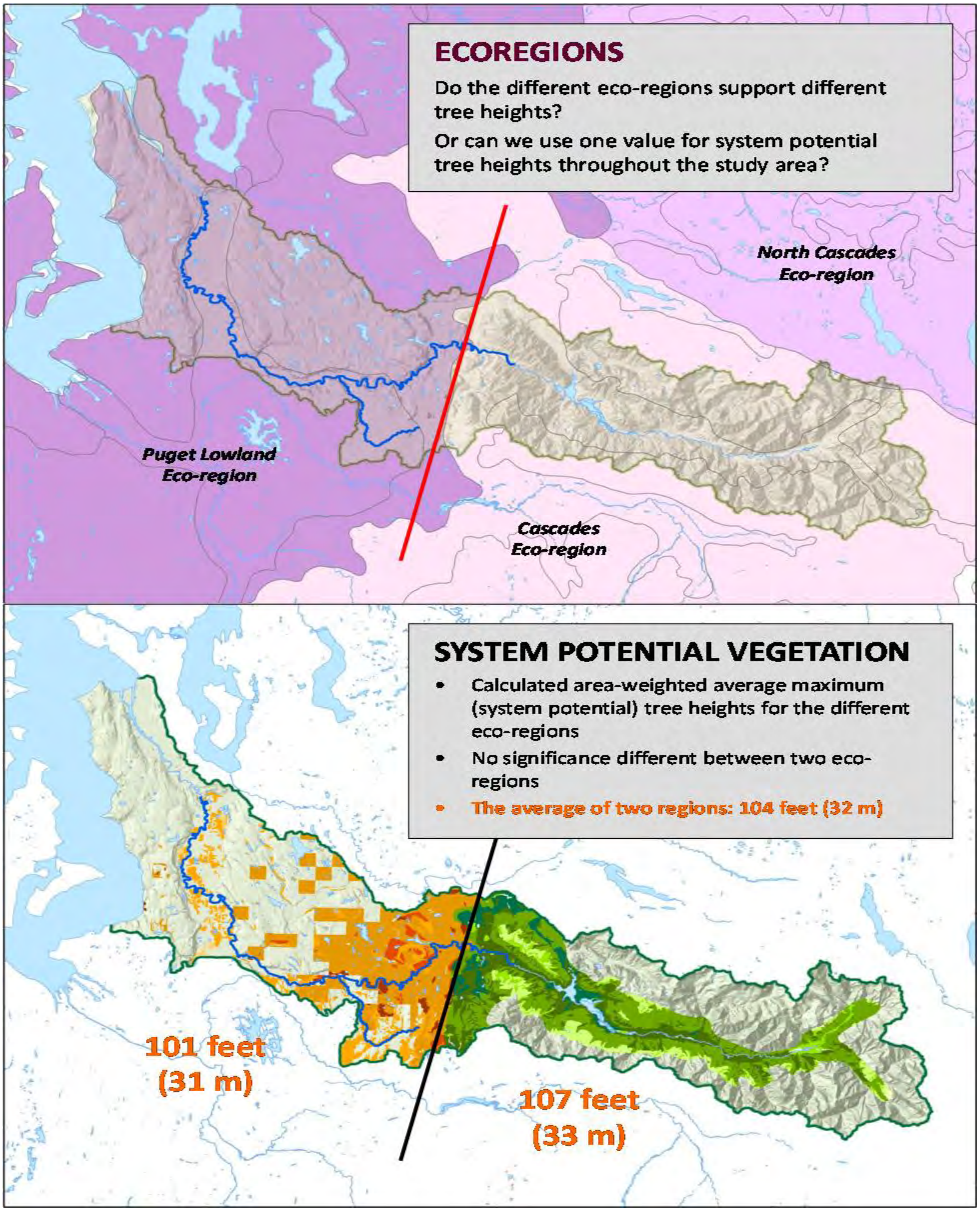

Figure 10. System potential vegetation in Green-Duwamish watershed.

A historical account of vegetation based on Kerwin and Nelson (2000) describes the following observations:

- Middle Green: young early successional deciduous species (willow, red alder, black cottonwood) on exposed bar surfaces
- Lower Green: coniferous dominated, forested wetlands & swampy meadows on exposed bar surfaces
- Terraces/stable floodplain surfaces: older stands of mixed coniferous & deciduous trees
- Other: bigleaf maple, Sitka spruce, western hemlock
- Western red cedar and Douglas-fir are reported to be the most common indigenous forest species

Based on the soils survey analysis using 100 year values, the average tree height was 40 m (124 feet) for the lower river urban sub-basins and ranging to 56 m (185 feet) in the most productive areas (Stohr, 2009).

The King County Riparian Shade Characterization Study (February 2005, p.17) reported the following observed values:

- Observed tree heights varied over a range of about 10 – 55 m, but they were most typically between 20 and 40m regardless of classified cover type.

- Observed canopy density ranged from 50 to 100 percent but was most typically between 80 and 100 percent.

Additionally, LiDAR data indicate that Near Stream Vegetation Heights show 90th percentile height values of 37m for current vegetation. Published temperature TMDLs for nearby Puget Sound watersheds have used the tree height values ranging from 37 to 55m (Table 6).

Table 6. System potential vegetation in nearby Puget Sound watershed based on published Ecology temperature TMDLs.

Watershed	WRIA	Height	Density
Bear-Evans	8	50m	85%
South Prairie Creek	10	55m	90%
Skagit	4	37-53m	75%
Stillaguamish	5	45m	85%

In summary, historical accounts gave us tree species and basal areas from which we might be able to approximate tree height. NRCS soil data analysis (100 index year) of the Green-Duwamish watershed provides a value of 104 feet (32 m); which is further supported by a King County (2005) field study which found typical tree heights in riparian vegetation stands along the Green River below Flaming Geyser State Park between about 100 and 115 feet (30 and 35 m).

TMDL Analysis for Temperature

Effective shade analysis

An objective of the temperature TMDL model is to assess the influence of current shade conditions on river temperatures and the potential improvements that could be gained through restoration of riparian shade along the river. The approach to developing model shade inputs and resulting model input data are described below.

Riparian and topographic shade inputs to the model were developed using available 6-ft resolution LiDAR data as described in King County (2003). Briefly, the difference between the Digital Surface Model (DSM; which is an elevation grid of the land surface including trees) and the Digital Ground Model (DGM; which is an elevation grid of the bare land surface without trees) was calculated using the Map Algebra feature of the Spatial Analyst extension of ArcGIS to produce a Digital Height Model (DHM). The DHM is assumed to approximate tree heights across the landscape, although in developed areas, buildings are included in the DSM. Initial testing of the use of LiDAR to develop riparian shade estimates for the Green River indicated that shade from buildings is negligible (King County 2005).

The LiDAR data were derived from flights conducted during the leaf-off period to optimize the accuracy of the DGM, so the initial DHM primarily represents light striking tree branches at various levels in the tree crowns of deciduous tree cover. To better represent summer tree canopy cover, a nearest neighbor maximum analysis was performed by including the surrounding cells (3 by 3 cell search), and the nearest neighbor maximum was then resampled to an 18-ft resolution using the Neighborhood Statistics tool in the Spatial Analyst extension. In previous testing on the Green and Sammamish Rivers, the nearest neighbor maximum and resampling approach resulted in much better fit of predicted shade to observed shade using analysis of hemispherical photographs taken mid-channel (King County, 2005).

ArcGIS (ArcMap version 9.2) was used to digitize lines representing the channel centerline and the left and right banks of the river during summer low flow (typically at 1:3000 scale). Delineation of the Upper Green mainstem relied primarily on orthophotos of the Middle Green River taken in 2006 as part of an ongoing flood study conducted by King County. The delineation of the upper 7.5 km of the Upper Green River model relied on the 2006 National Agricultural Imagery (NAIS) orthophotos. Delineation of the Lower and Middle Green River relied on 2005 orthophotos from Aerials Express.

Ecology’s ArcGIS version of TTools (Build 7.5.2), a GIS extension that automates GIS sampling routines, was used to estimate channel geometry and topographic/riparian shade inputs to the model in the following steps:

Step 1 of TTools established channel centerline sampling points every 50 m (164 feet) beginning at the upstream end of each delineated channel centerline and the points were then populated with the point latitude/longitude and aspect.

Step 2 calculated the channel width based on the distance between the left and right banks established with a line orthogonal to the aspect of each channel centerline point.

Step 3 sampled channel elevation at each point from the 6-ft DGM from the cell containing the point (1 cell setting).

Step 4 from the 6-ft resolution DGM sampled topographic shade angles to the east, west and south of each point in a 10 km search radius.

Step 5 sampled riparian tree heights from the 18-ft resolution DHM described above at 9 locations 5 meters apart on the left and right banks beginning 2.5 m beyond the lines defining the river banks.

The data generated using TTools were then transferred to Ecology's shade model (version 31b02). The shade model was modified to accommodate spatially explicit inputs of tree heights rather than the lookup table of riparian cover classifications typically used by Ecology. A global canopy density value of 90 percent was used, which is approximately the median of field observations of canopy density found in an earlier survey of riparian vegetation along the Green River (King County, 2005).

The shade model was also modified to allow the specification of the distance vegetation hangs over the stream channel (i.e., overhang distance) based on river edge tree heights rather than through a lookup table of vegetation classifications. Overhang was allowed to range from 0 to 2 m based on the ratio of the estimated tree height in the river edge buffer zone to a maximum tree height of 45 m. Therefore, a riparian buffer at the edge of the river with an average canopy height of 45 m would be estimated to generate a 2-m overhang. A canopy height of 20 m would be estimated to have an overhang of 0.9 m (2 m x [20 m/45 m]).

Water surface elevation input for the shade model was derived from two data sources. For the portion of the model reach between Tukwila and Flaming Geyser State Park, the recent HEC-RAS flood inundation model of the river developed by NHC (2007) was used to develop a low flow river profile, which provided water surface elevation predictions (relative to the NGVD 1988 consistent with the vertical datum of the available LiDAR data) at 243 unequally spaced locations. A 5th-order polynomial regression was fit to the HEC-RAS model-predicted water surface profile ($r^2 = 0.99$; $p<0.0001$), which was used to estimate water surface elevations every 50 meters between Tukwila and Flaming Geyser State Park. Above Flaming Geyser, the river centerline elevations sampled from the 6-ft resolution DGM using TTools was used to fit a second 3rd-order polynomial regression ($r^2 = 0.99$; $p<0.0001$), which was used to estimate water surface elevations every 50 meters from just above Flaming Geyser State Park to the upstream boundary below the Tacoma Public Utilities diversion.

Shade with and without overhang was predicted for August 2, 2006. The shade model settings are shown in Table 7. Shade without overhang was compared to observations based on hemispherical photographs from the channel center analyzed by Ecology and King County during the summer of 2006 since the hemispherical photography observations do not include shade due to overhanging vegetation. Modeled and observed Effective Shade results are shown in Figure 11. Inclusion of overhang adds an average of 3.5 percent and a maximum of 11.8 percent to the calculated Effective Shade.

Table 7. Shade model parameters for the Green River.

date	8/2/2001	(mm/dd/yyyy)
time zone	-8	(PST= -8hrs)
daylight savings	Yes	
latitude	47.30	(dec deg +N)
longitude	-122.18	(dec deg -W)
global riparian zone width	50	(meters)
shade calculation method	Chen	
solar radiation model	Ryan-Stolz	
cloud cover	0.5	(fraction from 0 to 1)
Ryan-Stolzenbach factor	0.8	(0.70-0.91, suggest 0.8)
Fixed canopy density	90%	(default 90%)
riparian extinction	Off	
minimum overhang	0	meters
maximum overhang	2	meters
limiting tree height for maximum overhang	45	meters

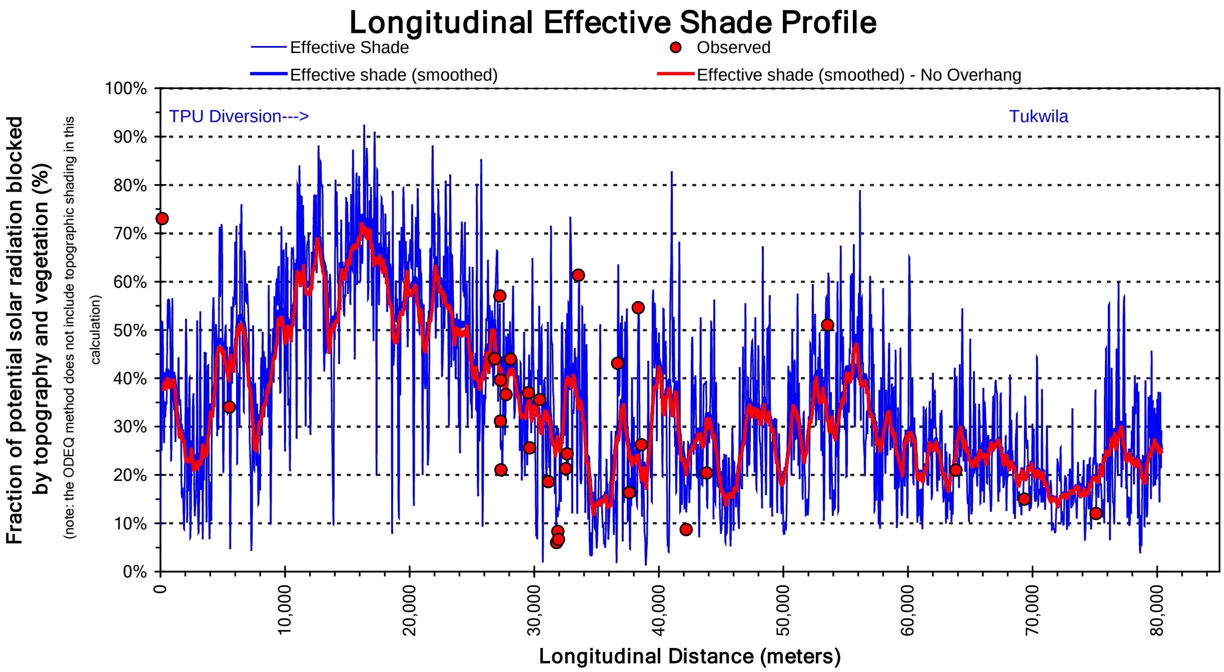

Figure 11. Comparison of predicted and observed Effective Shade, August 2, 2006. *Effective shade with 2-m maximum overhang and no overhang (smoothed only) are shown. Smoothed Effective Shade lines are based on a centered moving average over 20 points spaced 50-m apart.*

A direct comparison between observed and modeled Effective Shade is shown in the form of a scatter plot in Figure 12. It appears that on average the model slightly over-predicts Effective Shade (r^2=0.468; slope = 0.97). Average model prediction bias is 2.0 percent. This comparison is not as favorable as a previous comparison based primarily on data collected on the Sammamish River in 2004 (r^2=0.77; slope = 0.99; King County, 2005). However, the earlier comparison did not include locations with Effective Shade greater than 50 percent. For comparison median observed Effective Shade in the Sammamish River was 11 percent compared to a median of 29 percent in the Green River with a maximum observed of 73 percent.

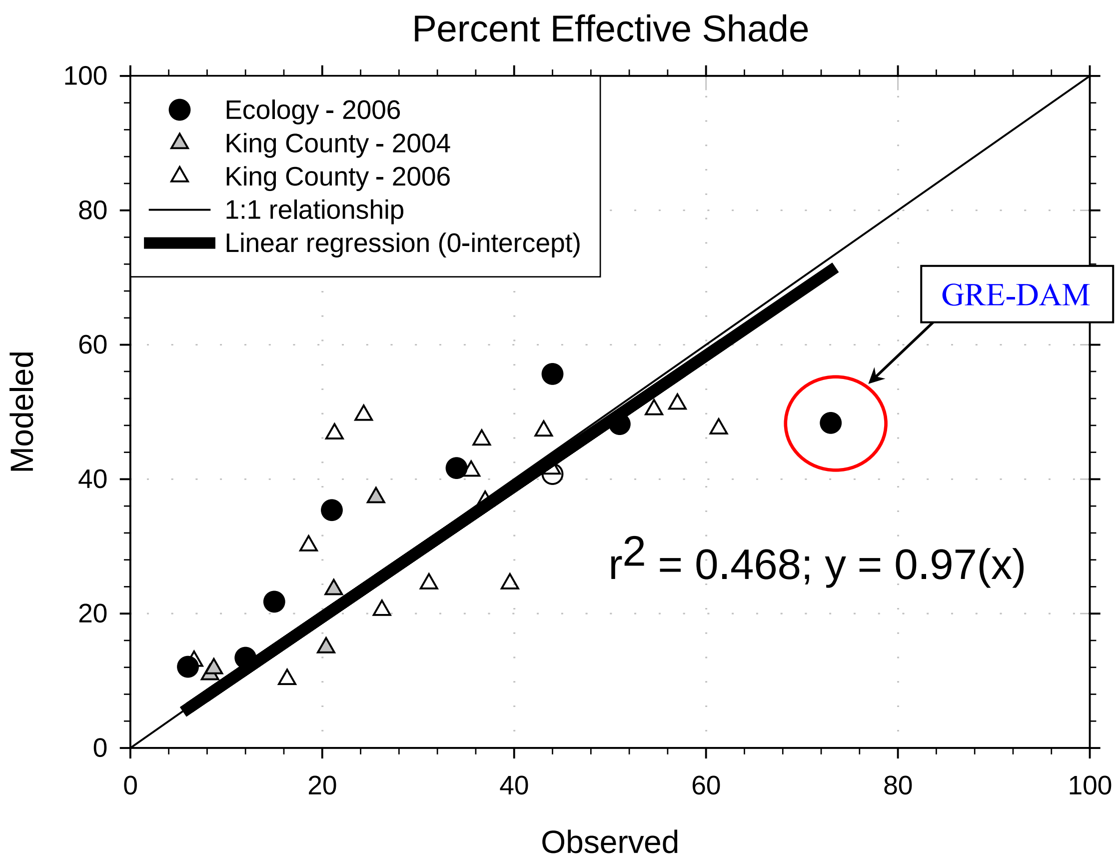

Figure 12. Comparison of predicted and observed Effective Shade, August 2, 2006. *The outlier identified by the red circle represents the comparison for Station GRE-DAM just below the Tacoma Public Utilities diversion.*

Some of the prediction error is also likely associated with positioning errors for the hemispherical photos. Although King County photos were registered with an accuracy of 5 meters or less, the coordinates for the Ecology photos are quite approximate as can be seen in Figure 13, which compares the hemispherical sky view relative to an aerial view from the Ecology sampling location at station GRE-DAM just below the Tacoma Public Utilities diversion. This also happens to be the location with the greatest difference between modeled and observed effective shade (Figure 12).

Figure 13. Top photo is hemispherical photograph taken by Ecology near GRE-DAM (photo site indicated by blue star in lower photo).

System potential effective shade for Green River

A System Potential tree height of 32 meters was used in the shade model to estimate system potential effective shade along the mainstem Green River. If the existing tree height at a particular location along the channel was greater than 32 m, the taller existing tree height was used in to model system potential effective shade. As in the shade model developed to best match shade model-predicted effective shade under existing conditions to effective shade measured using hemispherical photography (see above), riparian extinction was turned off and a fixed canopy density of 90 percent was used. This is also consistent with other shade model testing done on the Green River and Sammamish River (King County 2005). Figure 14 compares the calibrated Qual2kw model reach-averaged effective shade representing existing conditions and system potential effective shade assuming a minimum 32 m riparian tree height and a fixed 90% canopy density.

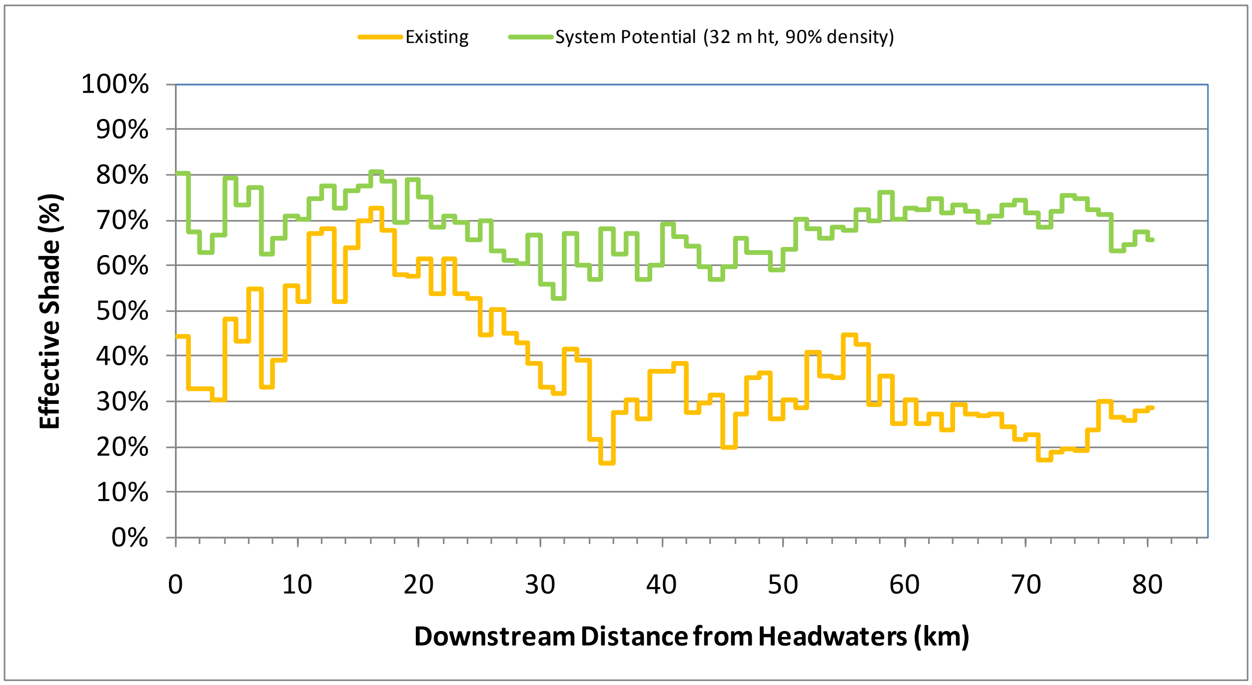

Figure 14. Current and system potential effective shade profile for the Green River model. *The ordinate axis represents the downstream distance from the study area headwaters at Palmer – just below Howard Hanson Dam.*

Sensitivity to tree height

Since it is possible that the system potential vegetation may actually be taller than 32 meters, a sensitivity analysis was done to determine the percent difference in system potential effective shade between 32-meter and 42-meter tress planted within the 45-meter riparian buffer. To evaluate the sensitivity of the shade model to tree height, a minimum tree height of 42 m was used in the shade model (Figure 15). A 42 m height was chosen for use in the sensitivity analysis because field observations conducted by King County (2005) in the riparian corridor along the Green River below Flaming Geyser State Park indicated that although trees as tall as 180 feet (55 m) were found, the tallest trees were more typically between about 130 to 150 feet

(40 and 45 m) tall. Therefore, an additional 10 meters was added to the specified system potential tree height of 32 m. The shade model with a minimum 42 m tree height indicates that on average an additional 7 percent of effective shade could be achieved with taller trees.

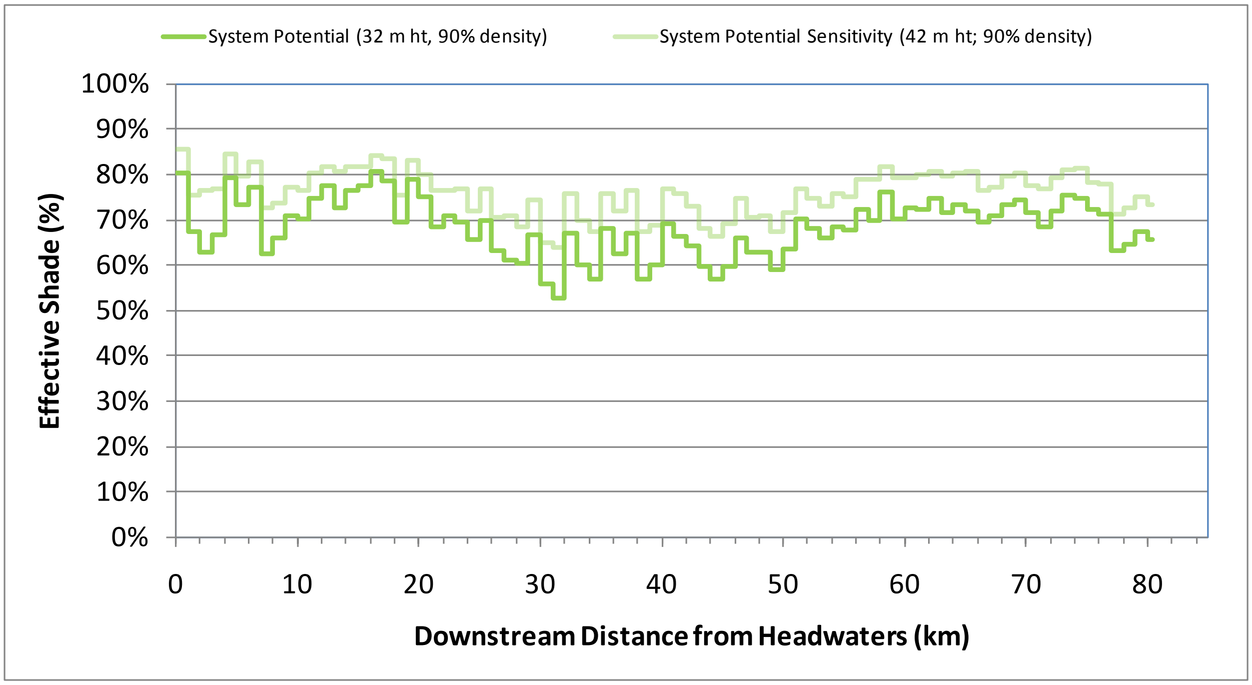

Figure 15. System potential effective shade based on 32 m and 42 m minimum tree height and 90 percent canopy density.

Sensitivity to buffer width

A sensitivity analysis was also performed to see the effect of narrowing the 45-meter width used for shade analysis to 25 meters. Narrowing buffer widths made an average difference of less than 2 percent in system potential effective shade (Figure 16).

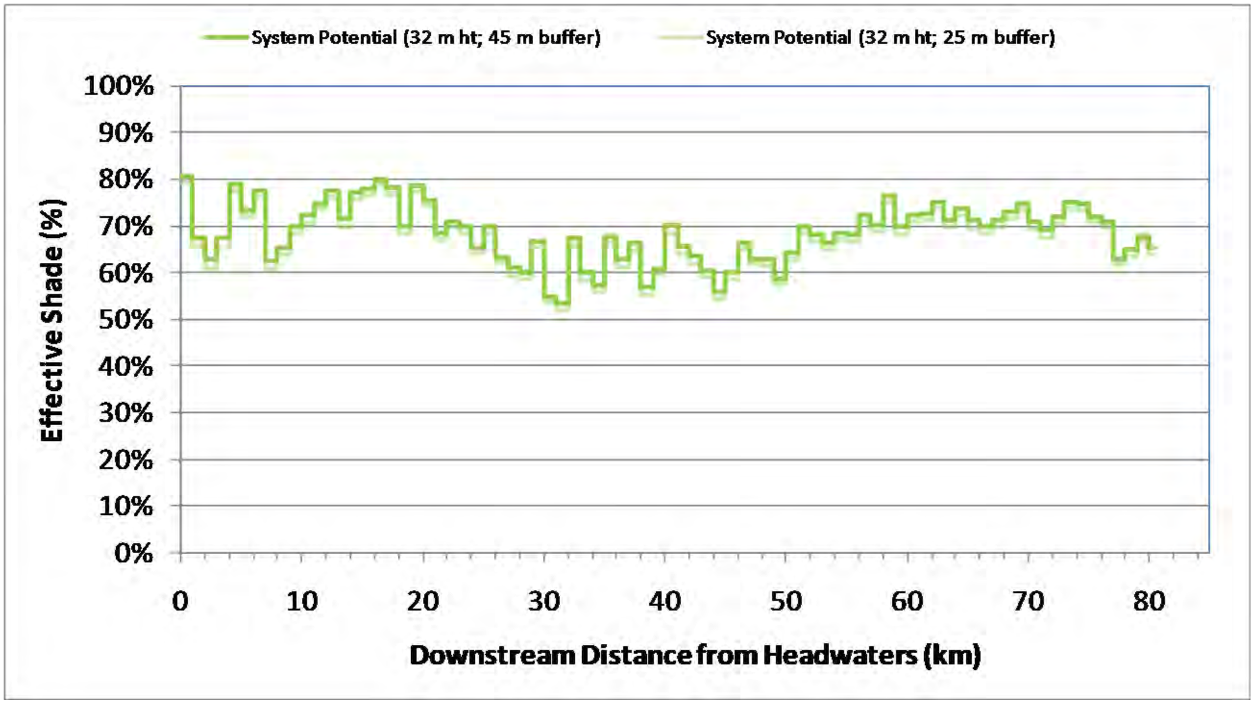

Figure 16. System potential effective shade based on 32 m minimum tree height and two buffer widths – 45 and 25 meters. *Canopy density was modified for each buffer based on canopy density as a function of buffer with found in Beschta et al. (1987).*

QUAL2Kw model

The model reach drains approximately 529 km^2 (130,800 acres) of the Green River basin that extends from below the TPU diversion downstream of Howard Hanson Dam to Tukwila just above the confluence with the Black River – the Black River enters at the downstream boundary and is not included in this drainage area estimate (Figure 17). The drainage to the upstream model boundary is approximately 597 km^2 (147,500 acres) and includes drainage between the TPU diversion and Howard Hanson Dam and the Upper Green sub-basin above Howard Hanson Dam.

Inputs of tributaries are represented as point sources in the model and include Palmer Pond Springs, Icy Creek, Newaukum Creek, Crisp Creek, Soos Creek, Mill Creek, and Mullen Slough. Remaining un-gaged surface and ground water flows are represented by net diffuse inflows distributed evenly along specified reaches of the river based primarily on observed longitudinal changes in flow and specific conductance.

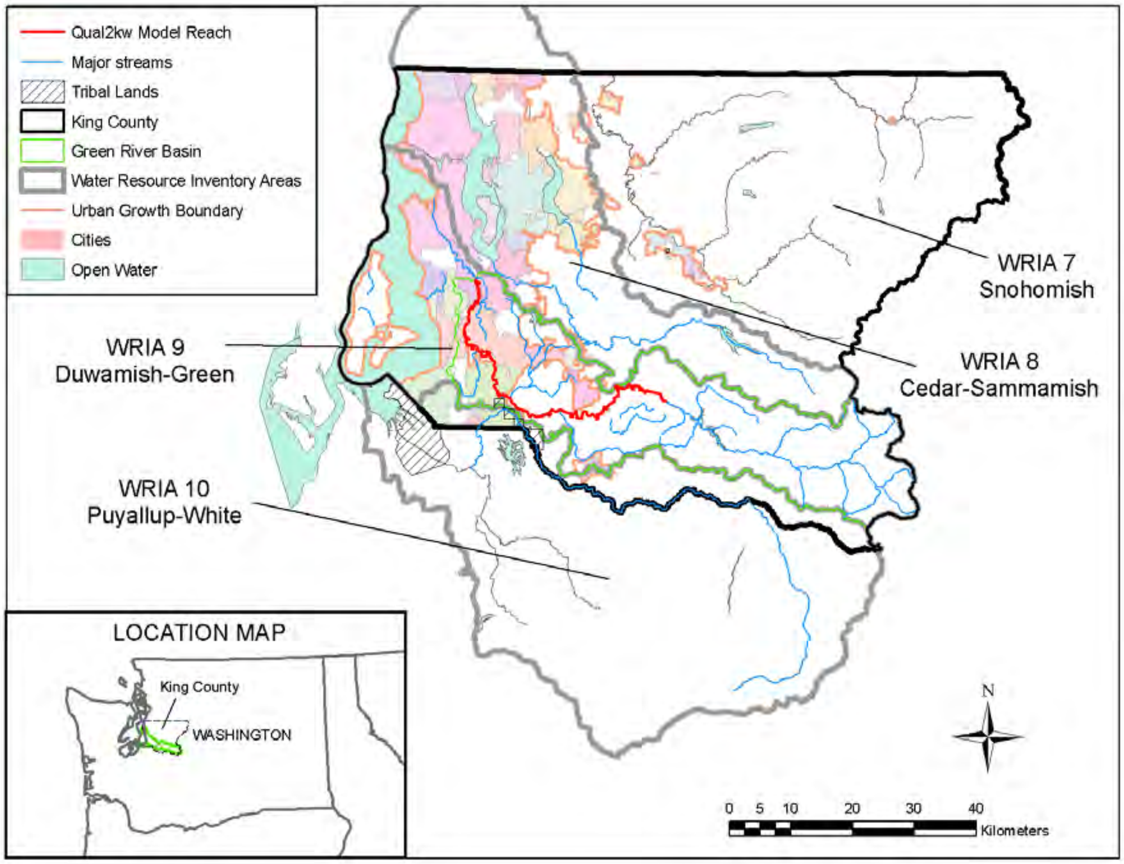

Figure 17. Location of the Green River basin and QUAL2Kw model reach.

All input data for the QUAL2Kw model are longitudinally referenced, allowing spatial and/or continuous inputs to apply to certain zones or specific river segments. The Green River mainstem was modeled in 1000-meter segments/reaches. The model was set up using the available data from the field monitoring sampling date of August 2, 2006 and for three other dates in July and August with relatively steady flow conditions and clear skies to demonstrate the ability of the model to consistently predict summer water temperatures observed in 2006.

Model calibration for river hydraulics (depth and velocity) was accomplished by adjusting Manning's n values based on available gauging data and estimated model geometry (width and slope). Final Manning's n values developed during the calibration were checked against estimates of Manning's n based on the TMDL study and USGS gage measurements (and model reach-scale slope), which provided evidence that the final Manning's n values used in the model were consistent with the available data.

Model calibration for temperature was achieved primarily by adjusting ungaged spring inputs above Flaming Geyser State Park and adjusting diffuse groundwater inputs over geohydrologically-consistent river reaches to best match observed daily mean temperatures. Calibration also involved modifying hyporheic zone thickness and percent hyporheic exchange in a manner consistent with large-scale changes in reach characteristics to best fit observed minimum and maximum daily temperatures. For example, gorge hyporheic exchange was limited based on observations that this reach is heavily scoured, sediment poor, with a bottom comprised primarily of large rocks and boulders. Adjustment of diffuse inputs and ungaged springs was also guided by adjustment of the alkalinity and specific conductance of these inputs to provide an internally consistent fit to observed flow, temperature, alkalinity, and specific conductance.

Following is a description of the specific approach used in this study. The field monitoring did not include collection of data during a second low flow period in 2006 for model testing. Water quality sampling was conducted on August 1, 2006, but sampling was more limited because water quality stations had a single grab sample and continuous sondes were installed at all locations about mid-day on August 1. And this was not considered to be separated enough in time for use as an independent data set for model testing.

Temperature model predictions were confirmed with instream data collected in summer 2006. The goodness-of-fit for the QUAL2Kw model was summarized using the average bias, average absolute mean error (AME), and root mean square error (RMSE) as a measure of the deviation of model-predicted values from the measured values. These model performance measures were calculated as:

$$ME\ (Bias) = \frac{1}{N}\sum_{n=1}^{N} P_n - O_n \qquad \text{(bias or mean error)}$$

$$\text{AME} = \frac{1}{N}\sum_{n=1}^{N} \left|P_n - O_n\right| \qquad \text{(absolute mean error)}$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} \left(P_n - O_n\right)^2} \qquad \text{(root mean square error)}$$

The river widths calculated from the digitized orthophotos every 50 meters by TTools (Step 2) were averaged over 1-km lengths, which provided the estimated stream width for the QUAL2Kw model. A 1:1 side slope was chosen to approximate the trapezoidal shape of the channel.

The bottom elevation of each 1-km reach was derived from two data sources. For the portion of the model reach between Tukwila and Flaming Geyser State Park, the recent HEC-RAS flood inundation model of the river developed by NHC (2007) was used to develop a low flow river profile, which provided water surface elevation predictions (relative to the NGVD 1988, which is consistent with the vertical datum of the available LiDAR data) and hydraulic depth at 243 unequally spaced locations. A 5th-order polynomial regression was fit to the HEC model predicted bottom profile (Figure 18) which was used to estimate QUAL2Kw model bottom elevations at 1-km increments up to Flaming Geyser State Park.

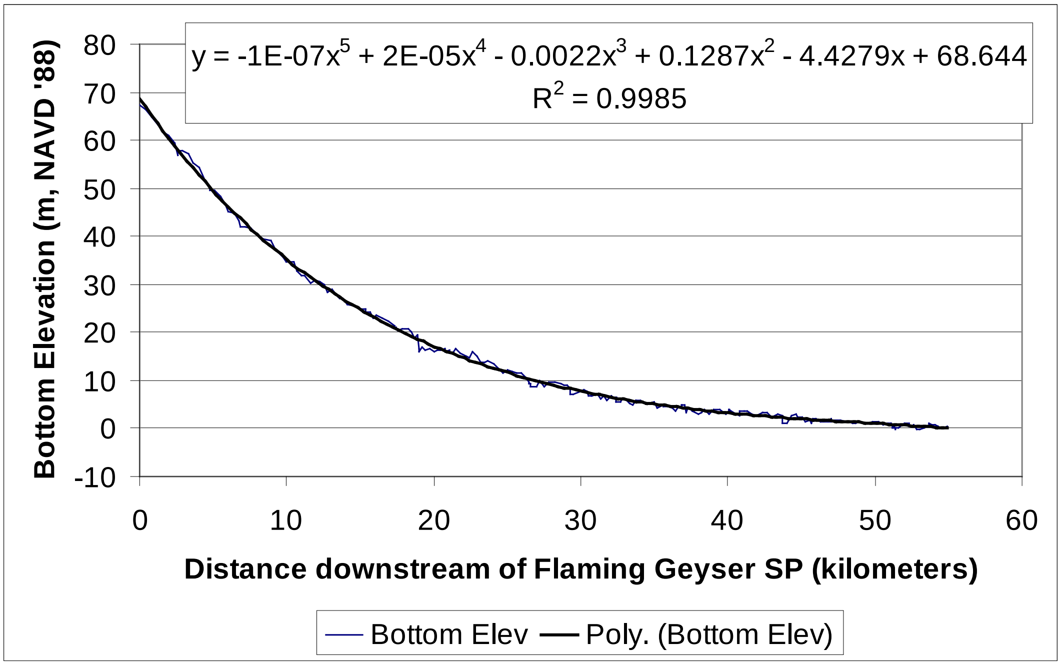

Figure 18. Green River mainstem bottom elevation from Flaming Geyser State Park to Tukwila predicted by HEC-RAS model with curve fit using a 5th order polynomial regression (m, NAVD 1988).

The model river bottom elevations for the portion of the model above Flaming Geyser were derived from the 3rd-order polynomial regression ($r^2 = 0.99$; $p<0.0001$) developed from river centerline elevations sampled from the 6-ft resolution DGM using TTools as described above for use in the shade model. The average river bottom elevation at 1-km intervals was estimated by subtracting 0.4 m (average water depth measured in the upper model reach during the TMDL study) from the polynomial regression estimate of the water surface elevation.

The final model geometry consisted of 81 segments extending from the headwater boundary condition just below the Tacoma Public Utilities water supply diversion near Palmer (beginning of segment 1) to a location just above the confluence with the Black River in Tukwila 80.4 km downstream of the headwater boundary. The first 80 segments are each 1 km long and the last downstream segment is approximately 0.4 km in length.

Model calibration

Initial model calibration and testing was conducted using the field data collected on August 2, 2006. QUAL2Kw requires an accurate characterization of hydrology, and the physics of how water moves through the system is one of the most important components of the model set up. Parameters that affected the hydrology, such as the flow balance and channel roughness, were therefore calibrated first, followed by temperature and DO, as described in the following detail.

Hydrology parameters for Green River

Field streamflow and cross-sectional geometry measurements provided the necessary information to derive values for S_0, A_c, Q and P in the Manning's equation. Since streamflow measurements were taken at stations distributed along the river, Manning's n values estimated from field data were used as initial values in nearby upstream and downstream reaches based on observed changes in bottom slope and channel geomorphology.

Manning's n values ranged from 0.11 to 0.14 in the upstream portion of the model, 0.075 through the gorge, and 0.025 to 0.05 from Flaming Geyser to the downstream boundary in Tukwila. These Manning's n values are within the range of values (0.012-0.20) reported in Chow *et al*. (1988).

Comparison of the modeled and observed longitudinal changes in flow, depth, velocity, alkalinity, and specific conductance are illustrated in Figure 19 through Figure 23. The relative contribution of gaged and ungaged tributary and diffuse sources and measured headwater inputs of flow, alkalinity, and conductance are provided in Figure 20.

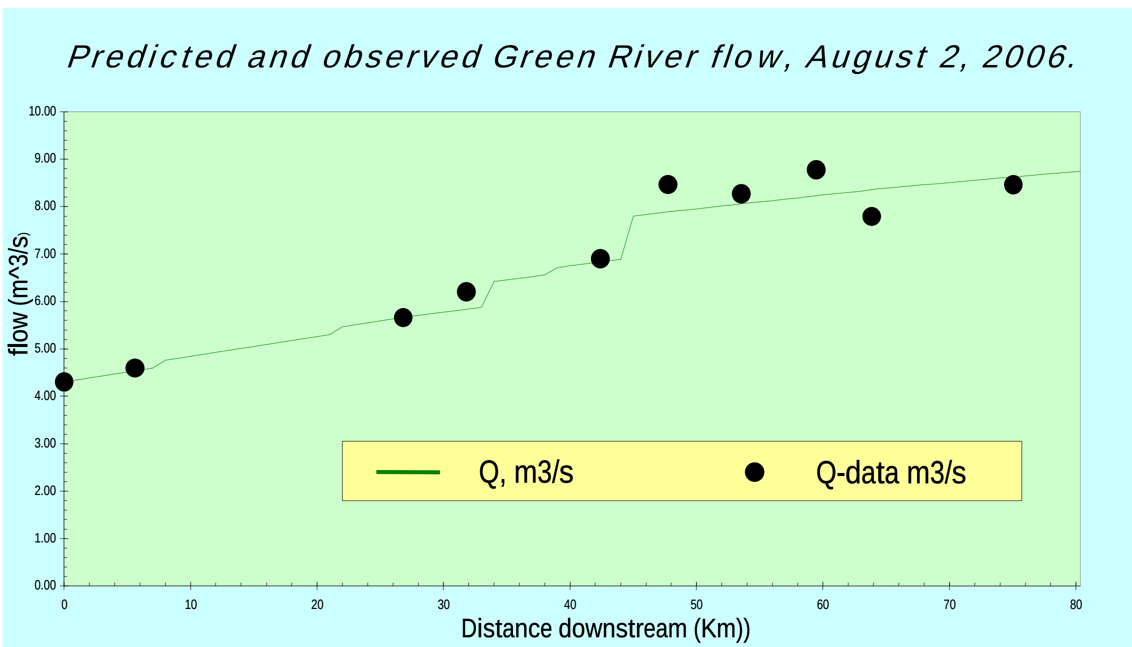

Figure 19. QUAL2Kw model-predicted and observed Green River flow – August 2, 2006.

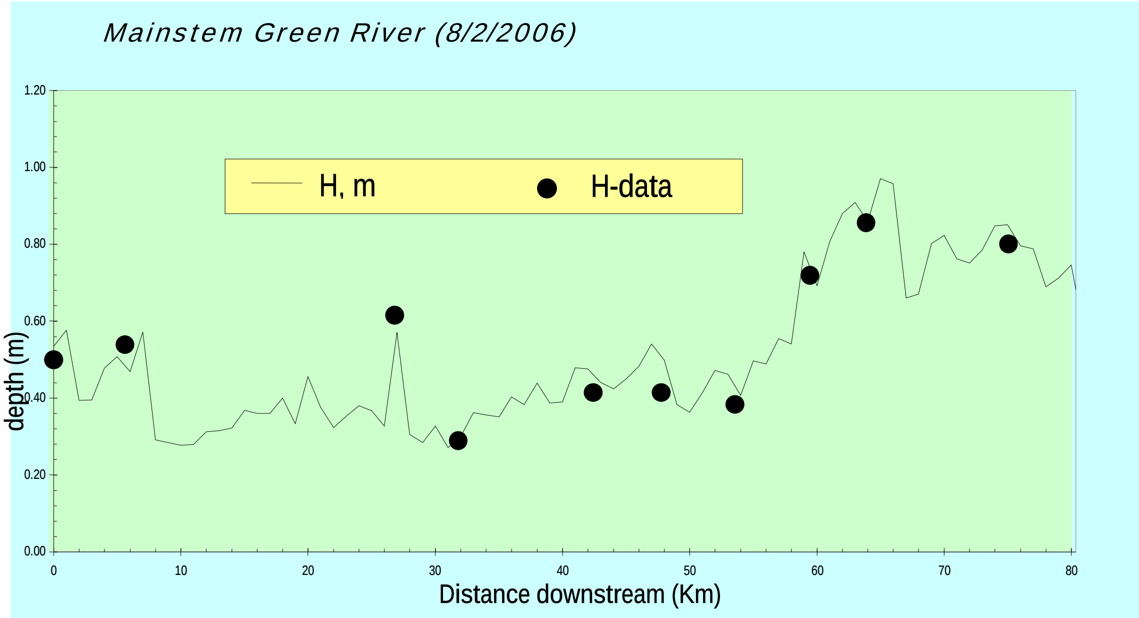

Figure 20. QUAL2Kw model-predicted and observed Green River depth – August 2, 2006.

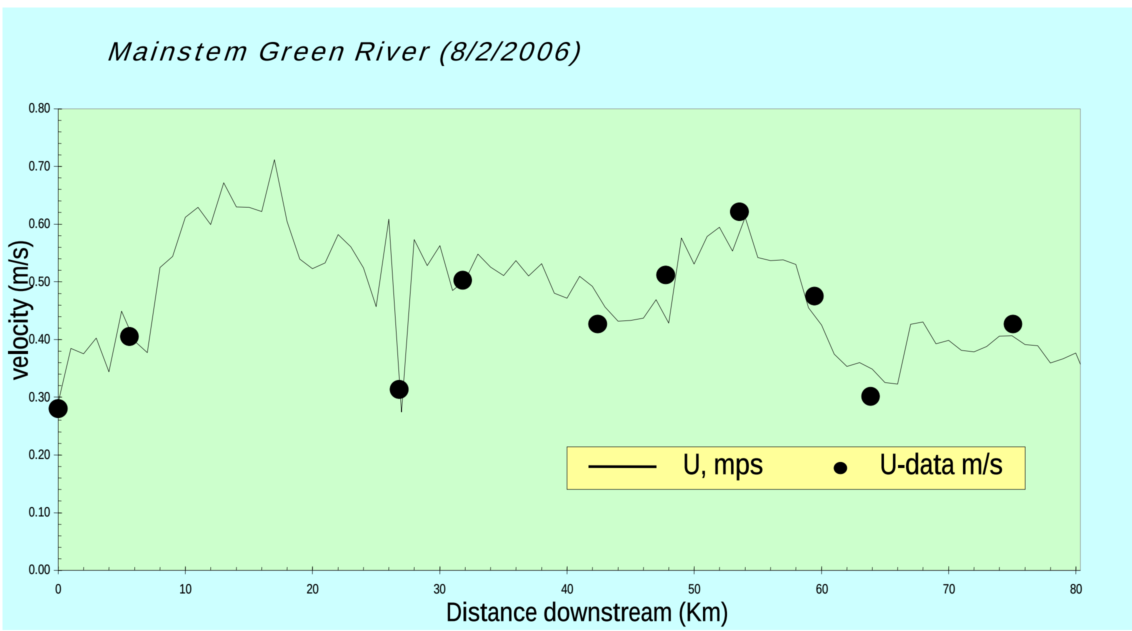

Figure 21. QUAL2Kw model-predicted and observed Green River velocity – August 2, 2006.

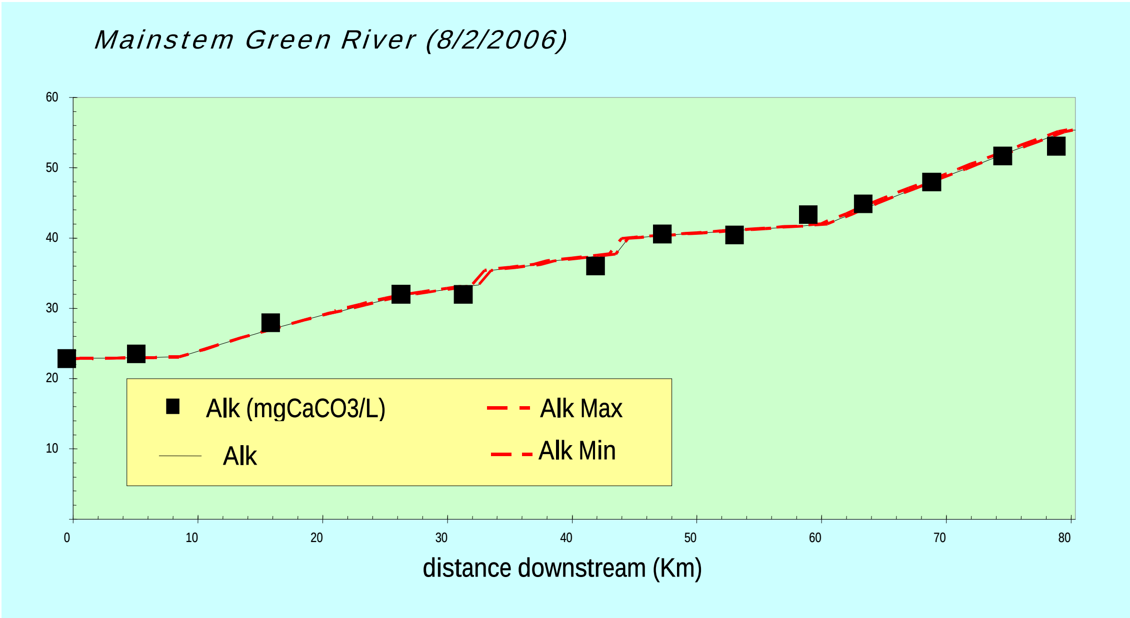

Figure 22. QUAL2Kw model-predicted and observed Green River alkalinity – August 2, 2006.

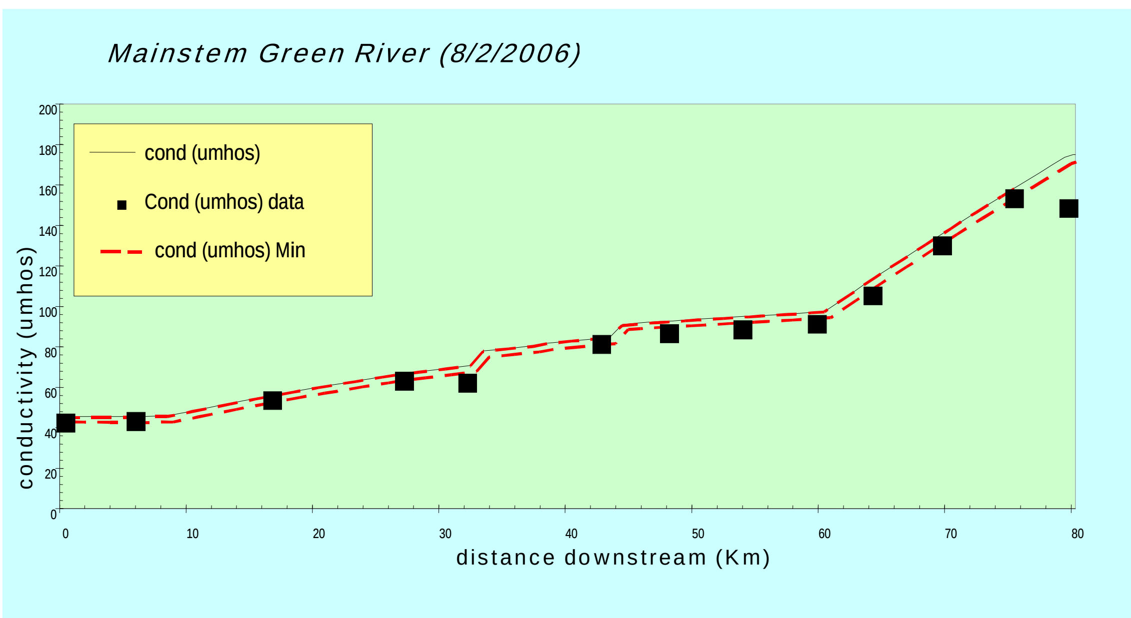

Figure 23. QUAL2Kw model-predicted and observed Green River conductance – August 2, 2006.

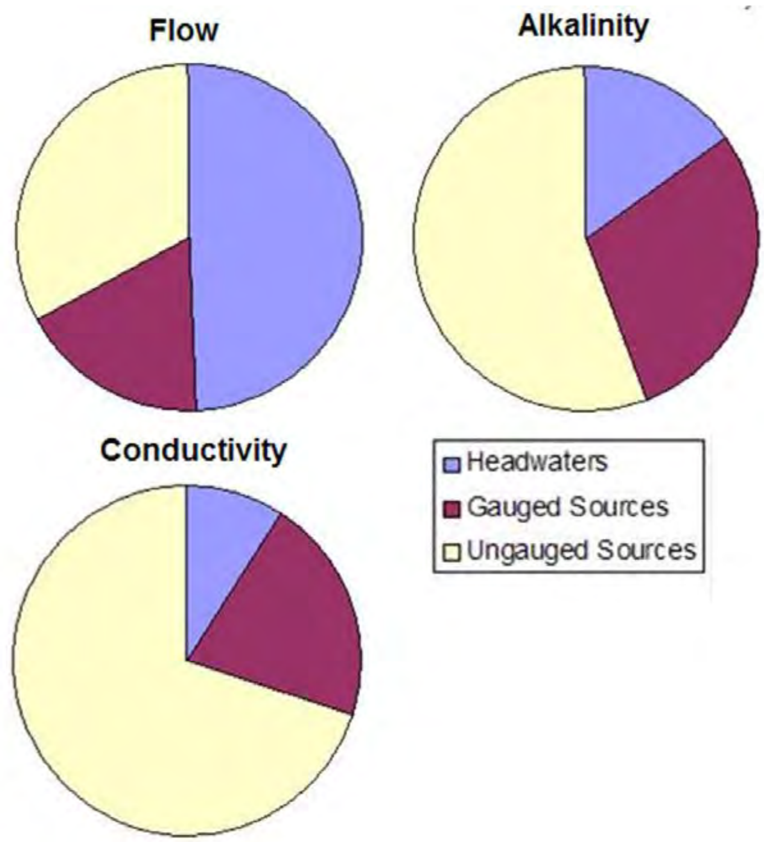

Figure 24. Relative inputs of flow, alkalinity and conductance from headwaters, gaged and ungaged sources. *Headwaters are the upstream model boundary just below the Tacoma Public Utilities diversion. Flows used for the model were from - August 2, 2006.*

Water velocity and hydraulic routing could not be confirmed using the travel-time study graph provided by the Seattle District Army Corps of Engineers, because the relatively low flows during the study were below the lower prediction bounds of the graph (Figure 25). Predicted travel time was greater than two days, which is consistent with the estimates shown in Figure 26.

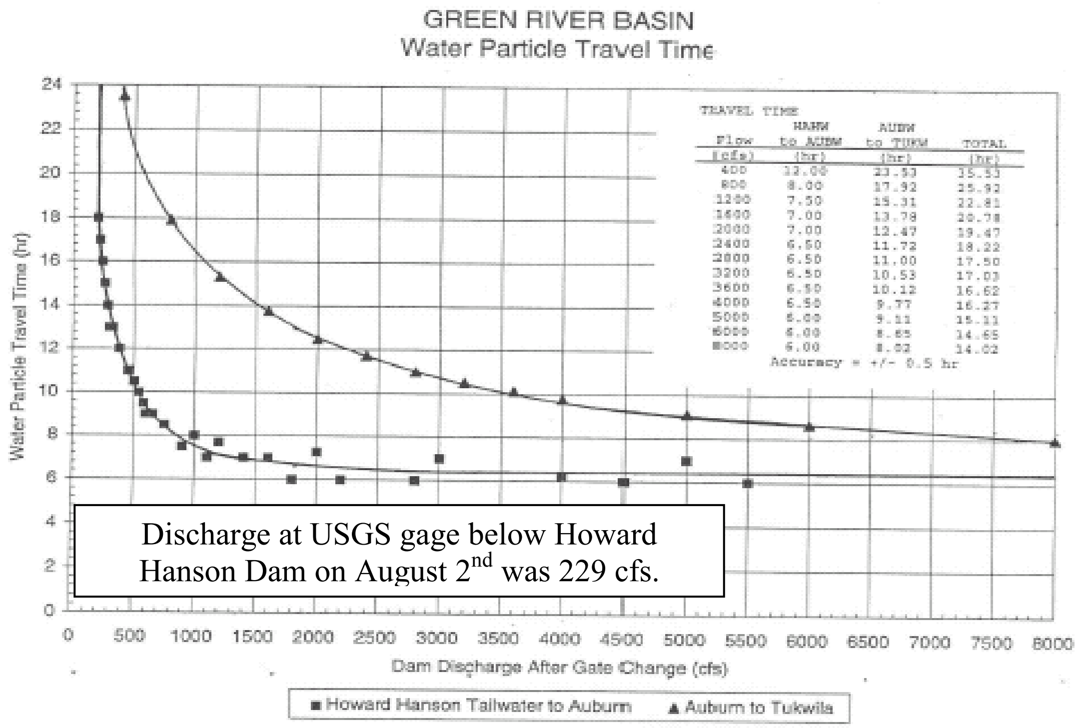

Figure 25. Green River time of travel between Howard Hanson Dam and Tukwila.

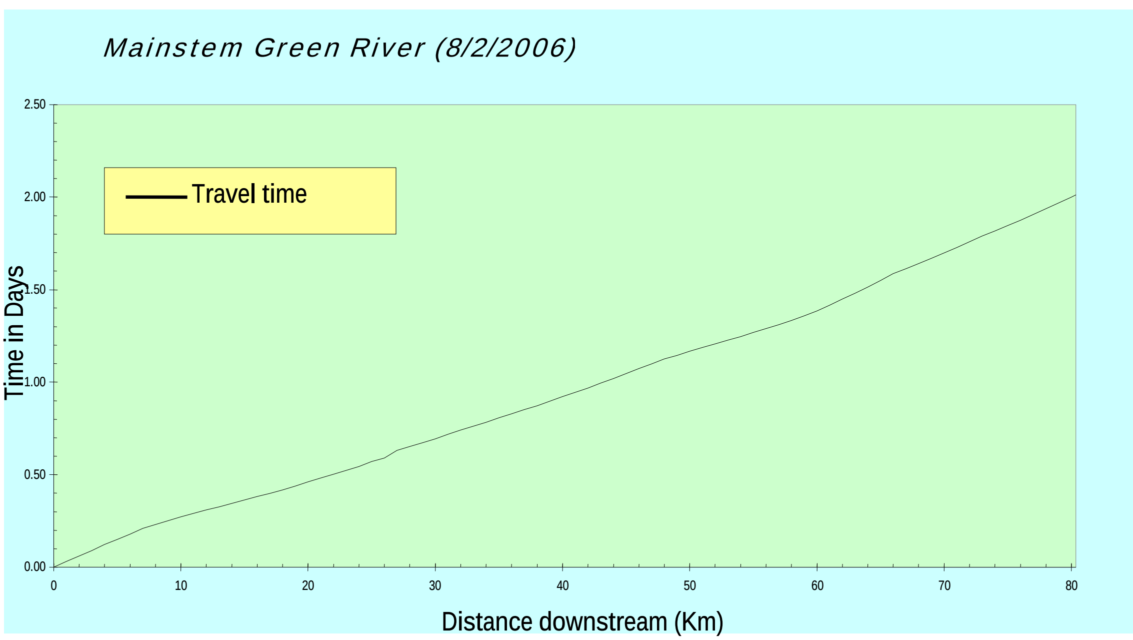

Figure 26. QUAL2Kw model-predicted time of travel in the Green River mainstem from the Tacoma Public Utilities diversion to Tukwila – August 2, 2006.

Temperature parameters for Green River

In addition to the hydrology parameters described in the previous section, other parameters that affect stream temperature include effective shade, solar radiation, air temperature, cloud cover, and relative humidity. These were all specified or simulated as time-varying functions (changing over the course of a day) in QUAL2Kw at 1000-meter intervals along the Green River. In addition, QUAL2Kw uses light and heat parameters and surface heat transfer models that govern the temperature regime of the system being modeled.

Following are descriptions of how specific input parameters were developed:

- Headwater temperature boundary conditions were established using monitoring data from August 2, 2006, from the most upstream TMDL study station on the Green River (GRE-DAM) just below the Tacoma Public Utilities diversion. Continuous temperature data were input as instantaneous hourly values (all data and modeling conducted in Pacific Daylight Time).

- Sediment thermal properties were based on the default values 1.6 Watts m^{-1} $^{o}C^{-1}$ for sediment thermal conductivity and 0.0064 cm^2 sec^{-1} for sediment thermal diffusivity (average values for streambed material).

- Hyporheic exchange flow was a calibrated parameter (values of hyporheic zone thickness and fraction of exchange flow were varied between a typical range of values) used to match the observed daily minimum and maximum temperatures – hyporheic exchange affects the minimum and maximum temperature, but has little effect on the daily average water temperature. Sediment porosity was set at a constant 40 percent, which was the default value and within the range of typical values (35 to 50 percent).

- Air temperature data were established from continuous air temperatures measured in the field on August 2. Hourly values were derived by linearly interpolating the instantaneous hourly temperatures measured at the eight monitoring stations along the river during field monitoring.

- Dew point temperature was established from continuous relative humidity data for August 2. Hourly values were derived by linearly interpolating the instantaneous hourly dew point temperature measured at the four monitoring stations along the river during field monitoring.

- Wind speed data for August 2 were retrieved from the National Climatic Data Center for Sea-Tac International Airport for use in the model. Instantaneous hourly values were used in the model with adjustment for wind sheltering and scaling from the measurement height (10 m) to the appropriate height for input to the evaporative heat loss equation (stated as 7 m in the model documentation). A wind sheltering coefficient of 0.7 was used (i.e., estimated input wind speed was reduced by 30 percent to account for sheltering by vegetation and topography), although sensitivity analyses (not shown) indicated that the model temperature predictions were relatively insensitive to small adjustment of the wind speed (wind adjustment factors ranging from 0.2 to 1.2).

- Hourly cloud cover data for August 2 were retrieved from the National Climatic Data Center for Sea-Tac International Airport for use in the model.
- Shade values were established by running the Shade model on August 2 using current riparian conditions. Hourly values were input as the hourly Effective Shade average over each model reach on August 2.
- Tributary point source temperatures were developed from monitoring data at the mouth of tributaries where temperature was monitored. Point source temperatures in QUAL2Kw were entered as a mean, half of the range, and time of maximum temperature.
- Diffuse inflow temperatures were adjusted within expected ranges (10 to 13 ^{o}C) for sources dominated by groundwater and groundwater dominated surface water sources to fit the model to observed mean temperatures on August 2.
- Direct or indirect sources of stormwater (such as stormwater outfalls or precipitation runoff) were not modeled.

Initial temperature model calibration attempts suggested a problem with the data and/or model. Regardless of reasonable adjustments in Manning's n, distributed inflow temperatures, or wind speed, the model consistently under-predicted downstream temperatures (Figure 27). This problem prompted some modifications to the QUAL2Kw model in an attempt to improve model temperature predictions. Because August 2 was partly cloudy, especially in the morning, and cloud cover is used in the model to adjust predicted incoming solar radiation as a function of latitude and time of day, the model was modified to allow input of observed solar radiation in hopes of reducing the error associated with the lack of spatially varying cloud cover inputs to the model.

Solar radiation data were available from four stations surrounding the basin (UW Seattle, NOAA ISIS at Sandpoint, Enumclaw, and WSU Puyallup). An hourly average time series was developed from the data from these four stations and used as input to the model. However, this change did not effectively improve the model temperature predictions for August 2 (Figure 28).

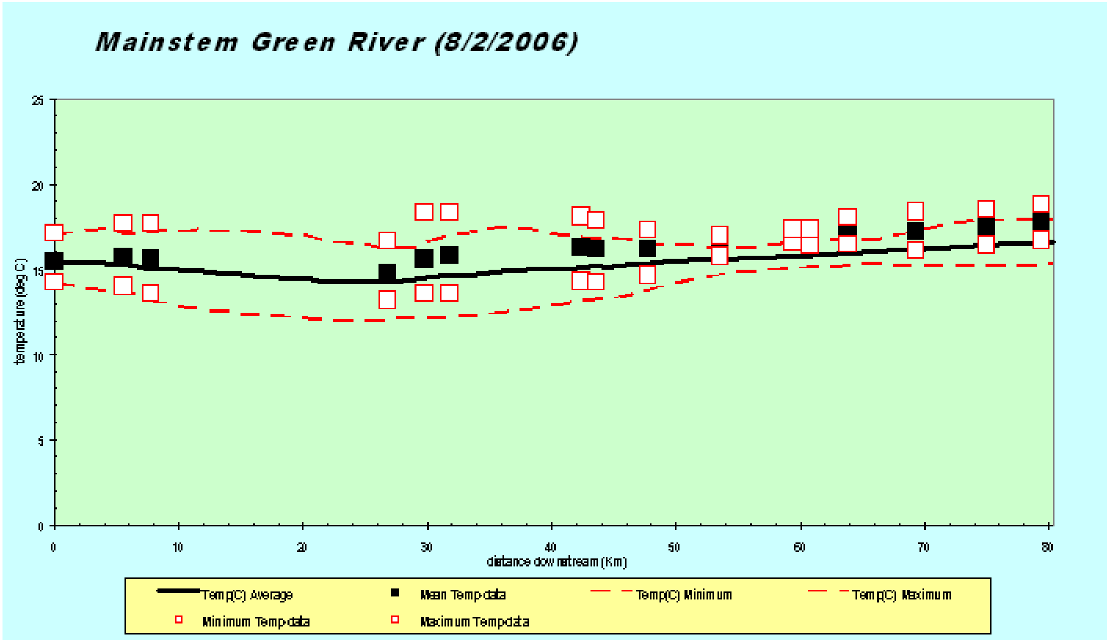

Figure 27. QUAL2Kw predicted Green River temperature for August 2, 2006, based on calculated solar radiation and Satterlund longwave formulation.

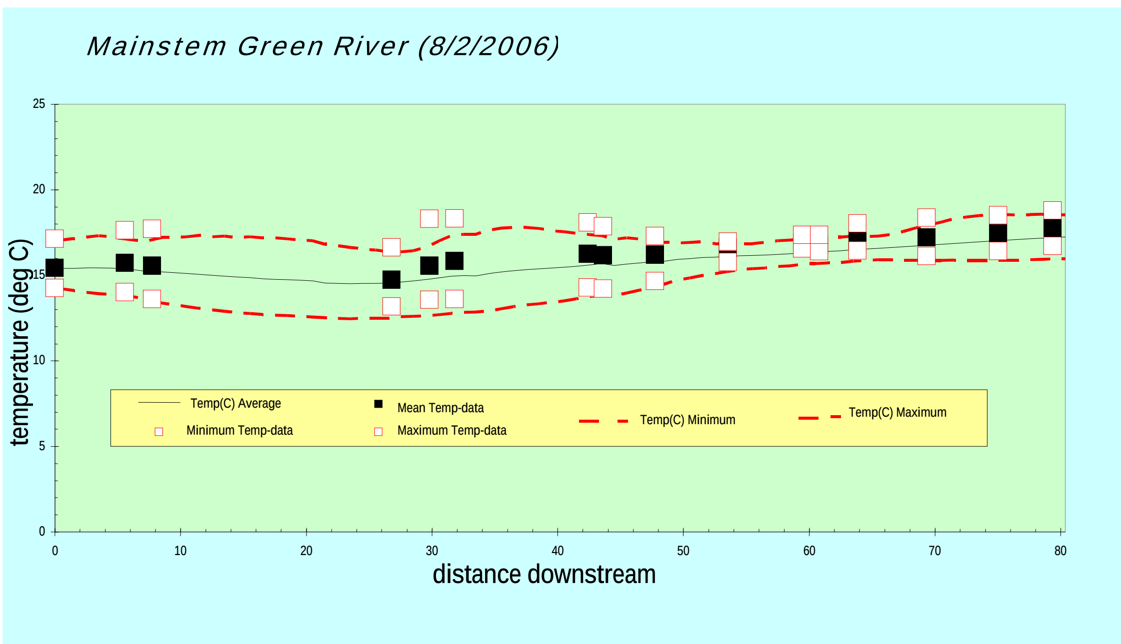

Figure 28. QUAL2Kw predicted Green River temperature for August 2, 2006, based on observed solar radiation and Satterlund longwave formulation.

Further model sensitivity analyses and research suggested that the temperature prediction errors might be related to the model-predicted longwave radiation component of heat exchange. QUAL2Kw provides the user with a number of optional empirical longwave formulations that estimate incoming longwave radiation from observed air temperature and/or atmospheric vapor pressure. The model was found to be sensitive to the choice of longwave model formulation used. Two studies were found that evaluated a number of the QUAL2Kw formulations against observed longwave data under cloudless sky conditions (Hatfield *et al*., 1983; Jiménez *et al*., 1987). Hatfield *et al*. (1983) indicated that the most accurate longwave formulations could typically predict longwave radiation within five percent based on comparison to data from stations located throughout the United States.

Hatfield *et al*. (1983) also found that models that considered only air temperature did not perform as well as formulations that considered atmospheric vapor pressure alone or in conjunction with air temperature. Brutsaert (1982) reviewed the literature available at the time and suggested as well to include the effect of atmospheric vapor pressure in the model. Brutsaert (1982) also modified a comparison by Satterlund (1979) that showed the formulations of Satterlund (1979) and Brutsaert (1982), which included vapor pressure effects, performed well over a wide range of observed longwave radiation values. Both of these formulations are available in QUAL2Kw.

All seven longwave formulations available in QUAL2Kw were tested, but the Brutsaert (1982) and the Satterlund (1979) formulations typically performed the best. The final calibrated temperature model employed the Satterlund (1979) formulation. The Satterlund (1979) formulation was also selected as part of improvements made to a relatively recent temperature model of the Fraser River (Foreman *et al*., 2001).

The QUAL2Kw model further adjusts the clear sky incoming longwave predictions based on cloud cover using the observed hourly fraction of sky cloud cover and a formula and coefficient of 0.17 suggested by Wunderlich (1972). However, Brutsaert (1982) indicated that the cloud cover coefficient could vary between 0.04 and 0.25 depending on the type of cloud cover. Other approaches for accounting for cloud cover have also been used (Sridhar and Elliott, 2002; Sridhar *et al*., 2004). For example, Sridhar and Elliott (2002) recalibrated the Brutsaert (1975) formulation using data collected from a network of stations in Oklahoma and found that a coefficient of 1.31 (rather than the original 1.24) was reasonably accurate on an hourly basis throughout the year without the need for additional adjustment for cloud conditions.

Several studies have pointed out the rather site specific nature and sensitivity of the various incoming longwave formulations to estimation of atmospheric moisture conditions. Perhaps the most significant source of error is the difficulty of using near ground measurements of air temperature and atmospheric moisture as surrogates for average temperature and moisture content of the entire atmospheric layer given variable lapse rates depending on moisture conditions and occurrence of unstable atmospheric conditions (Jiménez *et al*., 1987; Sridhar and Elliott, 2002). The effect of clouds on incoming longwave radiation is also difficult to assess since the longwave emission from clouds is not simply a function of the fraction of cloud cover but a function of the height and type of clouds (Brutsaert, 1982; Monteith and Unsworth, 1990).

The final calibrated temperature model required changing the cloud cover coefficient from 0.17 to 0.22, presumably due to additional longwave radiation from the particular regional cloud conditions on August 2. According to Brutsaert (1982), the value of 0.22 is equivalent to average cloud conditions. This is also the cloud cover coefficient used in a relatively recent temperature model of the Fraser River (Foreman *et al*., 2001). The light and heat exchange parameters for the calibrated model are provided in Table 8.

Table 8. Summary of light and heat exchange model parameters for the calibrated Green River mainstem temperature model.

Parameter	Value	Unit
Photosynthetically Available Radiation	0.47	
Background light extinction	0.25	/m
Linear chlorophyll light extinction	0.001	1/m-(ugA/L)
Nonlinear chlorophyll light extinction	0.05	1/m-(ugA/L)$^{2/3}$
ISS light extinction	0.05	1/m-(mgD/L)
Detritus light extinction	0.175	1/m-(mgD/L)
Macrophyte light extinction	0.015	1/m-(gD/m^3)
Solar shortwave radiation model		
Atmospheric attenuation model for solar	Observed	
Bras solar parameter (used if Bras solar model is selected)		
atmospheric turbidity coefficient (2=clear, 5=smoggy, default=2)	2	
Ryan-Stolzenbach solar parameter (used if Ryan-Stolzenbach solar model is selected)		
atmospheric transmission coefficient (0.70-0.91, default 0.8)	0.8	
Downwelling atmospheric longwave IR radiation		
atmospheric longwave emissivity model	Satterlund	
Evaporation and air convection/conduction		
wind speed function for evaporation and air convection/conduction	Brady-Graves-Geyer	

Figure 29 illustrates the model-predicted and observed temperatures in the Green River on August 2. The model error statistics for the final temperature model calibration run can be found in Table 9. A negative bias of -0.37 ^{o}C was calculated based on comparison with the available thermistor data. Absolute mean error and RMSE were 0.45 and 0.54 ^{o}C, respectively.

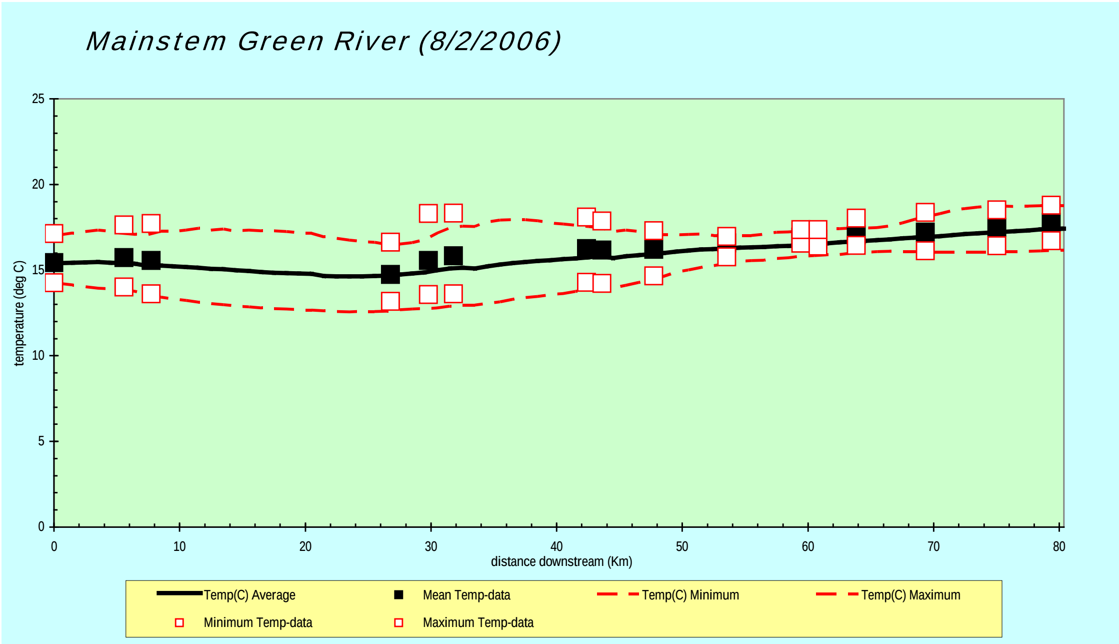

Figure 29. QUAL2Kw predicted Green River temperature for August 2, 2006, based on observed solar radiation, Satterlund longwave formulation, and longwave cloud cover coefficient of 0.22.

Table 9. Summary of temperature model bias, absolute mean error (AME), and root mean square error (RMSE) for calibration and model testing runs.

Date	Bias	AME	RMSE
7/23/2006	0.28	0.62	0.77
8/2/2006	-0.37	0.45	0.54
8/7/2006	0.41	0.67	0.78
8/18/2006	0.50	0.59	0.72

Model validation, sensitivity and error analysis

The calibrated model was then tested against temperature data for three other days in July and August. These days were selected based on evaluation of river flows observed at the two USGS gages and cloud cover, which determined that July 23, August 7, and August 18 were days preceded by and on which relatively steady flows and minimal cloud cover were observed. The DO component of the model could not be tested for another time period since data were limited to the single August 1 and 2 synoptic survey.

In order to confirm the hydraulic variables defined in the calibration run, only those variables that changed with time were changed. This included headwater and tributary temperatures, air and dew point temperature, wind speed, cloud cover, solar radiation and shade. All variables were input as the instantaneous hourly values for the selected testing date.

The flow from the two ungaged springs entered as point sources in the model were not changed. Diffuse flow inputs between the upstream boundary at the Tacoma Public Utilities diversion and Flaming Geyser and between Flaming Geyser and the USGS Auburn gage were scaled using the ratio between these diffuse inflows in the calibrated model.

Figure 30 through Figure 32 illustrate the model predicted and observed temperatures for July 23, August 7, and August 18. The temperature model error statistics for these model testing runs can be found in Table 9. A slight overall positive model bias ranging from 0.28 to 0.50 ^{o}C was calculated based on comparison with the available thermistor data. Absolute mean error and RMSE were somewhat higher than these same error statistics calculated for the calibration model run, but they were below 0.80^{o}C.

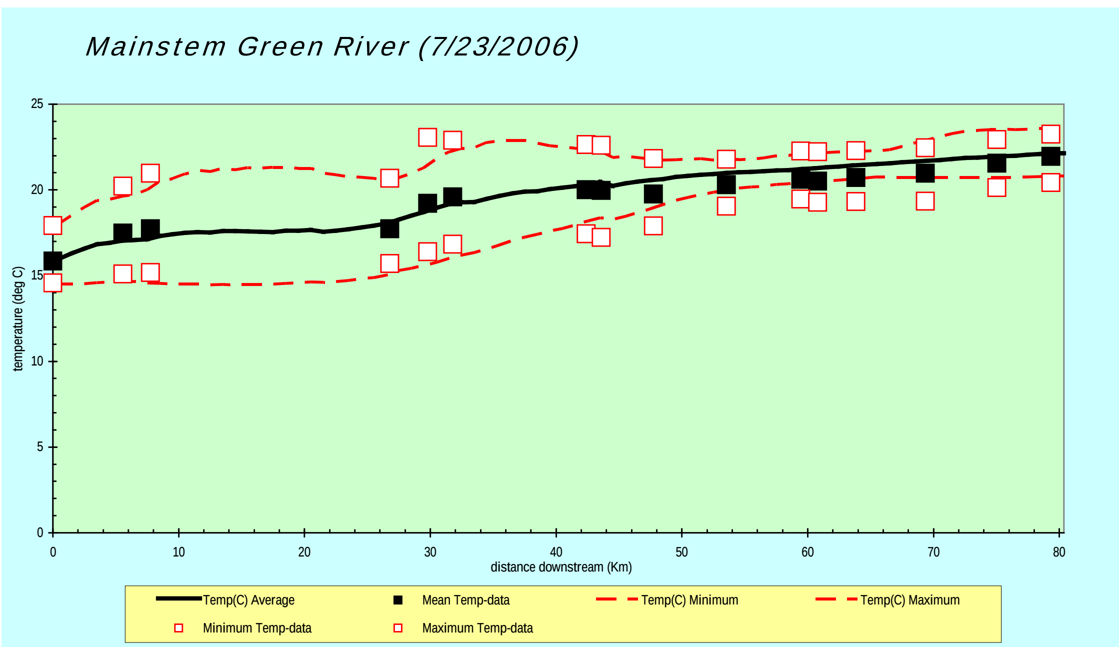

Figure 30. QUAL2Kw predicted Green River temperature for July 23, 2006, based on <u>observed</u> solar radiation, Satterlund longwave formulation, and longwave cloud cover coefficient of 0.22.

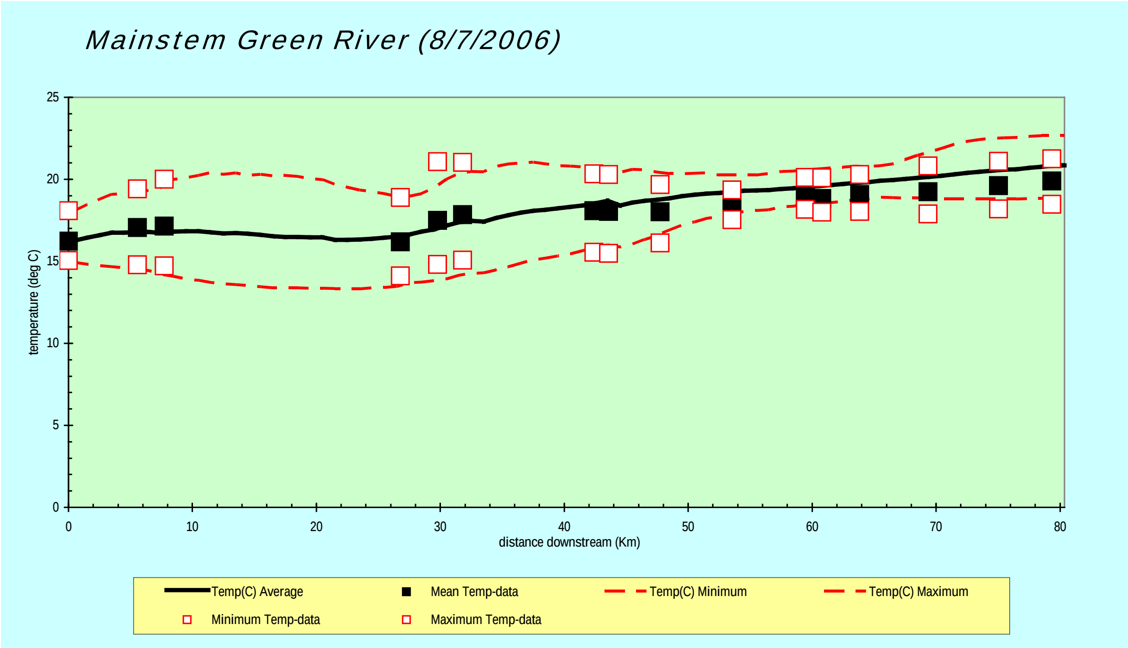

Figure 31. QUAL2Kw predicted Green River temperature for August 7, 2006, based on <u>observed</u> solar radiation, Satterlund longwave formulation, and longwave cloud cover coefficient of 0.22.

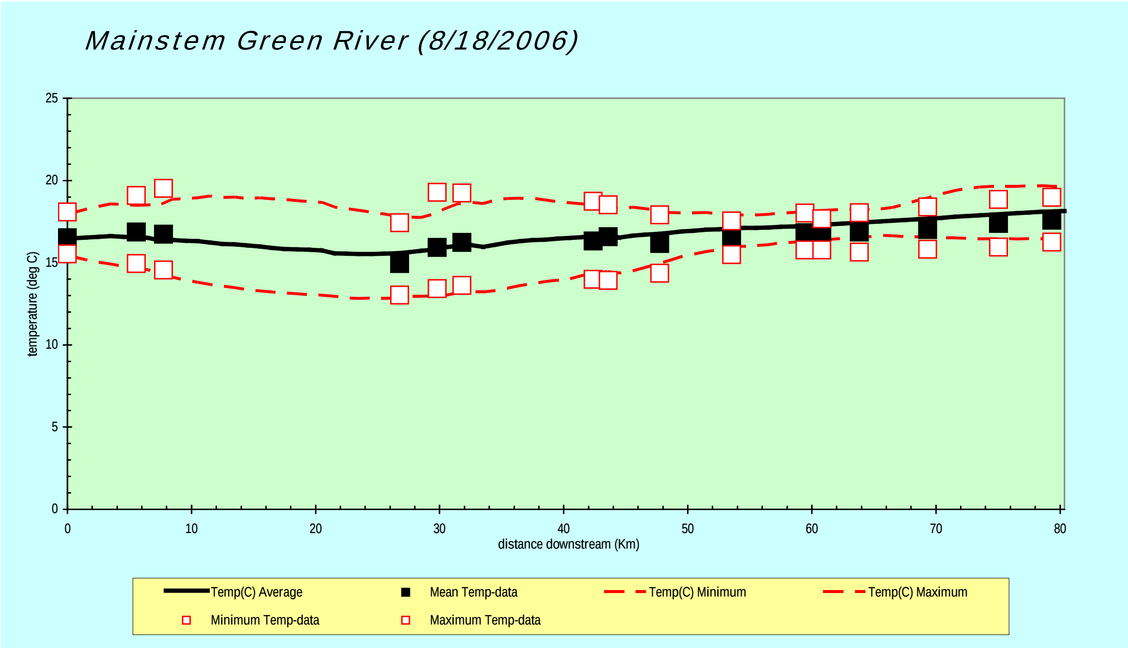

Figure 32. QUAL2Kw predicted Green River temperature for August 18, 2006, based on <u>observed</u> solar radiation, Satterlund longwave formulation, and longwave cloud cover coefficient of 0.22.

Compliance with standards

When natural conditions (prior to human caused effects) that influence a stream's temperatures cause a water body to exceed the specific temperature criteria given in Chapter 173.201A WAC, those "natural" temperatures become the accepted standard for that stream. This variance from the listed criteria applies only when the river meets the physical conditions tested by the model and does not negate the numerical criteria when the river is under other conditions. To predict natural conditions, Ecology has used the models described in this document to simulate shade scenarios that best mimic the conditions that would exist under natural "system potential conditions."

In modeling the Middle and Lower Green River it becomes apparent that during critical periods of the year that combine high air temperatures, high solar loading and low flows the 16°C criterion in the Middle Green River and a portion of the Lower Green River may not be achievable. The model shows that even with system potential shade conditions the water temperature may exceed the 16° criterion by 2 to 3 degrees. Current conditions within these reaches exceed the criterion by approximately 5.5 degrees.

Also, according to the model, the 17.5° criterion that affects the Lower Green River below the confluence with Mill Creek is nearly achievable when using 32m trees as a modeling parameter to create a system potential shade scenario. When using a 42m tree the river can achieve compliance with the 17.5° criterion. This needs to be contrasted with current conditions under which this area of the river is occasionally six degrees warmer than the state standard and above temperatures that are considered lethal for adult and juvenile salmonids.

Loading capacity

The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. EPA's current regulation defines loading capacity as "the greatest amount of loading that a water body can receive without violating water quality standards" (40 CFR § 130.2(f)). Loading capacities for temperature in the Green River basin are expressed as solar radiation heat loads based on system potential vegetation.

The system potential temperature is an estimate of the temperature that would occur under natural conditions. The system potential temperature is estimated using analytical methods and computer simulations proven effective in modeling and predicting stream temperatures in Washington. The system potential temperature is based on our best estimates of the mature riparian vegetation, riparian microclimate, and natural baseflows.

The system potential temperature does not replace the numeric criteria. It also does not invalidate the need to meet the numeric criteria at other times of the year and at other less extreme low flows and warm climatic conditions.

System Potential flow in temperature TMDL models is typically set to the 7Q10 (seven-day average flow with a ten percent chance of occurring in any year) flow condition when stream and river temperatures are at their peak – generally July to August in the Puget Lowlands. However, the flows in the Green River have been altered substantially by diversions and regulation of flows by Howard Hanson Dam completed in 1961. Diversions include Tacoma Public Utilities'

(TPU's) withdrawal below the dam for public water supply since 1913 and diversion of the White River for flood control, which entered the Green River in Auburn prior to 1906.

Rather than calculating a 7Q10 headwater flow, river instream flow rules and flow targets negotiated with the Muckleshoot Indian Tribe were reviewed to identify appropriate critical flows for use in the system potential model. In 1980, regulatory instream flow rules were established for the mainstem Green River (Chapter 173-509 WAC), but these rules did not affect TPU's withdrawal because their water right predated the instream flow rule. However, in 1995 an agreement was reached with the Muckleshoot Indian Tribe that would allow TPU to exercise rights to additional water stored in Howard Hanson Dam as part of the Additional Water Storage Project (AWSP) – their so-called Second Diversion Water Right (SDWR) – an additional withdrawal of 100 cfs (2.83 cms). The AWSP provides for municipal storage and enhanced conservation storage. Their initial water right to a maximum withdrawal of 3.20 cms (113 cfs) is called the First Diversion Water Right (FDWR).

Under the 1995 agreement, TPU must meet instream flow requirements at the Auburn gage that depend on conservation storage conditions at different times of the year. During the summer, the instream flow requirement at Auburn ranges from 9.91 cms (350 cfs) for wet conditions and 6.37 cms (225 cfs) under drought conditions (Table 10).

Table 10. Minimum Instream Flows (MIFs) at the Auburn Gage (USGS 12113000) for the First Diversion Water Right (FDWR).

Summer Conditions:	MIF at the Auburn Gage for the FDWR cms (cfs)
Wet	9.91 (350)
Wet to Avg.	8.50 (300)
Avg. to Dry	7.08 (250)
Drought	6.37 (225)

In addition to the FDWR minimum instream flow requirements, the Corps of Engineers is required to maintain at least 3.11 cms (110 cfs) at the Palmer gage (USGS 12106700). In order for TPU to exercise the SDWR, higher instream flow requirements must be met (Table 11)

Table 11. Second Diversion Water Right (SDWR) Minimum Instream Flows (MIFs).

	Minimum Flows Needed for SDWR cms (cfs)	
Time Period	Palmer	Auburn
July 15 - Sept. 15 **	5.66 (200)	11.3 (400)
Sept. 16 - July 14	8.5 (300)	no requirement

Since it would be unlikely that the SDWR would be exercised during fairly dry summer periods, instream flow rules for the FDWR were chosen to develop critical flow conditions for the system potential model. The drought condition flow requirement of 6.37 cms (225 cfs) at Auburn was chosen for use in developing the critical flow condition.

The next step was to estimate the July-August 7Q10 flow for Newaukum Creek and Soos Creek as these tributaries have sufficiently long continuous gauging records to allow for a statistically meaningful calculation of the 7Q10 flow. The 7Q10 flow for each tributary was determined by calculating the 7-day moving average of the daily average flow and finding the minimum 7-day flow for each year during the July-August period. These flows were ranked to calculate the flow with a 10 percent chance of occurrence in any year (i.e., 7Q10 flow). The estimated 7Q10 flow for Soos Creek and Newaukum Creeks was 0.595 and 0.340 cms and (21 and 12 cfs), respectively.

The average ratio of the Soos Creek and Newaukum Creek 7Q10 flows to the flows used in the calibrated August 2, 2006 model (average = 0.69) was then used to scale the other tributary point source flow inputs to represent 7Q10 inflow conditions. Diffuse flow inputs were not adjusted assuming that these primarily groundwater driven flows would be less affected by drought conditions and that the 7Q10 ratio adjustment might be overly conservative.

After modifying the tributary inflow rates to represent critical flow conditions, the headwater inflow was adjusted so that the model matched the 6.37 cms (225 cfs) minimum flow target at the USGS Auburn gage. The headwater flow required to meet the minimum flow target was 3.36 cms (119 cfs), which is above the minimum conservation flow target at Palmer of 3.11 cms (110 cfs). Headwater, tributary inflow and diffuse inflow temperatures were not changed from those established during the model calibration process.

The calibrated model was also modified to represent critical meteorological conditions. These changes included:

- Changing from the use of observed solar radiation used for model calibration to calculated solar radiation using the Ryan-Stolzenbach atmospheric attenuation model for solar radiation
- Setting cloud cover to zero
- Setting wind speed to zero
- Adjusting the air and dew point temperatures to represent critical conditions

The adjustment of air and dew point temperatures was done by calculating the seven-day moving average of the daily maximum temperature recorded at Sea-Tac International Airport from 1949 to 2008 and finding the maximum seven-day maximum air temperature for each year during the July-August period. These temperatures were then ranked to calculate the seven-day maximum temperature with a ten percent chance of occurrence in any year. Once the critical temperature period was identified, the hourly air and dew point temperature data represented by the critical seven-day period were averaged to create an hourly data set to represent the critical hourly temperature in the model (Figure 33).

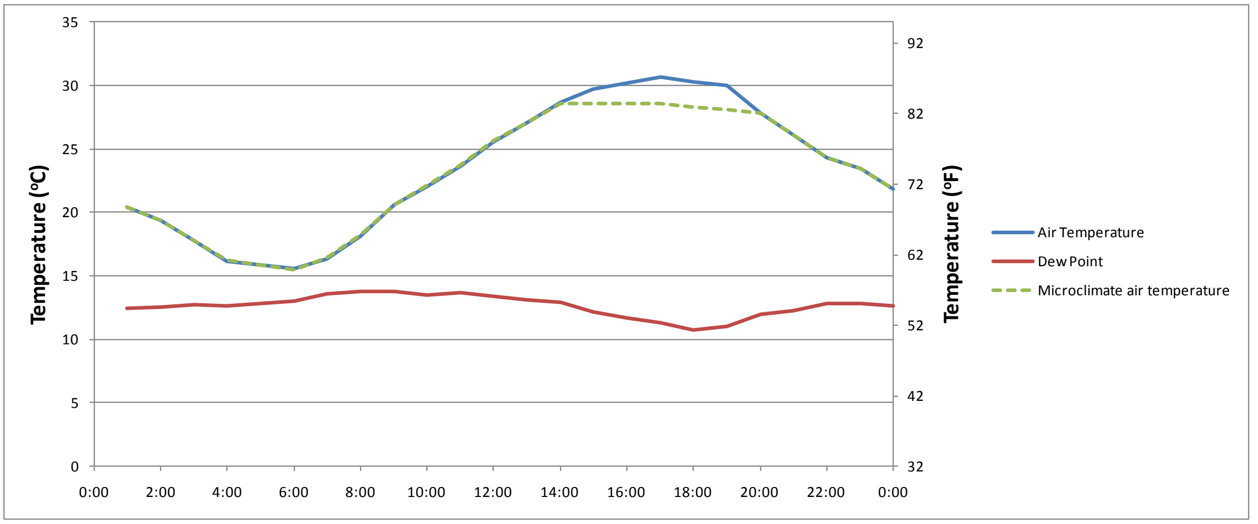

Figure 33. Hourly air and dew point temperatures used to represent critical weather conditions in the QUAL2Kw system potential model.

The peak air temperature was also reduced by 2 ^{o}C to represent a microclimate effect created by system potential vegetation. The hourly air temperature series adjusted to account for a riparian microclimate is shown in Figure 33.

In this study, a system potential temperature was estimated for a critical condition year (upper 90th percentile air temperature and critical low flows based on a combination of instream flow targets and tributary flows that occur once every ten years) identified as the 7Q10 condition. This condition can be considered the 'worst-case scenario' for stream temperature. The 7Q10 condition was simulated with cloud cover and wind speeds set to zero, and 7Q10 flows and air temperatures. These records dated as far back as 1953 for flows and 1949 for air temperature.

The calibrated QUAL2Kw model was used to determine the loading capacity for effective shade for mainstem Green River. Loading capacity was determined based on prediction of water temperatures under 7Q10 flow and climate conditions combined with the implementation of effective shade conditions.

The following scenarios for effective shade were evaluated for the 7Q10 flow and climate condition:

- Current shade. The effective shade produced by the current riparian vegetation condition.
- Maximum potential shade. Effective shade from system potential maximum mature riparian vegetation that would naturally occur along the Green River mainstem below Howard Hanson Dam. Mature vegetation was represented by height and densities and by a riparian vegetation width of 150 feet on each side of the stream. In this scenario, tributaries and the upstream boundary condition were **not** assumed to be well shaded and meeting temperature standards at the point where they discharge into the mainstem.

- Maximum potential shade minus areas with levees. This scenario used a GIS coverage of levees and revetments (rip-rap) from King County and assumed that the riparian area with levees do not have vegetation. Locations designated as revetments could contain vegetation in the adjacent riparian area and were therefore modeled as containing mature riparian vegetation.

The following additional scenarios were also evaluated to test the sensitivity of predicted water temperatures to other variables relevant to the watershed. Though load allocations are not based on the result of these scenarios, they provide additional information about the system and indicate other important factors that affect stream temperature.

- Microclimate improvements. Increases in vegetation height are expected to result in localized decreases in air temperature. In order to evaluate the effect of this potential change in microclimate on water temperature, the daily maximum air temperature was reduced by 2°C based on the summary of literature presented by Bartholow (2000).
- Sensitivity to tree height. To test the difference in shade and stream temperature that would be provided by taller trees a scenario using trees 42m tall (instead of 32m) was run.

The current 7Q10 critical condition results in daily maximum water temperatures that are warmer than 16°C in all of the evaluated reaches (Figure 34). The 17.5 °C standard below Mill Creek is also exceeded. The lower 12 km of the river are also predicted to exceed the 22°C threshold for lethality, as defined by the following excerpt from WAC 173-201A-200(1)(c)(vii)(A) and an Ecology study (Hicks, 2002) that evaluates lethal temperatures for coldwater fish:

"For evaluating the effects of discrete human actions, a 7-day average of the daily maximum temperatures greater than 22°C or a 1-day maximum greater than 23°C should be considered lethal to cold water fish species such as salmonids. Barriers to migration should be assumed to exist anytime daily maximum water temperatures are greater than 22°C and the adjacent down-stream water temperatures are 3°C or more cooler."

In addition, temperatures below the 22°C lethal value but above the 16°C standard impact other salmonid life stages and these impacts vary between different salmonid species (EPA, 2003).

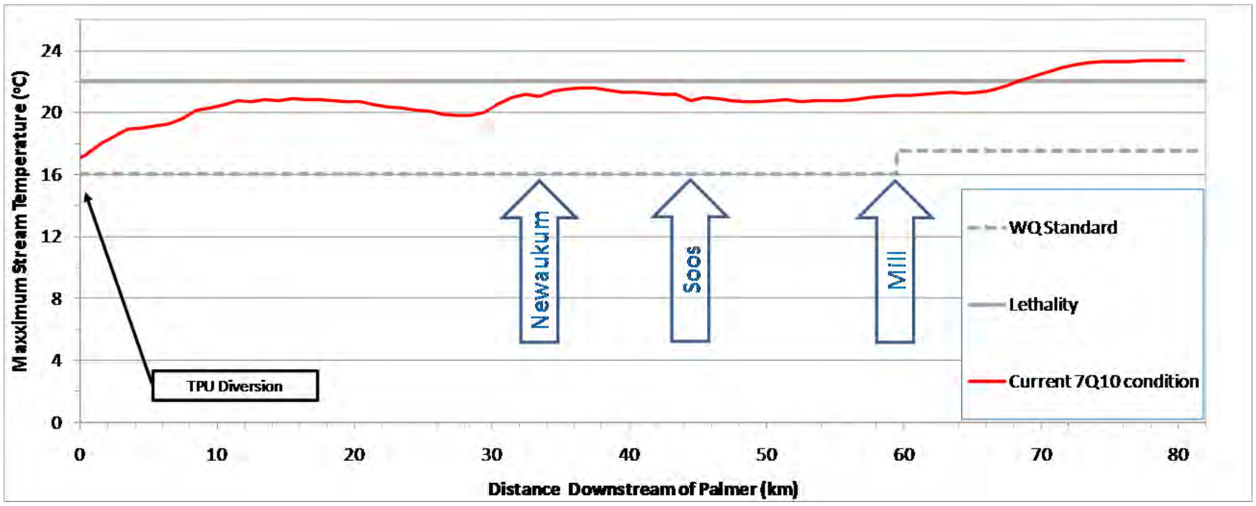

Figure 34. Maximum predicted Green River mainstem (Palmer to Tukwila) temperatures with current riparian vegetation under critical (7Q10) summer conditions.

Temperature improvements

Reductions in water temperature compared to current shade conditions are predicted for the system potential shade condition described above and presented in Figure 35.

Figure 35 presents the results of the different temperature modeling scenarios for the Green River. Significant temperature reductions are predicted with system potential mature riparian vegetation, but very minor improvements are predicted from riparian microclimate. Increases in effective shade from mature riparian vegetation have the potential to decrease water temperatures across all reaches, and almost bring the lower reaches downstream of the confluence with Mill Creek into compliance with the 17.5°C water quality standard protecting salmonid spawning, rearing, and migration uses. Potential reduced maximum temperatures under critical conditions are predicted to be greater than the 16°C numeric standard upstream of Mill Creek, but below the lethal limit for salmonids.

The scenario in which system potential shade is restored along the river except where existing levees may preclude vegetation indicates that under critical conditions temperatures above the lethal threshold may occur over the lower 6 km of the river.

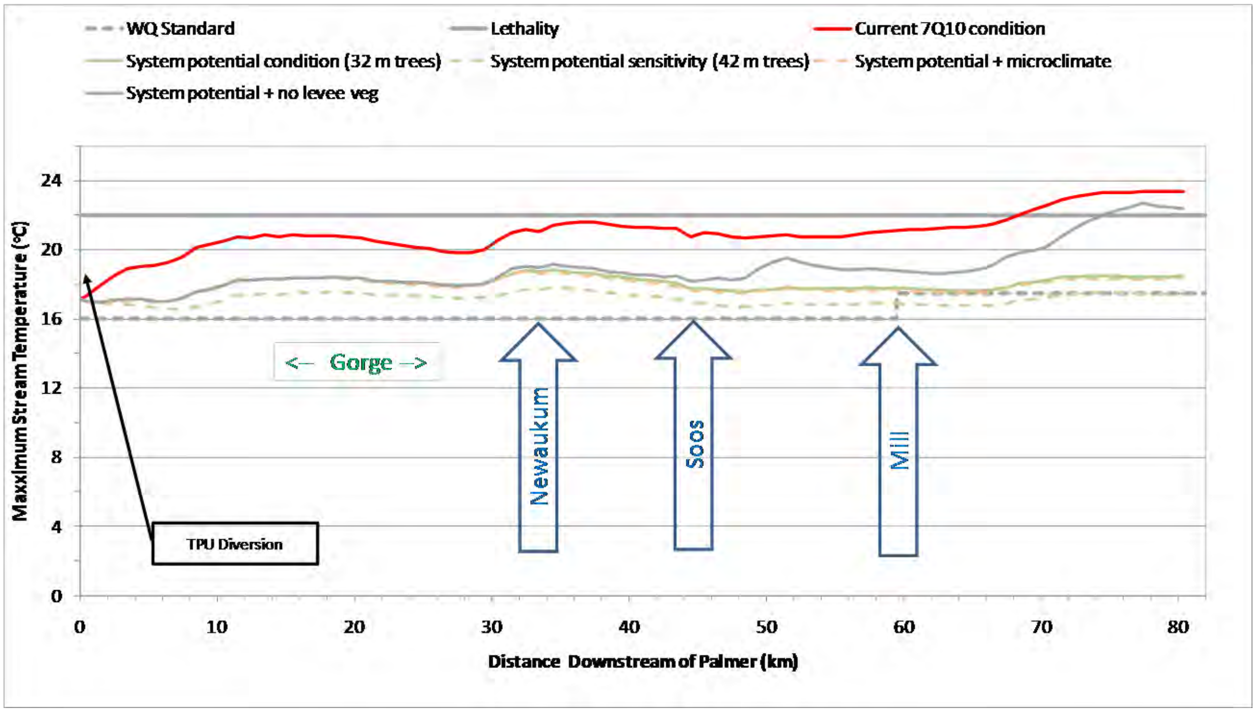

Figure 35. Maximum predicted Green River mainstem (Palmer to Tukwila) temperatures with current riparian vegetation *under critical (7Q10) summer conditions and system potential (mature) riparian vegetation under critical summer conditions. Figure 31 also shows the sensitivity of the model to taller 42-m high trees, microclimate, and a scenario in which mature riparian vegetation is not permitted along any bank of the river with levees.*

System potential riparian planting is predicted to improve river temperatures during critical periods from 3 to 5 degrees Celsius as shown in Figure 35. Also shown is the limitation on temperature improvements when system potential riparian growth is achieved throughout the Middle and Lower Green River but levees are left unplanted per federal policy. When levees are not planted it is predicted that temperatures will be one to four degrees warmer and that lethal temperatures will occasionally be present in the lower six kilometers of the study areas. It was not modeled in this study but it can safely be assumed that these dangerously high temperatures will continue downstream into the Duwamish River.

Load and Wasteload Allocations

Wasteload allocations

Facilities that discharge into state waters are subject to permit through the National Pollutant Discharge Elimination System (NPDES) that is administered by Washington State through the Department of Ecology. The federal Clean Water Act requires that a TMDL be completed on all 303(d) listed waters. If any NPDES permitted facilities that discharges into a 303(d)-listed stream are shown to, or presumed to contribute a pollutant identified on the 303(d) list for that water body, the TMDL process requires that they be assigned a wasteload allocation (WLA). The WLA both defines and limits the amount of any particular pollutant that may be associated with the discharge. The federal guidelines further require that the WLA described in the TMDL is in the form of a numeric, daily load. The WLA may be assigned to the permit holders either separately or in aggregate. The lack of a WLA assigned by the TMDL indicates that there is knowledge or a presumption that the pollutant does not exist in the discharge and, further, because there is expected to be a zero discharge the lack of a WLA defaults to an allocation of zero.

At this time, all NPDES permits for either direct or indirect discharges to the middle and lower Green River are for stormwater. Because these discharges may contribute warm water to the Green River or a tributary during a time of impairment, WLAs are necessary for these permitted sources. The Green River watershed has municipal stormwater sources, industrial stormwater sources, and gravel mining stormwater sources that are permitted to discharge into the mainstem or into tributaries of the Green River. No specific sampling or modeling of stormwater inputs to the Green River was done for this TMDL study. Stormwater Permit holders within the watershed are shown in Table 12.

Table 12. Facilities covered under permits within the Green River basin.

Type of Permit	Permit Holder	Ecology Permit Number
Phase I Municipal Stormwater	King County	WAR04-4501
Phase II Municipal Stormwater	City of Algona	WAR04-5500
Phase II Municipal Stormwater	City of Auburn	WAR04-5502
Phase II Municipal Stormwater	City of Black Diamond	WAR04-5505
Phase II Municipal Stormwater	City of Covington	WAR04-5510
Phase II Municipal Stormwater	City of Enumclaw	WAR04-5514
Phase II Municipal Stormwater	City of Federal Way	WAR04-5516
Phase II Municipal Stormwater	City of Kent	WAR04-5520
Phase II Municipal Stormwater	City of Maple Valley	WAR04-5525
Phase II Municipal Stormwater	City of Renton	WAR04-5559
Phase II Municipal Stormwater	City of SeaTac	WAR04-5541
Phase II Municipal Stormwater	City of Tukwila	WAR04-5544
Phase I Municipal Stormwater	Washington State Department of Transportation	WAR043000A

Type of Permit	Permit Holder	Ecology Permit Number
Industrial Stormwater Permit	Approximately 180 permits issued (varies over time)	
Gravel mining Stormwater	Approximately 1 (varies over time).	

State water quality standards limit any 7DADMax temperature increase caused by human actions to 0.3°C in a water body when the waterbody's temperature is warmer than the listed criteria (or within 0.3°C of the criteria) and that condition is due to natural conditions. "Human actions," as stated in the water quality standards (see Chapter 173-201A-200(1)(c)(i) WAC) does not distinguish between point source (permitted) and non-point sources, but does allow for the aggregation of all human sources. "Natural conditions" for the Green River have not been defined in this TMDL. However, "system potential temperature" has been determined by the model and can be used to offer an estimation of natural condition temperatures. This TMDL divides the 0.3°C allowance for human actions to allow a 0.2°C increase in 7DADMax temperature caused by the cumulative permitted discharges and 0.1°C 7DADMax for other human caused sources and a margin of safety.

Ecology's stormwater permits do not authorize discharges that would violate Washington State surface water quality standards, groundwater quality standards, sediment management standards or the human health-based criteria in the national Toxics Rule.

Ecology's use-based temperature criteria (WAC 173-201A (Table 200(1)(c))) are expressed in 7DADMax values. In order to be both consistent with these temperature criteria and practical (a receiving water may be affected by multiple stormwater outfalls with wide spatial distribution and controlled discharge rates), this TMDL expresses cumulative stormwater WLAs as a 7-day average daily (7DAD) loading value as measured at the TMDL monitoring points established in the TMDL study. Although the WLAs incorporate seven consecutive daily values, they are expressed as a single daily value and are consistent with the state's 7DADMax criteria.

The following bulleted criteria express the cumulative temperature WLA for all stormwater permittees:

- When a waterbody's temperature is warmer than state criteria due to natural conditions (or within 0.3°C), the cumulative discharge from all permitted sources may not cause the 7DADMax receiving water temperature under those conditions to increase more than 0.2°C (0.36°F). That allowable 0.2°C increase is quantified using the following equation, which provides a daily numeric loading value to assess compliance with the aggregate WLA.

$$WLA_{\text{critical period}} = \frac{\sum_{N=1}^{7}(\Delta T * Q_N * C_F)}{7}$$

Where:

$WLA_{\text{critical period}}$ = the waste load allocation in Kilocalories/day
ΔT= allowable cumulative temperature increase for point sources=0.2°C
Q_N= daily receiving water flow, in cfs,

N = day 1 through 7 of the 7DAD averaging period
C_F=2,446,665 (kcal·second)/°C·ft^3·day (a conversion factor to transform the units to Kilocalories/day)

- Appropriate best management practices required in the stormwater permit for controlling thermal loadings to surface waters are applied to the discharge to protect designated aquatic life uses.

At this time, Ecology anticipates that there will be no additional TMDL-required conditions in municipal stormwater permits and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees. Stormwater discharges may be considered for mixing zones as specified in WAC 173-201A-400, which should be applied in conjunction with the WLA mentioned previously.

Background

Precipitation that occurs from late spring to early fall that may run off or across heated surfaces can be initially quite warm, and thus, thermal loading from stormwater discharges has the potential to increase the temperature of receiving waters at certain times of the year. However, runoff cools rapidly during long rain events and is not expected to cause greater than a 0.2°C increase of the 7DADMax temperature.

Data collection and modeling did not focus on stormwater outfalls in this study. However, other studies have been carried out in the Snoqualmie watershed that are being used to generalize conditions and estimate stormwater effects within the Green River watershed. Results from a Snoqualmie River study (Snoqualmie River Temperature TMDL, Draft 2011.), based on one year's data, show that precipitation during the months that coincide with the highest Green River water temperatures is limited in occurrence and intensity It is unlikely, but the potential does exist that any stormwater runoff produced would raise river temperatures. It is further projected that the weather conditions that would produce periods of stormwater runoff would be associated with cooler air temperatures and cloud cover. The dataset used to make these projections is admittedly small, and further study needs to be completed to fully understand and quantify the relationship between stormwater runoff and Green River temperatures during critical, high temperature periods.

Based on the data available, stormwater discharges in the rural watersheds of western Washington are not believed to significantly contribute to surface water temperature impairment. However, temperature monitoring of representative stormwater outfalls that originate from large urban areas of impervious surfaces that are prone to solar heating may be appropriate. If it is determined, through future monitoring and studies in the Green River or other Puget Sound watersheds, that there are significant stormwater heat discharges to rivers or their tributaries Ecology may modify the WLAs and recommended actions in this TMDL, as needed.

Ecology's next round of municipal stormwater permits will be issued in mid 2012. WSDOT's permit is expected to be re-issued in March 2014. These permits are anticipated to include, for both Phase I and II jurisdictions, new regulatory requirements that are intended to minimize stormwater discharge from development and redeveloped areas. The permit language is also likely to include a requirement to implement low impact development (LID) practices to the maximum extent feasible. These are intended to minimize the generation of new stormwater and should capture on-site a large percentage of the stormwater generated by the smaller storms that occur from June through September. Many of the existing storm sewer systems in outlying areas transport stormwater in grass-lined ditches that already infiltrate some stormwater. Where underground pipes are conveying stormwater, a cooling effect due to thermal exchange within those pipes is expected to moderate discharge temperature.

A supplemental temperature standard of 13°C applies in portions of the Green River from September 15 to July 1, outside the critical period that was modeled for this TMDL, to protect spawning and incubation of salmonid species (Figure 3). No WLA was given for this time period; however, if future monitoring data shows that temperature criteria are being exceeded during this period, the TMDL may revisit this area.

Load allocations

Percent effective shade is used as a surrogate to describe an amount of reduction of solar heat load. In Table 13, POTENTIAL effective shade is a target of this TMDL and considered the load allocation in each of the listed reaches in the Middle and Lower Green River. CURRENT effective shade indicates the conditions at the time monitoring was completed. REQUIRED effective shade is determined simply by subtracting CURRENT shade from POTENTIAL shade.

Table 13. Effective shade and solar load allocations on August 2 to improve temperature conditions in the mainstem Green River below Howard Hanson Dam.

				Load Allocation			
Station	Distance from upstream boundary to end of reach (km)	CURRENT reach averaged effective shade (%)	CURRENT reach averaged solar heat load (W/m2)	POTENTIAL reach averaged effective shade (%)	POTENTIAL reach averaged solar heat load (W/m2)	REQUIRED increase in effective shade (%)	REQUIRED decrease in solar load (W/m^2)
just below TPU diversion	5.00	38%	159	71%	73	33%	86
	10.00	45%	141	70%	78	25%	63
	15.00	61%	99	75%	65	13%	34
	20.00	65%	89	77%	59	12%	30
	25.00	56%	111	70%	76	14%	35
Flaming Geyser	30.00	44%	142	64%	91	20%	51
Newaukum Creek	35.00	33%	170	59%	105	25%	65
	40.00	28%	183	63%	94	35%	89
Soos Creek	45.00	32%	172	63%	94	31%	78
	50.00	29%	180	62%	96	33%	85
277TH	55.00	34%	166	67%	83	33%	84
Mill Creek - Hwy 167	60.00	35%	164	71%	73	36%	91
Mullen Slough - OLD 167	65.00	27%	184	73%	69	46%	116
	70.00	25%	189	72%	71	47%	118
180TH	75.00	19%	204	72%	70	53%	134
	80.00	27%	185	68%	82	41%	104
Fort Dent State Park	80.30	28%	184	65%	88	38%	95

Figure 36 contrasts the areas where additional shade is required. The Lower Green River, in the reach bordered by an extensive system of levees and revetments, requires the greatest increase of effective shade while the reach going through the Green River Gorge requires the least.

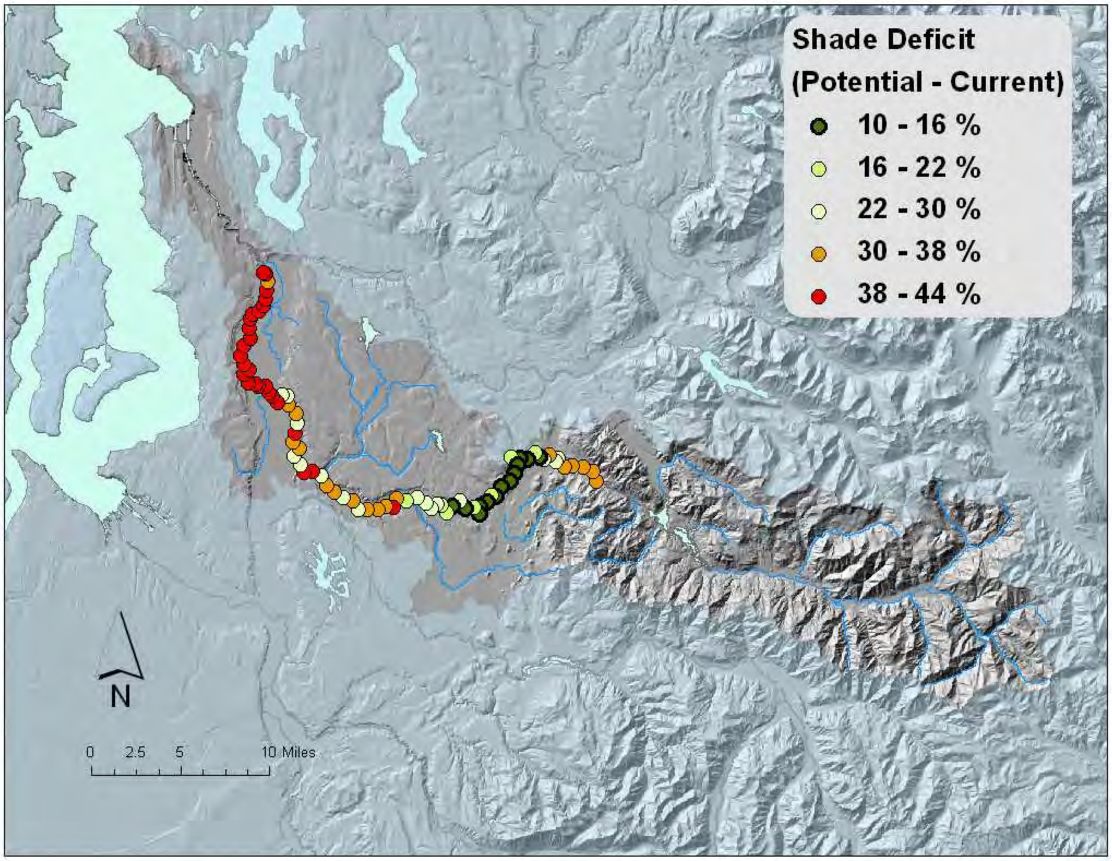

Figure 36. Effective shade deficit by 1,000 m increments along the mainstem Green River below Howard Hanson Dam. The deficit is the difference between the mature riparian shade condition and the current riparian shade condition.

Seasonal Variation

Load allocations for this TMDL were determined using a model that considered conditions that would describe a “worst case scenario”. Low flow, high air temperature and high solar loads were included in the calculations. These conditions may typically occur in the summer months of July and August. Since the load allocations resulting from the summer model runs resulted in requiring the maximum riparian protection to the stream, a fall scenario was not performed. Fall temperature criteria for salmon begin September 15. If a model evaluation were performed, it would need to be done with September climate conditions, an annual 7Q10 flow, and an estimate of the shade produced by the vegetation on September 15. Additional modeling would not change the resulting load allocation. If the resulting water temperature were below the state standard, the summer load allocation for effective shade would still need to be met to comply with the summer condition. If the resulting fall water temperature were greater than the state standard, the load allocation would still be the maximum potential shade.

Margin of Safety

The margin of safety (MOS) in a TMDL accounts for uncertainty about pollutant loading and water body response. The MOS may be implicit, i.e. incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e. expressed in the TMDL as loadings set aside for the MOS. In this TMDL, the MOS is addressed by using critical climatic conditions in the modeling analysis. The margin of safety in this TMDL is implicit because of the following:

- The 90th percentile of the highest seven-day-averages of daily maximum air temperatures for each year of record represents a reasonable worst-case condition for prediction of water temperatures in the middle and lower Green River.
- The lowest seven-day average flows during July-August with recurrence intervals of ten years (7Q10) were used to evaluate reasonable worst-case conditions.
- Coincident application of the 7Q10 flow and the worst-case warmest air temperature adds to the implicit margin of safety.
- Conservative model assumptions of 0 percent cloud cover and 0.0 m/s wind speed were used for critical condition model runs.

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Reasonable Assurances

When establishing a TMDL, reductions of a particular pollutant are allocated among the pollutant sources (both point and nonpoint sources) in the water body. No permitted point sources have been identified as significant contributors of heat pollution to the Middle and Lower Green River, however, modeling can directly link nonpoint heat pollution to specific land uses and specific sites that inhibit or prohibit the properly functioning riparian corridor needed to shade the river and provide cool water habitat. The areas identified as probable or potential sources of heat to the river will be targeted for attention. Education, outreach, technical and financial assistance, permit administration, and enforcement will all be used to ensure that the goals of this water clean-up plan are pursued as well as possible.

Several ongoing and planned projects in the Middle Green River to remove or set back revetments and restore the riparian corridor are already underway as described in the Implementation Strategy section of this document. Creating and restoring habitat in the Green River is especially urgent as two species of fish are already listed in the Endangered Species Act "Threatened" category and diminishing numbers of returning fish are seen in other species.

The Lower Green River presents unique and challenging problems that need to be addressed to achieve the functional riparian corridor necessary to protect water temperatures. The river runs through a confined course on an open valley floor, lined on both sides by a gauntlet of protective levees, revetments and steep banks that were designed to keep flood waters within the recognized channel area. Vegetation that can provide shade in this portion of the river is poor to non-existent. Temperatures in the Lower Green River are at times above the "lethal" level as defined by Chapter 173-201A WAC.

Federal certification of levees by the U.S. Corps of Engineers is necessary to provide financial protection to the vast urban infrastructure that exists in the Green River valley should floods ever occur. At this time, federal policy on levee maintenance does not allow adequate riparian vegetation to satisfy the shade requirements of the TMDL. Discussions between local, state, federal, and tribal governments to address the conflicts that exist between protecting salmonid habitat and preventing flood damage are ongoing. Resolving this conflict is an important and urgent issue. The possibility of a change in levee vegetation policy, levee set-back, and areas of levee removal are all part of those discussions.

Ecology believes that the activities listed in the Implementation Strategy already support this TMDL and add to the assurance that temperature in the Green River will meet conditions specified in Washington State water quality standards. This assumes that the activities described below are continued and maintained and that negotiations over levee policies are productive.

While Ecology is authorized under Chapter 90.48 RCW to impose strict requirements or issue enforcement actions to achieve compliance with state water quality standards, it is a goal of the TMDL process to achieve clean water through cooperative efforts.

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Implementation Strategy

Introduction

This implementation strategy section explains the roles and authorities of cleanup partners (those organizations with jurisdiction, authority, or direct responsibility for cleanup), along with the programs or other means through which they will address these water quality issues. This strategy also offers general ideas and non-specific actions that may help guide the directions of the "next steps" of implementation. The amount of participation, commitment to the projects and funding availability is still unknown. Following the approval of this TMDL Ecology will begin the preparation of an Implementation Plan which will add specificity and actions to this strategy.

What needs to be done?

This implementation strategy summarizes actions that will help improve water quality in the Green River. It describes the potential roles and authorities of the cleanup partners (whose organizations have jurisdiction, authority, or direct responsibility for cleanup). It also describes the programs or other means through which they will address these water quality issues.

Subsequent to the U.S. Environmental Protection Agency (EPA) approving this *Middle and Lower Green River Temperature TMDL/Water Quality Improvement (TMDL) Report*, interested and responsible parties will work together to develop a more detailed plan of action. The plan will describe and prioritize specific actions to improve water quality and achieve water quality standards. Ecology facilitates this process by seeking input and commitments from local governments, agencies, districts, businesses, and communities to participate in actions that will help identify and correct pollution sources and protect stream quality. When possible, Ecology contributes funding to support local efforts.

Currently, several agencies and groups in the Green River watershed actively conduct educational and stream restoration projects that help remediate the water quality impacts to the river and its tributaries. State and local governments, King Conservation District, and others actively plan and develop stream restoration projects and other watershed activities that help improve temperature in the watershed.

This strategy also summarizes many actions recommended by other restoration plans for the Green River watershed and its sub-watersheds. Integral to achieving cooler waters will be the continuation of ongoing projects that provide shade to the river. The TMDL study evaluated approaches to reducing temperature in the middle and lower reaches of the river, which will in turn improve dissolved oxygen, establishment of mature full riparian vegetation for shade, and microclimate. The TMDL models show that the combined effects of mature riparian vegetation and the associated microclimate improvements result in the greatest temperature improvements in the river.

What the models do not consider is the feasibility and level of cooperation for implementing these various approaches. Some of the properties along the river are privately owned and in other areas publicly-owned properties are already heavily developed with levees, paved roadways, and structures that preclude easy restoration. Thus, employing the model's assumed buffer width of 45 meters (148 feet) for establishing mature riparian vegetation everywhere on both sides of the river will be challenging. Furthermore, once the obstacles to planting are overcome, the additional shade provided from new riparian vegetation will require many years, at a minimum, for the trees to attain mature height. Regardless, planting new or restoring riparian vegetation of any buffer size that is deemed feasible can still provide value and is encouraged.

While the influence of groundwater was not specifically part of the model used to determine temperature scenarios, the positive effect of minimizing runoff and infiltrating water into the ground is well documented. Maintaining or enhancing groundwater recharge through the use of Low Impact Development (LID) practices and infiltration of stormwater/reclaimed water in some places may help provide temperature benefits in a shorter timeframe. In addition, enhancing groundwater recharge may mitigate the effects of inadequate shade in some areas.

Looking into the future and urban growth potential in the basin, it is also necessary to incorporate actions that minimize further degradation of riparian habitat and baseflow loss. The WRIA 9, *Salmon Habitat Plan* recommends policies of reducing impacts of human population growth and development (land use) including 1) *Uphold the growth management and concentration principles of the King County Countrywide Planning Policies (1994)*, and 2) *Encourage the use of the Built Green ™ building program (or other comparable programs) to provide incentives for developers* (Green/Duwamish, 2005). Management options such as minimizing new impervious surfaces through LID practices and acquiring economically feasible alternative water sources (e.g., local reclaimed water) can be used to increase summer baseflows and may counteract the impact of reduced groundwater recharge to the tributaries and the river.

The modeling of the Green River primarily examined the effect of shade in the mainstem river, incorporating assumptions about the temperatures and the flow regimes of the tributaries entering the river. In general, the model shows that decreasing the temperatures and increasing the flows in the tributaries helps to maintain lower temperatures in the mainstem. Concurrent to restoration work being accomplished on the Middle and Lower Green River will be several ongoing projects in the tributaries. The *Newaukum Creek Temperature Total Maximum Daily Load* (planned for publication in June, 2011) describes several projects currently underway and others in planning that will directly affect temperature in this major tributary to the Green River.

Table 14 is a list of strategies that apply to the Green River and its tributaries. Specific actions will be developed to address the strategies and will be described in an implementation plan that will be developed within a year of the approval and adoption of this TMDL.

Table 14. Summary of implementation strategies and timeframes to improve temperature in the Middle and Lower Green River.

Implementation Strategies
Provide more shade and improve riparian areas
Assess potential planting sites along the Middle and Lower Green River and along tributaries.
Encourage riparian planting projects
Locate available funding for watershed restoration projects
Complete the necessary negotiations with USCOE and other agencies and/or municipalities that own or control levees and the adjacent properties to allow an adequate riparian buffer to be developed along the length of the lower Green River.
Incorporate TMDL actions into local regulatory programs and policies.
Protect cool groundwater and enhance current summer baseflows
Promote Low Impact Development (LID) practices that are demonstrated to be environmentally sound.
Consider TMDLs during SEPA and other land use planning reviews.
Minimize stormwater runoff to the maximum extent feasible using techniques that do not put groundwater or surface water quality at risk.
Restore and/or create beneficial wetlands.
Increase water conservation
Consider economically-feasible alternative water sources such as community water systems.
Reduce unauthorized water withdrawals through enforcement.
Monitoring
Conduct in-stream water quality & flow monitoring.
Periodically re-run the temperature model based on new data
Effectiveness monitoring

Provide more shade and improve riparian areas

Riparian areas (streamside buffers) perform many valuable roles in protecting water quality. In addition to its direct role in blocking incoming solar radiation, riparian vegetation creates an area of moderated microclimate, prevents erosion, and provides large woody debris for instream habitat. It can also filter out unwanted substances before they are carried into streams by surface runoff. Cooler water holds more oxygen to support fish and other aquatic life.

River reaches in the Middle and Lower Green River are listed in Table 13 along with the current and potential effective shade. Table 13 also shows the percent improvement needed to meet the system potential shade required. This tool will help identify and prioritize areas in the most need of attention.

Benefits of shade are also cumulative. The further upstream shade is provided, the greater the length of stream deriving temperature benefits. Riparian restoration and preservation of existing high value habitat should also be focused upstream from these high shade deficit reaches.

Summary of strategies

- **Assess potential planting sites along the Middle and Lower Green River and its tributaries, particularly in the high shade deficit areas.**

  Much of this work has already begun. King County, Tacoma Public Utilities, the US Corps of Engineers, Washington Dept. of Fish and Wildlife and others have all been coordinating through the WRIA 9 Watershed Ecosystem Forum to scope, prioritize and plan projects that have been identified in the *Habitat Limiting Factors and Reconnaissance Assessment Report* (2000).

- **Encourage riparian planting projects**

  Riparian restoration and planting projects are recognized as priority activities and often score well in competitive grant project evaluations. The presence of a TMDL on a water body will often add weight to the recognized value of a project.

- **Locate available funding for watershed restoration projects**

- **Complete negotiations with USCOE, land managers, local government and private owners that will allow planting on or the set-back of levees**

  The ability to plant trees and other vegetation that form a full riparian corridor providing adequate shade up to and along the wetted edge of the river is an essential element of this TMDL. Methods to provide shade in the areas with the U.S. Army Corps of Engineers (COE)-certified levees must be found to make this TMDL successful. Many levees are owned and operated by the local municipalities along the river. Federal, state and local governments and private landowners must come together to create set-backs of levees and riparian planting areas where possible.

- **Incorporate TMDL actions and incentives into local regulatory programs and policies that improve and protect local water quality.**

  Local governments should use their sensitive area protection authority (under the Shoreline Management Act and Growth Management Act) and incorporate relevant TMDL actions and incentives in the revision or development of their Critical Areas Ordinances, Shoreline

Management Plans, and other land-use regulations to protect and improve the quality of degraded riparian areas. The public should be provided with information explaining how those authorities will optimize stream shading for temperature and restore and protect critical habitat.

Protect cool groundwater and enhance current summer baseflows

Cool groundwater flowing into the Green River benefits the river's water quality throughout the year, especially during the warmer, drier, summer months. In addition to keeping overall water temperatures low, groundwater seeps and inputs through the hyporheic zone can also provide important fish refuge areas from surrounding high water temperatures. Therefore, headwater areas, important wetlands, and sources of groundwater (e.g. seeps and springs) throughout the Green River watershed should be protected and recharged to maintain hydrologic integrity and a temperature regime that supports core salmonid life stages.

Wherever people live, there will be an increase in roofs, roads, and parking lots, so adverse impacts to water quality will likely occur in those areas. Additional population growth will place further pressures on the Green River. Additional forested areas may be cleared for housing and other new development that could decrease buffers on streams and wetlands. The development will likely increase impervious areas (which will increase winter runoff and reduce groundwater recharge).

Growing populations need clean drinking water and places to live. Any water management strategy in the basin should recognize the benefits of maintaining summer baseflows while meeting the community's need for water. Outside of urban areas, groundwater is the key source of water for new development. There will be an increased demand for water supply, and it will be important to minimize the degradation to groundwater recharge that could continue to occur as a result of population growth and development.

Summary of strategies

- **Infiltrate stormwater and/or reclaimed water to the maximum extent possible, including through the use of Low Impact Development (LID) practices where feasible.**

  Municipalities should evaluate their stormwater drainage systems (MS4s) for opportunities to infiltrate stormwater, where feasible, rather than directly discharging to creeks and rivers.

  To reduce the effect of new and existing stormwater discharges, local government should advance the use of LID practices in new development and redevelopment. Local jurisdictions should develop incentives to encourage LID practices.

- **Consider economically-feasible alternative water sources to augment irrigation withdrawals (such as use of reclaimed water) and groundwater drinking water source.**

  Water districts and cities have a responsibility to provide water to their respective communities. All water purveyors should be compliant with water conservation rules and support efforts to enhance groundwater recharge. The economic feasibility of obtaining alternative water supply sources is an important factor to consider in the strategy.

Reclaimed water is an alternative to potable water for some uses and can be used for irrigation of parks, nurseries, athletic fields, and golf courses, and for routine city maintenance of storm drainage systems, such as street sweeping and cleaning drains.

- **Consider TMDLs during State Environmental Policy Act (SEPA) and other local land use planning reviews.**

  If a land-use action under review is known to potentially impact stream temperature as addressed by this TMDL, then the project may have a significant adverse environmental impact. SEPA lead agencies and reviewers are required to look at potentially significant environmental impacts and alternatives and to document that the necessary environmental analyses have been made. Land use planners and project managers should consider findings and actions in this TMDL to help prevent new land uses from violating water quality standards. Ecology recently published a focus sheet on how TMDLs play a role in SEPA impact analysis, threshold determinations, and mitigation (http://www.ecy.wa.gov/biblio/0806008.html)**.** Additionally, the TMDL should be considered in the issuance of land use permits by local authorities, such as King County Department of Development and Environmental Services and municipal governments.

- **Restore and/or create wetlands in areas that will increase groundwater recharge to benefit the stream.**

  Existing wetlands in the floodplain could be reconnected to streams to allow seasonal inundation and groundwater recharge. Areas with suitably-permeable soils should be identified where percolation ponds could be installed to allow infiltration of stormwater and treated reclaimed wastewater being mindful of the need to protect groundwater quality.

- **Protect cool headwaters, wetlands, and sources of groundwater (e.g. seeps and springs).**

  County and city planning departments should protect and acquire existing high-value habitats or areas with high likelihood of restoration success. This includes streamside lands with springs and side channels that provide habitat, refuge, and cooler water for salmonids.

- **Increase water conservation in Green River tributaries.**

  In areas served by groundwater sources, increased water conservation could help maintain summer base flows and reduce summer water temperature in the creeks. Reduction of illegal surface water withdrawals would also be effective in helping maintain flows.

- **Examine the feasibility of purchasing and transferring existing water rights.**

  This TMDL encourages projects that work with local individuals or businesses to voluntarily retire water rights and help ensure sufficient flow levels are protected. The Washington Water Trust works to benefit water quality, fisheries, and recreation in Washington's rivers and streams by acquiring existing water rights from willing sellers through purchase, lease, or gift.

- **Reduce unauthorized water withdrawals through enforcement**.

  Ecology, through the rulemaking process, closed Green River and its tributaries to any further consumptive surface water diversions in 1980. The closed-basin status should be maintained and illegal withdrawals eliminated. Ecology is required to consider the interrelationship between groundwater and surface water when making permitting decisions for consumptive groundwater withdrawals within the basin.

Forest practices

Although not covered under this TMDL, monitoring for this study indicated that water in the mainstem Upper Green River flowing out of Howard Hanson Reservoir and into the Middle Green River did not always meet the state water quality criterion of 16°C. This data will be used to include the Howard Hanson Reservoir on the 303(d) list. Much of the land in this portion of the watershed is forested and is subject to the state forest practices rules. Meeting state temperature standards at the upstream edge of the Middle Green River will be imperative in maintaining cool temperatures as the water in the mainstem moves downstream.

The state's forest practices rules were developed with the expectation that the stream buffers and harvest management prescriptions were stringent enough to meet state water quality standards for temperature and turbidity, and provide protection equal to what would be required under a TMDL. As part of the 1999 agreement, new forest practices rules for roads were also established. These new road construction and maintenance standards are intended to provide better control of road-related sediments, provide better stream bank stability protection, and meet current best management practices.

To ensure the rules are as effective as assumed, a formal adaptive management program was established to assess and revise the forest practices rules, as needed. The agreement to rely on the forest practices rules in lieu of developing separate TMDL load allocations or implementation requirements for forestry is conditioned on maintaining an effective adaptive management program.

Consistent with the directives of the 1999 Forests and Fish agreement, Ecology conducted a formal 10-year review of the forest practices and adaptive management programs in 2009:

> http://www.ecy.wa.gov/programs/wq/nonpoint/ForestPractices/CWAassurances-FinalRevPaper071509-W97.pdf

Ecology noted numerous areas where improvements were needed, but also recognized the state's forest practices program provides a substantial framework for bringing the forest practices rules and activities into full compliance with the water quality standards. Therefore, Ecology decided to conditionally extend the CWA assurances with the intent to stimulate the needed improvements. Ecology, in consultation with key stakeholders, established specific milestones for program accomplishment and improvement. These milestones were designed to provide Ecology and the public with confidence that forest practices in the state will be conducted in a manner that does not cause or contribute to a violation of the state water quality standards.

The success of this TMDL project will be assessed using monitoring data from streams in the watershed.

Monitoring

During the implementation of the TMDL, monitoring will help (1) to identify polluted areas and sources of pollution, (2) to track water quality trends, and (3) to verify that actions taken are and will remain appropriate in protecting local waters.

- **Continue existing monitoring efforts throughout the watershed.** King County, the U.S. Corps of Engineers and Tacoma Public Utilities currently have stream monitoring programs in the watershed. Data from these monitoring programs not only track trends in water quality in the Green River, but will help assess the beneficial impacts from future restoration and implementation actions.

- **Periodically re-run the QWAL2Kw model with current data**

- **Effectiveness monitoring** for the Green River watershed will tell us whether actions to improve temperature are effective. Ecology reviews all of the relevant actions taken to improve the water quality in the river and its tributaries over a five-year period and compares them with the water quality data. This allows us to see what is working, what is not working, and what changes may be needed to improve water quality.

Who needs to participate?

The following government agencies, citizen groups, and tribes have regulatory authority, influence, information, resources, or other involvement in activities to protect and restore the health of the Green River watershed.

Federal, tribal, and state entities

U.S. Environmental Protection Agency

The 1997 Memorandum of Agreement between the Environmental Protection Agency, Region 10 and Ecology requires that EPA and Ecology jointly evaluate the implementation of TMDLs in Washington. These evaluations address whether interim targets are being met, whether implementation measures such as best management practices (BMPs) have been put into effect, and whether NPDES permits are consistent with TMDL wasteload allocations.

EPA provides technical assistance and funding to states and tribes to implement the Clean Water Act. For example, EPA's Clean Water Act Section 319 grants, combined with Ecology's grant and loan funds, are made available to stakeholders through Ecology's annual Water Quality Grant and Loan Process. On occasion, the EPA also provides other grant monies (104(b)(3)) to address storm water pollution problems.

U. S. Army Corps of Engineers

Washington State Department of Ecology

EPA delegated authority to Ecology to implement many aspects of the federal Clean Water Act. These include the National Pollution Discharge Elimination System (NPDES) permitting and the total maximum daily load (TMDL) program. The Green-Duwamish watershed (WRIA 9) is within the jurisdictional area of Ecology's Northwest Regional Office (NWRO). To address any municipal stormwater permitting needs of this TMDL, the NWRO has one municipal stormwater engineer and two municipal stormwater specialists who provide technical assistance and auditing activities for the Phase I and Phase II municipal stormwater permits across the region. Ecology's headquarters also has several staff that can help identify and distribute education and outreach materials to stormwater permit holders.

Ecology has a Water Quality Improvement Lead assigned to the implementation of the Middle and Lower green River Temperature TMDL who will assist the stormwater permit holders and other environmental agencies and groups. Ecology's Environmental Assessment Program may assist in effectiveness monitoring as the TMDL is implemented.

Ecology also helps local governments with funding for water quality facilities and activities through the Centennial Clean Water Fund, 319 Fund and State Revolving Loan Fund. The full range of Ecology funding opportunities is discussed under the section "Funding Opportunities." Ecology's Grant Specialists assist local government in the development of stream restoration and water quality improvement projects.

Ecology will be responsible for organizing meetings of the stakeholders' workgroup no less than annually and will lead additional meetings as requested by the workgroup.

Ecology is authorized under Chapter 90.48 RCW to impose strict requirements or issue enforcement actions to achieve compliance with state water quality standards.

Washington State Department of Transportation

The Washington State Department of Transportation (WSDOT) implements their NPDES Municipal Stormwater Permit and Stormwater Management Program Plan (SWMPP) in all applicable Phase I and Phase II coverage areas. Implementation of the permit includes, but is not limited to, the following:

- discharge inventory and mapping.
- Illicit Discharge Detection and Elimination (IDDE).
- stormwater design per the WSDOT Highway Runoff Manual (stormwater BMP design manual equivalent to Ecology's Stormwater Management Manual).
- water quality monitoring (at selected sites statewide per the Permit requirements).
- stormwater BMP retrofit program.
- highway maintenance program.

Between 1995and 2009, WSDOT was regulated under Ecology's Phase I NPDES Municipal Stormwater permits. WSDOT's current permit was issued in February 2009 and modified in May 2010. WSDOT's Stormwater Management Program Plan (SWMPP) was updated in 2009.

WSDOT actively participates in TMDL processes in cases where WSDOT is assigned a WLA or action items in a TMDL.

Muckleshoot Indian Tribe

The Muckleshoot Indian Tribe's Usual and Accustomed Area (U&A) was determined in the U.S. Supreme Court case, U.S. v. Washington, for fisheries resources that are culturally and economically important to the Tribe. The U&A area covers all or portions of several basins; the Green-Duwamish watershed is one of these basins. The Muckleshoot Indian Tribe Fisheries Division (MITFD) has an active resource protection staff and may assist in stream restoration and water quality improvement efforts. MITFD staff review permits for all of the jurisdictions in the TMDL area and will continue to monitor these permits and restoration projects to evaluate whether the TMDL is implemented and not adversely affected by future land actions.

Puget Sound Partnership

In 2007, the Washington State Legislature established the Puget Sound Partnership (Partnership) to lead the recovery of Puget Sound to health by 2020. The Partnership replaced the Puget Sound Action Team in coordinating regional efforts to restore and protect the biological health and diversity of Puget Sound by protecting and enhancing Puget Sound's water and sediment quality, its fish and shellfish, and its wetlands and other habitats.

In December, 2008, the Partnership produced the 2020 Action Agenda that establishes science-based goals to achieve recovery and protection. The 2020 Action Agenda addresses habitat protection; toxic contamination; pathogen and nutrient pollution; stormwater runoff; water supply; ecosystem biodiversity; species recovery; and capacity for action.

The Partnership is working with tribal and local governments, community groups, citizens and businesses, and state and federal agencies to develop and carry out the Action Agenda. Seven geographic action areas were established around the Sound to address and tackle problems specific to those areas.

Local government resources

Implementation of this TMDL will depends upon the support and participation of King **County**, and the cities of **Auburn**, **Tukwila**, **Kent** and **Renton**.

WRIA 9 Watershed Ecosystem Forum

The WRIA 9 Watershed Ecosystem Forum is comprised of representatives of 17 local governments, as well as businesses, community groups, and state and federal agencies that have worked together since 2000 to protect and restore salmon habitat. The predecessor of this group, the WRIA 9 Steering Committee, came together to develop the WRIA 9 Salmon Habitat Plan, which was ratified by all 27 member jurisdictions in 2005 and approved by NOAA Fisheries as part of the Puget Sound Chinook Conservation Plan in 2007.

This is an important organization within the watershed, serving the greater community as a forum of local governments, facilitator and point of communication. This organization is working within the jurisdictional area represented by its members and with other similar WRIA organizations to establish funding mechanisms that will support the organization and the funding of watershed salmon recovery projects.

King Conservation District

The King Conservation District (KCD) is a non-regulatory municipal public agency created under Chapter 89 RCW that administers programs to conserve the natural resources of King County.

Tacoma Public Utilities

Nonprofit and volunteer organizations

Adopt-A-Stream Foundation

The Adopt-A-Stream Foundation (AASF) is a non-profit organization based in south Everett, Washington. Created in 1981, AASF's mission is to increase public awareness of the importance of creeks, streams and rivers and fish and to restore to health to those waterways damaged by people or nature.

AASF carries out its mission by producing and distributing environmental education materials nationally and internationally, conducting S*treamkeeper Academy*™ events for school and community groups throughout the Pacific Northwest, and providing local communities with stream and wetland restoration assistance. In addition, AASF is developing the Northwest Stream Center, a regional environmental learning facility that has stream and wetland ecology and fish and wildlife habitat as its central themes. AASF's long-term goal is to stimulate everyone to become a *Streamkeeper*™, taking actions necessary to protect and enhance their home watersheds.

Stewardship Partners

Stewardship Partners helps private landowners restore and preserve the natural landscapes of Washington State. They promote and implement incentive-based programs that encourage landowners to participate in fish and wildlife conservation and restoration activities while simultaneously meeting their economic needs through sustainable land management.

Washington Water Trust

Washington Water Trust (WWT) is a private, nonprofit organization established in 1998 to restore instream flows in Washington's rivers and streams. WWT works to benefit water quality, fisheries and recreation in Washington's rivers and streams by acquiring existing water rights from willing sellers through purchase, lease or gift.

Local Businesses

Local businesses are responsible for taking actions to prevent pollution their activities may generate. Local businesses in turn can be partners in increasing public awareness on the local water quality issues in the Green River Watershed.

Local Citizens

Local citizens play a critical role in improving the water quality of the Green River.

Schedule for achieving water quality standards

Because effective shade does not cool a stream as much as it blocks solar loading and prevents it from heating, achieving state temperature standards in the Green River will be a multi-decade effort. As riparian buffer is planted there may be little measurable change noted until trees grow tall enough to provide significant shade. It is estimated that project planning, developing a new or mitigating existing levee maintenance policy, setting back levees where appropriate, purchasing available property and moving existing infrastructure to accommodate riparian plantings will be a decade long process. Implementation of the riparian improvements required to achieve compliance with temperature standards will be completed within an estimated ten years of EPA approval of this TMDL. Once planted, trees may take 30 to 50 years before they reach full mature heights and provide the shade necessary to meet the model's predictions.

Measuring Progress toward Goals

Monitoring progress

A monitoring program for evaluating progress is an important component of any implementation plan. Monitoring is needed to keep track of what activities have or have not been done, measure the success or failure of target actions, and evaluate improvements in water quality. Monitoring should also be done after water quality standards are achieved (compliance monitoring) to ensure that standards continue to be met. A monitoring plan will be developed to be included with the *water quality implementation plan*.

Adaptive management

Adaptive management involves testing, monitoring, evaluating applied strategies, and incorporating new knowledge into management approaches that are based on scientific findings. Natural systems are complex and dynamic. The way a system will respond to human management activities is often unknown and can only be described as probabilities or possibilities. In the case of TMDLs, Ecology uses adaptive management to assess whether the actions identified as necessary to solve the identified pollution problems are the correct ones and whether they are working. Successful implementation of this TMDL will require not only ongoing scientific investigation but the negotiation of state and federal policies, a high level of financial investment, and the cooperation of the many government agencies, Native American tribes, municipalities, non-profit foundations, and citizens that have interests in the Green River watershed. As a water quality implementation plan is developed in the future, an adaptive management process will be included in the plan that addresses scientific, financial and social issues.

Summary of public involvement methods

Refer to Appendix F for a complete listing of public involvement activities.

Conclusions

Portions of the Green River and its tributaries have water quality impairments for temperature. The Green River supports several salmon species, including Puget Sound Chinook, bull trout, Coho, chum, pink, sockeye, steelhead/rainbow, and cutthroat trout.

TMDL studies and modeling conducted in 2006 show that the river is not meeting water quality standards for temperature at all times. The critical time of year, combining annual minimum flow and annual maximum temperature in the Middle and Lower Green River, typically occurs in late summer. Under current conditions, the maximum predicted temperatures during the critical period can occasionally exceed the 22^{O} C (71.6°F) 7DADMax lethal temperature for salmon. Temperatures can regularly exceed the 16°C (60.8°F) criterion for “Core Summer Salmonid Habitat” and the 17.5°C (63.6°F) criterion for “Salmonid Spawning, Rearing and Migration.”

Establishing and improving mature riparian vegetation for shade along the middle and lower Green River and on the tributaries to the river is expected to improve stream temperatures and increase the stream's oxygen-carrying capacity. Modeling showed the lower reaches of the Green River, below the city of Auburn, need from 33 % to 53% increase in effective shade. Some restoration projects are already underway or in planning within the basin to help reduce the shade deficit. More projects are needed.

Along the Lower Green River human development, including levees for flood control, residences, industry, roads, agricultural, and other commercial uses near and bordering on the river's banks make it difficult and expensive to create and restore a riparian corridor that will keep the river cool and create fish habitat. Moreover, modeling scenarios show that under current Corps of Engineers levee maintenance policies that restrict riparian planting and vegetation, the river cannot meet state temperature standards.

Once levee maintenance policies are changed or levee set-backs are accomplished to allow planting on or inside levees, and developed properties are moved or adapted to accommodate shade producing vegetation, it will take approximately 45 years of growing time for trees to create the system potential shade needed to meet requirements predicted by the model. Long-term progress toward meeting goals will be measured by re-evaluating buffer conditions and additional modeling to determine stream length exceeding standards approximately every ten years. If the modeled length of stream channel and the condition of the riparian corridor falls behind the implementation schedule, the rate and type of restoration projects should be altered in accordance with the adaptive management strategy that will be developed as part of the future water quality implementation plan.

Funding for TMDL implementation projects is available through EPA; Ecology's Centennial Clean Water Fund, Coastal Protection Fund, and other sources; King County's Grant Exchange Programs; King Conservation District Programs; the state Salmon Recovery Funding Board; and various other funding sources. Several organizations are available to organize and manage projects when funding is available.

"The best time to plant a tree was 20 years ago – the next best time is right now."

Anon.

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Appendices

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Appendix A. Glossary, Acronyms, and Abbreviations

Best management practices (BMPs): Physical, structural, or operational practices that, when used singularly or in combination, prevent or reduce pollutant discharges.

Char: Char (genus *Salvelinus*) are distinguished from trout and salmon by the absence of teeth in the roof of the mouth, presence of light colored spots on a dark background, absence of spots on the dorsal fin, small scales, and differences in the structure of their skeleton. (Trout and salmon have dark spots on a lighter background.)

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Critical condition: When the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or designated water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 (see definition) flow event unless determined otherwise by the department.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the state of Washington) for each water body or segment, regardless of whether or not the uses are currently attained.

Diel: Of, or pertaining to, a 24-hour period.

Diurnal: Of, or pertaining to, a day or each day; daily. (1) Occurring during the daytime only, as different from nocturnal or crepuscular, or (2) Daily; related to actions which are completed in the course of a calendar day, and which typically recur every calendar day (for example, diurnal temperature rises during the day and falls during the night.)

Effective shade: The fraction of incoming solar shortwave radiation that is blocked from reaching the surface of a stream or other defined area.

Existing uses: Those uses actually attained in fresh and marine waters on or after November 28, 1975, whether or not they are designated uses. Introduced species that are not native to Washington, and put-and-take fisheries comprised of non-self-replicating introduced native species, do not need to receive full support as an existing use.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform bacteria are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100mL).

Hyporheic: The area under and along the river channel where surface water and ground water meet.

Load allocation: The portion of a receiving water's loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading capacity: The greatest amount of a substance that a water body can receive and still meet water quality standards.

Margin of safety: Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving water body.

Municipal separate storm sewer systems (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains): (1) owned or operated by a state, city, town, borough, county, parish, district, association, or other public body having jurisdiction over disposal of wastes, stormwater, or other wastes and (2) designed or used for collecting or conveying stormwater; (3) which is not a combined sewer; and (4) which is not part of a Publicly Owned Treatment Works (POTW) as defined in the Code of Federal Regulations at 40 CFR 122.2.

National Pollutant Discharge Elimination System (NPDES): National program for issuing and revising permits, as well as imposing and enforcing pretreatment requirements, under the Clean Water Act. The NPDES permit program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to, atmospheric deposition; surface water runoff from agricultural lands; urban areas; or forest lands; subsurface or underground sources; or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System Program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Phase I stormwater permit: The first phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to medium and large municipal separate storm sewer systems (MS4s) and construction sites of five or more acres.

Phase II stormwater permit: The second phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to smaller municipal separate storm sewer systems (MS4s) and construction sites over one acre.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than five acres of land.

Pollution: Such contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Riparian: Relating to the banks along a natural course of water.

Salmonid: Any fish that belong to the family *Salmonidae*. Basically, any species of salmon, trout, or char. www.fws.gov/le/ImpExp/FactSheetSalmonids.htm

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and watercourses within the jurisdiction of Washington State.

Surrogate measures: To provide more meaningful and measurable pollutant loading targets, EPA regulations [40 CFR 130.2(i)] allow other appropriate measures, or surrogate measures in a TMDL. The Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program (EPA, 1998) includes the following guidance on the use of surrogate measures for TMDL development:

> *When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional "pollutant," the state should try to identify another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not.*

System potential: The design condition used for TMDL analysis.

System potential channel morphology: The more stable configuration that would occur with less human disturbance.

System potential mature riparian vegetation: Vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

System potential riparian microclimate: The best estimate of air temperature reductions that are expected under mature riparian vegetation. System potential riparian microclimate can also include expected changes to wind speed and relative humidity.

System potential temperature: An approximation of the temperatures that would occur under natural conditions. System potential is our best understanding of natural conditions that can be supported by available analytical methods. The simulation of the system potential condition uses best estimates of *mature riparian vegetation, system potential channel morphology, and system potential riparian microclimate* that would occur absent any human alteration.

Total maximum daily load (TMDL): A distribution of a substance in a water body designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Wasteload allocation: The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality-based effluent limitation.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) List: Section 303(d) of the federal Clean Water Act requires Washington State periodically to prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited water bodies (ocean waters, estuaries, lakes, and streams) that fall short of state surface water quality standards, and are not expected to improve within the next two years.

1-DMax or 1-day maximum temperature: The highest water temperature reached on any given day. This measure can be obtained using calibrated maximum and minimum thermometers or continuous monitoring probes having sampling intervals of 30 minutes or less.

7-DADMax or 7-day average of the daily maximum temperatures: The arithmetic average of seven consecutive measures of daily maximum temperatures. The 7-DADMax for any individual day is calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the three days prior and the three days after that date.

7Q2 flow: A typical low-flow condition. The 7Q2 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every other year on average. The 7Q2 flow is commonly used to represent the average low-flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q2 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every 10 years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report.

BMPs	Best Management Practices
cfs	Cubic feet per second
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
NAF	New Approximation Flow
NPDES	National Pollution Discharge Elimination System
NSDZ	Near-stream disturbance zones
RM	River mile
TIR	Thermal infrared radiation
TMDL	Total maximum daily load (water cleanup plan)
USFS	United States Forest Service
USGS	United States Geological Survey
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resources Inventory Area
WWTP	Wastewater treatment plant

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Appendix B. Supplemental temperature standards

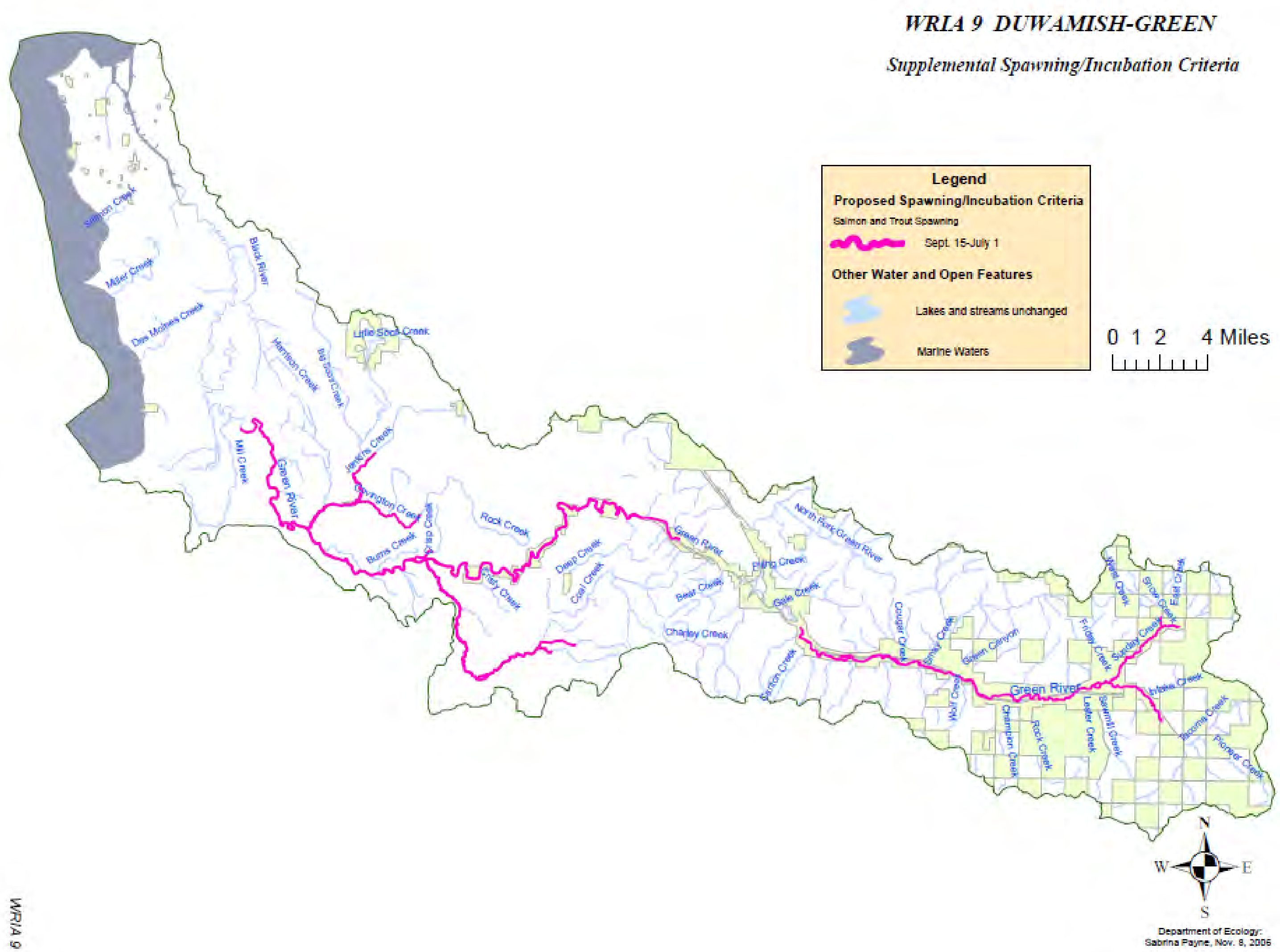

Figure B- 1. Map of where the supplemental spawning and incubation criteria applies in WRIA 9 Green-Duwamish Watershed.

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Appendix C. Global climate change

Changes in climate are expected to affect both water quantity and quality in the Pacific Northwest (Casola et al., 2005). Summer streamflows depend on the snowpack stored during the wet season. Studies of the region's hydrology indicate a declining tendency in snow water storage coupled with earlier spring snowmelt and earlier peak spring streamflows (Hamlet et al., 2005). Factors affecting these changes include climate influences at both annual and decadal scales, and air temperature increases. Increases in air temperatures result in more precipitation falling as rain rather than snow and earlier melting of the winter snowpack.

Ten climate change models were used to predict the average rate of climatic warming in the Pacific Northwest (Mote et al., 2005). The average warming rate is expected to be in the range of 0.1-0.6°C (0.2-1.0°F) per decade, with a best estimate of 0.3°C (0.5°F) (Mote et al., 2005). Eight of the ten models predicted proportionately higher summer temperatures, with three indicating summer temperature increases at least two times higher than winter increases. Summer streamflows are also predicted to decrease as a consequence of global climate change (Hamlet and Lettenmaier, 1999).

Recent studies have highlighted the likelihood of future changes in the timing, type, and amount of precipitation and increasing air temperature in the Pacific Northwest attributed in part to human-induced climate modifications (Casola *et al*., 2005; Barnett *et al*., 2008). Research has already identified significant increasing trends in air temperature (Mote *et al*., 2003a-b), decreasing spring mountain snow pack (Hamlet *et al*., 2005; Mote *et al*., 2005; Mote 2006), earlier timing of spring runoff in mid- (transient) to high (snowpack dominated) elevation basins (Casola *et al*., 2005; Stewart *et al*., 2005), and lower summer flows in transient basins like the Green River due to reduced snowpack and earlier timing of snow melt (Casola *et al*., 2005). Increased evapotranspiration resulting from higher temperatures may also contribute to further reductions in streamflow (Imhoff *et al*., 2007).

Effects on the frequency, amount, duration, and intensity of precipitation are still rather uncertain. Unlike temperature, which is projected to increase beyond historic year-to-year variability in the coming decades, forecasted shifts in precipitation in the near future are within historic variability which is driven by poorly understood decadal shifts in hydroclimate (Casola *et al*., 2005). Nonetheless, there is some evidence that total November precipitation in the Puget Sound basin has increased over the last century (Polebitski and Palmer, 2006: King County 2010). Other studies also point to greater frequency of extreme precipitation events in the Pacific Northwest (Diffenbaugh *et al*., 2005; Salathé, 2006).

There is also evidence that increasing air temperatures have already resulted in increasing temperatures of Pacific Northwest lakes (Arhonditsis *et al*., 2002; Winder and Schindler, 2004), rivers (Morrison *et al*., 2002; Casola *et al*., 2005), and streams (King County[2]). Water temperature increases in response to increasing air temperatures is consistent with the mechanistic understanding and modeling of water temperature dynamics (Stefan and Sinokrot, 1993).

[2] http://green.kingcounty.gov/WLR/Waterres/StreamsData/trends.aspx, accessed July 22, 2008.

The average future warming rate in the Pacific Northwest is expected to be in the range of 0.1 to 0.6 ^{o}C (0.2-1.0^{o}F) per decade, with the best estimate of 0.3 ^{o}C (0.5^{o}F) (Mote *et al*., 2005). Superimposed on the apparent secular upward trend in local air temperature are short and long term oscillations resulting from large scale shifts in ocean and atmospheric circulation patterns such as the Pacific Decadal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO).[3] Detailed analysis of historic data and climate impact modeling indicate that most of the warming in the latter part of the 20th century was human-induced (Hamlet *et al*., 2005; Barnett *et al*., 2008).

In an analysis of projected climate change impacts on the benefits of Chinook salmon habitat restoration in the Snohomish River basin, Battin *et al*. (2007) suggested that focus on low elevation habitats would be more successful than restoration of the transient reaches most susceptible to climate change impacts. Overall, there are a number of factors that ultimately determine summer water temperatures, but the key features that can potentially be managed include instream flows, riparian vegetation, floodplain and hyporheic zone dynamics, and channel morphology. A holistic approach founded on an understanding of the historical stream channel, riparian zone, and alluvial aquifer systems was recommended by Poole and Berman (2001) as the proper context for successful ecological restoration of stream ecosystems.

The expected changes coming to our region's climate highlight the importance of protecting and restoring the mechanisms that help keep stream temperatures cool. Stream temperature improvements obtained by growing mature riparian vegetation corridors along stream banks, reducing channel widths, and enhancing summer baseflows may all help offset the changes expected from global climate change – keeping conditions from getting worse. It will take considerable time, however, to reverse those human actions that contribute to excess stream warming. The sooner such restoration actions begin and the more complete they are, the more effective we will be in offsetting some of the detrimental effects on our stream resources.

These efforts may not cause streams to meet the numeric temperature criteria everywhere or in all years. However, they will maximize the extent and frequency of healthy temperature conditions, creating long-term and crucial benefits for fish and other aquatic species. As global climate change progresses, the thermal regime of the stream itself will change due to reduced summer streamflows and increased air temperatures.

The state is writing this TMDL to meet Washington State's water quality standards based on current and historic patterns of climate. Changes in stream temperature associated with global climate change may require further modifications to the human-source allocations at some time in the future. However, the best way to preserve our aquatic resources and to minimize future disturbance to human industry would be to begin now to protect as much of the thermal health of our streams as possible.

[3] Details of the PDO and ENSO may be found at http://www.jisao.washington.edu/pdo/ and http://www.elnino.noaa.gov/, respectively.

Appendix D. Site descriptions and monitoring locations

Table D-1. Site identification codes and descriptions. “x” indicates that monitoring occurred.

Station ID	River Mile	Description	Water temp	Air temp	RH	Hemi/ shade	Periphyton	Continuous DO/pH	Nutrients	Flow
Green River										
09-GRE-DAM	60.9	below Tacoma Water Headworks Diverson Dam	x		x	x	x	x	x	x
09-GRE-KAN	57.6	at Cumberland-Kanaskat Rd	x	x		x	x	x	x	x
09-GRE-GOR		at Green River Gorge Rd							x	
09-GRE-FLA	43.1	at Flaming Geyser Park, near end of SE Flaming Geyser Rd.	x			x			x	x
09-GRE-WHI	41.4	at 212th Way SE (Whitney Bridge)	x		x	x	x	x	x	x
09-GRE-GRE	35.0	at Green Valley Rd.	x		x	x	x	x	x	x
09-GRE-8TH		at 8th St. NE in Auburn	x	x		x			x	
09-GRE-277	27.9	off Green River Rd. under 277th St. bridge	x			x	x		x	x
09-GRE-167	24.0	upstream of Mill Ck. under HWY 167 bridge	x	x		x		x	x	x
09-GRE-OLD	21.5	at Meeker St. near the "Old Fishin' Hole"	x			x			x	x
09-GRE-212		at S 212th St.	x	x		x			x	
09-GRE-180	14.4	at SE 180th St. (SW 43rd St.)	x			x	x		x	x
09-GRE-FOR		under Interurban Ave. bridge near Fort Dent	x		x	x		x	x	
09-GRE-COM		under 42nd Ave. S bridge at Tukwila Community Center	x			x			x	
09-GRE-BOE		downstream of 102nd Ave. at Boeing foot bridge	x			x			x	
Green River Tributaries										
09-CRI-GRE	40.1*	Crisp Ck. at Green Valley Rd.	x			x			x	x
09-SOO-USG	33.8*	Soos Ck. at USGS gaging station upstream of hatchery	x			x	x	x	x	x
09-MIL-WAS	23.9*	Mill Ck. at Washington Ave.	x			x	x	x	x	x
09-FRA-FRA	21.7*	Mullen Slough at Frager Rd.	x			x			x	x
Newaukum Creek (King County stations)										
X322	40.7*	Newaukum Ck. near the mouth off of 358th SE	x				x	x	x	x
E322		Newaukum Ck. at SE 400 St. bridge	x				x	x	x	
AC322		Trib. upstream of confluence with Newaukum Ck.at 236th St. SE	x				?	x	x	
AN322		Newaukum Ck. just upstream of confluence with trib. at 236th St.	x				x	x	x	
G322		Newaukum Ck at bridge on SE 424th St.	x				x	x	x	
R322		Newaukum Ck. off 416th St., down pipeline trail	x				x	x	x	
N322		Newaukum Ck. at Veazie Cumberland Rd. crossing	x	x			x	x	x	
Q322		Newaukum trib. off Veazie Cumberland Rd., ditch north of TPU trail	x				?	x	x	

* Green River river-mile where creek enters

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Appendix E. Additional data sources for the Green River TMDL Study

A variety of data are needed to develop and test water quality models. The primary source of water quality, stream flow, and meteorological data for establishing model inputs and model testing was a TMDL study conducted during summer low-flow conditions in 2006. The Sampling Plan for this study was developed as a cooperative effort between Ecology and King County (Roberts and Jack, 2006). The data collected as part of this effort are summarized by Swanson *et al.* (2007).

Additional data used in the development of these models included meteorological data obtained from Ecology for Renton Municipal Airport, Boeing Field, Enumclaw, and the Washington State University station in Puyallup, WA. King County also obtained 2006 meteorological data for Sea-Tac International Airport and solar radiation data from the Seattle campus of the University of Washington and a station at the National Oceanic and Atmospheric Administration (NOAA) facility along the shore of Lake Washington in Seattle. The locations of these stations with respect to the mainstem Green River models are shown in Figure E-1. The types of data available from these stations are summarized in Table E- 1.

Table E- 1. Summary of available meteorological data.

Station	frequency	Air temperature	Dew point	Relative Humidity	Wind speed	Cloud cover	Solar Radiation
08-GRE-167	30-min	x					
09-GRE-212	30-min	x					
09-GRE-8TH	30-min	x					
09-GRE-DAM	30-min	x	x				
09-GRE-FOR	30-min	x	x				
09-GRE-GRE	30-min	x	x				
09-GRE-KAN	30-min	x					
09-GRE-WHI	30-min	x	x				
Boeing Field	hourly	x	x		x	x	
Enumclaw	hourly	x		x	x		x
NOAA - Sandpoint	hourly						x
WSU Puyallup	15-min	x	x	x	x		x
Renton Municipal Airport	hourly	x					
Sea-Tac Int. Airport	hourly	x	x		x	x	
UW Seattle	1-min	x	x		x	x	x

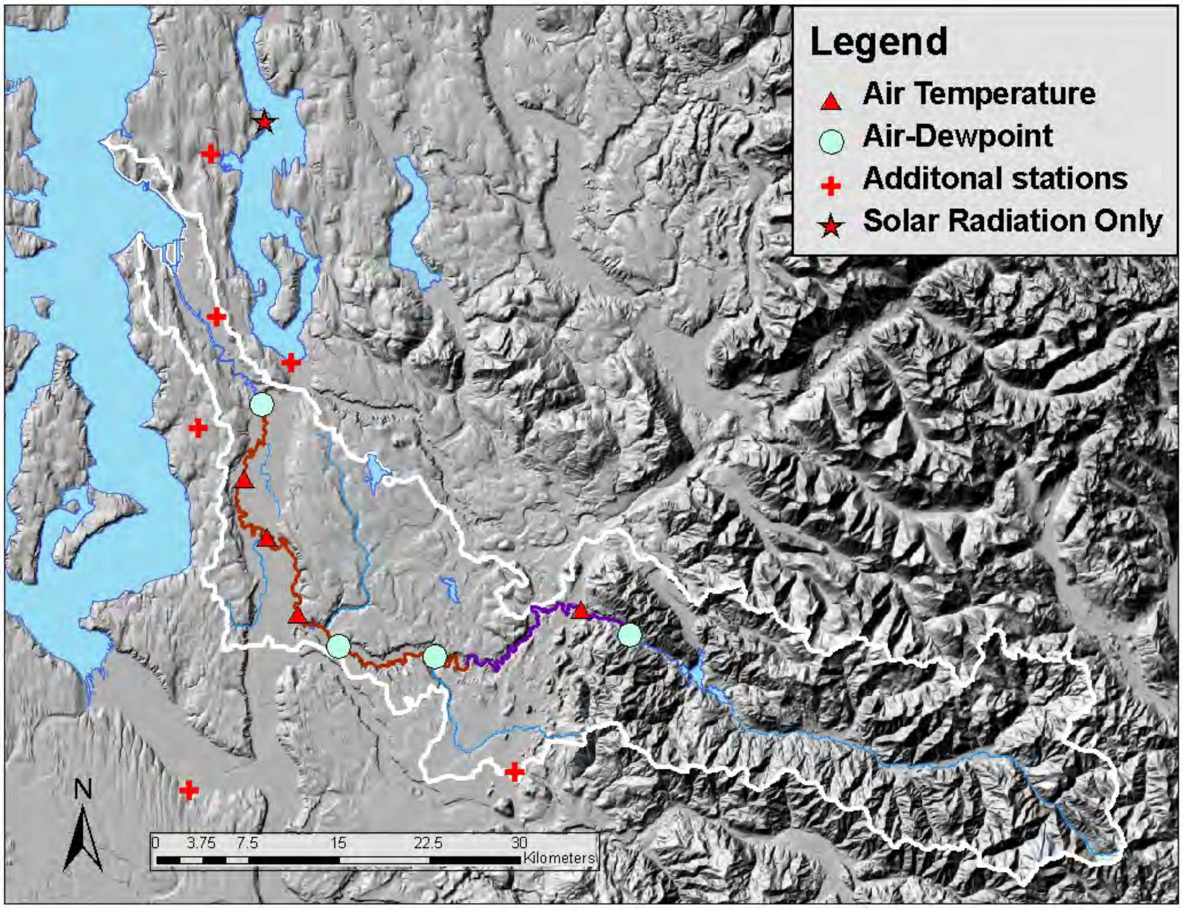

Figure E-1. Meteorological data source locations. Lower-Middle Green River model reach shown in red and upper Middle Green River model reach shown in Purple.

Required QUAL2Kw model input data include hourly air temperature, dew point, wind speed, and cloud cover. The model calculates incoming solar radiation as a function of cloud cover and coefficients related to attenuation of solar radiation through the atmosphere. The model was modified for this project to allow input of observed solar radiation. When using observed solar radiation, cloud cover input was still used in the incoming longwave radiation model algorithm to account for enhanced longwave radiation from cloud moisture.

Additional stream flow data were obtained from 1 King County and 5 United States Geological Survey (USGS) gauging stations. Crisp Creek flow was measured by King County (based on continuous stage recording) and Ecology (direct measurement) and Green River flow below the Tacoma Diversion near Palmer was measured by USGS (based on continuous stage recording) and Ecology (direct measurement). The USGS was the source of inflow data for the major tributaries to the Green River – Soos Creek and Newaukum Creek. The flow measurements made by the USGS at Auburn below Soos Creek provided additional data for model testing. In addition to flow estimates, Ecology also provided estimates of average water depth and velocity for model testing.

USGS data available for same parameters at TPU and Auburn. All flow monitoring locations are shown in Figure E-2.

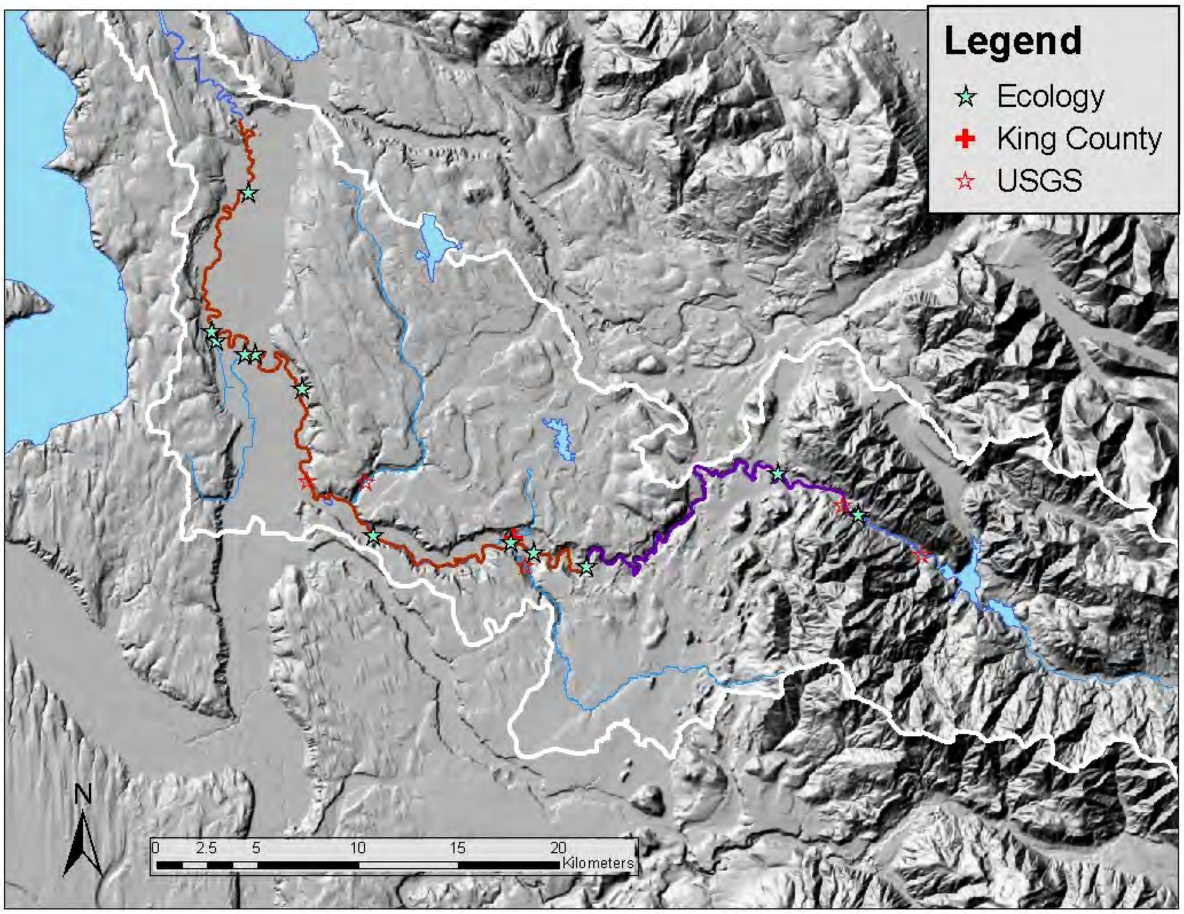

Figure E-2. Flow monitoring locations. Lower-Middle Green River model reach shown in red and upper Middle Green River model reach shown in Purple.

Ecology collected continuous temperature data at 14 mainstem locations and 5 tributaries (Newaukum, Crisp, Soos, Mill, and Mullen). Additional continuous temperature data were obtained from 9 King County gages. Seven of the King County stations were somewhat redundant and provided an independent comparison to the Ecology monitoring data. Of the 2 remaining stations, GRT14 above Icy Creek in the Upper Green River model reach provided additional data for model testing. All temperature monitoring locations are shown in Figure E-3.

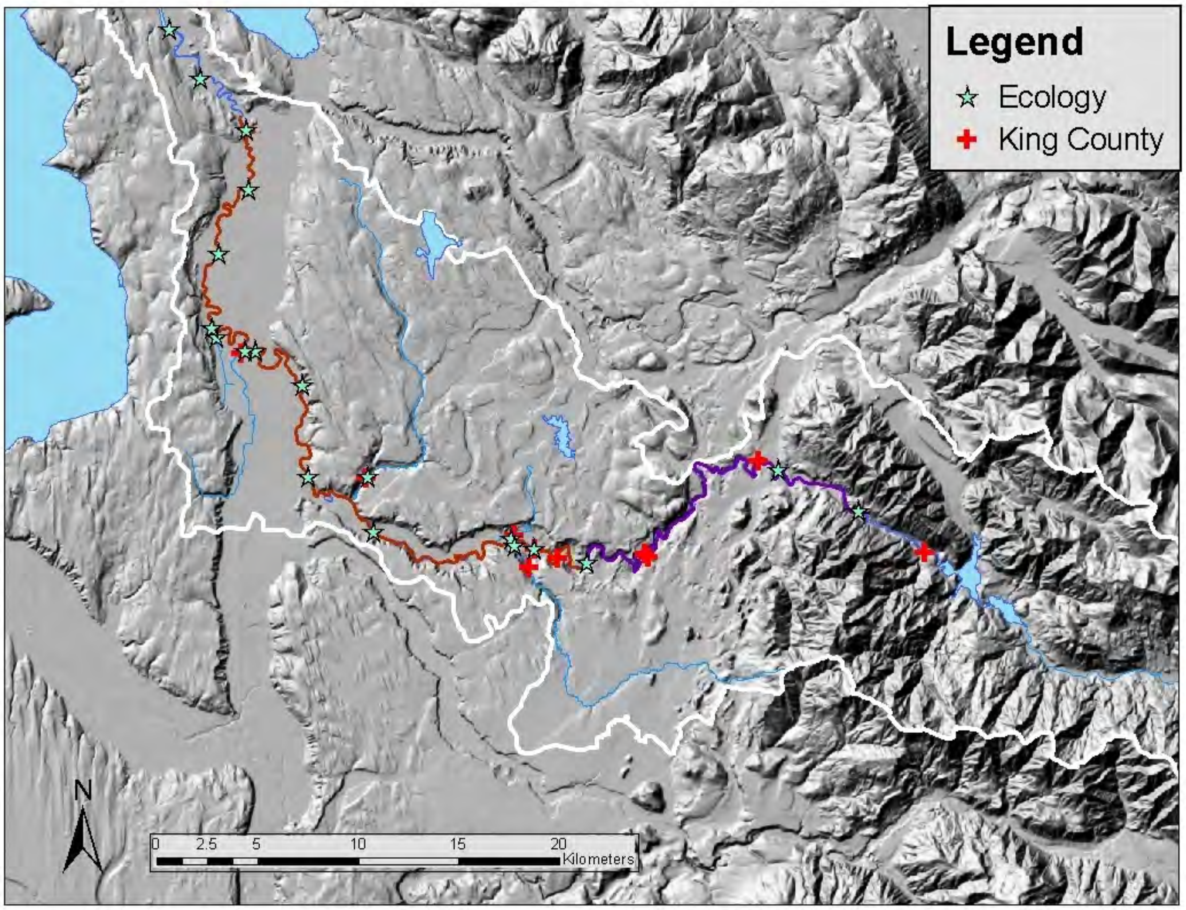

Figure E-3. Temperature monitoring locations. Lower-Middle Green River model reach shown in red and upper Middle Green River model reach shown in Purple.

Ecology collected continuous measurements of dissolved oxygen (DO), pH, specific conductance (SC), and temperature at 9 locations during the Green River TMDL study using multi-parameter data logging sondes. Three of these locations were sited to represent the inflow from Newaukum, Soos, and Mill Creeks. Continuous DO, pH, SC, and temperature measurement locations are shown in Figure E-4.

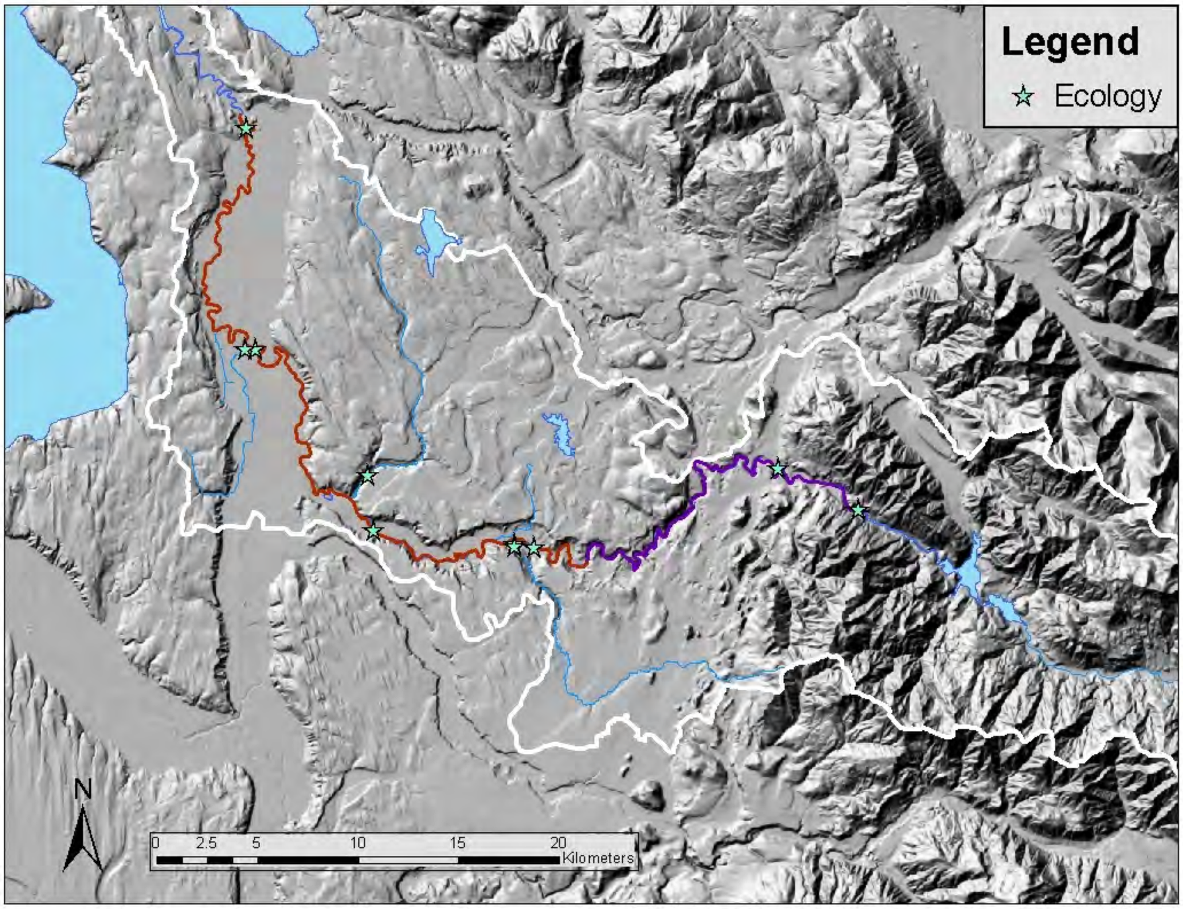

Figure E-4. Continuous multiparamter sonde monitoring locations. Lower-Middle Green River model reach shown in red and upper Middle Green River model reach shown in Purple.

Water quality grab sampling in support of the TMDL model development effort was conducted by Ecology on August 1 and 2 of 2006. A total of 15 mainstem locations and 5 tributary inflows were sampled (Newaukum, Crisp, Soos, Mill, and Mullen). Sampling locations are shown in Figure E-5.

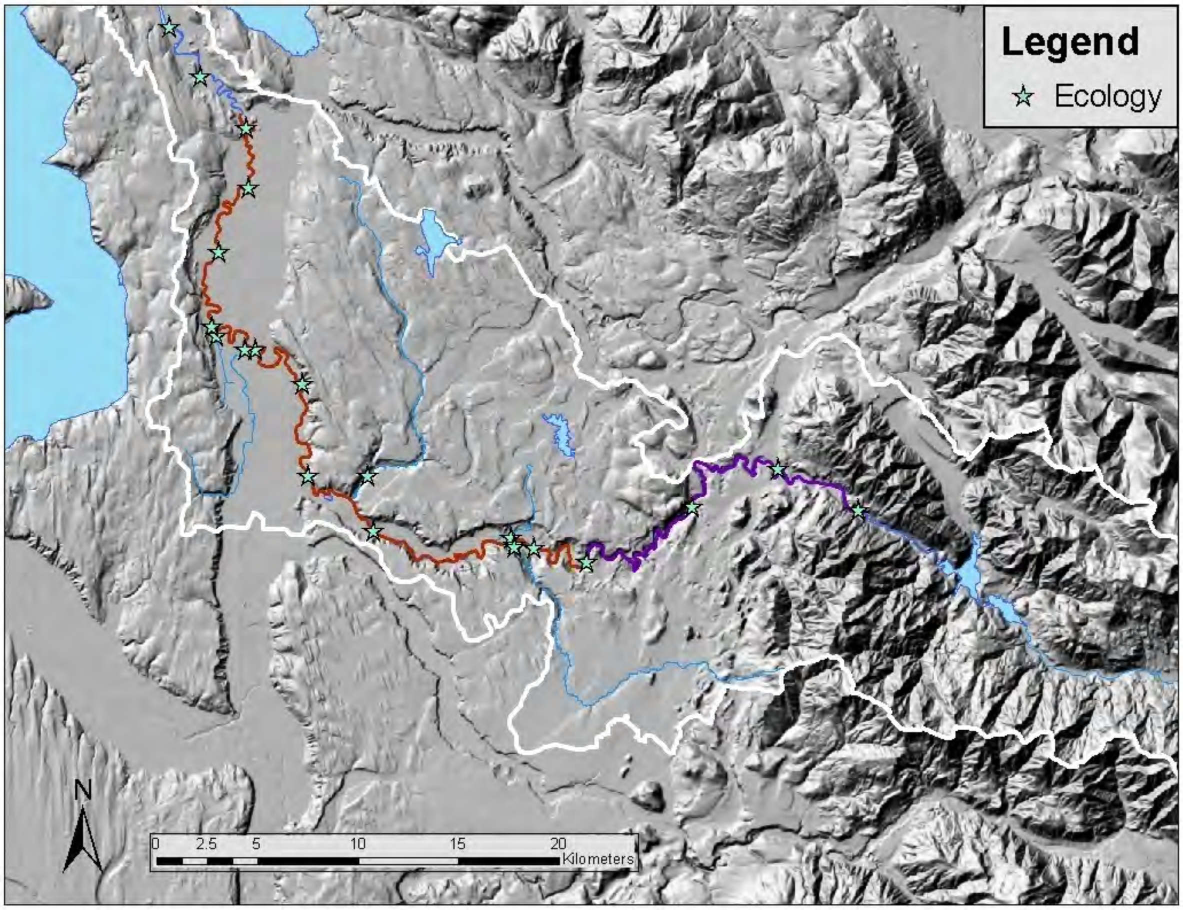

Figure E-5. Water quality grab sampling locations. Lower-Middle Green River model reach shown in red and upper Middle Green River model reach shown in Purple.

Ecology collected digital hemispherical photos of Green River mainstem canopy cover at 14 locations. However, photos from the center of the channel were only possible at 9 locations. King County also collected 16 hemispherical photos on September 28, 2006 between Flaming Geyser State Park and a point approximately 6 kilometers upstream of the confluence with Soos Creek. These photos were taken from near the center of the channel using an oared raft. Hemispherical photo locations are shown in Figure E-6. Periphyton was measured by Ecology at 6 mainstem locations. These locations are shown in Figure E-7.

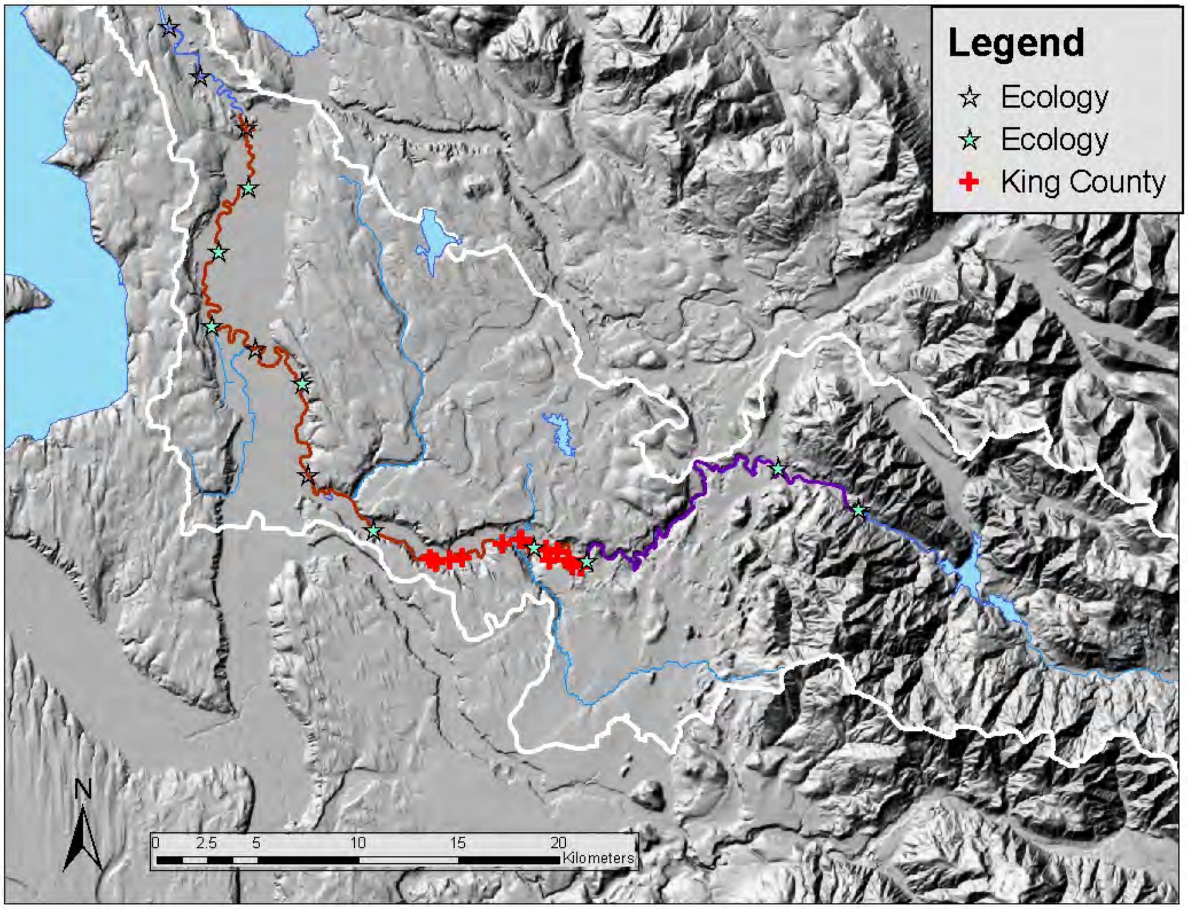

Figure E-6. Hemispherical photography locations. Colored Ecology symbols indicate where photos were taken from the center of the channel. Lower-Middle Green River model reach shown in red and upper Middle Green River model reach shown in Purple.

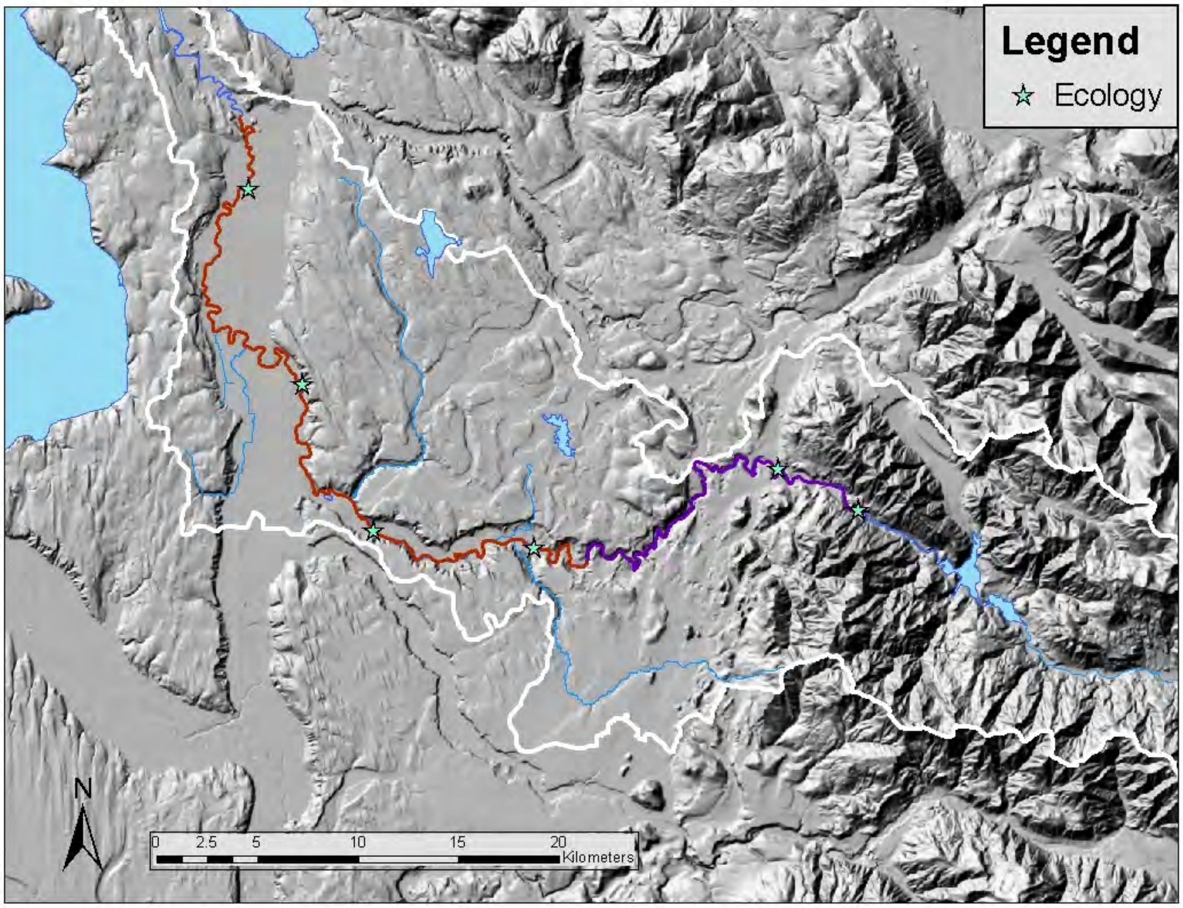

Figure E-7. Periphyton sampling locations. Lower-Middle Green River model reach shown in red and upper Middle Green River model reach shown in Purple.

Geographic information system (GIS) data available from King County were also used to develop river bathymetry and shade inputs (riparian and topographic) for the models. GIS data sources included high resolution (6-ft) LiDAR (Light Detection and Ranging) derived digital ground model (DGM) and digital surface model (DSM), 30-ft resolution DGM, and recent high resolution (on order of 1-ft) orthophotos (2002, USGS; 2005 – Aerials Express; 2006 – National Agricultural Imagery Program) of the study basin. King County also provided high resolution mosaic of 2006 orthophotos of the Lower and Middle Green River that were collected as part of the flood study mentioned above.

The model bathymetry for an ongoing flood inundation study of the Green River below the gorge (NHC, 2007) was also used to derive bathymetry inputs for the model reach that extends from Tukwila to Flaming Geyser State Park.

Appendix F. Record of public participation

Ecology engaged the public in several ways in the TMDL process to address temperature problems in the Green River watershed. Beginning in spring 2006, Ecology staff met with key stakeholders in the basin including King County, Muckleshoot Indian Tribe, King Conservation District and others.

Ecology met with key governmental and community partners on July 31st , 2008 to share status on the temperature and dissolved oxygen TMDL studies for the Green River and Newaukum Creek. Participants included representatives from the cities of Kent, Enumclaw, Covington and Auburn; USEPA; Corps of Engineers; WA Dept of Agriculture; Muckleshoot Indian Tribe and King County.

The WRIA 9 Ecosystem Form was brief on the continued development and the proposed completion date of June 30, 2011 for TMDL at their quarterly meetings in the fall of 2010 and spring of 2011.

The public comment period for the Draft TMDL ran from May 25 to June 23, 2011 and gave the public, including key stakeholders, a chance to review and provide feedback on the proposed final draft report. A public meeting was hosted by Ecology on the Green river Temperature Total Maximum Daily Load at Auburn City Hall from 6:30pm to 9:00pm on June 14, 2011. In advance of the public meeting, the following outreach steps were taken to involve public.

A newspaper display ad notifying public of a combined meeting on the Green River and Newaukum Creek temperature TMDLs was published in five local papers down the Newaukum Creek and Green River watersheds. The ad appeared on Friday, May 20; Wednesday, May 25; and Friday, June 10.

The display ad was shown a total of nine times in local newspapers throughout the subject watersheds;

- Friday May 20: display ad placements in each of four newspapers in middle and lower Green River watershed: Auburn Reporter (circulation: 24,738), Kent Reporter (circulation: 27,650), Maple Valley & Covington Reporter (circulation: 24,184), and the Renton Reporter (circulation: 30,035).
- Wednesday May 25: display ad ran in the Enumclaw Courier-Herald newspaper (circulation: 13,116).
- Friday June 10: additional display ad placements in the four newspapers in Auburn, Kent, Maple Valley/Covington, and Renton.

In addition, on May 25, 2011, the Draft Green River Temperature Total Maximum Daily Load report was delivered in-person on May 25, 2011 to the Muckleshoot tribal offices and libraries at:

- Enumclaw
- Covington

Dept. of Ecology Public Meeting & Comment Period -- Stream Temperature

Green River & Newaukum Creek Temperature Reduction Action Plans

The State Department of Ecology would like your comments on two draft documents that include technical information and plans to address high-temperature problems in the Green River and in Newaukum Creek.

These reports outline actions that are already underway--or are still needed--to lower temperatures in these waters. The goal is to lower temperature levels in these streams and meet the State's Water Quality Standards. We want your comments on these reports and welcome you to share your thoughts with us and your neighbors.

A public meeting will be held June 14 at Auburn City Hall,

25 W Main Street, Auburn WA 98001-4998

Open house, presentations, & discussion begin at 6:30 pm

- A 30 day comment period will run from May 25th through June 23rd 2011.
- For a *Report* copy after May 24, call local library reference, or 425-649-7110.
- To submit written comments (must be received by June 23), go to:

http://www.ecy.wa.gov/programs/wq/tmdl/GreenRvrTMDLsummary.html

Or, contact the Ecology Department office: c/o Chris Coffin, Dept. of Ecology, 3190 160th Ave SE, Bellevue WA 98008-5452; email: ccof461@ecy.wa.gov

If you have special accommodation needs or require this publication in an alternate format please contact: DouGlas Palenshus at (425) 649-7041 (Voice) or (425) 1-800-833-6388 (TTY).

- Auburn
- Kent
- Foster (Tukwila)

Other notifications:

- As relevant WQ documents were developed, links were established and appeared on Ecology's updated Green and Newaukum web pages.
- The public comment period and public meeting appeared on Ecology's public events calendar available by the internet.
- Information about the TMDLs was distributed by Ecology stormwater specialists to stormwater staff at nine local government offices on May 26, 2011.

During the week of May 30, 2011, Ecology's Communication Manager sent a news release to several local-area newspapers. On May 27, 2011, a message from Chris Coffin, with an attached copy of the newspaper display ad, and the enclosed four page paper "Focus on Green River Watershed" (following) was sent to approximately 150 addresses composed of individuals and organizations that had participated in some fashion or expressed interest in Ecology's activities regarding these projects.

A focus sheet (4 pages) on temperature problems in Green River and Newaukum Creek watersheds was prepared, put on the website and distributed at the public meeting on June 14, 2011.

Streamside vegetation is the key!

Trees and shrubs create important shade. Their removal increases the amount of sun that can hit and warm water, and reduces cool microclimate zones near streams and rivers. In considering the many decisions we make in choosing our watershed land management activities, the absence of such plants is the *major* factor that increases stream temperatures. *Tree removal reduces the amount of shade on the water and allows more sun to heat the stream.*

Erosion: Another problem related to tree removal is the erosion arising from poorly-managed forest lands, agricultural areas, or construction sites that results in bank deterioration and landslides. These events can cause heavy sediment loads and flooding as they make streams shallower and wider. All this allows more sun on the water, reduces available high quality salmon spawning habitat, and affects how well colder groundwater interacts with surface waters to cool streams.

Tributary to Newaukum Creek

Water withdrawals: There are other human caused factors that increase stream temperatures too. Less water means warmer water. Water withdrawals for various purposes, including irrigation, reduce the amount of cool water stored in the ground to feed the local creeks during the summer when flows are already critically low. Reduced flows make streams slower and shallower, allowing them to become warmer during the dry summer months.

Impervious surfaces and wetland destruction: Areas of impervious surface such as pavement and wetland destruction, allow more runoff water to heat up and flow directly to waterways. (Remember the *hot tin roof* effect, and going barefoot over hot blacktop in the summertime?). And as wetlands disappear, the sponge effect that helps store precipitation and that contributes cool water in summer seasons is lost. This can also worsen seasonal floods.

Green River issues

The middle and lower sections of the river need more shade. Currently, the system of levees, low water flow, warm weather, and summer water temperatures create impacts that can become lethal for salmonids. Portions of the river below Howard Hanson Dam and upstream from Auburn need improvement, but below Auburn conditions worsen. Levees, roads, and development too near the banks of the river create serious problems. These areas fail to provide cooling vegetation and shade to block heat from the sun, have lost the capacity to provide habitat functions, and generally inhibit good water quality. Shade will help.

The Green was one of the most productive salmon rivers in the state, but at least one major salmon run has gone extinct and others are suffering.

Newaukum Creek issues

Newaukum Creek is one of the major tributaries of the Green River and supports several salmon and trout (salmonid) species including Puget Sound Chinook. The creek is too warm during summer and may be harming these fish that need cold water to survive.

Maximum summer temperatures exceed the 16°Celsius (60.8°F) standard for salmon summer habitat. Ecology expects that plantings of streamside trees and shrubs for shade will improve stream temperatures. The middle *plateau reach* of Newaukum Creek or the Enumclaw Plateau needs the most shade.

Understanding and correcting problems

When a stream appears to be too warm, Ecology collects water quality data to confirm the problem and collaborates with others to understand and improve water quality. Ecology and its community partners used detailed monitoring data and analysis to develop computer models for the Green River and its tributaries. These models help us all understand how factors such as streamside vegetation, sunlight, wind speed, and stream flow relate to stream temperature.

Modeling results were used to help develop effective solutions that the local community can act on to lower stream temperatures during critical periods. These steps will improve water quality and help prevent loss of threatened and endangered fish species and other sensitive organisms.

What can we *all* do to reduce stream temperatures?

Citizens and organizations, including local governments, can act now to help protect and restore water quality in the Green River Watershed by taking at least one of the following actions to help reduce water temperatures in streams.

- **Protect and restore streamside vegetation:** Get involved in restoration projects to improve streamside (riparian) areas where streams have been straightened and channelized and trees have been removed. Trees shade the water, create cool microclimates, and increase stream bank stability. Restoration projects help prevent stream shallowing from sedimentation and widening from erosion, and can help re-establish connections with the natural floodplain and with cool groundwater resources. Woody debris, native plant material, and insects that fall into water can also provide food and habitat for fish.
- **Plant tree borders:** Streamside landowners can plant trees that shade streams and help reduce air temperatures by providing a cool microclimate near the stream. Plants also filter excessive amounts of sediments, fertilizers, or other nutrients from lawns and agricultural areas.
- **Conserve water:** Increased flow in streams helps keep the water cool. Practice wise use of water near streams to help protect flows during late-summer low-flow conditions. Reduce lawn areas for watering or use less-consumptive irrigation methods. Use deep soaks early in the morning or late in the evening to minimize evaporation and leave more water in the stream or in groundwater resources that 'recharge' stream flows.
- **Reduce impervious areas:** Less pavement near streams for roads or parking lots reduces precipitation becoming heated by the sun and allows a greater proportion to infiltrate cooler soils. This recharges and conserves water in the ground for dryer seasons. Water allowed to infiltrate during storms does not run off to waterways so quickly and helps reduce flooding.

Developing action plans for the Green and Newaukum watersheds

Ecology's plans to bring down stream temperatures for each of these watersheds were developed with help from local agencies, Native-American tribes, businesses, and residents. The coordinated and sustained efforts of all these groups are needed for these plans to be effective.

Review copies are also at local libraries for comment until June 23, 2011.
Send comments to:
Chris Coffin 3091 160th Ave. SE, Bellevue, WA 98008-5452
Email: chris.coffin@ecy.wa.gov
See: http://www.ecy.wa.gov/programs/wq/tmdl/GreenRvrTMDLsummary.html

Please consider coming to a public meeting to learn more:
Auburn City Hall Council Chambers June 14 at 6:30 p.m.

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Appendix G. Response to public comments

The following summarized comments were received during the public comment period for the Middle and Lower Green River Temperature TMDL Water Quality Improvement Report. Comments regarding factual inaccuracies, improved wording, or those that clarify policy positions by other government agencies have been directly incorporated into the text of this report. All other comments are summarized below. Some comments have been combined in order to avoid redundant responses to similar or related comments.

1. **Comment**: The document includes a model scenario that assumes a complete absence of riparian vegetation along levees. However, the levees do not occupy the entire 45 meter width of the area that the model regarded as not having vegetation. It seems that the model scenario exaggerates the scale and significance of vegetation management on the levees by also including a lack of vegetation on adjacent lands.

   Response: *The levees themselves, including open access and inspection space on the back side of the levee occupy approximately ½ to 2/3 of the space that would ideally contain optimal shade producing vegetation (32 meter trees). The most beneficial shade will be provided by the trees that are located nearest the river's edge, and within the levee footprint, with trees further back providing some, but diminishing thermal protection to the river. Not all, but much of the area that lies on the back side of the levees has been built out with residential, industrial and commercial infrastructure, including roads, bridges and utilities. The modeled scenario described was used to illustrate a worst-case scenario and focus on difficulties provided by levee vegetation policy and human development. Shade provided from trees grown off the land-side of the levee,s but within the 45 meter modeled buffer, would provide some protection to the river and be an improvement to the existing conditions. However, it would not be adequate to produce site potential shade. Subsequent to this modeling being completed, an advisory committee studying the effects of the levee system has requested additional modeling scenarios to fill in gaps of knowledge and answer questions not covered in this TMDL. Ecology is hopeful that continued examination of this topic will lead to viable activities that are able to address the high water temperatures.*

2. **Comment**: There was little discussion of flow and its effect on water temperature. There is no model analysis presented of how flow might influence water temperature yet it should be an important element of the model.

   River flow is a significant component for water temperature modeling. Increased flows will result in faster travel time, reduced solar inputs to a parcel of water, and ultimately changes in the thermal dynamics of the river.

   Summer and fall flow augmentation by HHD usually provides greater flow to the river than would exist based simply on inflow to the dam this time of year. Without augmentation, flow would be less with potentially higher water temperatures. The HHD Additional Water Storage Project includes future spring storage for the purpose of further augmenting flow during the summer and fall. This measure, if implemented, could influence downstream water temperatures.

Response: *In modeling the Green River a flow regime of 225 cfs was used to approximate the lowest flow expected during the critical period established for high solar heat load (July and August). The minimum flow of 225 cfs used in the model is set by agreement and regulation and is not expected to go lower except in times of extreme drought. The model did not explicitly examine the effect of higher flows, however it would be expected that higher flows of cool water would change the temperature curve of the river for some distance downstream. All possible remedies to keep the river cool, such as flow augmentation, will be welcome discussion topics as an implementation plan is developed to improve temperature conditions.*

3. **Comment**: We question why stormwater point sources are required to receive wasteload allocations or even be part of this TMDL, given various statements in the report related to stormwater not being considered a significant source that impacts temperature. We request that WSDOT be removed from this TMDL.

   Response: *While stormwater is not considered a significant contributing factor to thermal loading during the late summer critical period, there may be summer storms, which do cause stormwater thermal waste loads. Accordingly, WSDOT is included in the categorical waste load allocation (WLA) for permitted stormwater in the Middle and Lower Green River temperature TMDL.*

4. **Comment**: Suggest revising the test to clarify who will be responsible for performing monitoring. We believe Ecology should be responsible for compliance monitoring.

   Response: *Ecology may conduct effectiveness monitoring during and after implementation of the TMDL. Also, Ecology may conduct compliance monitoring in the future, may rely on existing data or data provided by other sources. This TMDL is not requiring monitoring by permit holders nor is it asking that additional monitoring requirements be added to stormwater permits.*

5. **Comment:** WSDOT has not performed a QA/QC check on the water quality or flow data presented in this report, nor **have** we recomputed the math behind derived values, and reserve the right to make corrections if errors are found at a later date.

   Response: *Ecology prepares Quality Assurance Project Plans (QAPPs) for all of its TMDLs and documents its findings in the final TMDL submitted to EPA. Water Quality Policy 1-25 describes the TMDL dispute resolution policy, which should begin no later than 30 days from the time the final TMDL is made available to the public (http://www.ecy.wa.gov/programs/wq/tmdl/documents/1-25Pol-TMDLDispResolrev.pdf) Should WSDOT review the study procedures or findings in the future beyond the dispute resolution period set forth in Policy 1-25 and find errors that it believes need to be corrected, Ecology will review, comment, and make corrections to the TMDL (if needed) as resources allow.*

6. **Comment**: To be consistent with regulations and guidelines used to establish TMDLs, we feel it is Ecology's responsibility to characterize the sources of pollution and assign numeric WLAs only when there is credible, site specific data or information indicating that WSDOT facilities are a significant source or contributor of the pollutant of concern. In the absence of site specific stormwater outfall data, a numeric WLA assigned to WSDOT is presumptuous and without just cause.

   Response: *Federal regulations state that it is reasonable to express allocations for NPDES-regulated stormwater discharges from multiple point sources as a single categorical wasteload allocation when data and information are insufficient to assign each source or outfall individual WLAs. See 40 C.F.R. § 130.2(i). Discharges from WSDOT facilities are included in the categorical WLA for permitted stormwater in the middle and lower Green River watershed because, although rare, late summer stormwater discharges can and do occur.*

7. **Comment**: Suggest deleting the numeric WLA. The WLA should be assigned in the form of actions since site-specific data is not available to assign numeric WLAs.

   Response: *Wasteload Allocations (WLAs) and Load Allocations (LAs) must be expressed in numeric form in TMDLs. See 40 C.F.R. § 130.2(h) & (i).*

8. **Comment**: Suggest replacing "All appropriate best management practices in the stormwater permit for controlling thermal loadings to surface waters are applied to the discharge to protect designated aquatic life uses" with the following: "Compliance with the permit constitutes compliance with the goals of this TMDL." The action as previously stated is vague and this revision would provide clarity and consistency with the last sentence in the third paragraph on this page.

   Response: *The bulleted sentence refers to BMPs "in the stormwater permit". In other words compliance with the permit is being called out with special attention to any BMPs that may help control thermal loadings to surface waters. The Green River temperature TMDL is not recommending any additional actions for stormwater permittees* ***beyond*** *compliance with their permit.*

9. **Comment**: Whether precipitation is cooled by the ground or not depends on relative temperatures. This bears more investigation for western WA, i.e. is precipitation always warmer than the ground? sometimes? and if so, during what season and at what frequency? Stormwater discharging directly from pavement may heat or cool streams depending on precip, temp, pavement temp and heat capacity, storm duration, and receiving water temp (i.e. runoff from pavement may be warm at the beginning of a storm, but that may be transient); e.g. from the Snoqualmie temperature TMDL: " Runoff from late spring or early fall rainfall onto heated pavement may be quite warm initially, but that runoff cools rapidly during long rain events and is not expected to cause a 0.3°C increase of the 7-day average temperature.". I think we can all agree that infiltrated precipitation does improve baseflows, and that strong flows are warmed less by solar radiation (and warm air?) than are weak flows.

Response: *Comment noted*.

10. **Comment**: Since shading has been modeled as the solution to the thermal problem in the river, and stormwater has not been identified as part of the problem, it seems inappropriate to emphasize infiltration to this degree, with regard to the TMDL.

    Response: *Stormwater has been identified as a* ***potential*** *source of heat to the river but, as mentioned in the text, its contribution of heat is untested and unknown at this time. Infiltration is becoming an accepted and recommended method of dealing with stormwater runoff under certain scenarios where ground water can be protected.*

11. **Comment**: The text mentions problems with calibrating the model. Has the model calibration problem been fixed?

    Response: *Yes, the problem was fixed and the model calibrated well.*

12. **Comment**: "The model shows that even with system potential shade conditions the water temperature may exceed the 16° criterion by 2 to 3 degrees." Does this mean that > 16 deg C is a natural condition?

    Response: *"Natural conditions" were not determined. "System potential temperature" is an approximation of the temperatures that would occur under natural conditions. System potential is our best understanding of natural conditions that can be supported by available analytical methods. The simulation of the system potential condition includes best estimates of mature riparian vegetation, system potential channel morphology, and system potential riparian microclimate that would occur absent any human alteration.*

13. **Comment:** There are a total of 16.3 miles of levee enrolled in the current Rehabilitation and Inspection Program (RIP) program that is subject to the Corps levee vegetation criteria. All of this is downstream of RM 30 within the lower Green watershed, and most (10 miles) is on the right bank, and thus provides limited shade potential from the sun during the afternoon when heating is most acute. Between RM 31 (Auburn) and RM 12 (Tukwila) there are 38 miles of total river bank. About 43% of the river bank thus is subject to the Corps vegetation standards. Most of the river in this reach is thus outside of the RIP and therefore beyond the influence of the Corps vegetation policy. There are no eligible levees in the RIP located in the middle Green River upstream of Auburn. The report mentions the level of development in the lower Green River. Major roads and parking lots are prominent features adjacent to the river in many places especially towards the downstream end of the study area. These roads are heat sources that likely play a role in water temperatures. Even where levees have substantial vegetation, the area on the landward side of the levee can be essentially devoid of meaningful plant cover within the riparian areas modeled in the TMDL. This diversity of the riparian corridor should be better characterized.

Response: *Ecology does not intend to minimize the diversity of the lower Green River's riparian corridor. This comment illustrates the complexity and the difficulty we face in resolving water quality and salmon habitat issues in the river.*

14. **Comment:** Document indicates that an 'empty and barren lakebed' exists immediately upstream of Howard Hanson Dam (HHD). HHD is operated to provide low flow augmentation and water supply during the summer months. In most years the reservoir is maintained at a relatively high elevation throughout the summer. Substantial drawdown typically occurs in September and October to augment flows. In most years the reservoir is emptied by November 1. This operation means that the reservoir contains substantial volumes of water into October. There is not an empty and barren lakebed during the summer months. Furthermore, during the time period in question (July and August), water is drawn from relatively deep in the reservoir and discharged to the lower river. This water is generally colder than inflow to the dam. HHD therefore provides a cooling effect most of the time in July and August. In some years, it may be possible to deplete this reservoir of cold water which would result in discharging warmer surface waters from the reservoir compared to inflow waters. This typically does not occur until late August or early September, if it occurs at all.

    Response: *The text was modified to express this comment. King County data from a site just below the dam (GRT17) indicates occasional temperatures above the 16°C criterion in August and September.*

15. **Comment:** The forested upper watershed can be a source of warmer water during July and August. Temperature monitoring of the Green River inflow to Howard Hanson Reservoir by the Corps shows that Reservoir inflow temperatures are typically greater than Reservoir outflow temperatures during July and August. Green River inflow temperatures often exceed 16°C during low flow July and August time period. Because Howard Hanson Dam discharges water from near the bottom of the reservoir (which can be greater than 100 feet deep during July and August), the pool at Howard Hanson Reservoir provides a source of deep cooler water for discharge during July and August. During many years, the Green River inflow ranges from 2 to 4°C warmer than the Reservoir outflow during July and August.

    Response: *The text was modified to reflect this comment.*

16. **Comment:** Temperature modeling results shown in Figure ES-3 are different than data shown in Figure 35. Water temperatures in ES-3 are warmer than those shown in Figure 35. Which data are the correct final model results? Lethality line at 22°C for a 1-day maximum temperature should be 23°C. On page 68 the document states that 22°C is for a 7-day average of the daily max and 23°C is for a 1-day max.

    Response: *An incorrect graphic (ES-3) was inserted in the Executive Summary of the draft version of this document. The correct graphic was shown in Figure 35. This error has been corrected. The lethality line of 22°C is for a 7 day average daily* *maximum temperature (7-DADMax). All of the temperature lines on the graphic essentially represent 7-DADMax.*

17. **Comment:** The sentence suggests that Corps levee maintenance policy is responsible for not meeting temperature standards 'throughout the Green River'. This is misleading and should be reworded.

    Response: *Text changed from "throughout the Green River" to "in the lower Green River".*

18. **Comment:** The supplemental temperature standard needs additional explanation. Is this standard in the WAC, has it been accepted by EPA. Figure 6 needs to show 13°C vs. 9°C standard using different colors on map. The standard has no relevance to the TMDL and we do not understand why it is being included in this document.

    Response: *This information was included to inform the reader that there are other temperature standards in the river that must be met during certain time of the year but were not evaluated in this TMDL.*

19. **Comment:** Indicates that 9º C is necessary 'to protect summer reproduction by native char'. Figure 6 is referenced indicating that this criteria would apply to most of the river. Please note there is no spawning population of char native to the Green River. The 9º C criterion does therefore not seem justified nor is it referenced elsewhere in the document.

    Response: *The reference to native char is included in language taken from the water quality standards. You are correct in noting that it is not applicable in the area covered by this TMDL. The language was removed from the text.*

20. **Comment:** States 'eighteen of 19 locations in the Green River… violated state water quality standards for temperature'. Please describe the one station on the Green River that did not violate the temperature standard. Where was the station located?

    Response: *The statement was in error. The text has been modified to say "All thirteen of the stations monitored by Ecology on the Green River mainstem exceeded the relevant temperature standards."*

21. **Comment:** Why does the model start at the TPU diversion and not at HHD tailwater? Setting the upstream boundary of the model 4 miles downstream from HHD needs to be explained in document. Similar question for page 50, second paragraph.

    Response: *The model boundary started at the TPU diversion because that is the furthest upstream point where water quality sonde data were collected that were used to establish the boundary condition for conductance and alkalinity. No similar data were available for the location just below Howard Hanson Dam. This is also the* *furthest upstream location where dissolved oxygen, pH and nutrient data were measured so it is the furthest possible upstream location for the boundary of the water quality model, QUAL2Kw. The TMDL project boundary is given as Howard Hanson Dam but the modeled area, as stated in the document, has an upper boundary at the Tacoma Public Utilities diversion.*

22. **Comment:** QUAL2Kw was used to model only 1 day. Temperature standard is a 7 day average of daily maximum. Recommend QUAL2Kw model at least 7 days to allow comparison with temperature standard and to account for 2 day travel time between model boundaries. Please describe time step used in the model?

    Response: *QUAL2Kw simulates dynamic changes in water temperatures and other water quality variables due to hourly changes in boundary conditions and meteorology over the course of the day. The time step for the numerical integration is typically in the range of 5 to 11 minutes but can be set to values between < 1 minute up to 45 minutes. QUAL2Kw simulates dynamically change conditions of water quality for each time step. For the Green River the time step was set to 1.4 minutes. The flow in rivers, point sources, and non-point sources is assumed to be constant, but all other water quality conditions are dynamic.*

    To address the 7-day averaging period of the water quality standard for temperature, the critical condition model for this study used a minimum instream flow in the mainstem, 7-day low flows for tributary inputs and 7-day average weather conditions (e.g. air temperature and dewpoint). Therefore, the computed daily minimum and maximum water temperatures represent 7-day average conditions. The numerical integration is computed for a specified number of days that is usually about 3 times the travel time of the river to reach a dynamic equilibrium throughout the entire length of the stream. Once a dynamic equilibrium is reached it is not necessary to continue the simulation any longer because conditions during the following days do not change. For the Green River, the travel time from the headwater to the outlet is approximately 2 days and the numerical integration was computed for 6 days to achieve dynamic equilibrium conditions.

23. **Comment:** Boundary condition maximum temperature at Km 0 is shown as about 18°C on July 23, 2006. However, HHD tailwater temperature had a maximum temperature of < 16°C on that day. Why is the temperature so much warmer to start the model at the TPU diversion? Did this TMDL look at changes in temperature between HHD and TPU diversion and how these changes impact downstream water temperatures when setting up the boundary?

    Response: *The Ecology thermistor at 09-GRE-DAM at the upstream model boundary indicated a maximum temperature of 17.92 ^{o}C on 7/23/2006, a mean temperature of 15.85 ^{o}C and a minimum of 14.57^{o}C. Continuous King County data collected just below the dam (GRT17) confirm that outlet temperatures from the dam were less than 16 ^{o}C on July 23rd. Based on the results of the modeling, it seems very likely that solar radiation input to the river between the dam and the TPU diversion* *can result in an increase in peak daily temperatures suggesting that riparian restoration efforts should not neglect the restoration of system potential vegetation along this reach of the river. The effect of the dam operations, or the TPU diversion, on river temperatures was implicitly not within the scope of the modeling effort. Not modeling the few miles between the outlet of the dam and the TPU diversion does not invalidate the conclusion of the modeling that restoration of riparian vegetation will result in reduction of temperature maxima in the river, particularly in the downstream reach were temperatures reach potentially lethal levels.*

24. **Comment:** Recommend using statistical analysis of the long history of inflows to Howard Hanson Dam to determine the Green River 7Q10 flow at the upstream boundary of the model. System potential flows are a representation of natural flows under 7Q10 conditions. The long history of inflows to Howard Hanson Dam would allow for a statistical approach to calculate natural flows, similar to what was used to calculate 7Q10 flows for Newaukum Creek and Soos Creek.

    Response: *This approach would be reasonable and was considered for use but it ignores the fact that the flows are currently regulated/augmented in summer so that flows in the river are no longer equal to what enters the reservoir.*

25. **Comment:** Please state the system potential flows used for the model at the upstream boundary.

    Response: *The modeled flow at the boundary is provided is 119 cfs, as stated in the text. This is near the minimum conservation flow target at Palmer of 3.11 cms (110 cfs), but the final upstream boundary flow depends on the flows specified for the tributaries and the minimum flow target at Auburn.*

26. **Comment:** Use of a microclimate temperature for system potential vs. no temperature adjustment for current conditions is not valid when comparing model runs to determine how shade impacts water temperature. For an analysis of natural vs. current conditions, one cannot adjust the natural condition temperature to be 2°C less for the model run, this introduces a bias. Moreover, such an adjustment would introduce a second variable being changed to only one simulation.

    Response: *The microclimate evaluation was done as a sensitivity analysis and was not the basis of any of the actual scenarios evaluated (system potential, current, levee, etc.). Furthermore, the 2°C adjustment was not of the modeled river temperature data, but of the input air temperature and the adjustment was only to the peak air temperature as illustrated in Figure 33. Also, the sensitivity analysis showed that the model-predicted maximum temperatures were relatively insensitive to the small adjustment to the air temperature.*

27. **Comment:** Indicates that the model assumes levees have no vegetation. This is a common theme throughout the document (pg 77, 82, Conclusion). Current Seattle District Corps of Engineers vegetation standards allow for woody vegetation on

levees enrolled in the Rehabilitation and Inspection Program (RIP).This is known as the Seattle District levee vegetation variance. The variance allows woody vegetation with a stem diameter of up to four inches on both the landward and riverward slope of the levee; this type of woody vegetation is more than the default national Corps policy. Up to 12 inches diameter is permitted on overbuilt levees. Additionally, engineering judgment may allow trees and shrubs larger than these diameters in cases where the vegetation is not deemed a threat to levee integrity. Furthermore, the Corps along with King County repaired approximately two miles of levee in 2008 along the river. This included constructing benches on the riverward side of the levee that were planted with woody vegetation. King County maintains additional levees that are enrolled in the RIP that contain similar benches with vegetation. This indicates that a zero vegetation assumption for levees in the lower Green River is an inaccurate reflection of current conditions. An intermediate level of vegetation (something other than zero or mature) would seem a more appropriate assumption for the analysis. And this is probably a more realistic future condition. Levee vegetation standards for levees in the RIP program are currently being reviewed by the Corps at the national level. This could affect the standards for levee vegetation in Seattle District in the future, but the specific outcome of the review won't be known until the completion of the review, currently scheduled for late 2011.

Response: *Modeled scenarios presented the "worst case" and the "best case" along the levee system in the lower river, as well as the "current condition" (data was collected in 2006). The river system does have several areas of plantings and riparian improvements that have been established since the data for this report was collected. While there are numerous scenarios that could be modeled with any number of conditions it was felt that these were the important scenarios to develop for this TMDL. This modeling exercise demonstrated that shading the levees with a tall healthy buffer is of upmost importance to maintaining cool water in the lower Green River. This TMDL did not go into depth determining how we would facilitate achieving a proper riparian corridor but did demonstrate that it is absolutely necessary to do so. Since the release of the draft of this document a scenario with a 25m buffer and 32m tree height has been run and requests for additional model scenarios have already been made by the Corps and other participants preparing information for the review mentioned in your comment. Ecology will help as we are able with the preparation of the review*

28. **Comment:** Document states that 'a 7-day average of the daily maximum temperatures greater than 22°C or a 1-day maximum greater than 23°C should be considered lethal to cold water fish species…" Model run is for 1 day; however the 7-day 22°C lethality temperature is being used and shown on figures. Should use the 1-day 23°C lethality temperature with a 1-day model run. The 1-day 23°C temperature is stated in the conclusion on page 91.

Response: *The 7-day Max of 22 ^oC is a more appropriate standard for comparison to the steady-state model results. The text on page 91 was changed to identify the 7-day Max 22 ^oC standard instead of the 23°C 1-day Max.*

29. **Comment:** What temperature was used for the upstream boundary of the model? Because the boundary condition temperature forces the model, the document needs to clearly state how the upstream temperature was derived.

    Response: *The upstream temperature came from the Ecology thermistor data collected at Station 09-GRE-DAM. A description of how all model parameters were collected in included in the document text.*

30. **Comment:** Document states 'federal policy on levee maintenance does not allow for adequate riparian vegetation to satisfy the shade requirements of the TMDL' with reference to ongoing discussions about such policy. No details are provided on the 'shade requirements'. Is the requirement for mature vegetation along the entire middle and lower Green River including all levees at a width of 45 meters? Note that this is wider than the levees enrolled in the RIP (see comment 22).

    Response: *Full site potential shade (as modeled) requires a 45m buffer width with a 32m tree height. It is recognized that 45m is beyond the footprint of the levees and to achieve a 45m buffer will be a daunting task involving a number of managers and governments along the river. A 25m/32m tree height buffer was also modeled (unpublished) after the draft for document was written that shows a tremendous improvement, even with the reduced width. This informs us of the importance of the tree height and tells us that, while 45m is our target, 25m will be a major improvement.*

31. **Comment:** This section implies that the Corps can setback levees along the Green River. Levees are owned and operated by the local municipalities along the river. These municipalities would be responsible for deciding whether to setback any levees. This includes acquiring land for that process. While setting back levees is not within the power of the Corps, we generally support levee setbacks and encourage all sponsors to pursue this option to both eliminate potential damages from floods and for environmental considerations. Please correct the final document to accurately represent these facts.

    Response: *Text added to reflect comment.*

32. **Comment:** This section states 'water in the mainstem Upper Green River flowing out of Howard Hanson Reservoir and into the Middle Green River did not always meet the state water quality criterion of 16°C. This data will be used to include the Howard Hanson Reservoir on the 303d list'. Temperature data collected on the mainstem Green River at the inflow and outflow of Howard Hanson Reservoir in 2006 show the daily maximum inflow temperatures to be greater than the daily maximum outflow temperatures for July and August. Green River inflow

temperatures often exceed 16°C during low flow July and August time period. Because Howard Hanson Dam discharges water from near the bottom of the reservoir (which can be greater than 100 feet deep during July and August), the pool at Howard Hanson Reservoir provides a source of deep cooler water for discharge during July and August. During many years, the Green River inflow ranges from 2 to 4°C warmer than the Reservoir outflow during July and August. As air temperatures cool in late August and early September, inflow temperatures become cooler quicker than the outflow temperatures from Howard Hanson Dam due to the retention of heat in the reservoir pool.

Response: *When adequate, credible data exist, and are made available to Ecology, indicating a water body is not in compliance with state water quality criteria that waterbody is added to the list of impaired waters – the 303(d) list. Once on the 303(d) list an evaluation will be made by Ecology or another designated entity to address the impairment, determine the causes and, if other than from natural causes, propose a solution. Data is available that show temperatures above criteria are occasionally observed just below Howard Hanson Dam.*

33. **Comment:** The discussion of designated aquatic uses mentions use by salmonids of this area but fails to mention that that Chinook salmon in the Green River are listed as a threatened species by NOAA Fisheries. I believe there should be a stronger tie between improvement of water quality and recovery of a listed species.

Response: *The text did primarily compare water quality standards with existing water quality conditions. The standards are "use based" and try to protect the most sensitive of the uses in the river. In the case of the Green River the criteria within the standards have been developed around the needs of salmonids. This obviously includes Chinook but that should have been better emphasized. The text has been modified in the section "Aquatic life resources".*

34. **Comment:** The document references a WRIA 9 Basin Salmon Recovery Council. The group was known as the WRIA 9 Steering Committee.

Response: *This error was corrected in response to this comment*.

35. **Comment:** The discussion about planting trees does not mention the need for wider buffers in order to reduce windthrow of trees within the buffer width. This should be taken into consideration when determining the width needed on a site by site basis.

Response: *The model used did not consider windthrow but it will be an important element as implementation activities progress.*

36. **Comment:** This (TMDL project) strongly supports the efforts of the Green/Duwamish and central Puget Sound (WRIA 09) Lead Entity in our salmon recovery efforts.

Response: *Comment acknowledged.*

37. **Comment:** Many of the restoration projects and programs identified in the Green/Duwamish and Central Puget Sound Watersheds (WRIA 09) Salmon Habitat will have a direct improvement on water temperature. I welcome the opportunity to work with (Ecology) to identify projects to include in the Implementation Plan.

    Response: *Projects associated with the Green/Duwamish and Central Puget Sound Watersheds (WRIA 09) Salmon Habitat improvement efforts are considered an indispensible component of this temperature TMDL implementation. We look forward to working with the WRIA 9 Watershed Ecosystem Forum toward water quality improvement in the Green River.*

38. **Comment:** We appreciate the detailed information and analyses provided in this report, including those concerning the constraint on the potential to improve water temperatures for salmon arising from federal PL 8499 levee vegetation maintenance policies.

    Response: *Ecology is grateful for the contribution made by the Green River temperature modeling to help inform decisions regarding levee vegetation maintenance policies.*

39. **Comment:** The Green River is likely among the most severely temperature-impaired river corridors in Western Washington, and can be expected to grow warmer over time as climate and urbanization trends continue. As the report data indicates, summer water temperatures are excessively high in the lower river and this is strongly associated with deficient riparian shade. Temperatures frequently far exceed state standards, with 7DMDA reaching 23°C in Tukwila in 2006 for example. The lower Green River is a critical migration corridor for anadromous fish with individual populations numbering in the thousands for Chinook and coho and millions for pink salmon. We are very concerned that important treaty fisheries resources are at risk due to the temperature problems in the Green River.

    Response: *Comment noted. In helping develop and submit this TMDL, Ecology is doing what it can to restore and protect the valuable fisheries resources in the lower Green River.*

40. **Comment:** Figure 35 of the draft Water Quality Improvement Report illustrates that under critical flow conditions without improvements to riparian vegetation, water temperatures are predicted to exceed the 16°C water temperature standard for all reaches assessed and the 17.5 °c standard for reaches downstream of the confluence with Mill Creek. Under these conditions, the lower 12 KM of the river are predicted to exceed the lethality threshold of 22°C for salmonids. Significant temperature improvements (3 to 5°C cooler) are expected if mature riparian vegetation is planted all along the river. However, Figure 35 illustrates that if mature riparian vegetation is prohibited on levees to comply with US Army Corps of Engineers' national

vegetation maintenance standards, temperatures would be 1 to 4 °c warmer than with system potential riparian shade, and lethal temperatures will continue to occur in the lower 6 KM of the river. Until mature riparian vegetation can be planted in all riparian areas including those with levees, or, the levees are set back to allow development of an unrestricted vegetated riparian buffer, this TMDL will not successfully improve water temperatures to healthy and safe levels for salmonids.

Response: *Comment noted. Ecology agrees that levees and levee vegetation policies impose some constraints on the temperature improvements recommended by this TMDL. Again, Ecology believes that the contribution made by the Green River temperature modeling will help inform decisions regarding levee setbacks and levee vegetation maintenance policies.*

41. **Comment:** The potential for alternative management actions to control water temperatures, such as substantially increased instream flow and floodplain function, is generally limited in the lower Green River. We strongly encourage the Department of Ecology to continue to direct its various programs to address the need for riparian shade on all land uses in the Green River during the implementation phase of the TMDL.

    Response: *Comment noted. Riparian shade will continue to be the emphasis of implementation for this TMDL especially because potential alternative management actions to control water temperatures such as increased instream flow and floodplain function are limited in the lower Green River.*

42. **Comment:** From where in the pool above Howard Hanson Dam do water releases come? Libby Dam in Montana had a similar problem, and they discovered they could mix colder water from a low elevation in the pool with water from the surface, and so reduce the temperature of water being released below the dam. It might be possible to do this at Howard Hanson Dam. I suggest inquiries be made of this possibility.

    Response: *The Corps of Engineers informs us that releases come from near the bottom of the reservoir, the coolest part of the lake. The Corps suggest that flow augmentation should be a subject for discussion to help mitigate high temperatures. We will explore this further as the development of the Implementation Plan progresses.*

43. **Comment:** Levee design is based on having no vegetation within the base or interior of a levee. The reason is, roots of large trees will eventually rot, providing a place for water under pressure to find a pathway through the levee, flooding the land the levee is supposed to protect. Water will be under pressure, by virtue of the river being higher than the land on the other side of the levee. However, this link is no longer workable. One would have to make inquiries to USACE for engineering requirements for levees to check validity of this claim

Response: *Ecology understands that the levees are in place to prevent flooding, offering safety and protection from property damage. We do not suggest that the protection be compromised but do ask that all the* uses of the river and all the alternatives to support those uses be considered.

44. **Comment:** The Corps, at Howard Hanson Dam, started a 50 year program in 1994 of adding large woody debris (LWD) and gravel to the upper Green River below the dam. This was based on a biological opinion from NOAA for salmon recovery. The program has 33 years to go. Tacoma Water and the Corps are cooperating on this program. At least two reports have been written on the amounts of LWD in the river since the program started. This wood should help reduce water temperatures.

    Response: *LWD is known to sometimes allow the scouring of deep holes in the river bed, providing refuge for fish; however it will provide very little shade nor block solar radiation. This TMDL study found that the lack of adequate shade is the primary source of river warming.*

45. **Comment:** The idea of setting levees back has been proposed, and is being used by King County Water and Land Resources, to allow for trees to be planted on river shores, to provide shading. One levee setback will be done this summer/fall at the town of Pacific on the White River. Another setback was done on the Cedar near Renton in 2008, which has resulted in bridge impacts, a power failure and boating accidents. The engineering of the Cedar levee setback was so faulty, the project had to be re-done. The 2008 project added 55 groups of 3 trees, held together with large chain. The anchoring for this LWD was undersize, and the buoyancy of the wood was not accounted for. Many large living cottonwoods have come down in the area. The suggestion has been made that during levee setbacks, re-engineering the river should not be done. Instead, just let the river find its own path.

    Response: *Ecology acknowledges this commenter's valuable experience with levee setbacks and agrees that we should learn from past setback projects.*

46. **Comment:** A PhD in biology has written to me that the tropolones in Cedar are toxic to aquatic life. This is why Cedar is used for home decking, as it does not admit the rotting that occurs with other wood left open to weather. Therefore, it seems best not to plant Cedars to provide shade along streams, because when they fall into streams it will not help provide food for endangered species of fish.

    Response: *The TMDL does not consider the potential adverse effects of certain tree species on water quality and aquatic life. There are many other tree species that can be uses in planting riparian buffers besides cedar.*

47. **Comment:** The densification of Seattle will make it difficult to get room for trees along the river. Maybe adjustments can be made in Seattle's Comprehensive plan to allow room for trees, especially on the south and west sides of streams.

Response: *Ecology agrees that it will take extensive planning and resources to accommodate the needed riparian buffers for the Green River. Ecology will continue to advocate that adequate resources be devoted to acquiring and restoring adequate riparian buffer areas.*

48. **Comment:** In the "Summary of strategies", first bullet: "Infiltrate stormwater and/or reclaimed water to the maximum extent possible…" The word "possible" should be changed to "feasible" to be more consistent with NPDES Municipal Stormwater Permit language.

    Response: *The "strategies" given in this section are not action items but are meant to provide direction when developing the Implementation Plan for this TMDL. Ecology believes that it will be important to examine all **possible** scenarios and then, working with stakeholders, determine what may be **feasible**. The word "possible" was used deliberately.*