DRAFT

Green / Duwamish Watershed

Water Temperature Report

June 2002

Prepared for:

Green Duwamish Watershed Water Quality Assessment

Submitted by:

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

DRAFT

Green / Duwamish Watershed

Water Temperature Report

June 2002

Prepared for:

Green Duwamish Watershed Water Quality Assessment

Submitted by:

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

201 S. Jackson St, Suite 600
Seattle, WA 98104
206-296-6519
http://www.metrokc.gov/

Alternative formats available

206-263-6317 TTY Relay: 711

EXECUTIVE SUMMARY

This report provides a synopsis of current and historical water temperature studies in the Green-Duwamish watershed focusing on concerns for anadromous and resident salmonids, and impaired water bodies as defined by the 303(d) list. This report is a part of the overall Green-Duwamish River Water Quality Assessment (GD-WQA), a comprehensive monitoring and modeling effort by the King County Department of Natural Resources and Parks (DNRP).

The purpose of this report is to: (1) summarize temperature data collected as part of the reconnaissance temperature study of the GD-WQA, (2) provide a synopsis of temperature data collected in the past decade within the Green-Duwamish basin, and (3) provide a foundation for the development of a comprehensive data collection effort designed to support water temperature modeling of the Green-Duwamish watershed.

King County deployed sixteen continuously recording temperature probes in July 2001 as part of the reconnaissance temperature study of the GD-WQA. These sites and 14 other sites operated by the King County gauging program were used to characterize current temperature conditions in the Green-Duwamish watershed. Summer temperatures at five sites on the mainstem ranged from 13 to 21^{o}C. During 2001, downstream temperatures on the mainstem were typically 1-2^{o}C warmer than upstream temperatures near the dams. The water temperatures of tributaries ranged from 9 to 10 ^{o}C at the mouth of Icy Creek, with little diurnal fluctuation, and from 15 to 29 ^{o}C near the mouth of Springbrook Creek, with daily fluctuations of up to 10 ^{o}C.

Studies have been carried out during the past decade by multiple agencies and entities, including the King County DNRP (and its predecessors such as Metro and the Surface Water Management Division), the Muckleshoot Indian Tribe (MIT), Corps of Engineers, U.S. Geological Survey, the University of Washington and the cities of Tacoma and Kent. Earlier studies involved collection of primarily discrete (i.e. instantaneous measurements) temperature data, whereas recent studies have focused on continuous temperature recording. Maximum summer temperatures often exceeded the Washington state temperature standards for Class A waters (18 ^{o}C), particularly on the lower reaches of the Green River and tributaries with more developed watersheds. The maximum summer temperatures recorded on the Green River mainstem by MIT in 1992 and King County in 1995 were between 23 and 24 ^{o}C.

In summer 2002, King County will initiate a more developed and comprehensive temperature study in the Green-Duwamish watershed to collect data for calibration of a temperature model. This information will be essential baseline condition data to serve as inputs to thermal regime modeling efforts, as well as being useful in many other ecological and project planning efforts.

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

This report provides an assessment of the water temperature conditions in the Green-Duwamish watershed focusing on concerns for anadromous and resident salmonids. Water temperature was identified in the WRIA 9 Habitat Limiting Factors and Reconnaissance Assessment Report (Kerwin, J. and Nelson, T.S., 2000) as a possible or probable factor of decline on the mainstem and tributaries of the Green-Duwamish River. Preferred temperatures for salmonids are usually reported in the range of 10 to 15^{o}C, with upper lethal temperatures between 23 and 28^{o}C (Kerwin, J. and Nelson, T.S., 2000). While maximum temperatures are important, the duration of high temperatures matters as well, affecting the sublethal or stress impacts to fish.

This report is a part of the overall Green-Duwamish River Water Quality Assessment (GD-WQA), being carried out by the King County Department of Natural Resources and Parks (DNRP) (King County, 2002a). The primary goal of the GD-WQA is to develop analytical tools for evaluating current and future water quality conditions in the Green-Duwamish watershed and to provide water quality information to a variety of clients internal and external to King County.

Temperature is one of the most readily acquired water quality parameters, but can be difficult to predict and model. Site specific temperature data are not necessarily indicative of temperature patterns at larger scales. This is because of the many factors that influence the thermal dynamics of any water body. Physical influences on water temperature in rivers and streams include water quantity (flow), water depth, riparian conditions: vegetation type & height and degree of shading, groundwater and surface water inflow, air temperature, local weather patterns, stream basin geomorphology, land use, and stream order. Stream temperatures are dynamic because of this complexity a number of parameters are required to accurately predict how the temperature varies in a stream.

This monitoring program is a critical first step in addressing water temperature as a factor of decline for salmonids and providing information to assist in salmon recovery efforts in the region. Knowing the extent and duration of elevated temperatures in the mainstem could assist in selecting areas to increase side channel or lateral cooler refuges. This information can also be used to evaluate and select habitat protection or restoration projects to ensure that current or future water temperature conditions can support salmonids at key life stages.

1.1. Purpose

The purpose of this report is as follows:

(1) To summarize continuous temperature data collected as part of the reconnaissance temperature study carried out for the GD-WQA from July 2001 to the present (data through February 2002 is presented in this report). This reconnaissance study targeted known or likely cool water sources and warm-water areas, as well as key tributaries and mainstem locations. Summary information is presented in section 2.
(2) To provide a synopsis of both discrete and continuous temperature data collected in the past decade within the Green-Duwamish basin. Section 3 summarizes the data that have been collected by numerous agencies or independent efforts. In particular, continuously recorded temperature in the mainstem and selected tributaries is of greatest interest to ecologists, modelers and water quality planners.
(3) To provide a foundation for the development of a comprehensive data collection effort designed to support water temperature modeling of the Green-Duwamish system. By

assessing existing data, identifying data gaps, and evaluating problems, we can improve the Sampling and Analysis Plan (SAP) for the comprehensive temperature study.

1.2. Endangered Species and Clean Water Act Implications

The WRIA 9 Habitat Limiting Factors and Reconnaissance Assessment Report identified temperature as a possible or probable factor of decline in the Green-Duwamish Basin (Kerwin, J. and Nelson, T.S., 2000). High water temperatures could be creating adverse habitat conditions for egg incubation, juvenile salmonid rearing, and blocking or delaying summer migration of adult summer steelhead and chinook. If limiting, temperature would be an important water quality issue to characterize and evaluate because of its importance in the life history of salmonids in the Green / Duwamish system.

Preferred temperatures for salmonids are usually reported in the range of 10 to 15 ^{o}C, with upper lethal temperatures between 23 and 28 ^{o}C (Table 1 and reference therein). While maximum temperatures are important, the duration of the high temperatures matters as well, affecting the sublethal or stress impacts to fish. Water temperature influences metabolism, behavior and survival of fish and other aquatic organisms. At less than optimal temperatures, salmonid metabolism and growth are greatly reduced. Above optimal temperatures, salmonid metabolism is used for maintenance instead of growth. In either extreme, salmonid fitness is limited (Bjornn and Reiser, 1991). NOAA (1996) determined that "properly functioning conditions" include maximum water temperature thresholds of 15.7 °C for spawning and 17.9 °C for rearing and migration of anadromous salmonids. Salmonids can tolerate temperature extremes, but often they will migrate out of an area if temperature fluctuations are too dramatic (Bjornn, 1978).

Temperature conditions necessary for various salmonid species are summarized in Table 1.

Table 1. Important Temperature Conditions for Salmonids

Table 1 was adapted from: http://www.nwr.noaa.gov/1salmon/salmesa/4ddocs/4dws4c.htm.

Temperatures Needed by Salmonids	Cutthroat	Steelhead	Chinook	Bull Trout
Spawning/Egg Incubation	10°C	13-15°C	5-14.5°C	2-4°C
Juvenile Rearing	15°C	10-13°C	12-14°C	10-12°C
Adults/Migration	<22°C	10-15.5°C	10-15.5°C	<15.5°C
Degraded/Stressed	>18°C	>15.5°C	>15.5°C	>13°C
Lethal	28°C	23°C	26°C	23°C

Existing Washington State temperature standards are based on a surface water classification system (Table 2). Tributaries draining to the Green River are Class AA above River Mile (RM) 42 and Class A for the remainder of the basin.

Table 2. Washington State temperature standards for surface water

Surface water classifications	Temperature Standards	Applicable reaches within the Green /Duwamish Basin
Class AA - fresh water	16 °C	River Miles: 42 to head waters

Class A - fresh water	18 °C	River Miles: 11 to 42
Class B - fresh water	19 °C	River Miles: 0 to 11
Class B - marine	21 °C	River Miles: 0 to 11.

In addition to those listed in Table 2, there are marine water standards for Class A and Class AA waters. There are no Class A or Class AA marine surface waters in the Green-Duwamish watershed. Analysis in support of Ecology's proposed use-based[1] standards has determined that the existing standards are inadequate to fully protect all aquatic communities (Hicks, 2002). The proposed temperature criteria are listed in Table 3.

Table 3. Proposed Water Quality Criteria for Temperature.

Key Species or Life-Stage Protected	7-Day Average of Daily Maximums	21-Day Average
Bull Trout and Dolly Varden (Char)	11.5 ºC	--
Spawning of Salmon, Steelhead and Trout	13 ºC	9 ºC
Rearing of Salmon, Steelhead and Trout	17 ºC	14 ºC
Rearing of Redband Trout	18 ºC	16 ºC

Table adapted from http://www.ecy.wa.gov/biblio/0010066.html.

Most studies on record show that summer water temperatures in parts of the Green River watershed routinely exceed the state standards (WAC 173-201) of 16 ºC for Class AA and 18 ºC for Class A (King County, 1994; Caldwell, 1994; Kerwin and Nelson, 2000). The most severe temperatures occur downstream of Auburn, in the zones where the river is diked and riparian trees are largely absent (Grette and Salo, 1986). The lack of riparian vegetation producing lateral habitats with little shade reduces the quality of juvenile rearing habitat, which may reduce juvenile fish survival or cause early exit of juvenile fish to the Duwamish estuary. The function of the riparian zone with regards to temperature is not to shade the stream directly, but to cool riparian air temperatures. This will not reduce daily maximum temperatures, but will increase the rate of cooling.

Another habitat requirement may be the presence of refuges from high summer temperatures, either areas of localized cooling (from groundwater inflow), or access to cooler pools or tributary streams. A shortage of refuge, if high summer temperatures are present, may limit fish populations in that reach of the stream. A related concern to high water temperatures is the effect on dissolved oxygen concentrations. Literature values for salmonids tend to agree that oxygen levels greater than 5 mg/l are optimal (Davis, J.C., 1975). Temperature combined with factors such as pollutants and biological oxygen demand could lower dissolved oxygen below this minimum, placing additional stress on fish populations.

[1] Applying use-based standards requires that waterbodies be assigned to appropriate use-categories, such as char spawning or salmon spawning, etc. Not all use-category definitions are detailed here (e.g., char spawning, warm water species spawning) as they are either not applicable to the Green-Duwamish watershed or superceded by a more stringent use-category standard.

2. RECONNAISSANCE TEMPERATURE STUDY

In July 2001, King County initiated a reconnaissance water temperature study to support modeling efforts as a part of the GD-WQA. A temperature model is being developed to examine temperature as a potentially limiting factor for salmonid recovery, and to support development of a TMDL for the watershed. In order to model temperature accurately, an ongoing data collection effort on the mainstem river and tributary creeks is required.

2.1. Field Data Collection

Sixteen sampling sites were selected that would enhance the data collection efforts of years past, as well as to augment the ongoing studies being conducted by King County and other agencies (Figure 1). Onset Stowaway™, and Onset Tidbit™ thermistors were placed inside polyethylene foam pipe insulation sleeves, and then cabled into 12" lengths of perforated steel sign posts.

Deployment occurred in late July 2001, during which attempts were made to conceal the cabling and thermistor unit as much as was practicable to reduce the chances of vandalism and theft by cabling onto solid riparian growth (trees, shrubs) or infrastructure. The thermistor units were programmed to record water temperatures at 15-minute intervals during the initial sampling period of July - October 2001. Data were downloaded twice during this warm water period. At the end of October 2001, all units were reset to collect data hourly for the winter season. All the thermistors were collected at the end of February 2002 to be downloaded and refurbished. Calibration tests were also run to record any drift or differences between thermistors. These units were retooled and deployed in mid-March of 2002.

Until completion of the final Sampling and Analysis Plan (SAP), defining the expanded range of data parameters and sampling locations, temperature monitoring will continue at the sixteen sites initially selected. Some minor changes in site locations have occurred since the initial deployment. Two sites (Kanasket-Palmer and the Coal Downstream) were moved during the re-deployment in February 2002. The Kanasket-Palmer was relocated for better access to the mainstem Green River and the Coal Downstream location was moved to a more "discrete" location on the mainstem due to frequent removal of the thermistor by fishing and outdoor enthusiasts.

2.2. Study Data Synopsis

The data collected during this effort are presented and summarized in Table 4. The reconnaissance sites and 14 other sites operated by the King County gauging program were used to characterize current temperature conditions in the Green-Duwamish watershed (Figure 2). Figure 2 presents each site from upstream to downstream for the July - October 2001 with a plot of the middle 70% of the temperature records along with the geometric mean at each site. The individual site temperature plots are also presented in Appendix B.

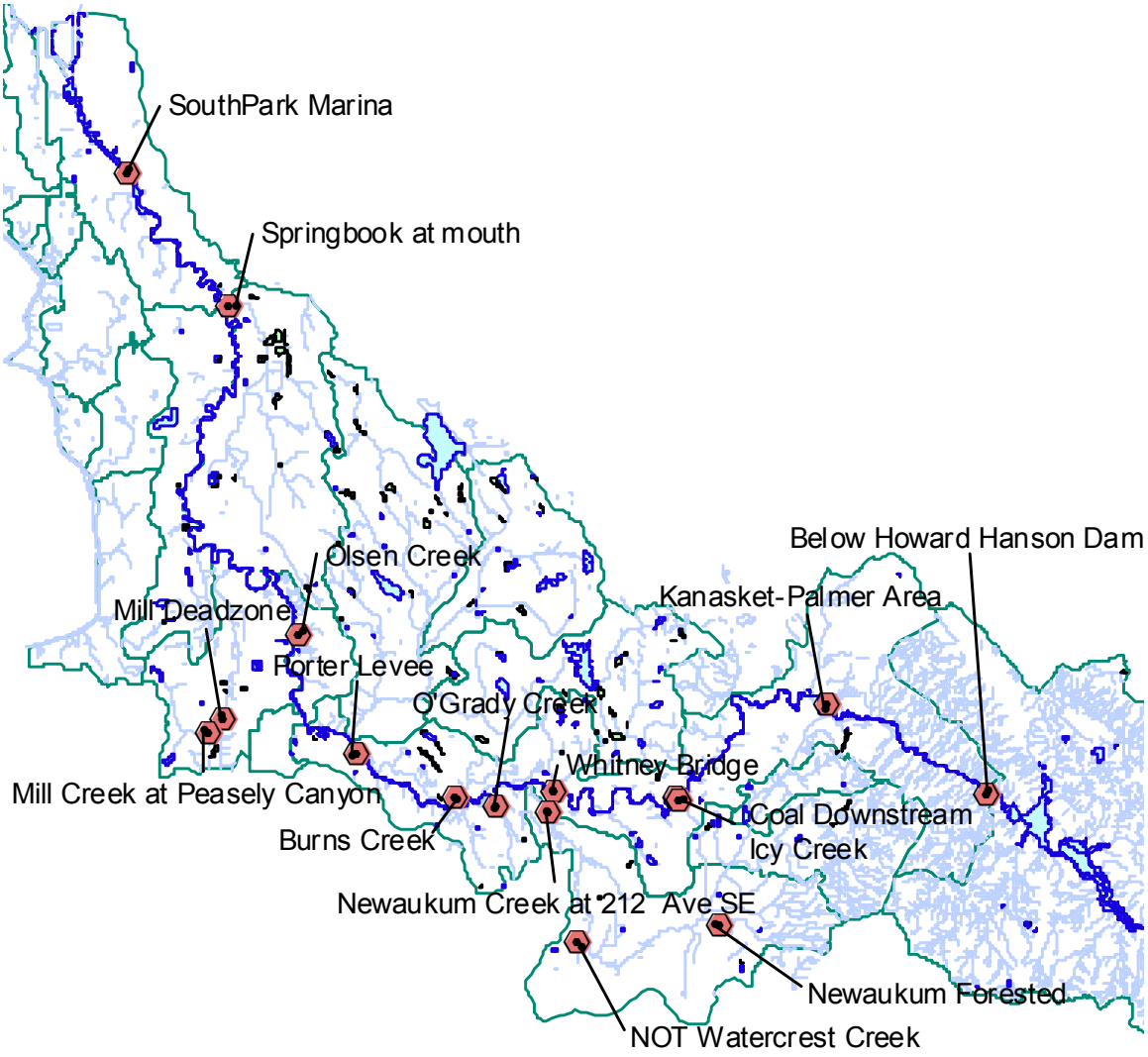

Figure 1. Reconnaissance temperature sites for 2001.

Figure 2. Schematic of Green River Temperatures from August 2001 to February 2002.

See separate pdf file.

Table 4. Maximum and minimum water temperatures for the Reconnaissance sites.

ID	Name	Max_temp	Min_temp	date_range	Notes
GRT-01	South Park Marina	21.0 ºC	4.1 ºC	Jul01-Feb02	
GRT-02	Springbrook Creek	29.4 ºC	4.4 ºC	Jul01-Feb02	
GRT-03	Olsen Creek	16.2 ºC	3.2 ºC	Jul01-Feb02	
GRT-04	Porter Levee	20.5 ºC	3.5 ºC	Jul01-Feb02	
GRT-04b	Mill Creek at Peasley	16.3 ºC	-3.1 ºC	Jul01-Feb02	Low Min temp refers to being exposed to the air for a period of time
GRT-05	Mill Creek Dead Zone	15.9 ºC	3.9 ºC	Jul01-Feb02	
GRT-06	Burns Creek	16.6 ºC	5.4 ºC	Jul01-Feb02	
GRT-07	O'Grady Creek	13.6 ºC	3.7 ºC	Jul01-Feb02	
GRT-09	Newaukum @ 212th	17.7 ºC	8.2 ºC	Jul01-Oct01	Thermistor lost. Re-deployed Mar02
GRT-10	Whitney Bridge	21.4 ºC	3.9 ºC	Jul01-Sep01	Thermistor stolen. Re-deployed Nov01
GRT-11	Not Watercress Creek	14.3 ºC	1.8 ºC	Jul01-Feb02	Low Min temp refers to being exposed to the air for a period of time
GRT-12	Newaukum Forested	13.8 ºC	1.5 ºC	Jul01-Feb02	Low Min temp refers to being exposed to the air for a period of time
GRT-13	Icy Creek	10.6 ºC	7.5 ºC	Jul01-Feb02	
GRT-14	Coal Downstream	--	--		No Data; see note.
GRT-16	Palmer Bridge	18.9 ºC	0.6 ºC	Jul01-Feb02	Low Min temp refers to being exposed to the air for a period of time
GRT-17	Below Dam	16.0 ºC	2.0 ºC	Jul01-Feb02	Low Min temp refers to being exposed to the air for a period of time

NOTE: "--" indicates no water temperature data due to thermistor being continually removed from water.

Summer temperatures at five sites on the mainstem ranged from 13 to 21^{o}C. During 2001, downstream temperatures on the mainstem were typically 1-2^{o}C warmer than upstream temperatures near the dams. The water temperatures of tributaries ranged from 9 to 10 ^{o}C at the mouth of Icy Creek, with little diurnal fluctuation, and from 15 to 29 ^{o}C near the mouth of Springbrook Creek, with daily fluctuations of up to 10 ^{o}C.

2.3. Analysis / Statistical Techniques

All the data collected were downloaded and collated on an Excel™ spreadsheet. Raw data were normalized using a natural logarithmic transformation and the averages for each sampling site along with the standard deviation intervals were determined. Each individual site was plotted on a standard scale graph

to represent the actual data collected and the range and magnitude of daily and seasonal fluctuations (Appendix B).

Analysis of these data revealed several locations that continue to be warm water areas as well as areas that are consistent cold water sources for the watershed. Comparison of data from several locations is useful in highlighting areas that require further study. Figure 3 is a plot comparing the uppermost site, below Howard Hanson Dam (Grt-17) to lowermost site at South Park Marina (Grt-01) on the mainstem. Figure 4 is a plot comparing the coldest summer temperatures from Icy Creek (Grt-13), and the highest recorded summer temperatures from Springbrook (Grt-02).

The comparative analysis between years and sites will require more data collected over time, as well as meteorological data to normalize the variations observed during different sampling periods.

2.4. Problems

There were a few instances where river levels rose rapidly during the winter, and the strong current moved the thermistors downstream causing them to be pulled taut on their anchoring cables. When the river levels subsequently dropped, in at least two cases this caused the thermistors to be stranded for some time out of the water. This issue may be remedied by an instream anchoring system. The choice the anchor needs further review due to loss of data at site GRT-09 (Newaukum @ 212th St). At this location, the thermistor could not be found due to the loss of the anchor. It is assumed this anchor was transported downstream during a large storm event.

Most of the problems that arose during the course of the initial temperature sampling survey had to do with thermistors being compromised by vandalism or theft. Unfortunately, several incidences of vandalism occurred at different locations (GRT-10 & GRT-14) and some valuable data were lost. This may be addressed by rethinking our installation protocol, trying to place the units more discretely, and looking for instream anchoring locations that are less likely to be discovered, removed, and/or tampered with.

Placement of thermistors in the stream channel was found to be an important consideration as well. For example, the original thermistor site at Whitney Bridge was located on the comparatively shallower and more exposed right bank (facing downstream) of the Green River. Before this unit went missing sometime following the first data retrieval, it showed a broader range of daily values, and a higher daily average than other mainstem sites regardless of whether they were located upstream or downstream. When the replacement thermistor was deployed, it was installed on the opposite side of the river in order to be in deeper water, less exposed and less prone to disturbance. This would be a great location to have thermistors on either bank in order to quantify the differences inherent between less exposed thalweg sampling sites and more exposed shallow bar sites.

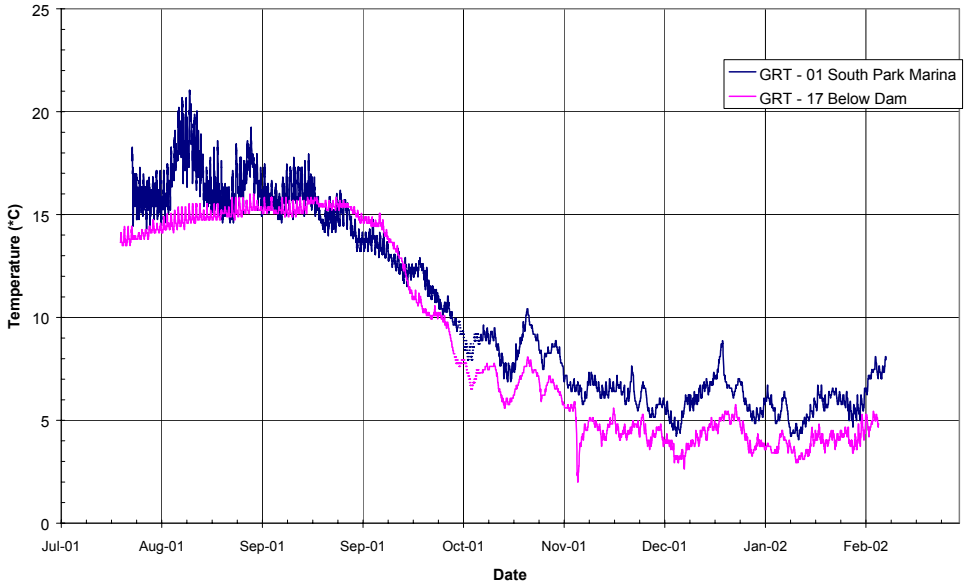

Figure 3. Plot of uppermost site (GRT-17) and the lowermost site (GRT-01) on the mainstem Green-Duwamish River

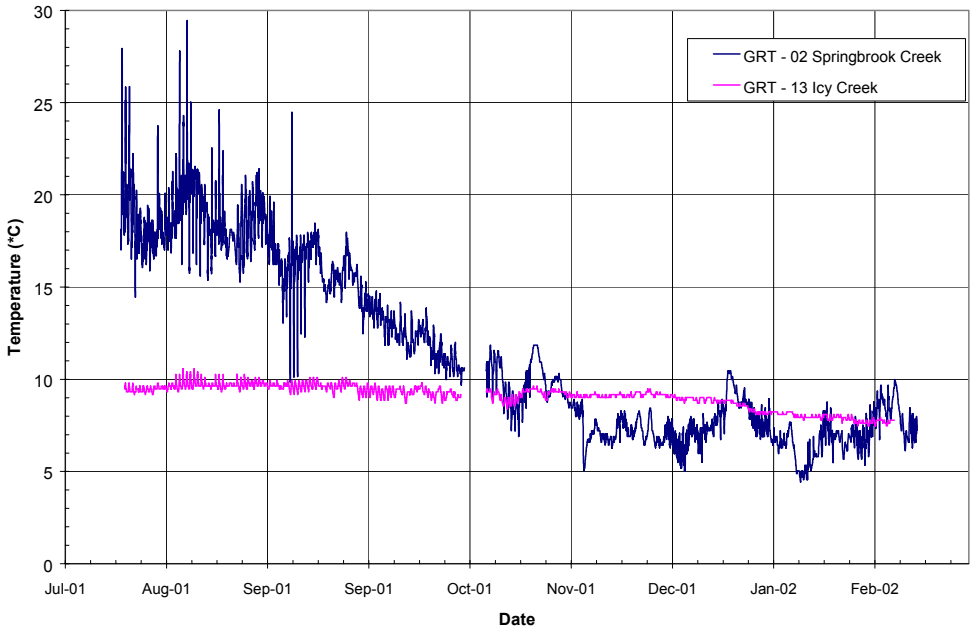

Figure 4. Plot the thermistor locations with the least (GRT-13) and most (GRT-02) variation in recorded water temperatures.

3. ONGOING & HISTORICAL TEMPERATURE STUDIES

Temperature data has been collected by multiple agencies/organizations over the years. This section presents an overview of these studies and their results. A time of ten years was selected as a cut-off in presenting temperature data due to the large number of studies with temperature being recorded. Appendix A contains a list of these studies. In this section, a few of these historical temperature studies are discussed. They are grouped according to the type of data collection. Some older studies are also reviewed because of the longer data record and their usefulness in studying long-term temperature trends.

3.1. Discrete Data Collection

Discrete data collection studies are those in which temperature was measured once during a set time period, such as once a month or once a day.

3.1.1. King County:

3.1.1.1. Water and Land Resources Division (WLRD)

Since 1970, ongoing ambient monitoring of streams within the Green watershed occurs monthly at 23 stations (Figure 5). Temperature is one of several field parameters measured during each water quality sampling event. Figure 5 displays the locations of the current STREAMS program sample sites. Numerous other sites throughout the watershed have been sampled, but are no longer active.

Duwamish River water temperatures have been recorded monthly at stations 0305, 0307, 0309 and 0311 (Figure 5). These stations have seen an overall increase of maximum temperatures of approximately 2°C since the 1970s (Kerwin, J. and Nelson, T.S. (Eds.). 2000; Figure 6). The frequency of freshwater temperature criterion exceedances has increased from one in the 1970s to three in the 1980s, and seven from 1990 to 1998. The frequency of marine water temperature criterion exceedances has increased from three in the 1970s to 13 in the 1980s, and 15 from 1990 to 1998. However, due to sampling depth (0.5 m) and location of stations 0307 and 0309, the freshwater water criterion is more applicable. Using the freshwater criterion for the 16th Avenue and East Marginal Way bridge stations, and the marine criterion at the West Waterway Spokane Street Bridge station, there was one exceedance in the 1970s, three in the 1980s, and six in the 1990s (through 1998).

3.1.1.2. Soos Creek Basin

There has been a trend towards increasing temperatures at most tributaries in the urban and urbanizing areas of the region over the past 20 years, probably attributable to urbanization and development and loss of riparian vegetation (King County, 2002b).

A recent analysis of 20-year trends (1980-99) in King County streams examined trends for data collected at 223 sites including four stations (A320, C320, D320, G320) in the Soos Creek Basin (Figure 7). Time-series plots were used as a preliminary screening tool to examine trends. If a trend was suggested by the time-series plot, the data were then assessed using a Seasonal Kendall's Trend test to test for statistically significant trends.

Temperature has increased at 19 of 23 sites in the study over the 20-year period, including three of four in the Soos Creek basin (based on the Seasonal Kendall's Trend test) (Figure 7, for Soos, Covington,

Jenkins, and Little Soos creeks). The report (King County, 2000) concluded that most of this increase is probably attributable to urbanization and development, including increased stormwater runoff, and loss of riparian vegetation. This is because there were no temperature trends detected for the same period from two sites on the Middle Green River (stations A319 and B319), both of which are in areas that have experienced little development.

3.1.1.3. Surface Water Management Division (SWM)

In August and September of 1994, 17 mainstem and tributary sites between Fort Dent Park at river mile 12 and Cumberland-Kanasket Bridge at RM 58 were visited 6 times to collect air and water temperature, dissolved oxygen, and conductivity data. Mainstem temperatures ranged from 15.3 to 22.2 ºC.

3.1.1.4. METRO

In 1992, METRO measured temperature at four sites on the lower and middle Green River. The reported summer morning maximum temperatures ranged from 17 to 22.7 ºC for the following areas:

near I-405 and Fort Dent Park (RM 12)	21-22.7 ºC
above Soos Creek (RM 34)	18 ºC
Whitney Bridge (RM 41.5)	17-18 ºC.

3.1.2. Army Corp of Engineers

The Army Corp of Engineers owns the telemetry and gauging/staff equipment that is operated by the U.S. Geological Survey. Temperature measurements are recorded at the Howard Hanson Dam outfall *currently looking into timeframe and dataset size*.

3.1.3. City of Tacoma

The City of Tacoma records temperature at the Tacoma Diversion Dam. (*looking into timeframe and dataset size*)

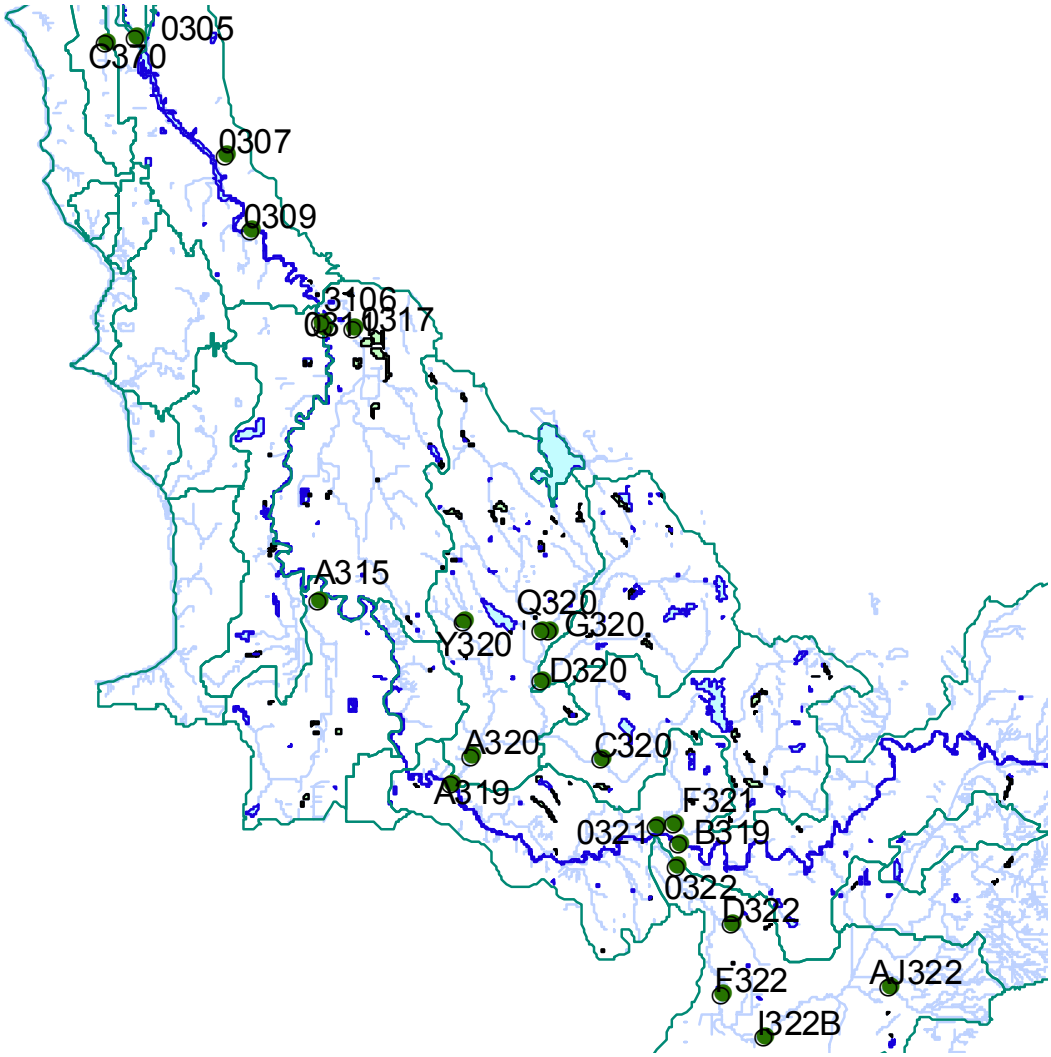

Figure 5. King County Streams water quality locations as of 2002.

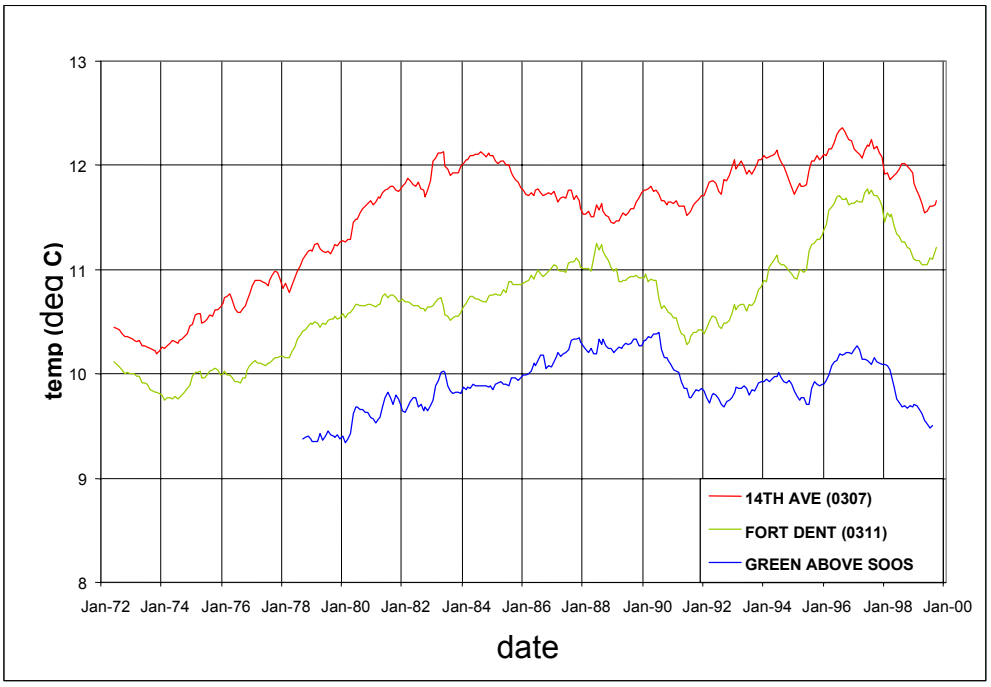

Figure 6. Plot of discrete water temperature data with a 5-yr moving mean for selected STREAMS sampling sites: 0307, 0311, and A319.

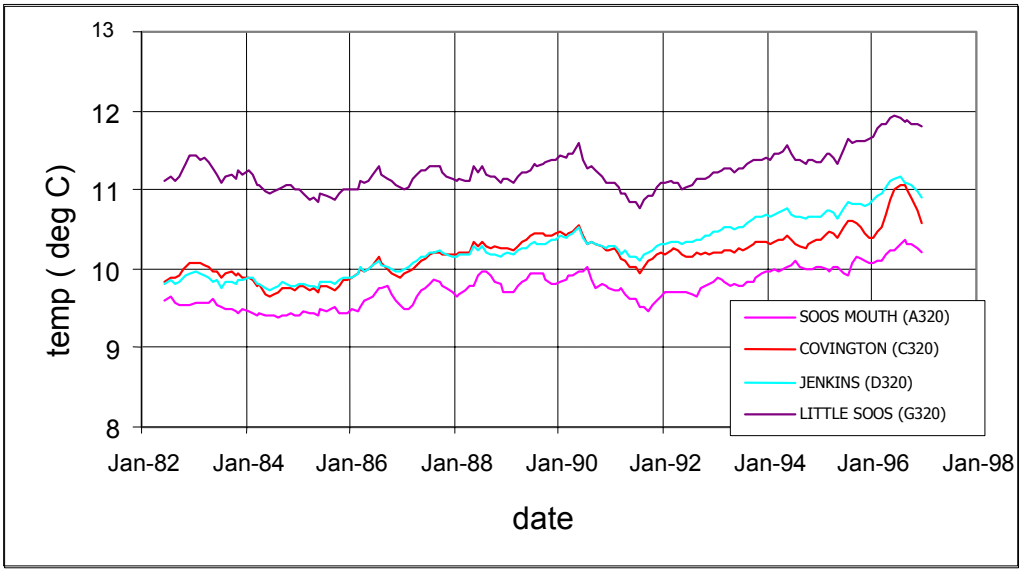

Figure 7. Plot of discrete water temperature data with a 5-yr moving mean for Soos Creek Basin stream sampling sites: A320, C320, D320, and G320.

3.2. Continuous Data Collection

Continuous data collection refers to studies that record temperature numerous times throughout the day. Most of these studies recorded temperatures at 15 minute intervals during summertime. Hourly temperatures were typically recorded if they were monitored during other seasons.

3.2.1. King County:

3.2.1.1. WLRD

King County operates numerous gauging stations throughout the Green / Duwamish watershed as well as the rest of King County. Seventeen of these stations are within the GD-WQA project boundaries and they have continuous temperature recorders. Table 5 summarizes this information and Figure 8 displays their location on a map.

Table 5. King County stream gage sites with continuous water temperature recorders.

GAGE NUM	SITE_NAME	GAGETAG	STATUS	DATE INSTALLED
03F	Mill Creek (north) ab. Kent Facility, B317	Streamflow, Water Temperature	Active	03/01/02
03G	Springbrook at O'Grady, A317	Streamflow, Water Temperature	Active	11/01/01
09A	Covington Creek near Mouth, at 168th WY SE	Streamflow, Water Temperature	Active	10/01/94
26A	Jenkins Creek near Mouth	Streamflow, Water Temperature	Active	10/01/94
40D	Crisp Creek at Green River RD, F321	Streamflow, Water Temperature	Active	10/01/97
44F	Green WQA-Urban, I322B	Streamflow, Water Temperature	Active	02/01/01
44G	Green WQA-Agricultural, D322	Streamflow, Water Temperature	Active	01/22/01
54A	Soos Creek at Mouth	USGS streamflow, KC Water Temp.	Active	10/01/94
54C	Green WQA-Residential, Y320	Streamflow, Water Temperature	Active	03/01/81
54H	Soosette Creek Above SR 18	Streamflow, Water Temperature	Active	10/01/95
54I	Little Soos Creek at 164thAV SE	Streamflow, Water Temperature	Active	10/01/94
HC5	Hamm Creek South Fork, A307	Streamflow, Water Temperature	Active	10/01/98
mf1	Mill Creek (south) near Peasley Canyon,	Streamflow, Water Temperature	Active	10/01/98

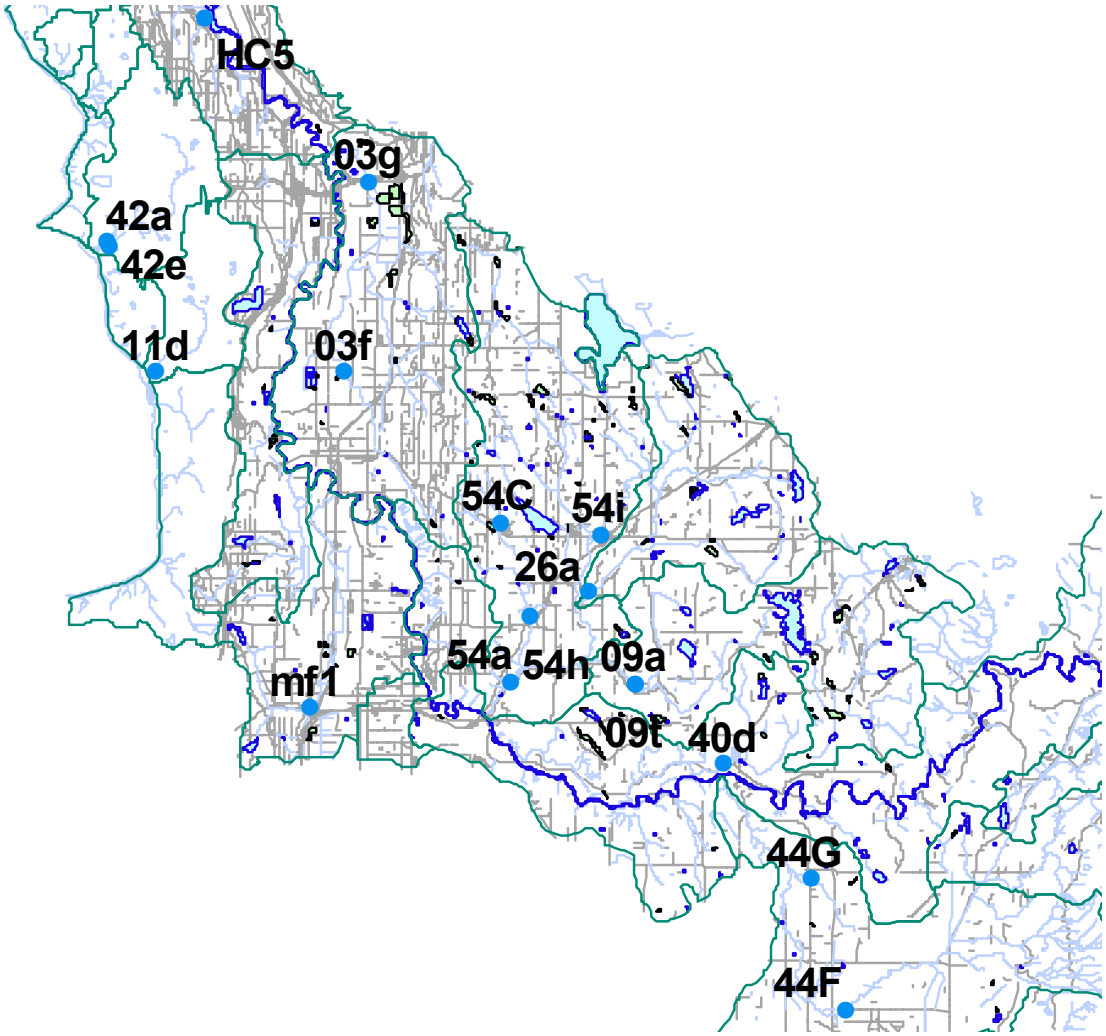

Figure 8. King County stream gage sites with continuous temperature recorders.

3.2.1.2. SWM

In 1995, SWM monitored eight stations along the Green River for air and water temperature, and two other stations were monitored only for water temperature (Figure 9). By monitoring both air and water temperature, it was reasoned, temperature changes can be traced as the river seeks atmospheric equilibration. These sites are located from Bicentennial Park at RM 13 upstream to the Cumberland-Kanasket Bridge at RM 58 (Table 6). The furthest downstream station, Bicentennial Park, was selected to avoid temperature effects derived from the salt wedge and tidal influence of Puget Sound waters. Table 7 summarizes the daily maximum water temperatures for July and August 1995.

3.2.2. Muckleshoot Indian Tribe (MIT) Studies

The Muckleshoot Indian Tribe completed two main studies that investigated temperature in the Green River. The first was entitled "Green River Water Temperature Characteristics" (Fishery Sciences, 1984). This study's purpose was to compile stream temperature information

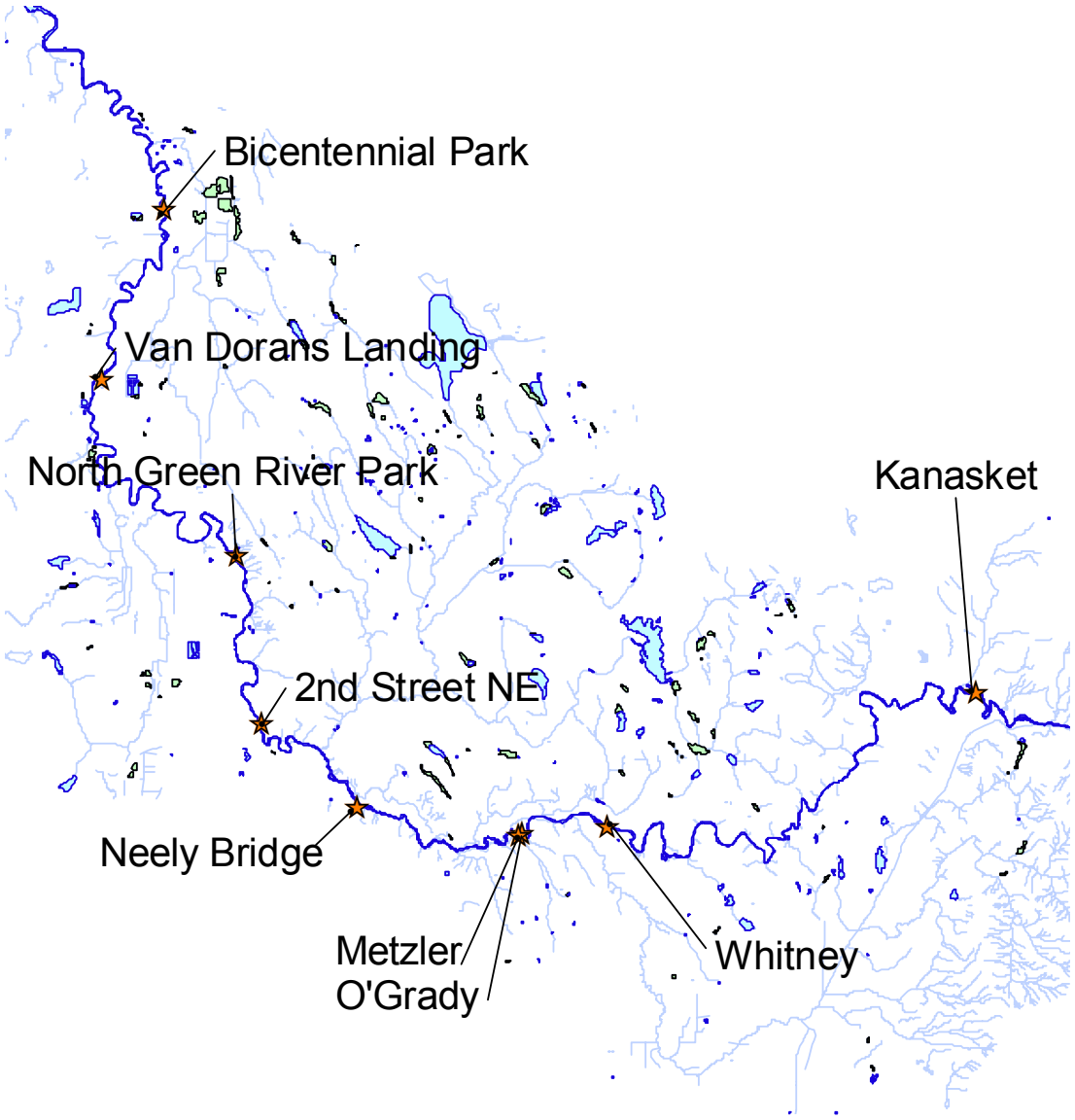

Figure 9. Locations for 1995 King County SWM continuous temperature study.

pertaining to the Green-Duwamish River watershed, determine if problems exist, and discuss the extent of and possible solutions to any problems.

The second study, entitled "Green River Temperature Investigation 1992" (Caldwell, 1994), summarized temperature data collected by the Muckleshoot Tribe on the mainstem of the Green River in the summer and early fall of 1992. This was partly in response to a Army Corps of Engineers report (Grette and Salo, 1986) that indicated that elevated Green River temperatures caused a delayed upstream migration of early-run fall chinook and may also influence use of the lower Green River by juvenile steelhead, chinook, and coho. The objective of the study was to document temperatures in the Green River between RM 12 and RM 64.5, describe the extent and duration of high summer temperatures, and investigate temperatures in deep pools and shallow stream margins. The following conclusions were drawn from this study:

- The maximum summer temperatures in 1992 were 23.5 °C and 22.5 °C at RM 35 (Neely Bridge) and RM 41.5 (Whitney Bridge), respectively, during mid August;

- Temperatures over 18 °C were measured between two and three times more often at RM 13 (in the lower Green River) than RM 41.5 (Middle Green River); and

- Temperatures in deep pools between RM 35 and 41.5 were found to be the same as in other habitats except for shallow stream margins in the same reach had the potential to be 0.5-2.0 °C higher than deeper habitats, depending on whether the shallow water was flowing or standing. In the shallow waters, water velocities and not water depth was the most important factor influencing temperatures.

There were three temperature stations in the Lower Green River included in the MIT's study in 1992. The stations were located along the mainstem in Tukwila (RM 13), Kent (RM 20) and Auburn (RM 27). The following findings were presented for the Lower Green River:

- The maximum summer temperatures in July and August were between 23.0 and 24.0 °C at RM 13. The degree-hours value above 18.0 °C (an indicator of the duration of elevated temperatures) was three times the value measured in the Middle Green (RM 41.5). Minimum temperatures at RM 13 during July and August were high, 15-16 °C, compared to most other stations;
- The maximum summer temperatures were 23.0 and 22.5 °C at RM 20 and 27, respectively. The degree-hour values above 18.0 °C were approximately 70 and 50 percent, respectively of the value at RM 12; and the study concluded that these temperatures were within the range where salmon would avoid this reach if possible. It was also concluded that there is potential for blockage or delay of upstream migration of adult fish in August.

3.2.3. U.S. Geological Survey: Puget Sound NAWQA

The Puget Sound NAWQA assembled temperature data for all basins draining into Puget Sound. Within the Green/Duwamish Basin, 18 sites were chosen to represent temperature conditions during the late 1990s. It is important to note that some of these sites are duplicative with the King County data collected in 1995 and 1998. The following link is reference for this information: http://wa.water.usgs.gov/pugt/green/greenmap.html and this information is presented in Table 8 from upstream to downstream. Summaries of daily maximum water temperatures are presented in Tables 7, 9 and 10.

The maximum summer temperatures for the USGS only sites during the 1996-1997seasons ranged from 15.1 to 23.1 ºC. The lowest temperatures were recorded in the Lester region (above Howard Hanson Dam) and the highest recorded temperatures were from the Mill Creek site.

The USGS operates numerous streams gages within King County and a few of these locations record temperature. The gage at Auburn had collected continuous temperature data from 1952 - 1986. From 1963-1986, the maximum summer temperatures ranged from 18 to 22.5ºC.

Table 6. King County 1995 Water and Air Temperature Monitoring Locations and Available Historical Data.

Site	*Approx. River Mile*	*Water Gage*	*Air Gage*	*Historical Temperature Data at Site or Nearby*[1]
Cumberland-Kanasket Bridge	58	X	X	KC
Whitney Bridge	42	X	X	MIT, KC

Metzler side channel	40	X		None
O'Grady side channel	40	X		None
Neely Bridge	35	X	X	MIT, KC
Auburn	32	X	X	USGS, KC
North Green River Park	26	X	X	MIT, KC
Van Doran's Landing Park	19	X	X	MIT, KC
Bicentennial Park	13	X	X	MIT, KC

[1]"MIT" refers to the *Green River Temperature Investigation*; "KC" refers to King County's 1992 temperature study; "USGS" is temperature data recorded at the USGS gage.

Table 7. Summary of daily maximum temperatures for King County's 1995 data.

Location\Date	River Mile	Jul-95	Aug-95	Max Summer Temp.
Kanasket	58	19.6 ºC	19.9 ºC	19.9 ºC
Whitney Bridge	42	23.1 ºC	21.9 ºC	23.1 ºC
Neely Bridge	35	22.7 ºC	21.6 ºC	22.7 ºC
Auburn-2nd St	32	21.2 ºC	19.0 ºC	21.2 ºC
North Green Rvr Park	26	22.7 ºC	21.1 ºC	22.7 ºC
Bicentennial Park	13	22.4 ºC	22.9 ºC	24.4 ºC

The "max summer temp." is the maximum recorded value for this time period.

3.2.4. University of Washington Temperature Study

The University of Washington (UW) is involved in a 3-year pilot study looking at ways to accurately predict water temperatures based on remotely sensed data. As part of this study, UW has been recording continuous temperature data within the Soos Creek Basin. Initially in 2000, UW installed 13 probes to record water temperatures. The number of probes increased in spring of 2001 to 19 water temperature probes. In addition to water temperature, this study is also recording air and ground temperature at selected sites. Table 11 lists these sites from headwaters to the mainstem Green River as well as presenting the maximum recorded temperatures at these locations. Appendix D contains figures of the temperature monitoring locations as presented by UW temperature study's web site (http://depts.washington.edu/strmtemp/).

3.2.5. City of Kent

An effort to monitor temperature during the summer season at 26 locations is ongoing by the city of Kent. The duration of this effort is unknown at this time. Current and future communication efforts will yield more specific information about this study including its timeline and data availability.

Table 8. USGS Puget Sound NAWQA water temperature locations.

Location	Source	Dates	RM
Green River above Twin Camp Creek near Lester	**USGS**	1996-1997	90.7
Intake Creek near Lester (1997 ONLY)	**USGS**	1996-1997	0.3
Green River near Kanasket (Kanasket/Palmer)	**KC**	1995	58.0
Green River near Black Diamond (Whitney Bridge)	**KC**	1995	42.0
Newaukum Creek near Black Diamond	**USGS**	1996-1997	0.8
Crisp Creek near Black Diamond (KC gage 40D)	**KC**	1998	0.9
Green River above Soos Creek near Auburn (Neely Bridge)	**KC**	1995	35.0

Little Soos Creek near Covington (KC gage 54I)	**KC**	1998	0.6
Jenkins Creek near Covington (KC gage 26A)	**KC**	1998	0.4
Soosette Creek near Covington (KC gage 54H)	**KC**	1998	1.3
Big Soos Creek above Hatchery near Auburn	**USGS**	1996-1997	0.9
Green River below Big Soos Creek near Auburn (2nd Street NE)	**KC**	1995	32.0
Green River near Auburn (USGS gage 12113000)	**KC**	1998	32.0
Green River at Kent (North Green River Park)	**KC**	1995	26.0
Mill Creek near mouth at Orillia	**USGS**	1996-1997	0.1
Green River above Black River at Tukwila (Bicentennial Park)	**KC**	1995	13.0
Springbrook Creek at Tukwila	**USGS**	1996-1997	1.0
Duwamish River at Golf Course at Tukwila	**USGS**	1996-1997	10.4

RM refers to the approximate river mile for that waterway.

Table 9. Summary of daily maximum temperatures from the USGS 1996-1997.

Location\Date	River Mile	Jul 96	Aug 96	Summer 1996	Jul 97	Aug 97	Summer 1997	Max Summer Temp.
Green River	90.7	15.8	14.9	15.8	13.4	14.5	14.5	15.8
Intake Creek	0.3	--	--	--	14.2	15.1	15.1	15.1
Newaukum Crk	0.8	19.5	18.5	19.5	17.7	18.1	18.1	19.5
Big Soos Creek	0.9	20.1	19.4	20.1	19.4	19.4	19.4	20.1
Mill Creek	0.1	23.1	20.4	23.1	21.8	22.3	22.3	23.1
Springbrook Crk	1.0	20.5	19.2	20.5	19.2	19.2	19.2	20.5
Duwamish River	10.4	19.5	19.0	19.3	16.9	18.9	18.1	18.7

-- refers to a location where temperature was recorded only 1 summer season; "max summer temp." is the maximum recorded value for this time period. All temperature measurements are presented as degree Celsius.

Table 10. Summary of daily maximum temperature for King County's 1998 data

Location\Date	River Mile	Jul-98	Aug-98	Max Summer Temp.
Crisp Creek near Black Diamond; (40d)	0.9	15.6	15.6	15.6
Little Soos Creek near Covington; (54I)	0.6	19.7	22.9	22.9
Jenkins Creek near Covington; (26a)	0.4	17.8	17.3	17.8
Soosette Creek near Auburn; (54h)	1.3	20.0	18.1	20.0
Green River near Auburn; (USGS)	32.0	22.9	21.4	22.9

The "max summer temp." is the maximum recorded value for this time period. (XX) refers to the gauging location where the temperature data was recorded. All temperature measurements are presented as degree Celsius.

Table 11. University of Washington water temperature sites and maximum temperatures.

Stream name	Site id	summer 2000	spring 2001
Big Soos	BS1	19.0	18.9
Big Soos	BS1.6	--	23.4

Big Soos	BS1.5	--	18.0
Big Soos	BS2	15.6	16.3
Big Soos	BS3	17.8	17.2
Little Soos	LS2	--	18.9
Little Soos	LS1	22.3	19.7
Jenkins	JE2	13.9	13.5
Jenkins	JE1	18.3	14.2
Jenkins	JE26	17.3	*
Lake Sawyer	LKSR1	--	23.3
Covington	CO1	25.1	22.2
Covington	CO2	17.9	18.5
Covington	CO4	14.1	16.0
Covington	CO9	17.8	*
Soos (mainstem)	SO1	19.4	17.1
Green River	GR3	--	14.7
Green River	GR1	21.0	15.9
Green River	GR2	20.6	*

"--" refers to sites that were added in 2001; "*" refers to sites where maximum water temperature data not reported for Spring 2001. All temperature measurements are presented as degree Celsius.

3.2.6. Mt. Baker - Snoqualmie National Forest (USFS)

In the early 1990s, continuous temperature data were recorded at 9 different locations during summer to early fall. These locations are in the Upper Green River Basin above the Howard Hanson Dam. The maximum recorded temperatures at these locations ranged from 12.2 °C to 16.7 °C.

4. FUTURE NEEDS

This section presents areas/needs that should be addressed by future work. The GD-WQA will be expanding the temperature study started by the reconnaissance work in the Summer of 2002.

4.1. Data Gaps

This section summarizes data gaps in continuous temperature data collection started by the Reconnaissance Temperature Study. (*no real order at present*)

- A need for more sites that are currently being monitored to precisely model temperature throughout the Green Duwamish watershed. Some basins have abundant thermistors, such as Soos Creek Basin, while other, such as Mill Creek/Mullen Slough, have little.
- More lower Green mainstem sites would be useful. Between Porter Levee (RM35) and the South Park Marina (RM5), there are no mainstem thermistor sites.
- Determining influences of known cold water inflows such as Icy Creek and Palmer Ponds. Additional thermistor deployments upstream and downstream of these cold water inflows may be helpful in quantifying the relative cooling provided by these larger volume spring fed tributaries.
- Outlets of lakes (e.g., Lake Sawyer, Lake Meridian)
- Lack of thermistors at most water quality sampling (GD-WQA) sites.
- Determining additional warm water inputs to the Green, such as Springbrook Creek.
- The need to obtain more localized meteorological information. Air temperature, relative humidity, wind speed, and incident solar radiation all are important factors influencing stream temperatures.
- Little to no physical site assessment data. These data are likely to include riparian cover, degree of cover, thickness of cover and many others.
- Little bathrymetric data showing deeper pool areas.

4.2. Additional Research Factors

In addition to temperature, other factors should be considered that affect thermal regimes or exist due to these thermal regimes. Other areas worthy of more detailed focus are as follows:

4.2.1. Dissolved Oxygen and Temperature:

When temperatures are high, it has been found that dissolved oxygen is correspondingly low. Further investigation of oxygen levels in the river below Kent, where high water temperatures were observed, would confirm whether dissolved oxygen concentrations are low enough to hinder salmonids and migration, as well as to define the extent and duration of the problem. If they are low, management actions could include modification of the channel and river bottom to create turbulence for oxygen mixing (and diverse habitat conditions as well). Intermittent mechanical mixing could also be initiated.

4.2.2. Benefits of added riparian shading:

While the Green River is too wide in many reaches for riparian vegetation to directly shade the entire channel, temperature differences were measured between reaches of similar elevation and different riparian character (Caldwell, 1994). Maximum temperatures were similar, but the extent and duration of high temperatures was lower in reaches with riparian trees and/or trees on top of diked banks. A modest modeling effort could supply managers with information regarding potential benefits of increased shading. Other benefits of upgraded riparian areas such as improvement of nearshore habitats and potential improvement in macroinvertebrate populations exist as well and can be described in a qualitative way.

4.2.3. Temperatures and Flow:

1) Quantity of Flow: The impact of altered flow regimes and associated temperature impacts have not been quantified. With proposals for altered flow regimes being examined by City of Tacoma and the ACOE, a modeling effort could predict the impact of these proposed changes on instream temperatures. A quantification of this relationship would allow assessments of temperature as a limiting factor in conjunction with minimum instream flows. Management actions could include augmentation of flow during critical times. Flow augmentation could be from Howard Hanson Dam.

2) Flow Velocity: A factor shown to be more influential in water temperature regimes was not water depth, but water velocity. Shallow slow-velocity lateral areas (side channels and along bars) tended to have higher temperatures than the deeper areas where the river was well mixed at the temperature of the whole river (Caldwell, 1994). These lateral areas are important potential juvenile rearing habitat. This implies that an important function of summer flow levels may be in keeping shallow edge and lateral habitats mixed with the main river flow. An important effect of lowered summer flows may not just be dewatering of shallow habitats, but their thermal disconnection at flows where water is still present but not moving. The temperatures observed in these side channels were potentially life threatening to salmonids, causing fish to move into deeper water, which may in turn expose them to increased predation by larger fish (Bjornn and Reiser, 1991).

3)Howard Hanson Dam (HHD) releases: Inflow temperatures to the HHD reservoir exceed 16^{o}C during the summer in most years (ACOE 1995). As a result of drawing water from the lower, colder stratum, releases from HHD during the early summer are usually below expected normal temperatures. Later in the summer and in early fall, as cooler water is depleted and warmer surface water is released, temperatures are higher than would be expected under a natural, unimpounded flow. These artificially higher temperatures can adversely affect salmon spawning behavior and may accelerate maturation of developing salmon eggs (TPU, 1999).

4.3. Sampling and Analysis Plan

The Reconnaissance Temperature Study has laid the foundation for creating a Sampling and Analysis Plan (SAP) for a continuous temperature study. This SAP will detail the process of data collection for continuous water temperature monitoring as well as outling and obtaining the necessary input parameters for water temperature modeling.

This study will include additional stations for water temperature monitoring, collection of meteorological data (e.g., solar radiation, air temperature, relative humidity), soil/ground temperature, and groundwater temperatures. In addition, information will be collected on riparian conditions, such as vegetation, shading, slope, and aspect that affect water temperature conditions.

Appendices

A. List of temperature related Reports (Present to 1990) on the Green / Duwamish Watershed (report_T_table.xls) See separate pdf file.

B. Data from Recon (2001) monitoring (..\2001-2002 Thermistors\GreenTemp2001.xls)

C. Data from KC SWM (1995) monitoring (..\1995 Data & Support\Green95 sorted.xls)

D. Data from UW Temperature Study (http://depts.washington.edu/strmtemp/).

References:

ACOE. 1995. Howard Hanson Dam Draft EIS for Operation and Maintenance. U.S. Army Corps of Engineers. Seattle District. Seattle, WA.

Bjornn, T.C. 1978. Survival, production, and yield of trout and chinook salmon in the Lemhi River, Idaho. University of Idaho, College of Forestry, Wildlife and Range Sciences Bulletin 27, Moscow.

Bjornn, T. C. and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 83-138.

Caldwell, J. E. 1994. Green River Temperature Investigation 1992. Muckleshoot Indian Tribe, Auburn, WA.

Davis, J.C. 1975. Minimal Dissolved Oxygen Requirements of Aquatic Life with Emphasis on Canadian Species: a Review. Journal of Fisheries Resources Board of Canada, vol. 32(12). 2295-2332.

Fishery Sciences. 1984.

Grette and Salo. 1986. The Status of Anadromous Fishes of the Green/Duwamish River System. U.S. Army Corps of Engineers, Seattle, WA.

Hicks, M. 2000. Preliminary review draft discussion paper: Evaluating standards for protecting aquatic life in Washington's surface water quality standards. Temperature criteria. Washington State Department of Ecology. Water Quality Program. Olympia, WA.

Hicks, M. 2001. Evaluating standards for protecting aquatic life in Washington's surface water quality standards. Temperature criteria. Draft discussion paper and literature summary. Washington State Department of Ecology. Water Quality Program. Olympia, WA. Prb. No. 00-10-070.

Kerwin, J. and Nelson, T.S. (Eds.). 2000. Habitat Limiting Factors and Reconnaissance Assessment Report, Green/Duwamish and Central Puget Sound Watersheds (WRIA 9 and Vashon Island). Washington Conservation Commission and King County Department of Natural Resources. Seattle, WA.

King County. 2000. Water quality monitoring of streams draining to the Sammamish River and Northern Lake Washington: Draft report. King County Water and Land Resources. Seattle, WA

King County. 2002a. Scope of Work: Green-Duwamish Watershed Water Quality Assessment. Department of Natural Resources & Parks. Water and Land Resources Division. Seattle, WA

King County. 2002b. Water Quality Monitoring of Northern Lake Washington Streams. King County. Department of Natural Resources & Parks. Water and Land Resources Division. Seattle, WA

NOAA. 1996. Coastal salmon conservation: working guidance for comprehensive salmon restoration initiatives on the Pacific coast. National Marine Fisheries Service. National Oceanic and Atmospheric Administration. Seattle, WA.

TPU. 1999. Tacoma Water Habitat Conservation Plan. Tacoma Public Utilities. Tacoma, WA.