Quality Assurance Project Plan

Upper Yakima Basin Temperature Total Maximum Daily Load Study

by
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303(d) Listings for Temperature Addressed in This Study:

Waterbody Name	Twnshp	Rng	Sec	New ID #	Old ID #	Year Listed
Big Creek	20N	14E	29	OY16AG	WA-39-1073	1996, 1998 *
Cabin Creek	20N	13E	9	CX24KB	WA-39-1075	1996, 1998 *
Cherry Creek	17N	19E	31	FT68CJ	WA-39-1032	1996, 1998 *
Cooke Creek	19N	20E	20	SZ58XV	WA-39-1034	1996, 1998 *
Cooke Creek	17N	19E	21	SZ58XV		*
Log Creek	20N	13E	19	SP21BV	WA-39-1077	1996, 1998 *
Lookout Creek	19N	14E	21	HI56TE	WA-39-1558	1996, 1998 *
Manastash Creek, S.F.	17N	17E	17	WW44PW	WA-39-3020	1996, 1998 *
Meadow Creek	21N	11E	13	CL02YY	WA-39-1350	1996, 1998 *
Naneum Creek	19N	19E	3	MA29CN	WA-39-1025	1996, 1998 *
Swauk Creek	20N	17E	3	EQ32WA	WA-39-1400	1996, 1998 *
Swauk Creek	20N	17E	15	EQ32WA	WA-39-1420	1996, 1998 *
Taneum Creek	18N	17E	4	WF36AI	WA-39-1520	1996, 1998 *
Taneum Creek	19N	16E	28	WF36AI		*
Williams Creek	20N	17E	2	BI77WY	WA-39-1425	1996, 1998 *
Wilson Creek	17N	19E	30	PY59BF	WA-39-1020	1996, 1998 *

* Pending on approval of the Environmental Protection Agency to include these waterbodies in the 2002/2004 303(d) list.

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June 2005

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Abstract

The upper Yakima Basin has been selected for a temperature Total Maximum Daily Load (TMDL) study as required by the Federal Clean Water Act section 303(d). Data gathered by governmental, tribal, and private organizations were the basis for placing certain stream segments on the 1996, 1998, and 2002/2004[1] 303(d) lists for temperature.

This Quality Assurance (QA) Project Plan describes the technical study that will evaluate stream temperature in the upper Yakima Basin from Umtanum Creek north to the Wenatchee National Forest. Continuous temperature, streamflow, and groundwater data collection is planned for the summer of 2005. Data collection will build on previous efforts conducted by a variety of governmental and private organizations.

Water temperature will be characterized and load and wasteload allocations established to reduce heat sources in the system to achieve water quality standards. Washington State Department of Ecology cooperatively works with the Wenatchee National Forest (U.S. Forest Service), Kittitas County Water Purveyors, Kittitas County Conservation District, Kittitas Reclamation District, Yakama Nation, Bureau of Reclamation, Washington State Department of Fish and Wildlife, and the public.

[1] List has been submitted to EPA but has not been approved at the date of publication.

Introduction

The upper Yakima Basin Temperature TMDL will characterize water temperature and establish load and wasteload allocations to reduce heat sources in the system to meet water quality standards for surface water temperature. The high interest in water quality issues in this basin is demonstrated by the level of cooperative sampling and water management. Ecology hopes to build on previous efforts and work cooperatively with all contributing entities to generate a better understanding of stream temperatures in this basin.

The upper Yakima Basin resides in Water Resource Inventory Area (WRIA) 39. Figure 1 depicts the TMDL study area including 303(d) listed segments.

Project Objectives

The proposed study has the following objectives:

Characterize summer (June-September) stream temperature of the Yakima River tributaries (WRIA 39).

- Compile existing and historical data including: data collected by Kittitas Reclamation District, United States Forest Service, Yakama Nation, U.S. Bureau of Reclamation, and other potential data sources discovered during the study.

- Collect additional data in cooperation with Kittitas Reclamation District and other watershed groups.

Develop a predictive computer temperature model for Umtanum Creek, Taneum Creek, and Naneum Creek.

- Model the instream temperature regime at critical conditions.

- Evaluate the ability of various watershed Best Management Practices (BMPs) to reduce water temperature to meet water quality standards.

Establish a TMDL for temperature in the upper Yakima River tributaries.

- Develop a TMDL for thermal load to the stream (usually expressed as incoming solar radiation in units of Langleys/day).

- For ease of implementation, load allocations may be reported in terms of surrogates for solar radiation, such as shade, size of tree necessary in the riparian zone to produce adequate shade, channel width, channel width-to-depth ratio, or miles of active eroding stream banks.

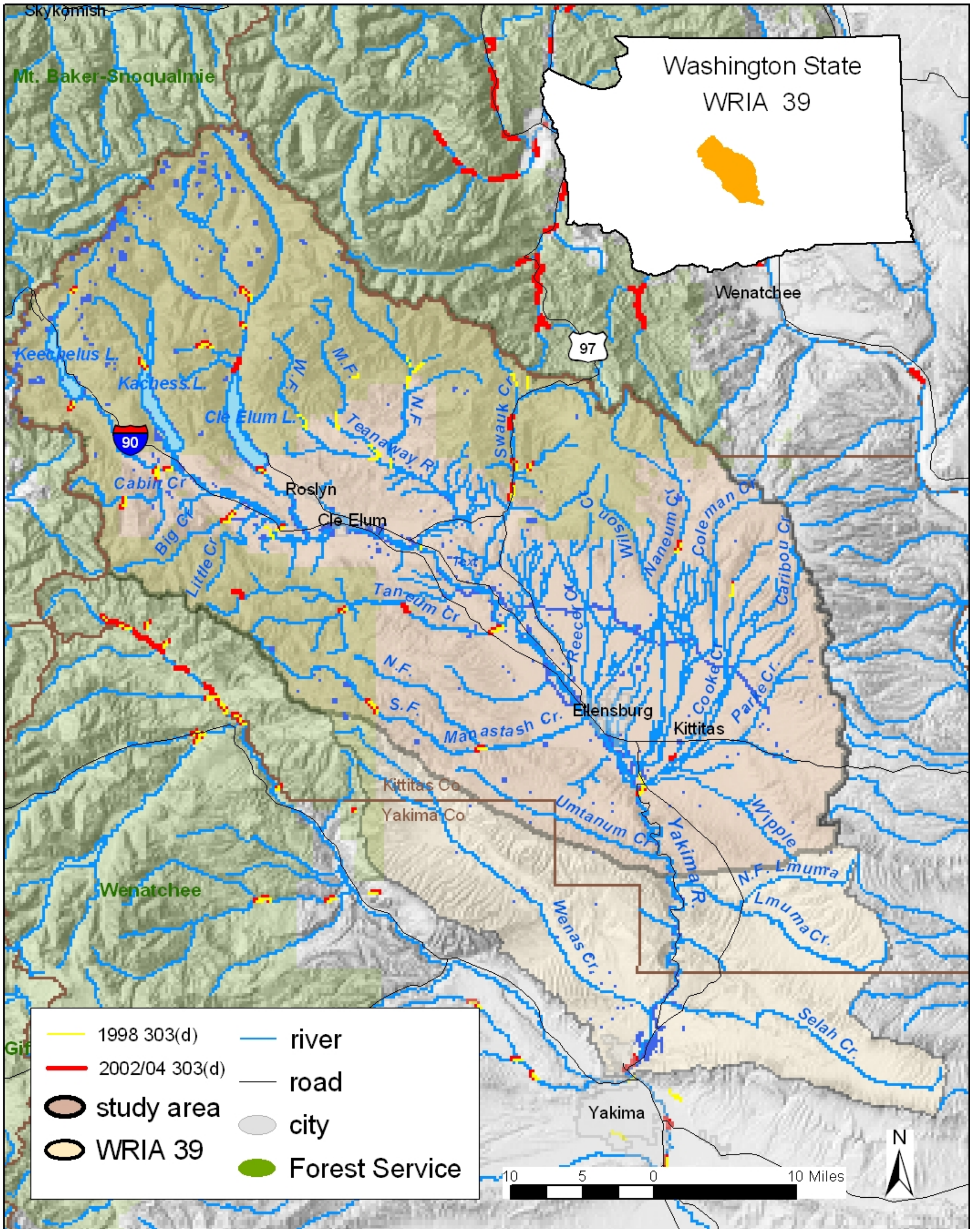

Figure 1. Upper Yakima Basin Temperature TMDL Study Area and Water Resource Inventory Area 39.

Water Quality Standards and Beneficial Uses

Water Quality 303(d) Listings
Ecology submitted and EPA approved lists of impaired waters, referred to as the 303(d) list after the relevant section of the Clean Water Act, in 1996 and 1998. Ecology has submitted, but has not received approval for the 2002/2004 list. The 2002/2004 version includes "listing categories" 1 through 5. All of the categories together represent the statewide assessment of Washington's water quality. Only Category 5 constitutes the 303(d) list of impaired waters. These waters require the preparation of TMDLs in accordance with the Clean Water Act. Table 1 lists the 303(d) stream segments impaired by temperatures, including Category 5 streams under the 2002/2004 guidelines. Note that Table 1 includes impaired stream segments addressed in this TMDL only (WQP Policy 1-11).

Table 1. Federal 303(d) Listed Streams Impaired by Temperature Addressed in the Upper Yakima Basin Total Maximum Daily Load (TMDL).

Waterbody Name	Twnshp	Rng	Sec	New ID #	Old ID #	Year Listed
Big Creek	20N	14E	29	OY16AG	WA-39-1073	1996, 1998 *
Cabin Creek	20N	13E	9	CX24KB	WA-39-1075	1996, 1998 *
Cherry Creek	17N	19E	31	FT68CJ	WA-39-1032	1996, 1998 *
Cooke Creek	19N	20E	20	SZ58XV	WA-39-1034	1996, 1998 *
Cooke Creek	17N	19E	21	SZ58XV		*
Log Creek	20N	13E	19	SP21BV	WA-39-1077	1996, 1998 *
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Meadow Creek	21N	11E	13	CL02YY	WA-39-1350	1996, 1998 *
Naneum Creek	19N	19E	3	MA29CN	WA-39-1025	1996, 1998 *
Swauk Creek	20N	17E	3	EQ32WA	WA-39-1400	1996, 1998 *
Swauk Creek	20N	17E	15	EQ32WA	WA-39-1420	1996, 1998 *
Taneum Creek	18N	17E	4	WF36AI	WA-39-1520	1996, 1998 *
Taneum Creek	19N	16E	28	WF36AI		*
Williams Creek	20N	17E	2	BI77WY	WA-39-1425	1996, 1998 *
Wilson Creek	17N	19E	30	PY59BF	WA-39-1020	1996, 1998 *

* Pending on approval of the Environmental Protection Agency to include these waterbodies in the 2002/2004 303(d) list.

Yakima Mainstem and other listings immediately below the three large reservoirs (Table 2) will not be addressed during this phase of the upper Yakima Basin TMDL project.

Table 2. Temperature Impaired Waterbodies on the 303(d) List Not Directly Addressed During the First Year of This Study.

Waterbody Name	Twnshp	Rng	Sec	New ID #	Old ID #	Year Listed
Yakima River	20N	13E	10	EB21AR	WA-39-1070	1996, 1998 *
Yakima River	20N	14E	36	EB21AR	WA-39-1060	1996, 1998 *
Cle Elum River	20N	14E	10	XN92GU	WA-39-1050	1996, 1998 *

* Pending on approval of the Environmental Protection Agency to include these waterbodies in the 2002/2004 303(d) list.

Category 2 are *Waters of Concern* and consist of waterbodies with some evidence of elevated temperatures, but insufficient data to approve them as impaired on the 303(d) list (WQP Policy 1-11). Waters of concern within the study area are Blue Creek, Caribou Creek, Cascade Canal, Cherry Creek, Cle Elum River, Cooke Creek, French Cabin Creek, Naneum Creek, North Branch Canal, Parke Creek, Thorp Creek, Town Canal, Umtanum Creek, Wilson Creek, Whipple Wasteway, and the Yakima River. Because temperature issues in the basin are not limited to the segments reported on the 303(d) list, this study concentrates not only on the temperature concerns of the listed segments but those in the entire study area as well.

Wenatchee National Forest Streams

The Wenatchee National Forest Water Temperature TMDL Technical Report developed load allocations for shade on USFS designated lands in WRIA 39 (Whiley, 2003). Therefore, this temperature TMDL will develop load allocations for all land within the study area, excluding Wenatchee National Forest land. Table 3 lists streams located within the Wenatchee National Forest with specified load allocations.

Forests and Fish Streams

Private timberlands fall under the jurisdiction of the Forests and Fish Agreement, which establishes riparian vegetation density targets for these lands (DNR, 1999). Because land use in the basin consists of a mix of public and privately managed timberlands, small private resorts and cabins, and irrigated agriculture, the basin is considered a mixed use watershed. In accordance with the section of Forests and Fish Agreement titled *TMDLs Produced Prior to 2009 in Mixed Use Watersheds*, load allocations will be developed in this TMDL for forest lands in the upper Yakima Basin Temperature TMDL study area. Also consistent with the Forests and Fish Agreement, implementation of the load allocations established in this TMDL for private and state forestlands will be accomplished via implementation of these forest practice regulations (DNR, 1999).

Table 3. Waterbodies Within the Wenatchee National Forest and WRIA 39 Included on the 1996 and 1998 303(d) Lists for Water Temperature.

Water Body	Subsection	WRIA	1996 WBID	1998 WBID	Township, Range, Section	1996 List	1998 List
Cooper R.	Co	39	WA-39-1055	WX84IT	22N,14E,16	X	X
Gale Ck.	Co	39	WA-39-1300	RZ54RL	22N,13E,32	X	X
Gold Ck.	Co	39	WA-39-1390	ZS28LG	22N,11E,01	X	X
Iron Ck.	Cn	39	WA-39-1440	YW62RW	21N,17E,03	X	X
SF Manastash Ck.	Cc	39	WA-39-3025	WW44PW	18N,15E,36	X	X
SF Taneum Ck.	Co	39	WA-39-1570	WJ69FI	19N,15E,27	X	X
Waptus R.	Co	39	WA-39-1057	XB92PJ	22N,14E,04	X	X
Blue Ck.	Cn	39	WA-39-1435	BU07PV	21N,17E,02	X	X

Water Quality Standards

The Washington State water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code (WAC), include designated beneficial uses, waterbody classifications, and numeric and narrative water quality criteria for surface waters of the state. Water quality classifications specific to the upper Yakima River Basin are in Table 4.

Table 4. Stream Classifications and Water Quality Temperature Standards of the Upper Yakima River Including Tributaries as Defined by WAC 173-201A.

Waterbody Name	Class	Standard (°C)
Yakima R., from mouth to Cle Elum R.(river mile 185.6)	A	21*
Yakima R. from Cle Elum R. (river mile 185.6) to headwaters	AA	16
Cle Elum R.	AA	16
Umtanum Cr.	A	18
Naneum Cr.	AA and A	16 or 18
Taneum Cr.	AA and A	16 or 18
All non-specified streams in Forest Service land	AA	16
All non-specified tributaries to an AA	AA	16
All non-specified tributaries to an A	AA or A	16 or 18

* Special condition.

Waterbodies not specifically classified under WAC 173-201A-130 or 173-201A-140 are accounted for in WAC 173-201A-120 General Classifications. The non-specified waterbodies that reside in national parks, national forests, or wilderness area are classified as AA or Lake. Non-specified tributaries of classified streams must be of equal or better classification. Non-specified streams flowing into Lake Class are Class AA unless otherwise specified.

Under Chapter 173-201A-030 WAC, numeric freshwater water quality criteria for Class AA, Class A, and Lake Class are described in the following designations:

- *Class AA.* Freshwater temperature shall not exceed 16.0°C due to human activities. When natural conditions exceed 16.0°C, no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C. Incremental temperature increases resulting from point source activities shall not, at any time, exceed t=23/(T+5), where T represents the background waterbody temperature and t is the maximum permissible temperature increase measured at the edge of the mixing zone. Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C when the temperatures are less than the standard.
- *Class A.* Water temperature shall not exceed 18.0°C due to human activities. When natural conditions exceed 18.0°C, no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C. Incremental temperature increases resulting from point source activities shall not, at any time, exceed t=28/(T+7). Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C.
- *Lake Class.* The water quality standards do not include numeric temperature targets, but lakes must maintain no measurable change from natural conditions.

The EPA is currently reviewing Ecology's proposed water quality rules revisions that will replace the 1997 standards following federal approval. In the proposed rule revision, the waterbody classification system is replaced by a beneficial-use-based designation. Under the new rule, waterbodies are required to meet water quality standards based on the beneficial uses of the waterbody. Once the water quality standards are approved, all ongoing studies must target any new numeric values. Revised values are derived differently than current values. Current values are based on daily maximums; revised values are derived from a 7-day maximum rolling average. Most current information and status on this revision can be found at http://www.ecy.wa.gov/programs/wq/swqs/rev_rule.html.

For example, a proposed change to the temperature standard includes *Core and non-core fish habitat*. These two designations refer to the quality of the spawning and rearing habitat. These will be very similar to the Class AA and A designations for extraordinary and excellent waters.

Beneficial Uses

Land use activities in the upper Yakima Basin include timber harvest, grazing, extensive irrigated agriculture, urbanization, and recreation. Important water use for agriculture and cities requires strong consideration when addressing water-related issues such as water quality. (USGS, 2005)

The water quality standards establish beneficial uses of waters and incorporate specific numeric and narrative criteria for water quality parameters. The criteria are intended to define the level of protection necessary to support all beneficial uses. The following lists beneficial uses of the waters in this specific area.

- *Municipal and Agricultural Water Supply and Stock Watering*. Agriculture and municipalities in the subbasin utilize both surface and groundwater.

- *Fish and Shellfish*. Spring Chinook salmon (*Oncorhynchus tshawytscha*), rainbow/summer steelhead trout (*Oncorhynchus mykiss*) bull trout/dolly Varden (*Salvelinus confluentus*), and mountain whitefish (*Prosopium williamsoni*) are the salmonid species in the upper Yakima River Basin. In the basin along the Yakima River, spring Chinook and summer steelhead spawn or rear from Yakima up to the base of the three reservoirs (Keechelus, Kachess, and Cle Elum), including tributaries such as Umtanum, Caribou, Coleman, Manastash, Taneum, Swauk, Little, Big, and Teanaway. Bull Trout furthermore utilize headwaters including creeks that flow into the three reservoirs. Other fish also reside in the watershed such as sculpin and suckers.

- *Wildlife Habitat*. Riparian areas are used by a variety of wildlife species dependent on the habitat.

- *Recreation*. Fishing, swimming, rafting, and boating.

Of the above listed beneficial uses, the one most affected by water temperature is the protection of fish resources in the watershed. Salmonids, amphibians, and certain aquatic insects are highly sensitive to temperature. High water temperatures can affect these species by decreasing the oxygen supply in the water, disrupting metabolism, increasing susceptibility to toxins, increasing vulnerability to disease, reducing ability to avoid predators, and reducing food supply.

Project Description

Study Area

The upper Yakima Basin is located on the eastern flank of the Cascade Mountains in central to southern Washington. The TMDL study area drains 1,594 square miles (2565.3 km^2) from the headwaters to the downstream boundary at Umtanum Creek (USGS, 2002). upper Yakima Basin streams fall within three ecoregions: the Cascade, East Cascade Slopes Foothills, and Columbia Basin (Figure 2).

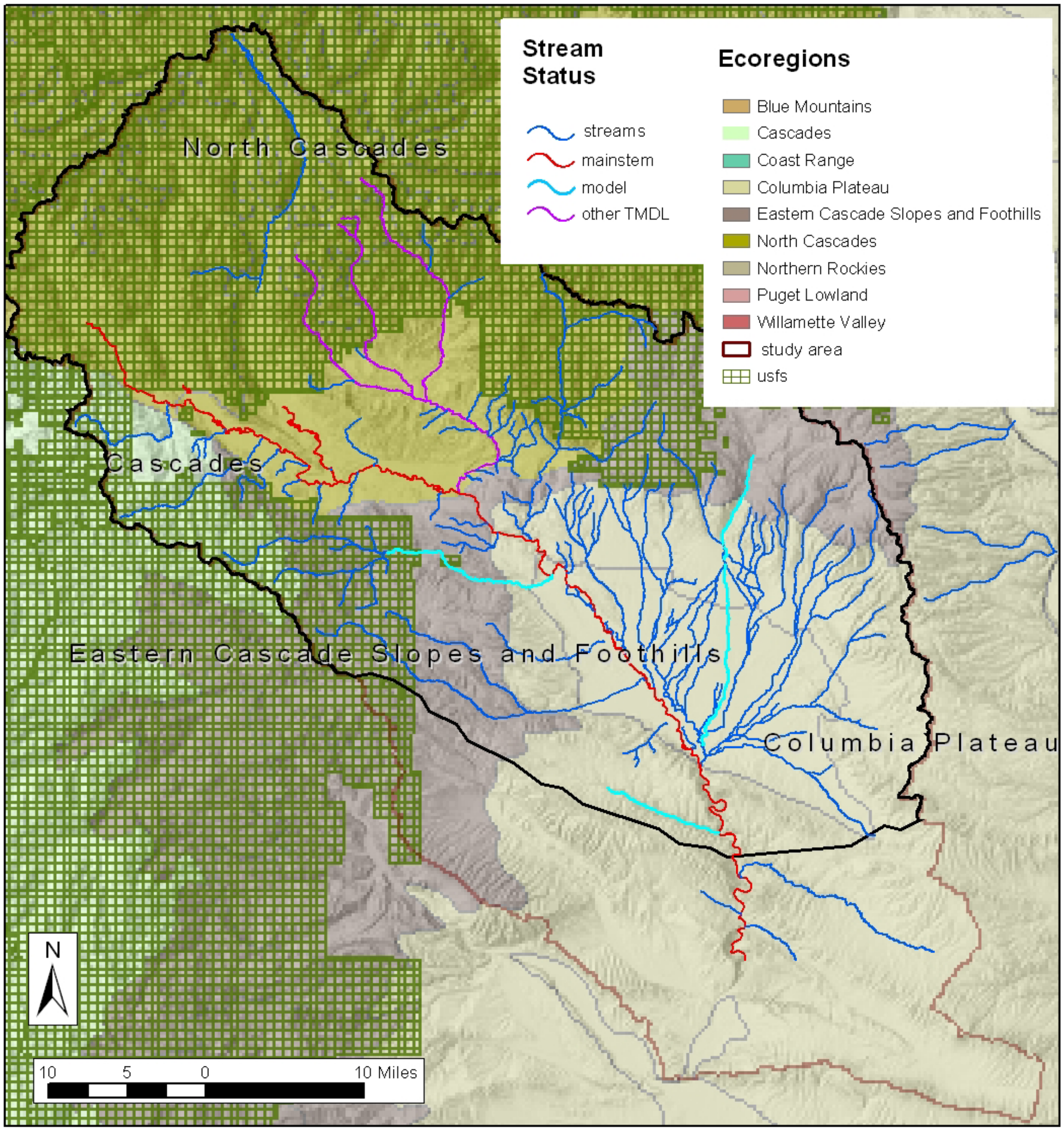

Figure 2. Ecoregions of Washington State and Watershed Resource Inventory Area (WRIA) 39.

Headwaters begin in the Wenatchee National Forest located to the north and west of the Yakima River. Designated Wilderness Area accounts for approximately 114 square miles located north of the three lakes (Keechelus, Kachess, and Cle Elum Lakes) and elevations of 8184 feet above mean sea level (USBR 2002). Forest and shrubs cover the majority of this area. Snowpack and glacier runoff together with precipitation naturally charge the river system with both surface water and groundwater inputs. Virtually all of the streams in the basin originate from these higher elevations and the snowpack provides most of the water for irrigation and streamflow.

Headwaters of tributaries east of the Yakima River, near Ellensburg and Kittitas, originate at relatively lower elevations (maximum heights of approximately 3950 feet). These streams flow through mixed-land stewardship. These headwaters are not part of the Cascade Range but instead transition to the Columbia Plateau. The vegetation is primarily shrub steppe with deciduous vegetation in the stream riparian areas. Conifers are also present especially in the higher elevations. Snowpack is ephemeral and contributes far less water to the system when compared to the Cascades. However, the Columbia Plateau represents an important aquifer system (Haring 2001).

Targeted Study Streams

Study streams include tributaries to the Yakima from river mile (RM) 140.4 upstream to National Forest Land. The study does not include tributaries to the Yakima River downstream of Umtanum Creek (RM 140.4) because there are no current 303(d) listings for temperature in that portion of WRIA 39. In addition, a multi-parameter TMDL technical assessment is underway for Selah Ditch and will establish load allocations for instream temperature (Bohn, 2005).

Ecology has resources to intensively study and develop a temperature model for three tributary streams in the basin during this phase of the upper Yakima Basin temperature project. The current proposal is to concentrate efforts on the following:

1. Taneum Creek.
2. Umtanum Creek.
3. Naneum Creek.

Swauk Creek may be modeled depending on available resources.

These streams flow through different ecoregions (Figure 2) and represent different areas of the watershed. In addition, these streams flow through relatively different geologic features and land-use practices. This study plans to extrapolate resulting conclusions about stream temperature causes and load allocations to tributaries that are not modeled but lie in a similar setting.

Although intensive work is planned for a subset of streams, continuous temperature monitor deployment is planned for a larger area. Monitoring locations are discussed in the Study Design section.

Stream sections that lie within National Forest boundaries, such as the upper Cle Elum and Kachess, have been addressed by the Wenatchee National Forest Water Temperature TMDL Technical Report (Whiley, 2003). In addition, a separate temperature TMDL has been completed for the Teanaway River (Stohr and Leskie, 2000). The upper Yakima TMDL will not address streams that are covered under these two documents. See the Historical Data Review section in this document for further descriptions of the other TMDLs.

Development of a predictive temperature model for the Mainstem Yakima River is not planned for this portion of the study. However, mainstem temperature data collection by KRD, and others, is continuing this year and will be very important for temperature modeling purposes at a future time. Because Mainstem Yakima River flows are highly managed and largely dependent on dam operations at the three large reservoirs, successful design of a temperature modeling project would require clear goals and participation from all agencies and co-resource managers far in advance of the project. Because this year is expected to have lower flows than normal, and because TMDL projects usually set load allocations based on a low flow that occurs for one week in only one out of ten years, this is an important year to maintain temperature monitoring in the mainstem. An additional year of study during 2006 is the most likely scenario, but the current scope of this study does not project that far in the future.

Taneum Creek

Taneum Creek flows through three ecoregions. Its headwaters begin in the Cascade ecoregion, the largest portion flows through the Eastern Cascades Slopes and Foothills ecoregion, and a short section near the confluence with the Yakima is in the Columbia Plateau ecoregion. (Figure 2). This watershed is largely undeveloped with some agricultural crop production and forestry (Haring, 2001). The lower watershed consists of private land ownership where four irrigation diversions exist from RM 3.5 to the Yakima confluence. The upper watershed includes a checkerboard of both private and public lands of Plum Creek and the United States Forest Service (USFS), respectively. Furthermore, Washington Department of Fish and Wildlife (WDFW) and the United States Bureau of Reclamation (USBR) manage most of the middle and lower sections of the watershed.

Taneum Creek joins the Yakima River at RM 166.1 on the right bank through a gently sloping alluvium. The upper reaches of Taneum Creek include steep canyons walls, upland meadows, and ridges over 6000 feet above mean sea level. At RM 12.7, the North Fork and South Fork join making Taneum Creek. The forks flow through heavily forested land for approximately 10 miles each.

The lower eight miles of Taneum Creek are Class A waters, while the portion above eight miles and into National Forest is Class AA waters. The Taneum watershed has four temperature impairments on the 303(d) list (Figure 1, Table 1, Table 3).

Taneum Creek supports resident and non-resident salmonids, with steelhead spawning and rearing in both forks. Spring Chinook experience limited upstream access at the Bruton diversion (CBSP, 1990; WDFW, 1998 as cited in Haring 2001).

Umtanum Creek

Umtanum Creek represents streams similar to those of the drier Columbia Basin ecoregion (Figure 2). Umtanum Creek joins the Yakima River at RM 140.4 on the right bank and drains approximately 64 square miles (103 km^2) with an approximate length of 16 miles. The watershed has very few roads and no development from the mouth to the falls at RM 7.8. This portion of the watershed supports nearly pristine deciduous and brushy riparian vegetation. In contrast, upstream of the falls there is far less riparian vegetation and habitat, with more development from roads, grazing, and seasonally inhabited homes. (Haring, 2001; USGS, 2002).

Naneum Creek

Naneum Creek represents many of the streams in the basin north and east of Ellensburg (Kittitas Valley agricultural area). The headwaters flow through the Eastern Cascades Slopes and Foothills ecoregion and the lower reaches flow through the Columbia Plateau ecoregion. Many creeks in this basin are relatively complex with many diversions and canal interactions. Upstream of the gate on Naneum Road there is limited human access; however, there are forest practice and power utility operations. Naneum Creek joins Coleman Creek that then discharges into Wilson Creek in the lower area of the watershed. Wilson Creek joins the Yakima River at RM 147.0 on the left bank.

Historically, the Kittitas Valley supported a shrub-steppe community with larger shrubs and trees near its many creeks. The creeks in the valley can naturally go dry without the contribution of irrigation. The higher elevation reaches support mixed conifer with some deciduous vegetation in the stream riparian zone. The lower watershed is almost entirely privately owned while the upper watershed has checkerboard ownership of public and private lands (Haring, 2001).

One 303(d) listing for temperature impairment exists on Naneum Creek (Figure 1 and Table 1). Many spring Chinook juveniles rear downstream of the lowermost passage barrier in the lower 2 to 4 miles of Wilson, Cherry, Naneum, Coleman, and Badger Creeks. Spring Chinook and steelhead spawn in these reaches as well (Haring 2001).

Climate

The climate in the upper Yakima Basin ranges from cool and moist in mountains to warm and arid in the valleys. Annual precipitation ranges from 80 to 140 inches near the Cascade crest to less than 10 inches in the valley. The western and northern parts of the basin primarily receive precipitation as snow during the months of November through March. Summer air temperatures range from 55°F (13°C) in the mountains to 82°F (28°C) in the valley (USBR 2002).

Climate Conditions for 2005

Predictions of summer streamflow for the Yakima Basin are available at www.wcc.nrcs.usda.gov/cgibin/newbor2.pl?state=wa&year=2005&month=5&basin=24. Streamflows in the Yakima are affected by reservoir storage, snowpack, summer precipitation, and water use. Status of the upper Yakima Basin as of May 1, 2005 when compared to normal is: reservoir storage is 97% of normal conditions, snowpack is 12%, summer precipitation is unknown, and water use is also unknown. Expectations are that summer streamflows will be much lower than normal because of the extremely low snowpack. Water sharing programs are being established to assist with the anticipated low flows and are expected to result in overall water use that is lower than normal. Actual flows that occur this summer are difficult to predict.

TMDLs typically calculate load allocations based on a low 7-day flow condition that only is expected to occur 1 out of every 10 years. If resulting flows for this summer are at that level, then the stream temperature analysis will need to make fewer assumptions. Analysis and modeling are also done for the lowest 7-day flow that is expected to occur every other year. This average condition modeling is done to help define an expected range of summer high temperatures. July and August are typical critical conditions for stream temperature. We expect to collect a large amount of streamflow data in July in case August flows in streams without agricultural input are much lower than a 1 in 10 year condition. If resulting flows ultimately are far lower, e.g. a 1 in 50 year condition, then data collection may need to occur a second year. Data collected in 2003 and 2004 by others in the basin can also be analyzed to allow a view of temperature conditions that have occurred under other flow scenarios.

Geology

The upper Yakima River Basin resides in two very different geologic provinces: the Cascade Mountain and the Columbia Plateau. The Cascade Mountains consists of continental and igneous formations. The Columbia Plateau consists of a series of basalt flows interspersed with sedimentary layers all collectively called the Columbia River Basalt Group. The alluvial basins are composed of glacial outwash filling in the Cle Elum, Kittitas, and upper Yakima valleys with sand, gravel, and silt (Haring, 2001).

Reservoirs

Four dams exist in the upper Yakima River Basin Study Area:

1. Kachess Dam and Lake.
2. Keechelus Dam and Lake.
3. Cle Elum Dam and Lake.
4. Easton Diversion Dam.

Collectively Kachess, Keechelus, and Cle Elum Lakes have an active capacity of 833,800 acre-feet. The lakes store and release water on a variable time scale based on snowpack, surface water runoff, amount of storage, irrigation needs, and fish behavior needs. Water is usually released beginning in July and ending near September. The United States Bureau of Reclamation (USBR) manages the reservoirs (United States Bureau of Reclamation, 2005).

The Yakima Basin irrigation system is a major component of the watershed with potential to influence instream temperatures. The irrigation system consists of a network of canals and existing stream beds with water primarily supplied by the reservoirs. Construction of some canals will allow them to pass under, or over, another stream at an intersection. Removable dikes along some of the canals can also divert, block, or take in the water where necessary.

From mid-April through November, streams carry more flow than canals early on. As the season progresses, canals gradually carry more flow than streams. In 1999, canals in the Wilson/Cherry Subbasin supplied approximately 4.5 times more the amount than that of streams (Joy, 1999).

Fish

The Federal Endangered Species Act (ESA) lists summer steelhead and bull trout as threatened in the upper Yakima Basin. Maps showing specific distribution can be found at www.nwr.noaa.gov/1salmon/salmesa/. In addition to salmonids, many other fish species of ecological importance utilize the study area.

Sources of Thermal Pollution

Thermal pollution can originate from point and nonpoint sources. Point source pollutants originate from a specific location such as a discharge from a municipal sewage treatment plant. In contrast, nonpoint source pollutant sources are distributed over a large area.

Point Source

The upper Yakima Basin Temperature TMDL will not address point sources that discharge directly into the Yakima River because the mainstem is not included. This includes the waste water treatment plants for the city of Cle Elum (NPDES permit #WA-002193-8) and Ellensburg (NPDES permit #WA-002434-1) and the Cle Elum Hatchery (NPDES permit #WA-G13501-6). The Hatchery acclimation ponds discharge seasonally from February to April and, therefore, do not affect temperature during the critical period. The mainstem of the upper Yakima River will be assessed for point source contributors at a future date.

The upper Yakima Basin Temperature TMDL will address the city of Kittitas water treatment plant as a point source (NPDES permit #WA-002125-3). Roslyn and Suncadia wastewater facilities will not be addressed because they discharge into Crystal Creek seasonally from October to May and at a time that does not coincide with the critical period. Furthermore, a project to combine Roslyn and Suncadia with the Cle Elum water treatment plant is underway.

Nonpoint Source

The upper Yakima Basin Temperature TMDL will be developed for heat (i.e., incoming solar radiation). Heat is considered a pollutant under Section 502(6) of the Clean Water Act. The transport and fate of heat in natural waters has been the subject of extensive study. Edinger et al. (1974) provide an excellent and comprehensive report of this research. Thomann and Mueller (1987) and Chapra (1997) have summarized the fundamental approach to the analysis of heat budgets and temperature in natural waters that will be used in this TMDL. Figure 3 shows the major heat energy processes or fluxes across the water surface or stream bed.

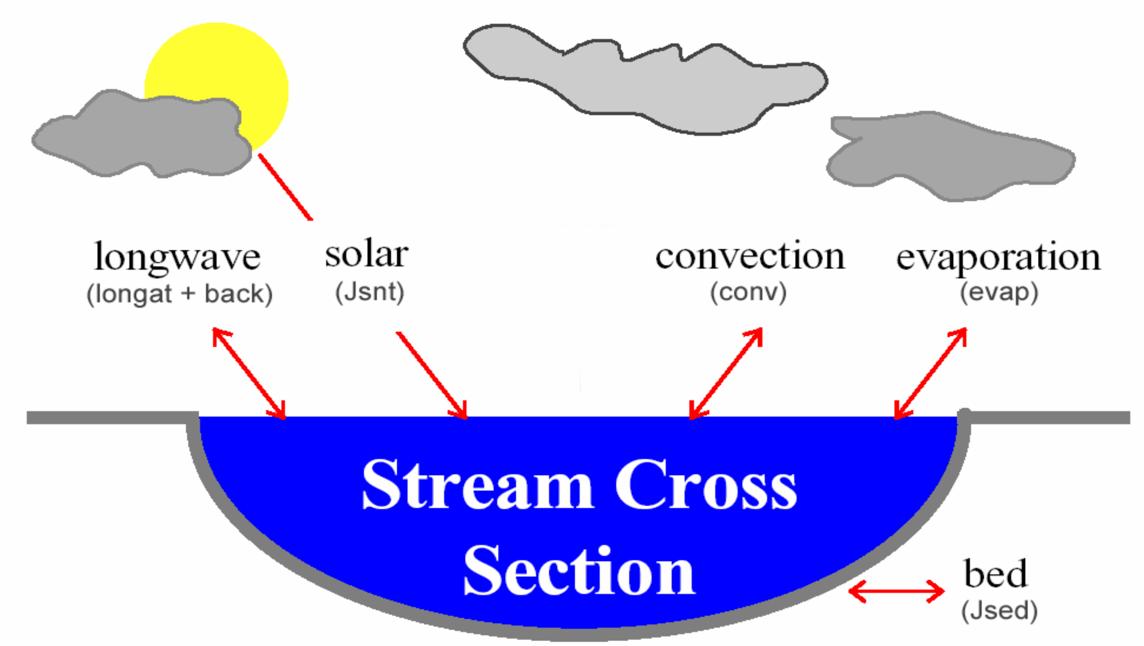

Figure 3. Surface Heat Transfer Processes That Affect Water Temperature.

Adams and Sullivan (1989) reported that the following environmental variables are the most important drivers of water temperature in forested streams:

- *Stream Depth.* Stream depth affects both the magnitude of the stream temperature fluctuations and the response time of the stream to changes in environmental conditions.

- Air Temperature. Daily average stream temperatures are strongly influenced by daily average air temperatures. When the sun is not shining, the water temperature in a volume of water tends toward the dewpoint temperature (Edinger et al., 1974).

- *Solar Radiation and Riparian Vegetation.* The daily *maximum* temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar heat flux. Daily *average* temperatures are less affected by removal of riparian vegetation.

- *Groundwater.* Inflows of groundwater can have an important cooling effect on stream temperature. This effect will depend on the rate of groundwater inflow relative to the flow in the stream and the difference in temperatures between the groundwater and the stream.

The heat exchange processes with the greatest magnitude are as follows (Edinger et al., 1974):

- *Shortwave Solar Radiation.* Shortwave solar radiation is the radiant energy that passes directly from the sun to the earth. Shortwave solar radiation is contained in a wavelength range between 0.14 μm and about 4 μm. The peak values during daylight hours are typically about three times higher than the daily average. Shortwave solar radiation constitutes the major thermal input to an unshaded body of water during the day when the sky is clear.

- *Longwave Atmospheric Radiation.* The longwave radiation from the atmosphere ranges in wavelength from about 4 μm to 120 μm. Longwave atmospheric radiation depends primarily on air temperature and humidity and increases as both of those increase. It constitutes the major thermal input to a body of water at night and on warm cloudy days. The daily average heat flux from longwave atmospheric radiation typically ranges from about 300 to 450 W/m^2 at mid latitudes.

- *Longwave Back Radiation from the Water to the Atmosphere.* Water sends heat energy back to the atmosphere in the form of longwave radiation in wavelengths ranging from about 4 μm to 120 μm. Back radiation accounts for a major portion of the heat loss from a body of water. Back radiation increases as water temperature increases. The daily average heat flux out of the water from longwave back radiation typically ranges from about 300 to 500 W/m^2.

The role of riparian vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in the scientific literature. Summer stream temperature increases due to the removal of riparian vegetation are well documented (for example Holtby, 1988; Lynch et al., 1984; Rishel et al., 1982; Patric, 1980; Swift and Messer, 1971; Brown et al., 1971; and Levno and Rothacher, 1967). These studies generally support the findings of Brown and Krygier (1970) that loss of riparian vegetation results in larger daily temperature variations and elevated monthly and annual temperatures. Adams and Sullivan (1989) also concluded that daily maximum temperatures are strongly influenced by the removal of riparian vegetation because of the effect of diurnal fluctuations in solar heat flux.

Summaries of the scientific literature on the thermal role of riparian vegetation in forested and agricultural areas are provided by Belt et al. (1992); Beschta et al. (1987); Bolton and Monahan (2001); Castelle and Johnson (2000); CH2MHill (2000); GEI (2002); Ice (2001); and Wenger (1999). All indicate that riparian vegetation plays an important role in controlling stream temperature. The important benefits that riparian vegetation has upon the stream temperature include the following:

- Near-stream vegetation height, width, and density combine to produce shadows that can reduce solar heat flux to the surface of the water.

- Riparian vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity, lower wind speeds, and cooler ground temperatures along stream corridors.

- Bank stability is largely a function of near-stream vegetation. Specifically, channel morphology is often highly influenced by land cover type and condition by affecting floodplain and instream roughness, contributing coarse woody debris and influencing sedimentation, stream substrate composition, and stream bank stability.

Rates of heating to the stream surface can be dramatically reduced when high levels of shade are produced and heat flux from solar radiation is minimized. There is a natural maximum level of shade that a given stream is capable of attaining, which is a function of species composition, soils, climate, and stream morphology.

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.

Mass transfer processes refer to the downstream transport and mixing of water throughout a stream system and inflows of surface water and groundwater. The downstream transport of dissolved/suspended substances and heat associated with flowing water is called advection. Dispersion results from turbulent diffusion that mixes the water column. Due to dispersion, flowing water is usually well mixed vertically. Stream water mixing with inflows from surface tributaries and subsurface groundwater sources also redistributes heat within the stream system. These processes (advection, dispersion, and mixing of surface and subsurface waters) redistribute the heat of a stream system via mass transfer. Turbulent diffusion can be calculated as a function of stream dimensions, channel roughness, and average flow velocity. Dispersion occurs in both the upstream and downstream directions. Tributaries and groundwater inflows can change the temperature of a stream segment when the inflow temperature is different from the receiving water.

Historical Data Review

A significant amount of data exists for most of the upper Yakima River Basin. This section provides a brief data review of the efforts most relevant to the present study and is not intended to encompass all historical data collection.

United States Bureau of Reclamation (USBR)

USBR has compiled large amounts of streamflow data, primarily at the reservoir releases and on the Mainstem Yakima River. USBR also monitors air and water temperatures at some locations. Data is available near-real-time for many sites through their Hydromet system on the internet (*http://www.usbr.gov/pn/hydromet/yakima/yaktea.html)*. The USBR plays a very active role in reservoir and streamflow management in the Yakima Basin. Daily streamflow and operations reports are also available on their internet site. Notable documents include the *Interim Comprehensive Basin Operating Plan for the Yakima Project Washington* (USBR, 2005).

The Kittitas County Water Purveyors (KCWP)

KCWP participates in a variety of activities in the upper Yakima River Basin that affect irrigated agriculture, water quality, and endangered species. KCWP is composed of Kittitas Reclamation District, Cascade Irrigation District, Ellensburg Water Company, West Side Irrigating Company, other irrigation entities, and private water-rights holders who collectively serve more than 91,000 acres of irrigated farmland in Kittitas County (KCWP, 2005). In recent years, the Kittitas Reclamation District (KRD) has collected large amounts of stream temperature data important for planning and modeling purposes. In 2003 and/or 2004, monitoring data was gathered on Naneum, Umtanum, Cabin, Cooke, Whiskey, Wilson, Currier, Parke, Badger, Caribou, Mercer, Teanaway, and Wipple. Figure 4 shows a summary of Maximum 7-day average temperatures collected by KRD and USFS for 2003. Figure 5 shows a temperature data graph of Naneum Creek from their website.

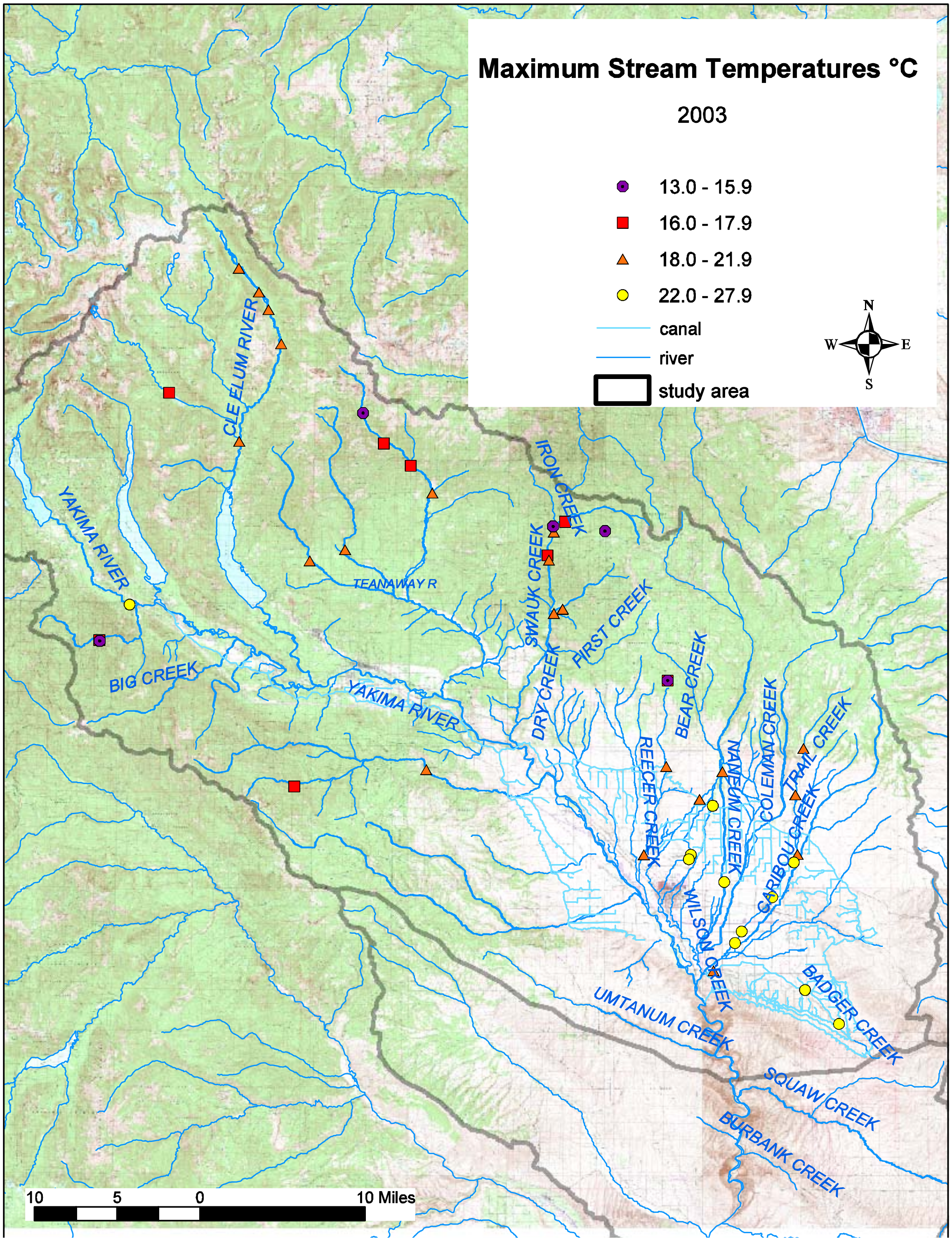

Figure 4. Maximum Stream Temperatures (°C) in the upper Yakima River Basin. Kittitas Reclamation District and United States Forest Service Provided These Data from 2003.

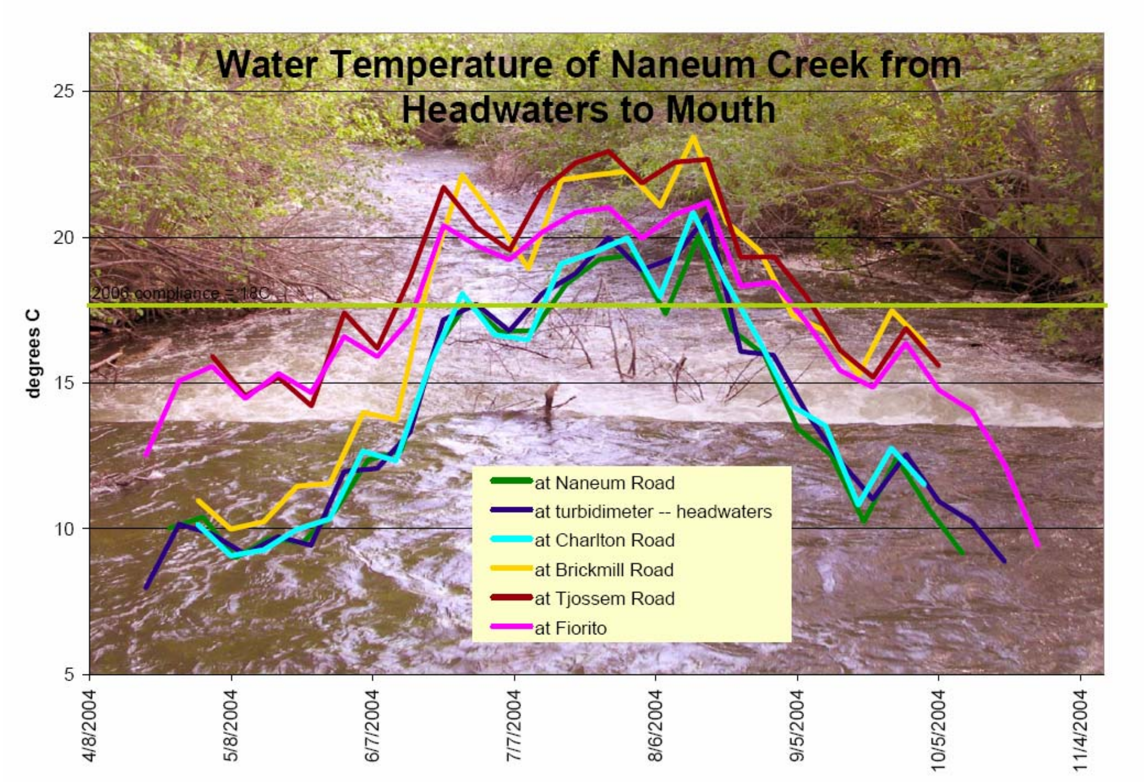

Figure 5. Water Temperature Graph for Naneum Creek, Provided by the Kittitas County Water Purveyors (Satnik and Olson, 2005).

The Reaches Project: Ecological and Geomorphic Studies Supporting Normative Flows in the Yakima River Basin, Washington

The Reaches Project investigated surface and groundwater interactions in the Yakima River watershed and identified the importance of floodplains as an integral part of a properly functioning ecosystem, particularly to fish. Piezometers were used to examine groundwater in five large reaches including the Cle Elum and Kittitas reaches. “Results indicated that, in most locations, groundwater was downwelling, or losing water, from the river into the hyporheic zone.” (Stanford, 2002, pg. 122) Exceptions to this generalization are some upwelling (groundwater migrating upward and into the surface water) near the Teanaway River near the Cle Elum reach. Areas more strongly influenced by upwelling of groundwater were moderated from the thermal regime in the main channel of surface water (Stanford, 2002).

Teanaway Temperature TMDL

The Teanaway Temperature TMDL was conducted during 1998 and the Detailed Implementation Plan was completed in April 2003 (Creech, 2003a). This TMDL concluded that increases in riparian shade, reduction in active channel width, and increases in streamflow can lower stream temperatures (Stohr and Leskie, 2000).

Wenatchee National Forest

A temperature TMDL technical report has been developed for the Wenatchee National Forest and will apply to the Forest Service land in the upper Yakima TMDL study area. The Wenatchee National Forest resides in WRIA 39 – upper Yakima, WRIA 38 - Naches, and WRIA 45 – Wenatchee. This TMDL established the effective shade levels necessary for temperature impaired waters on the 303(d) list to achieve the water quality standards. In addition, extrapolation of the stream classification system is applied to effective shade levels necessary to meet water quality standards throughout the forest. This study was completed in November 2003 (Whiley 2003).

USFS has consistently monitored a large number of stream sites in the upper Yakima Basin since the late 1990's. They have been a forerunner in data collection. Their data will be used in this study to establish water temperatures on, and emerging from, the forest. Some of the sites that USFS monitored in 2003 are shown in Figure 3.

Upper Yakima River Basin Suspended Sediment, Turbidity, and Organochlorine Pesticide TMDL Detailed Implementation Plan

This TMDL provides analysis of the data and includes action recommended for meeting water quality goals. Although this TMDL is not temperature specific, it does provide flow and temperature data as well as cooperative efforts from many organizations (Creech, 2003; Joy, 2002). Furthermore, relating all possible data and suggestions about a particular watershed allows us to better understand the ecological system. A collective understanding will make efforts to more efficiently and effectively protect and improve the environment.

Habitat Limiting Factors Analysis

In 1998, the Washington State Conservation Commission was tasked in House Bill 2496 with assessing the habitat-based factors limiting the success of salmonids in Washington State. Habitat Limiting Factors Reports are available for most Water Resource Inventory Areas (WRIAs) in the state. The conservation commission worked with a watershed Technical Advisory Group (TAG) to author the report for the upper Yakima (Haring, 2001). The TAG included members from tribes, local county groups, fisheries agencies, conservation districts, timber management groups and others. Some of the report findings are discussed below.

Fish habitat includes the biological, chemical, and physical components of the environment such as water quality, water quantity, stream morphology, riparian zones, upland terrestrial conditions, and ecosystem interactions lending to habitat. These components intertwine closely. For example, low streamflows can alter water quality by increasing temperatures and decreasing the amount of available dissolved oxygen, and concentrating toxic materials.

Historically, high annual spring flows defined the natural streamflow regime for the upper Yakima Basin. Gradually these flows taper off as fall approaches and groundwater becomes the primary contributor of streamflow. However, the basin's natural flow regime has been altered such that the spring runoff is stored and gradually released throughout the summer through hundreds of diversions as well as the existing natural rivers (United States Bureau of Reclamation, 2005). Resident bull trout have altered the timing of spawning to account for this altered timing of flow but remain challenged by subsequent alterations to habitat. Anadromous fish experience greater challenges because their migration often coincides with high flows. The altered flow regimes in the upper Yakima River Basin influence fish habitat and behavior.

Anadromous and resident fish need a certain amount of streamflow for reproduction and migration both upstream and downstream. The System Operations Advisory Committee (SOAC) evaluates factors affecting the production and survival of salmon and steelhead. The members of SOAC include fishery biologists from the U. S. Fish and Wildlife Service, Yakama Indian Nation, Washington Department of Fish and Wildlife, and irrigation entities known collectively as the Yakima Basin Joint Board. SOAC cooperates with the USBR in jointly recommending the processes and procedures to establish a biologically-based flow regime. Well managed biologically based flow will increase the opportunity of fish survival (SOAC, 1999).

Additional Data

The upper Yakima Basin is studied by a variety of organizations such as: Washington State Department of Fish and Wildlife (WDFW), USDA-Forest Service, Wenatchee National Forest, Cle Elum Ranger District (USFS), United States Geological Survey, United States Geological Survey (USGS), Yakama Nation, Kittitas County Conservation District and others.

Study Design

The TMDL technical assessment for the upper Yakima Basin will use riparian shade as a surrogate measure of heat flux to fulfill the requirements of Section 303(d) of the Clean Water Act. Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Effective shade accounts for the interception of solar radiation by vegetation and topography.

Heat loads to the stream will be calculated in the TMDL in a heat budget that accounts for surface heat flux and mass transfer processes. Heat loads are of limited value in guiding management activities needed to solve identified water quality problems. Shade will be used as a surrogate to thermal load as allowed under EPA regulations (defined as "other appropriate measure" in 40 CFR §130.2(i)). A decrease in shade due to inadequate riparian vegetation causes an increase in solar radiation and thermal load upon the affected stream section. Other factors influencing the distribution of the solar heat load also will be assessed, including increases in the width of stream channels.

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."

Technical Study

Field data collection for development of the temperature TMDL consists of five components:

- Continuous water and air temperature monitoring.
- Streamflow measurements.
- Groundwater monitoring using piezometers within the mainstem.
- Channel geometry surveys.
- Riparian habitat surveys.

Ecology plans to utilize data collected by separate organizations to supplement existing data collection efforts. The proposed monitoring stations and associated measurement parameters are listed in Table 5.

Table 5. Proposed Sampling Locations and Parameters.

Station Id	Stream Name	Site Description	Instream Temp.	Air Temp.	Piezometer	Relative Humidity
To be established based on river mile (RM) where the origin is at the stream's mouth.	Big Cr	Big Creek at SHU station, at Nelson Siding Rd	x	x		
	Cabin Cr	Cabin Cr near Yakima R confluence	x	x		
	Caribou Cr	Caribou Cr past Gage Rd dwnstrm of L. Caribou	x	x		
	Caribou Cr	Cariobu Cr at Tjossem Rd near Denmark Rd	x	x		
	Coleman Cr	Coleman Cr at Tjossem Rd	x	x		
	Coleman Cr	Coleman Cr at Fairview Rd	x	x		
	Cooke Cr	Cooke Cr at Cooke Canyon Rd, upper site	x	x		
	Cooke Cr	Cooke Cr above Kittitas STP	x	x		
	Cooke Cr	Cooke Cr below Kittitas STP	x	x		
	Dry Cr	Dry Cr at Hwy 10	x	x		
	Little Cr	Little Cr at Nelson Siding Rd	x	x		
	Manastash Cr	Manastash Cr at Brown Rd	x	x		
	Manastash Cr	Manastash Cr below North/South Fork	x	x		
	Naneum Cr	Naneum Cr past gate	x	x	x	x
	Naneum Cr	Naneum Cr upper site	x	x		
	Naneum Cr	1	KRD	KRD	x	
	Naneum Cr	2	KRD	KRD	x	
	Naneum Cr	3	KRD	KRD	x	
	Naneum Cr	4	KRD	KRD		
	Naneum Cr	5	KRD	KRD	x	
	Naneum Cr	6	KRD	KRD	x	
	Naneum Cr	7	KRD	KRD	x	
	Reecer Cr	Reecer Cr at Irene Rinehart City Park	x	x		
	Robinson Cr	Robinson Cr at Thorp Cemetery Rd	x	x		
	Robinson Cr	Robinson Cr at Thorp Hwy, nr Yakima R confluence	x			
	Swauk Cr	Swauk Cr at Hwy 10 bridge	x	x	x	
	Swauk Cr	Swauk Cr at Hidden Valley, Hayward Rd?	x	x		x
	Swauk Cr	Swauk Cr at Lauderdale Junction, SHU flow station	x	x	x	
	Taneum Cr	Taneum Cr at Forest Service Boundary	x	x	x	x
	Taneum Cr	Taneum Cr dwnstrm of Taneum Camp Ground	x	x	x	
	Taneum Cr	Taneum Cr upstream of canal gagestations	KRD	KRD	x	
	Taneum Cr	Taneum Cr at Yakima R. confluence	KRD		x	
	Teanaway R	Teanaway R below Lambert Rd at gage sta (manager?)	x	x		
	Tillman Cr	Tillman Cr at Reservoir Canyon Rd, South Cle Elum	x	x		
	Umtanum Cr	Umtanum Cr near Yakima R confluence	x	x	x	x
	Umtanum Cr	Umtanum Cr at Old Durr Rd	x	x	x	
	Umtanum Cr	Umtanum Cr at corner of Wenas and Umtanum Rd	x	x		
	Umtanum Cr	Umtanum Cr up most site	x	x	x	x
	Wilson Cr	Wilson Cr at Thomas Rd	x	x		

Note: Kittitas Reclamation District (KRD) will install and maintain instream and air thermistors throughout the upper Yakima River Basin.

Continuous Water and Air Temperature Monitoring

Continuous temperature monitoring stations will consist of both instream and air temperature thermistors co-located to characterize the instream temperature and air temperatures near the station. Thermistors will be programmed to record measurements at 30-minute sample intervals. The thermistors used for instream temperatures have an accuracy of ±0.2°C, and air temperature thermistors have an accuracy of ±0.4°C.

Instream thermistors will be placed in the stream thalweg (line of deepest water in a stream channel normally associated with the zone of greatest velocity in the stream) at a depth in the middle of the water column to minimize the potential for vandalism or damage to boats or individuals recreating in the river. Thermistor placement away from the streambank will reduce measurement bias from cool groundwater temperatures in gaining reaches and placement within the main channel of streamflow to avoid measurement bias from the warmer stream edges and from thermal stratification in pools. Stream temperature measurements, both longitudinally along the stream and vertically as a temperature profile, will be made to assure thermistor placement in a well-mixed area. Figure 6 provides a view of the proposed instream temperature sampling locations in the present study area. In addition, U.S. Forest Service and Kittitas Reclamation District sites are included because their data will be utilized for this study. Data from other organizations are welcome, but currently data sharing has yet to be established.

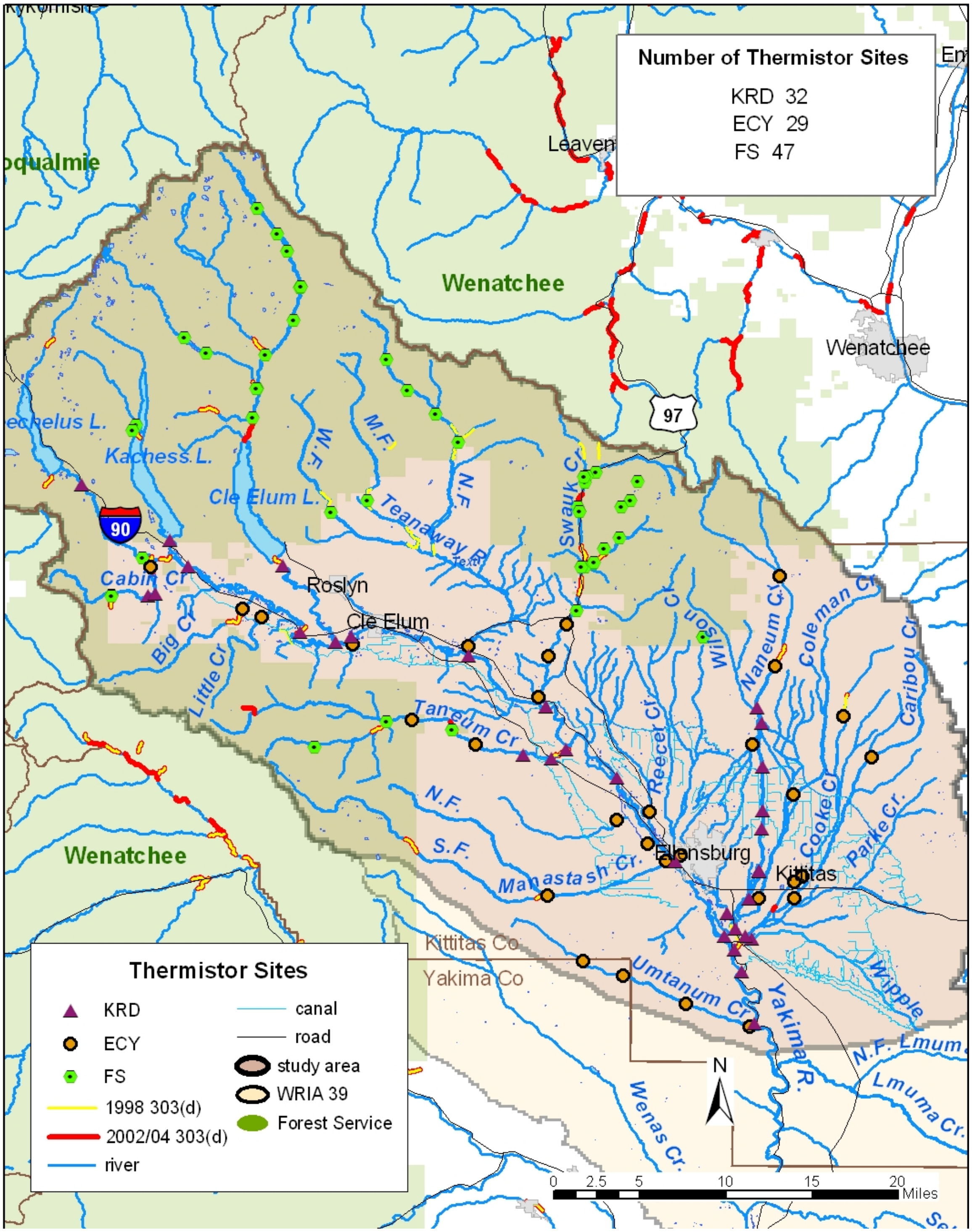

Figure 6. Proposed Stream Temperature Monitoring Stations, Including Those Installed and Maintained by Kittitas Reclamation District (KRD), Washington State Department of Ecology (ECY), and U.S. Forest Service (FS).

Figure 7 presents local weather stations for ongoing monitoring (including air temperature and relative humidity) and proposed monitoring locations for air temperature and relative humidity. The study design does not duplicate the efforts of those who manage weather stations but supplements those long-term sites with additional stations to provide finer spatial resolution necessary for modeling.

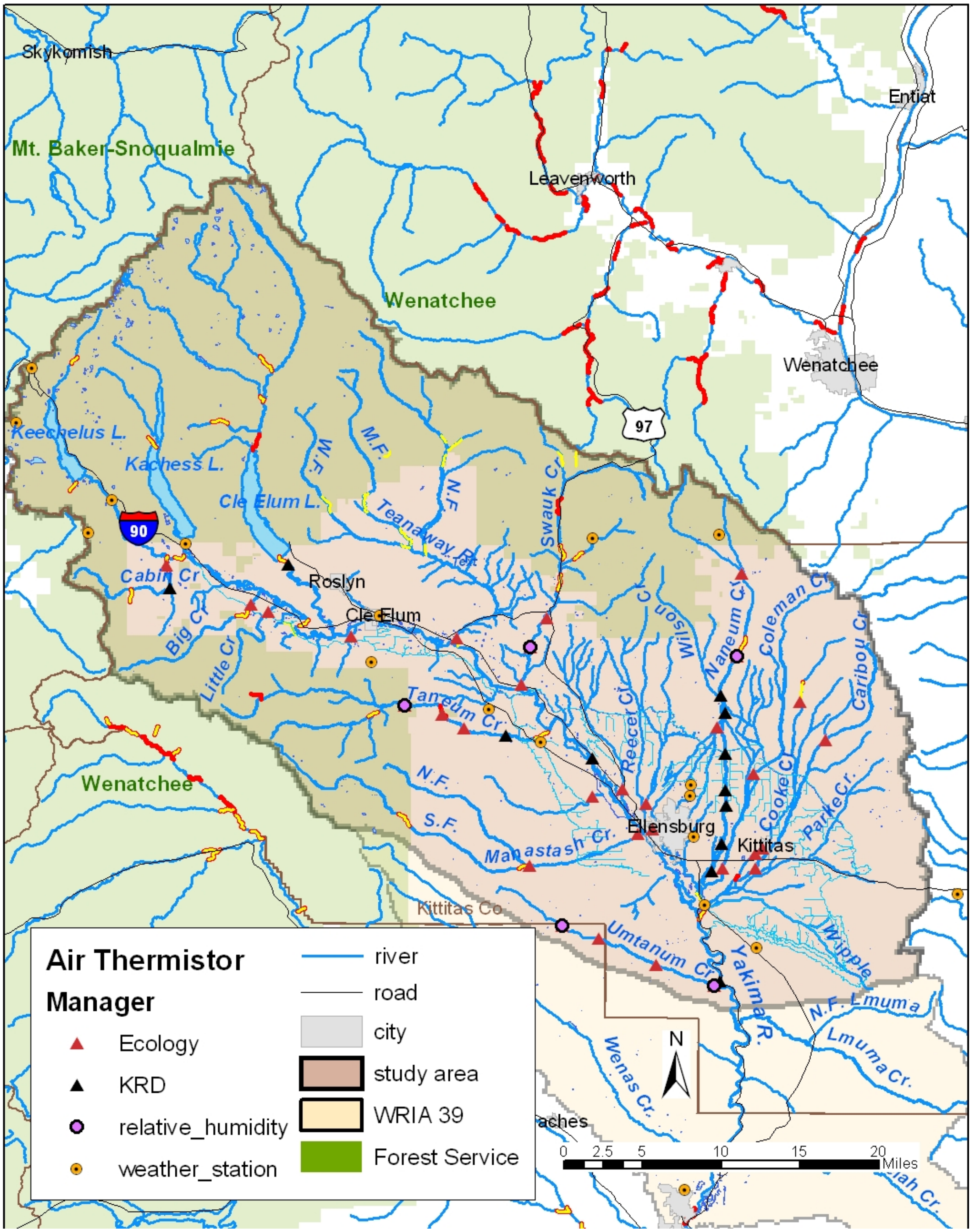

Figure 7. Proposed Air Temperature Sampling Locations, Relative Humidity (Includes Air Temperature) and Established Weather Stations Installed and Maintained by Kittitas Reclamation District (KRD) or Washington State Department of Ecology (Ecology).

Streamflow Studies

The upper Yakima Basin Temperature TMDL requires streamflow measurements to accurately represent pollutant loading and to understand how water moves within the system.

Permanent flow stations exist in the basin for both streams and canals (Figure 8) Organizations that manage these flow stations include: USBR, KRD, USGS, and Ecology. In addition, Ecology will install a temporary continuous flow station at the mouth of Umtanum Creek for the duration of the TMDL technical study. Taneum Creek currently has a continuous flow station and Naneum Creek has staff gages to indicate stage height (stream water depth) that correlate to streamflow by establishing rating curves.

Seepage runs conducted during baseflow conditions and the resulting flow mass balance will be used to determine both the tributary discharge to the Yakima River and streamflow lost or gained to groundwater (Figure 9). Several of the tributaries and canals are gauged and Ecology will perform discharge measurements at these locations to compare to established discharge rating curves.

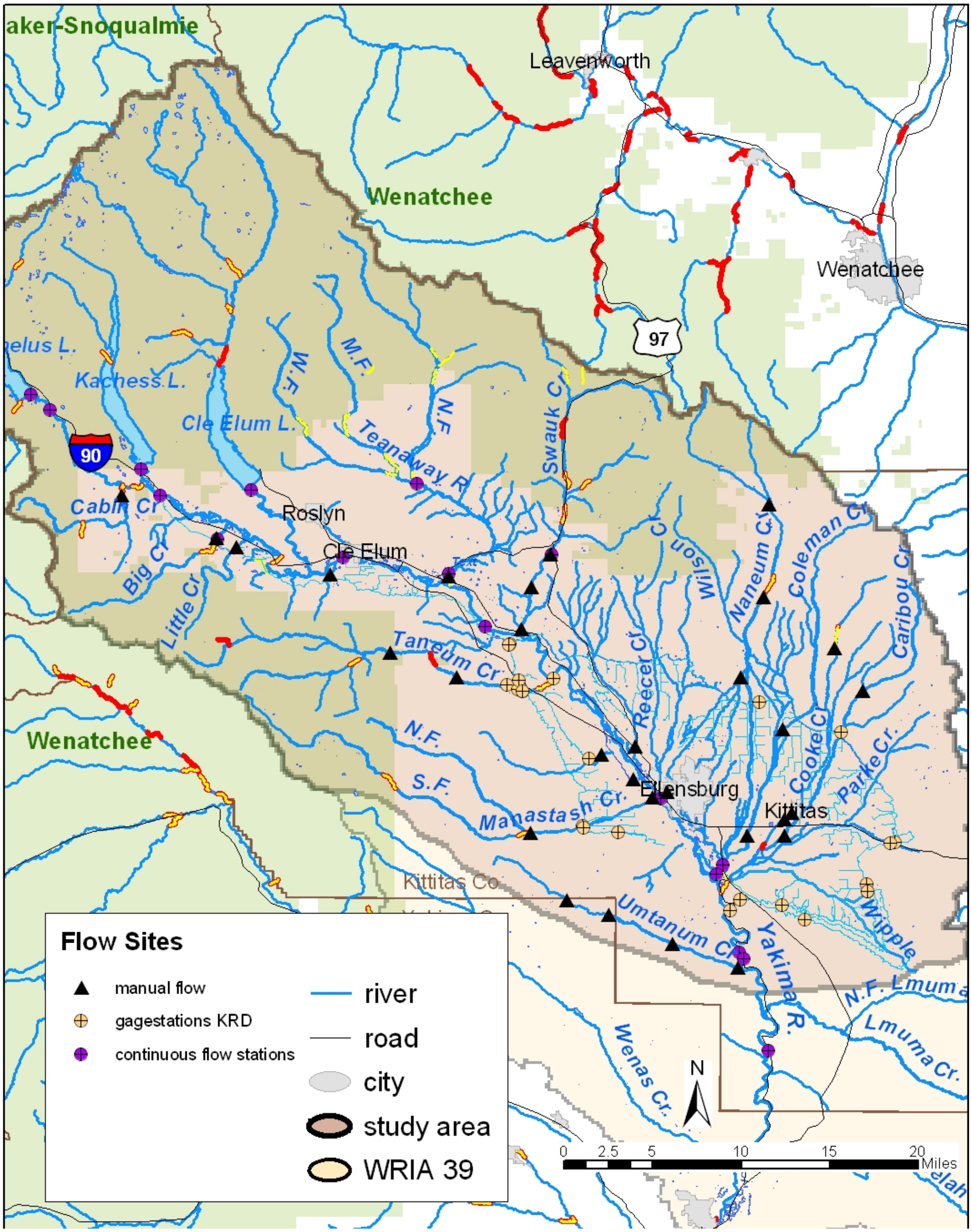

Figure 8. Flow Stations of the Study Area.

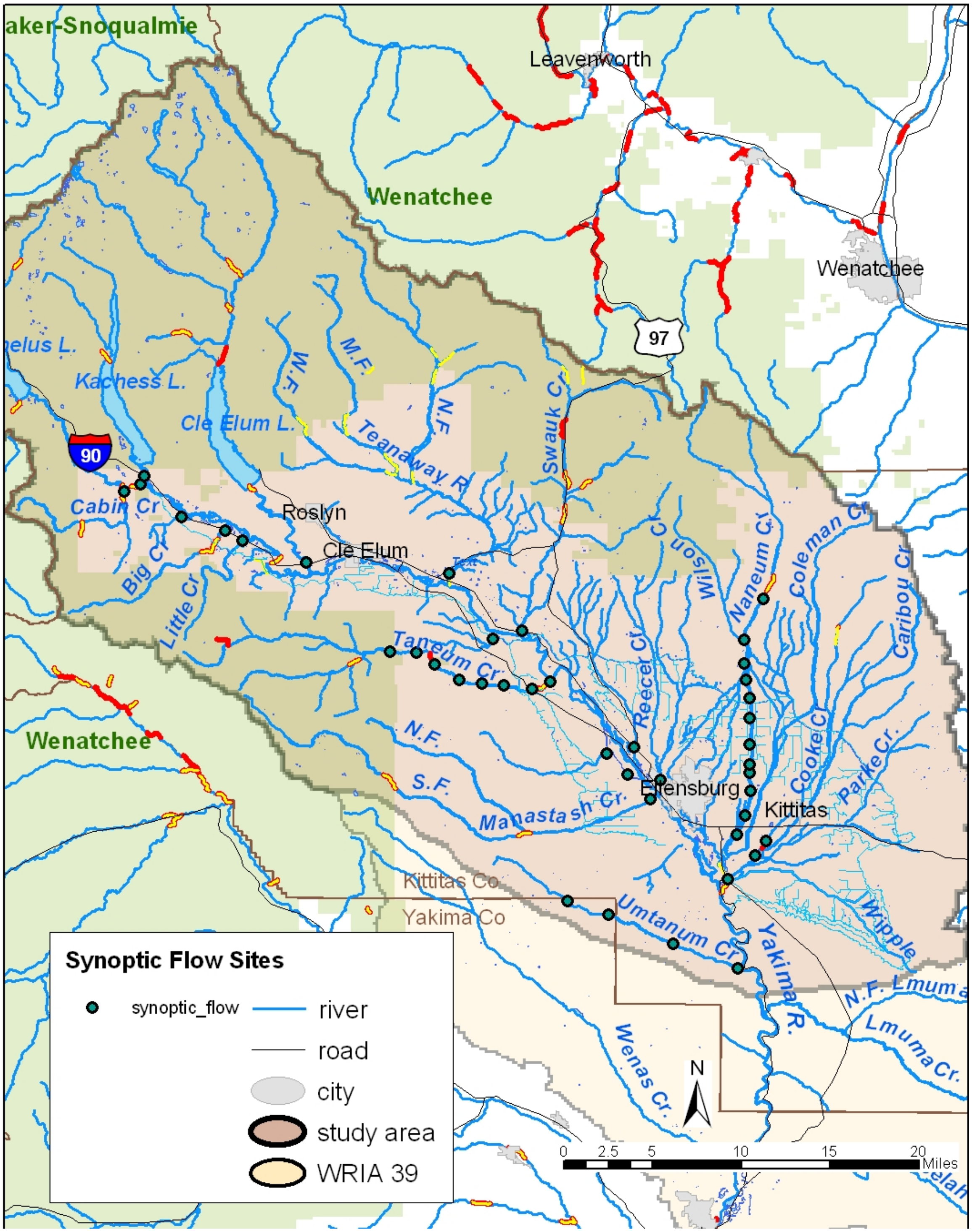

Figure 9. Proposed Synoptic Flow Sites.

Groundwater Monitoring

Groundwater studies will examine groundwater fluxes and associated heat transfers on Umtanum, Taneum, Naneum, and Swauk Creeks using mini-piezometers. Mini-piezometers are small-diameter pipes (1.5 inches) with perforated openings near the bottom tapering down to a sealed pinched end. They can be used to measure direction and magnitude of vertical hydraulic gradients by comparing water levels between the surface water and the aquifer. A subset of sites will be monitored for conductivity and temperature. Sites will be determined based on vertical hydraulic gradient (VHG). Approximately 16 mini-piezometers will be installed at stations in the tributaries to the upper Yakima River (Figure 10). The piezometers will be hand driven into the stream bed to a depth of approximately 5 feet.

Water levels in the piezometers will be measured monthly between May and October, 2005, using a calibrated electric well probe or steel tape in accordance with standard USGS methodology (Stallman, 1983). The head difference between the internal piezometer water level and the external creek stage provides an indication of the vertical hydraulic gradient and the direction of flow between the creek and groundwater. When the piezometer head exceeds the creek stage, groundwater discharge into the creek can be inferred. Similarly, when creek stage exceeds the head in the piezometer, loss of water from the creek to groundwater storage can be inferred.

The piezometers will also be instrumented with 2-3 continuously recording thermistors, placed at different depths based on a thermal profile measured at the time of installation, to determine the temperature of the groundwater within the hyporheic zone.

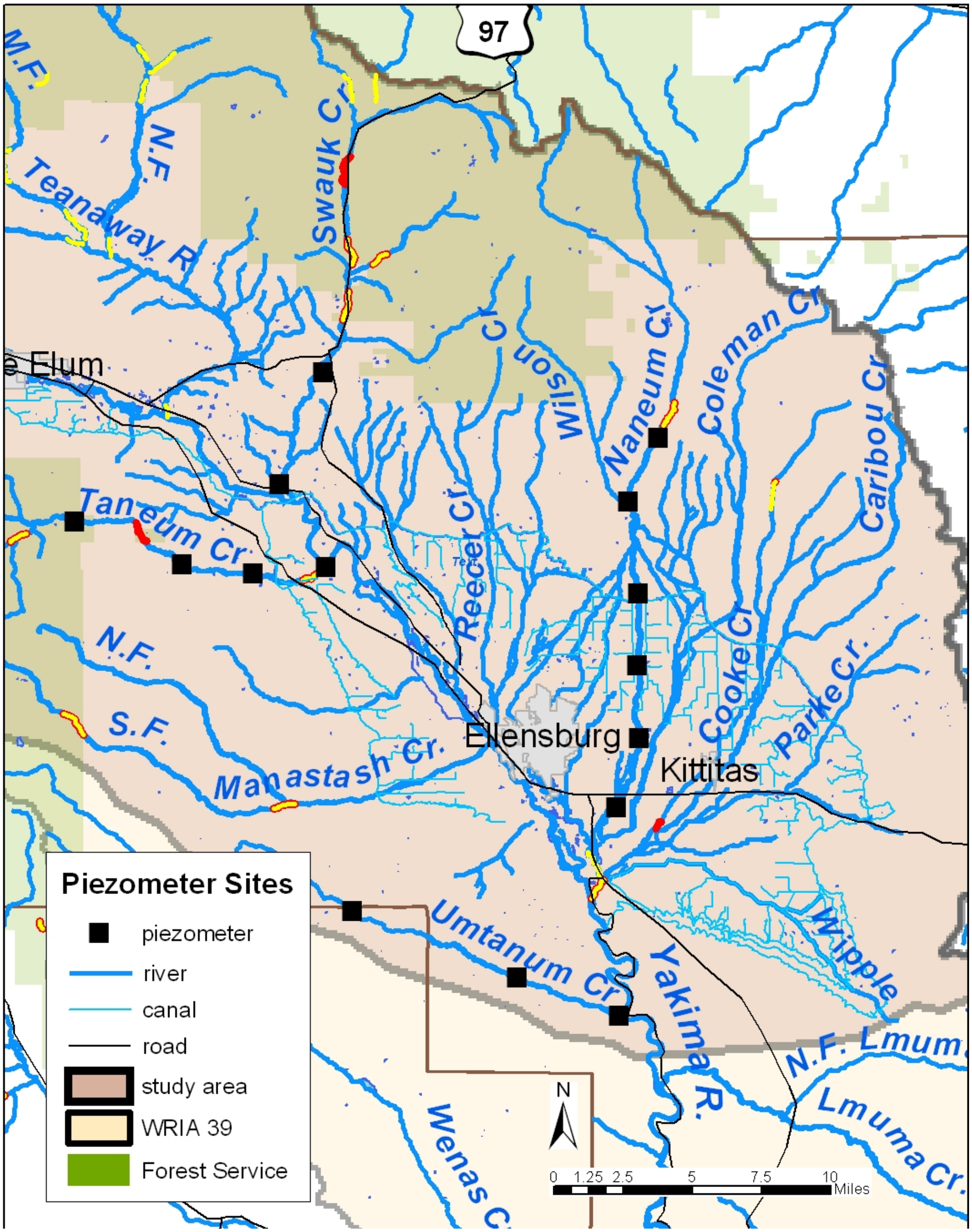

Figure 10. Proposed Piezometer Sites for the Upper Yakima River Tributaries.

Channel Geometry and Riparian Habitat Surveys

Thermal reach surveys will follow Timber-Fish-Wildlife (TFW) stream temperature survey methods (Schuett-Hames et al., 1999). The surveys will be conducted during summer conditions at selected temperature sites established by Ecology. Depending on stream access, field measurements will either be taken at 6 to 10 locations over a 300-meter thermal reach or at set intervals along the length of an entire stream. Measurements will consist of bankfull width and depth, wetted width and depth, effective shade, and channel type. Riparian Management Zone (RMZ) characteristics, such as active channel width, cover, size, density, and bank erosion, will also be recorded during the surveys. Riparian assessment includes 150 feet on both sides of the stream. Vegetation heights will be measured in the field using a laser range/height finder if necessary.

Image analysis of digital hemispherical pictures and field measurements taken using a Solar Pathfinder at the center of the stream will be used to estimate the total solar radiation contribution at the stream surface at each temperature monitoring station during the critical period. This data will provide validation for the site factor assumptions and effective shade predictions generated from the model described below.

Project Schedule

Table 6 lists the proposed schedule for data collection, analysis, modeling, and reporting throughout the project.

Table 6. Proposed Schedule for Upper Yakima Basin Temperature TMDL Activities.

Document or Activity	Completion Date
Final QA Project Plan	June 2005
Monitoring Activities	May 2005 through October 2005
Analyses, Modeling, and Report Writing	December 2005 through January 2007
Draft Technical Report for Supervisor Review	January 2007
Draft Technical Report for Internal Review	February 2007
Draft Technical Report for External Review	March 2007
Final Technical Report	June 2007
Environmental Information Management Data Entry	June 2006

Project Organization

The roles and responsibilities of Ecology project staff are as follows:

- *Anita Stohr, Nonpoint Studies Unit, Environmental Assessment Program, Technical Project Manager*. Responsible for overall project management of the study, including study design. Responsible for development of TMDLs for temperature, including model development and writing the technical report.
- *James Kardouni, Nonpoint Studies Unit, Environmental Assessment Program, Temperature Investigator.* Responsible for assisting with development of the temperature study, QA Project Plan, temperature field data collection and data entry to EIM, and writing sections of the technical report related to temperature data collection and data quality review.
- *Melanie Kimsey, Nonpoint Studies Unit, Environmental Assessment Program, Hydrogeologist*. Provides hydrogeologic assistance with study design, including interpretation of historical geology and groundwater data in the basin, groundwater data collection, data analysis, and report writing.
- *Chuck Springer, Stream Hydrology Unit, Environmental Assessment Program, Hydrologist*. Responsible for deploying and maintaining continuous flow gauges or staff gauges. Responsible for producing records of hourly flow data at sites selected for the study.
- *Darrel Anderson, Nonpoint Studies Unit, Environmental Assessment Program, Unit Supervisor*. Reviews the temperature portions of the QA Project Plan and TMDL report.
- *Will Kendra, Watershed Ecology Section, Environmental Assessment Program, Section Manager*. Responsible for approval of the QA Project Plan and final TMDL report.
- *Cliff Kirchmer, Environmental Assessment Program, Quality Assurance Officer*. Reviews QA Project Plan and all Ecology quality assurance programs. Provides technical assistance on QA/QC issues during the implementation and assessment of the project.
- *Jane Creech, Water Quality Program, Central Regional Office, TMDL Project Lead*. Acts as point of contact between Ecology technical study staff and interested parties and coordinates information exchange and meetings. Supports, reviews, and comments on QA Project Plan and technical report. Responsible for implementation, planning, and preparation of TMDL submittal document for EPA.
- *Jon Merz, Water Quality Program, Central Regional Office, Unit Supervisor*, Responsible for approval of TMDL submittal to EPA.
- *Tom Tebb, Central Regional Office, Section Manager*: Responsible for approval of TMDL submittal to EPA.

Quality Objectives

Temperature

Accuracy of the thermograph data loggers will be maintained by a two-point comparison between the thermograph and a Certified Reference Thermometer. The Certified Reference Thermometer, manufactured by HB Instrument Co. (part number 61099-035, serial number 2L2087), is certified to meet ISO9000 standards and calibrated against National Institute of Standards and Technology traceable equipment.

Manufacturer specifications report an accuracy of ±0.2°C for the Onset StowAway TidBit (-5°C to +37°C) and the Hobo Pro-Temp thermistors. The Onset StowAway TidBit (-20°C to +50°C) has a reported accuracy of ±0.4°C. The tidbits with a -20°C to +50°C range are necessary to measure air temperature because of the potential range of minimum and maximum temperatures anticipated in the basin. Water temperatures are measured using the tidbits with a -5°C to +37°C range.

If the mean difference between the NIST-certified thermometer and the thermal data loggers differs by more than the manufacturer's specifications during the pre-study calibration, the thermal data logger will not be used during field work.

Representation of the data is achieved by a sampling scheme that accounts for land practices, flow contribution of tributaries, and seasonal variation of instream flow and temperatures in the basin. Extra thermistors will be taken in the field during site visits and surveys to minimize data loss due to damaged or lost equipment.

Measurement and Sampling Procedures

Field sampling and measurement protocols will follow those described in the Timber-Fish-Wildlife (TFW) Stream Temperature Survey Manual (Schuett-Hames et al, 1999) and the Watershed Assessment Section (WAS) protocol manual (WAS, 1993). Temperature thermographs will be installed in the water and air in areas which are representative of the surrounding environment and are shaded from direct sunlight. To safeguard against data loss, data from the loggers will be downloaded midway through the sampling season. The stream surveys will collect data according to TFW protocols for bankfull width and depth, wetted width and depth, canopy closure, and channel type. Riparian management zone (RMZ) characteristics, such as width, cover, size, density, and windthrow, will also be recorded during the surveys. (Schuett-Hames et al., 1999).

Field Measurements

The Onset StowAway TidBits will be calibrated pre- and post-study in accordance with TFW Stream Temperature Survey protocols (Schuett-Hames et al., 1999a) to document instrument bias and performance at representative temperatures. A NIST-certified reference thermometer will be used for the calibration. At the completion of the monitoring, the raw data will be adjusted, based on the pre- and post-calibration results, if the temperature for the TidBit differs from the NIST-certified reference thermometer by more than the stated reported accuracy of the TidBit (i.e. by more than ±0.2°C or ±0.4ºC). The mean difference of the pre- and post-calibration values from the NIST thermometer reading will be used for calculating the adjusted temperature.

Variation for field sampling of instream temperatures will be addressed with a field check of the data loggers with a reference temperature measurement at all thermograph sites upon deployment, download events, and at TidBit removals at the end of the study period. Field sampling and measurements will follow quality control protocols described in the WAS protocol manual (WAS, 1993) and the TFW Stream Temperature Survey Manual (Schuett-Hames et al., 1999a).

Data Management Procedures

Temperature Modeling Using Qual2k

Field data measurements needed for stream temperature modeling are outlined in Table 7.

Table 7. Temperature Data Requirements.

		Model Requirement		Data Source		
	Parameter	**Shade**	**Qual2K**	**Ecology**	**Other Data Contributor**	**GIS**
Flow	discharge - tributary		X	X	X	
	discharge (upstream & downstream)		X	X	X	
	flow velocity		X	X	X	
	groundwater inflow rate/discharge		X	X		
	travel time		X	X		
General	calendar day/date	X	X	X		
	duration of simulation	X	X	X		
	elevation - downstream	X	X			X
	elevation - upstream	X	X			X
	elevation/altitude	X	X			X
	latitude	X	X			X
	longitude	X	X			X
	time zone	X		X		
Physical	channel azimuth/stream aspect	X	X			X
	cross-sectional area	X	X	X	X	
	Manning's n value	X	X	X		
	percent bedrock	X	X	X	X	
	reach length	X	X			X
	stream bank slope	X		X	X	
	stream bed slope	X	X			X
	width - bankfull	X		X	X	
	width - stream	X	X	X	X	
Temperature	temperature - groundwater		X	X		
	temperature - tributaries		X	X	X	
	temperature - water downstream		X	X	X	
	temperature - water upstream		X	X	X	
	temperature - air		X	X	X	
Vegetation	% forest cover on each side	X		X	X	
	canopy-shading coefficient/veg density	X		X	X	
	vegetation overhang	X		X		X
	distance to shading vegetation	X				X
	topographic shade angle	X				X
	vegetation height	X		X		
	vegetation shade angle	X				X
	vegetation width	X				X
Weather	relative humidity		X	X	X	
	% possible sun/cloud cover		X		X	
	solar radiation		X	X		
	temperature- air		X	X	X	
	wind speed/direction		X		X	

Data collected during this TMDL effort will allow the development of a temperature simulation model that is both spatially continuous and which spans full-day lengths. The GIS and modeling analyses will be conducted using four software tools:

- Oregon Department of Environmental Quality's TTools extension for ArcView (ODEQ, 2001) will be used to sample and process GIS data for input to the Shade and QUAL2Kw models.
- Ecology's Shade model (Ecology, 2003a) will be used to estimate effective shade along Naneum, Taneum, and Umtanum Creeks. Effective shade will be calculated at 50 to 100-meter intervals along the streams and then averaged over 500 to 1000-meter intervals for input to the QUAL2Kw model.
- The QUAL2Kw model (Chapra, 2001; Ecology, 2003b) will be used to calculate the components of the heat budget and simulate water temperatures. QUAL2Kw simulates diurnal variations in stream temperature for a steady flow condition. QUAL2Kw will be 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. For temperature simulation, the solar radiation, air temperature, relative humidity, headwater temperature, and tributary water temperatures are specified or simulated as diurnally varying functions. QUAL2Kw uses the kinetic formulations for the components of the surface water heat budget described in Chapra (1997). Diurnally varying water temperatures at 500 to 1000-meter intervals along the streams in the basin will be simulated using a finite difference numerical method. The water temperature model will be calibrated to instream data collected along the modeled segments.
- The USGS model VS2DI (Hsieh et al., 2000) will potentially be used to evaluate the continuous groundwater temperature data for selected (influent) piezometer sites to estimate both the temperature and volume of groundwater discharge to the river during summer baseflow conditions. These flux estimates will be integrated with stream seepage run information to estimate reach-specific streamflow gains and losses for later inclusion in the QUAL2Kw model development.

All input data for the Shade and QUAL2Kw models will be longitudinally referenced, allowing spatial and/or continuous inputs to apply to certain zones or specific river segments.

QUAL2K (or Q2K) is a river and stream water quality model that represents a modernized version of QUAL2E (Brown and Barnwell, 1987). QUAL2Kw is adapted from the QUAL2K model originally developed by Chapra (Chapra and Pelletier, 2003). Q2K is similar to Q2E in the following respects:

- *One Dimensional*. The channel is well-mixed vertically and laterally. Non-uniform, steady flow is simulated.

- *Diurnal Heat Budget*. The heat budget and temperature are simulated as a function of meteorology on a diurnal time scale.
- *Heat and Mass Inputs*. Point and nonpoint loads and abstractions (withdrawals or losses) are simulated.

The QUAL2Kw framework includes the following new elements:

- *Software Environment and Interface*. Q2Kw is implemented within the Microsoft Windows environment. It is programmed in the Windows macro language: Visual Basic for Applications (VBA). Excel is used as the graphical user interface.
- *Model Segmentation*. Q2Kw can use either constant or varying segment lengths. In addition, multiple loadings and abstractions can be input to any reach.
- *Hyporheic Exchange and Sediment Pore water Quality*. Q2K also has the ability to simulate the metabolism of heterotrophic bacteria in the hyporheic zone.

TTools

TTools is an ArcView extension developed by 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 was adapted from a program that was originally developed by the Oregon Department of Environmental Quality (ODEQ) as part of the HeatSource model. Shade.xls calculates shade using one of two optional methods:

- ODEQ's original method from the HeatSource model version 6 (ODEQ, 2003).
- Chen’s method based on the Fortran program HSPF SHADE (Chen, 1996). The method uses a slightly different approach to modeling the attenuation of solar radiation through the canopy (Chen et al., 1998a and 1998b).

All data will be assembled from Ecology field surveys and monitoring data. The model output from Shade is a model input to QUAL2Kw.

All continuous temperature data will be stored in a temperature database designed by Ecology that includes station location information and data quality assurance information. This database will facilitate summarization of the temperature data and create a data table to upload temperature information to EIM.

Environmental Information Management (EIM)

An EIM user study will be created for this TMDL study and all monitoring data will be available via the internet once the project data have been validated (the study name can be found on the front page of this QA Project Plan). The URL address for this geospatial database is: apps.ecy.wa.gov/eimreporting. EIM will accept the daily maximum, daily minimum, and daily average temperature summary from a continuous temperature data set. All temperature data will be uploaded to EIM by the temperature field investigator once all data has been reviewed for quality assurance and finalized.

Data Verification and Validation

Data Verification

Field and laboratory data will be verified and validated at the completion of the data collection period. Data verification refers to "the process of evaluating the completeness, correctness, and conformance/compliance of a specific data set against the method, procedure, or contract requirements" (EPA, 2002). Field staff will verify and document *in situ* while MEL staff will verify all lab-based data. All verification done by lab and field staff will be documented.

Data Validation

Data validation refers to "the evaluation of data beyond method, procedure, or contract compliance (i.e., data verification) to determine the analytical quality of a specific data set" (EPA, 2002). Principal investigators will validate data collected under the present QA Project Plan.

Continuous temperature monitoring data will be validated as real water temperatures by comparison with the paired air thermistor at each site to check for data ranges where the instream thermistor may have been recording air temperatures due to receding stream stage at the thermistor site. Pre-and post-study accuracy checks of all thermistors used for this study will identify any instruments that are not measuring within their manufacturer-specified accuracy range. If a thermistor does not pass the post-study accuracy check, then the data affected by that thermistor will be adjusted by the average difference of the pre-and post-study results.

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