Quality Assurance Project Plan

Total Maximum Daily Load Analysis for Temperature in Tributaries to Oakland Bay-Hammersley Inlet: Mill Creek, Cranberry Creek, and Johns Creek

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May 2005

Publication No. 05-03-107

This plan is available on the Department of Ecology home page on the World Wide Web at *http://www.ecy.wa.gov/biblio/0503107.html*.

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May 2005

Proposed 2002/2004 303(d) Listings Addressed in this Study:

Stream	Waterbody ID	Parameter
Mill Creek	ML22SI	Temperature
Cranberry Creek	HL95GY	Temperature
Johns Creek	TX75AG	Temperature

User Study ID: AAHM0004

Approvals

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Table of Contents

List of Figures and Tables

Page

Figures

Page

Figures (cont.)

Tables

Abstract

Johns Creek and three segments each of Cranberry and Mill Creeks have been included in the proposed 2002/2004 303(d) list for temperature. Therefore, in accordance with the Federal Clean Water Act, Total Maximum Daily Loads (TMDLs) for temperature must be established to bring these tributaries into compliance with water quality standards. This plan describes the approach for developing the temperature TMDL for these creeks, the necessary field work, and the follow-up temperature modeling to develop load allocations.

Temperature listings for these creeks are based on data collected by the Squaxin Island Tribe. Further data collection for these creeks will consist of continuous temperature, stream flow, riparian surveys, and an extensive groundwater study in the summer of 2005. Ecology will work cooperatively with the Squaxin Island Tribe to coordinate field work. Water temperature in the creeks will be characterized and load allocations established for heat sources to meet water quality standards. A QUAL2Kw model will be used for this purpose.

A final report will be available by September 2006.

Project Description

Some tributaries to the Oakland Bay and Hammersley Inlet in South Puget Sound have been placed on Washington State's proposed 2002/2004 303(d) list of waterbodies not meeting water quality standards for temperature (Table 1). Thus, under the Federal Clean Water Act of 1972, a cleanup plan called a Total Maximum Daily Load (TMDL) must be developed and implemented to address this impairment and bring the waterbody segments into compliance with the standard. This report is a project plan for proceeding with the TMDL analysis. Available data for the tributaries, collected by the Squaxin Island Tribe, are reported and the procedure for completion of the TMDL analysis is explained. Additional data will need to be gathered in the summer of 2005.

Table 1. Tributaries on the Proposed 2002/2004 303(d) List for Temperature.

Waterbody	Old Waterbody ID	New Waterbody ID	Reference	Location
Johns Creek	WA-14-1700	HL95GY	SIT 2000-2001 data at station John 2	Johns Creek Drive gage
Cranberry Creek	----	TX75AG	SIT 2001data at stations CRAN3 and CRAN4	Mason Lake Rd Bridge to above Lake Limerick
		TX75AG	SIT 2001 (Station CRAN1) and Ecology 1999 (Station CRA05)	At Highway 3 bridge
		TX75AG	SIT 2001 (Station CRAN2	Mickelson Road bridge
Mill Creek	WA-14-1500	ML22SI	SIT 2000 (Station MILL 1)	Dirt trail off Fireweed lane
	WA-14-1500	ML22SI	SIT 2000-2001 (Station MILL 2)	At the diner
	WA-14-1500	ML22SI	SIT 2000 (Station MILL3)	At Storybrook bridge

Study Area

Johns and Cranberry Creeks are tributaries to Oakland Bay, while Mill Creek is a tributary to Hammersley Inlet (Figure 1). These waterbodies are located in Water Resources Inventory Area (WRIA) 14, also known as Kennedy-Goldsborough Watershed, in Mason County, Washington. Land use is primarily commercial forest, with a relatively small percentage dedicated to residential development and agriculture. Oakland Bay is a short, narrow bay that angles abruptly northeast from its connection with Hammersley Inlet to the south. The bay ranges in width from 1000 feet to one mile and covers approximately 5.4 square miles. Both Johns and Cranberry Creeks are tributaries to Oakland Bay. Hammersley Inlet is one of the shallowest and narrowest of all inlets in South Puget Sound. The inlet is 6 miles long with an estimated surface area of 2.2 square miles. Mill Creek is a tributary to Hammersley Inlet.

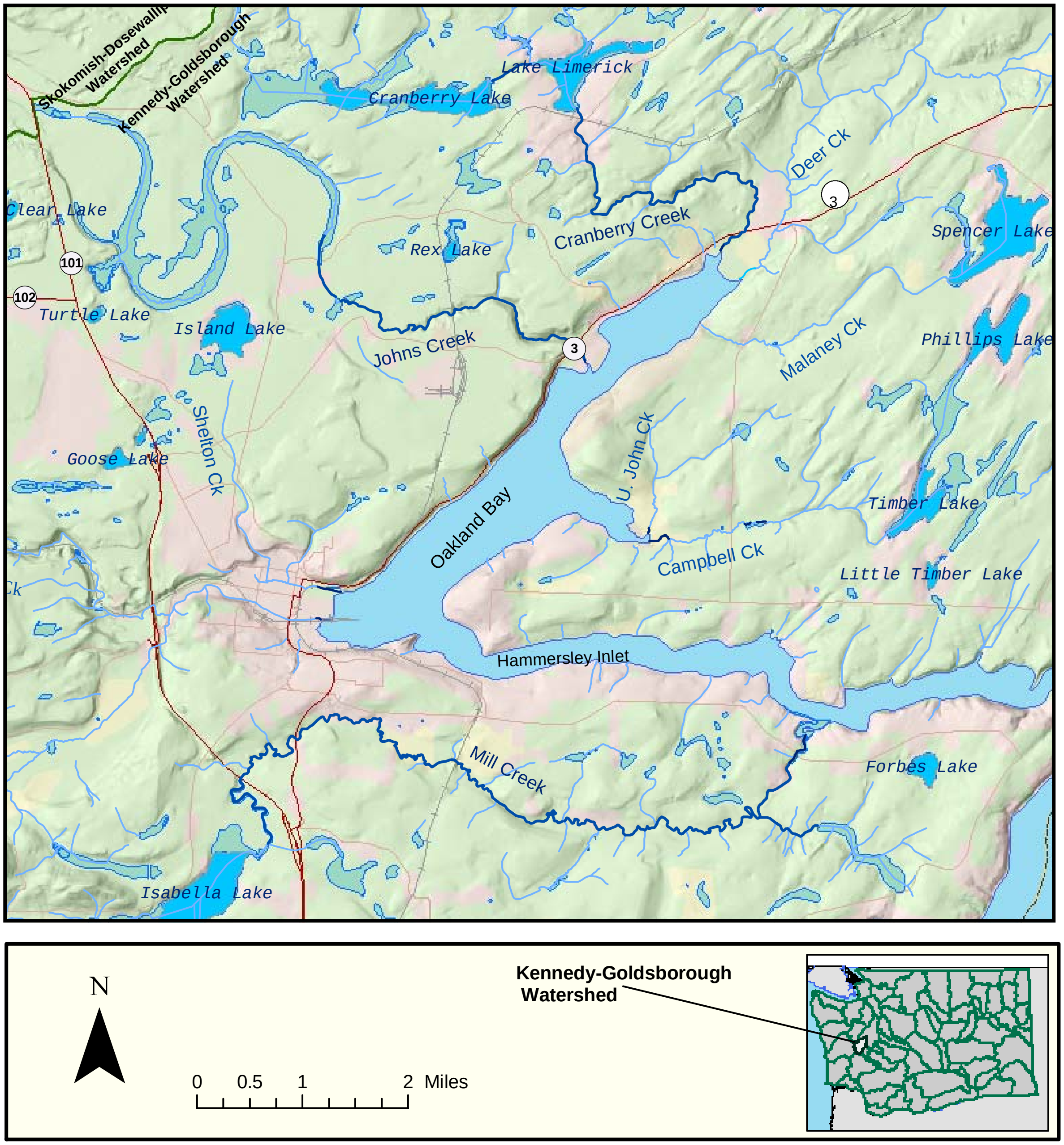


Figure 1. Map Showing the Location of Mill, Johns, and Cranberry Creeks.

Mill Creek

Mill Creek (Figure 1) is a 16 mile (Williams et al., 1975) long creek that drains an area of approximately 29 square miles. The stretch from Lake Isabella to the mouth of the creeks at Hammersley Inlet (east of Walker Park) is approximately 9.6 miles. Lake Isabella is approximately 200 acres with extensive wetlands at both the inlet and outlet. Gosnell Creek drains into Lake Isabella. Forbes Lake, a 39-acre lake about 1.5 miles west of the unincorporated area of Arcadia, also drains into Mill Creek (Brown and Caldwell, 1990). The maximum elevation of Mill Creek is 1214 feet (Schuett-Hames et al. 1996). Landuse along Mill Creek and Lower Gosnell Creek is primarily agricultural and residential, while Upper Gosnell and its largest tributary, Rock Creek, are surrounded by commercial timberlands. The mean annual discharge of Mill Creek is approximately 59 cfs (Ecology, 1983). Gosnell Creek, draining into Lake Isabella, meets water quality standard for temperature, based upon data collected at station MIL 4 just above Lake Isabella (John Konovsky, Squaxin Island Tribe, March 2004, Personal Communication). Therefore, Gosnell Creek will not be considered in this temperature TMDL.

Cranberry Creek

Cranberry Creek (Figure 1) originates in a series of lakes, flowing southeast to Oakland Bay. Cranberry and Limerick Lakes comprise the upper watershed and are natural except for Lake Limerick, a 129-acre lake created in 1966 by damming a wetland (Smith and Rector, 1994). Steelhead and coho pass through the lake via a fish ladder while chum use the lower channel. Juvenile sockeye have also been trapped below the dam (Squaxin Island Tribe Unpublished Data 1999).

Cranberry Creek drains approximately 15 square miles (Brown and Caldwell, 1990). The maximum elevation of the creek is 507 feet (Schuett-Hames, et al., 1996) with a mean annual discharge of 53 cfs (Williams et al., 1975). The reach of the creek between the mouth in Oakland Bay and below Lake Limerick is approximately 3.5 miles long. The segment between Lake Limerick and Cranberry Lake is approximately 0.52 miles.

Johns Creek

Johns Creek (Figure 1) begins at a five-mile wetland system and then follows a low-gradient, meandering course through glacial outwash before descending through a deep canyon at a gradient of approximately two-to-three percent to enter Oakland Bay through a wide delta. Johns Creek is 8.3 miles long (Williams et al., 1975) and drains an area of approximately 13.2 square miles. The maximum elevation of Johns is 340 feet (Schuett-Hames et al. 1996). The mean annual discharge is approximately 35 cfs (Williams et al., 1975). Some of the most productive shellfish beds in the bay are located at the mouth of Johns Creek. Most of the channel is accessible to fish. The stream hosts coho, steelhead, cutthroat, and two chum runs.

Sources of Pollution

Cranberry, Johns, and Mill Creeks are not meeting the state standard for stream temperature. All these creeks are characterized by lakes or large wetlands at headwaters with relatively high water temperatures resulting from large water surface areas exposed to sunlight. Lake Limerick is a man-made lake while Cranberry Lake is a natural lake, both located at the headwaters of Cranberry Creek (see Figure 1). Lake Isabella is also a natural lake at the headwaters of Mill Creek. A large wetland is located at the headwaters of Johns Creek. Longitudinal temperature profiles in these creeks, as obtained through a thermal infra red (TIR) survey conducted by the Squaxin Island Tribe in 2003, suggest that temperatures drop significantly in all these creeks in the downstream direction. However, the temperatures still exceed the state water quality standards. The drop in temperatures along these creeks is presumed to be a result of cooler groundwater inflow together with heat exchange between warmer water and cooler soil (stream bed) and/or cooler air (resulting from shade from riparian vegetation).

Water Quality Standards

Mill Creek is a tributary to Hammersley Inlet which is designated as Class A marine waters in the Washington Administrative Code (WAC) Chapter 173-201A. Johns and Cranberry Creeks are tributaries to Oakland Bay, which is designated as Class A marine waters in Chapter 173-201A, WAC. Thus, Mill, Johns, and Cranberry Creeks are also Class A waters as per WAC 173-201A-120.

Beneficial uses for Class A waters include water supply (domestic, industrial, agricultural); stock watering; fish migration; fish and shellfish rearing, spawning, and harvesting; wildlife habitat; primary contact recreation; sport fishing; boating and aesthetic enjoyment; and commerce and navigation. Water quality of this class shall meet, or exceed, the requirements for all, or substantially all, uses. The temperature standard for Class A freshwater (WAC173-201A-030 (2)) is as follows:

- Temperature shall not exceed 18˚C due to human activities.
- If natural conditions exceed 18˚C, 0.3˚C degradation is allowed.
- If natural condition is below 18˚C, the following degradations are allowed.
    - Nonpoint source activities shall not increase background by more than 2.8°C or bring the stream temperature above 18˚C.
    - Point sources shall not increase background by more than 28/(background temperature +7) or bring the stream temperature above 18C.

Proposed New Rule

Washington State has adopted a new rule on Water Quality Standards (WAC 173-201A) as of July 2003. The rule has not yet been approved by EPA and so has not yet gone into effect.
The temperature standard in the new rule is a 7-day average of daily maximum (DADM) temperatures not to exceed a use-based criterion. Table 602 of the new rule (WAC-173-201A) includes a list of specific uses for many waterbodies in Washington State. However, since Mill, Johns, and Cranberry Creeks are not listed in Table 602, Section WAC-173-201A-600 applies. Based on relevant designated uses in WAC-173-201A-600 (i.e. salmon and trout spawning, non-core rearing, and migration) and the aquatic life temperature criterion in Table 200(1)(c) (Section WAC-173-201A-200), the temperature standard is a 7-DADM temperature of 17.5˚C. In contrast, the existing standard for a Class A waterbody is a one-day maximum of 18˚C. The proposed temperature standard in the new rule for the designated beneficial use is as follows:

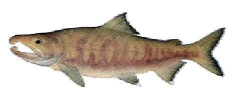
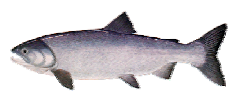
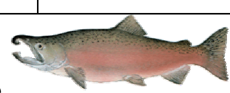
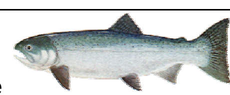
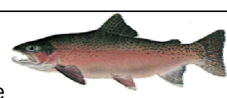
- The 7-DADM temperatures shall not exceed 17.5 ˚C due to human activities
- If natural conditions exceed 17.5 ˚C, 0.3 ˚C degradation is allowed.
- If natural condition is below 17.5 ˚C, the following degradations are allowed.
    - Nonpoint source activities shall not increase background by more than 2.8°C or bring the stream temperature above 18˚C.

- Point sources shall not increase background by more than 28/(background temperature +5) or bring the stream temperature above 18˚C.

- Temperatures are not to exceed the criteria at a probability frequency of more than once every ten years on average.
- If the temperature criteria are deemed not protective of spawning and incubation temperatures, the following will be applied.
    - Maximum 7-DADM temperatures of 9°C (48.2°F) at the initiation of spawning and at fry emergence for char.
    - Maximum 7-DADM temperatures of 13°C (55.4°F) at the initiation of spawning for salmon and at fry emergence for salmon and trout.

Documented anadromous salmon species in the tributaries to Oakland Bay/Hammersley Inlet watershed include chum, coho, chinook, steelhead, searun (coastal) cutthroat, rainbow trout, and incident reports of pink and sockeye (SASSI 1993; WDWF Priority Habitats and Species database) (Table 2). The critical species are the summer chum that spawn from early September. The Squaxin Island Tribe (SIT) will be checking all three creeks this summer in late August to update the spawning timing because SIT believes that the timing could be earlier than September in some years (Konovsky, 2004). For the spawning season, beginning late August/early September, a temperature criterion of 13˚C will apply. However, the temperature standards that will be used in this TMDL will be the ones that are in effect at the time the technical report is written.

Table 2. Salmon and Trout Species Present Within the Oakland Bay/Hammersley Inlet Watershed. Origin and Production Information Derived from SASSI (1993) and Tribal Data.

Species		Origin/Production	Spawn Timing
Summer Chum	 male  female	Native/natural spawning[1]	September – October
Mill/Johns Fall Chum		Mixed origin/natural spawning[2]	November – January
Shelton/Goldsborough Fall Chum		Native/natural spawning	December – January
Coho	male  female 	Mixed origin/natural spawning[3]	Late October – early December
Winter Steelhead	male  female	Native/natural spawning	February – March

1. Supplemented by native fish reared at Johns Creek Hatchery until October 1992; stock has been self-sustaining since that time (SASSI 1993).
2. Hood Canal hatchery stock from Minter Creek and other facilities may have affected genetic makeup. (SASSI 1993).
3. Long-term, off-station plantings make this a composite of native and introduce non-native stocks (SASSI 1993).

Historical Data Review

Most of the available temperature and flow data were gathered by the Squaxin Island Tribe at various stations along Mill, Johns and Cranberry Creeks. These are discussed below.

Mill Creek

Continuous temperature monitoring data were gathered by the Squaxin Island Tribe (SIT) in June-September 2003 at three locations (Figure 2) in Mill Creek downstream of Lake Isabella. Station ML3 is below Lake Isabella, at Storybrook bridge near US Highway 101; Station ML2 is downstream of Station ML3 near State Highway 3, at the diner; and Station ML1 is further downstream, on a dirt road off Fireweed Lane (Figure 2).

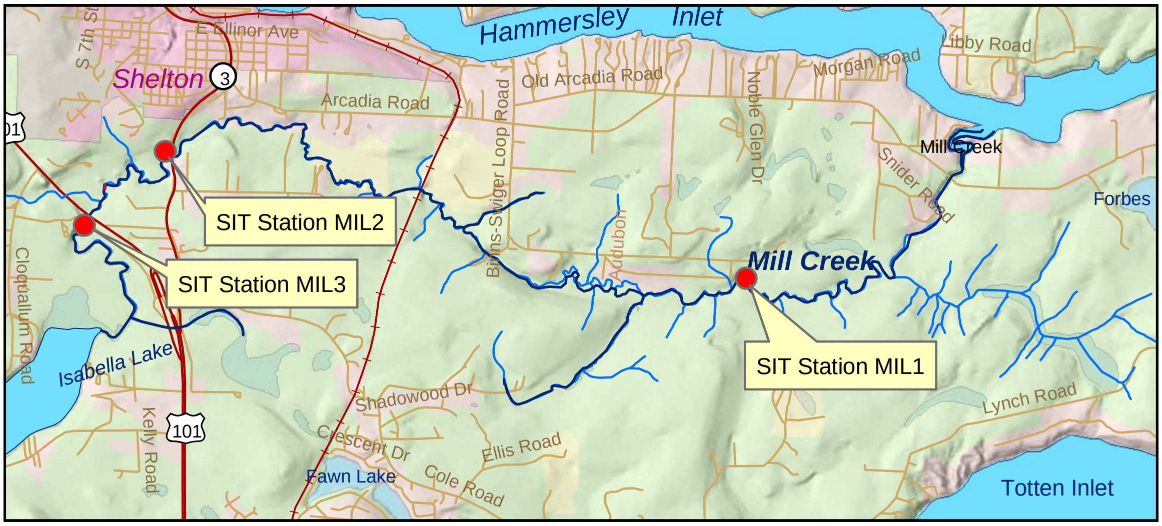


Figure 2. Mill Creek with Location of the Squaxin Island Tribe Monitoring Stations Below Isabella Lake.

Stream Temperature

The daily maximum temperatures and the 7-day average of daily maximum (DADM) temperatures measured at the three SIT sites are shown in Figures 3 and 4, respectively. Temperature excursions of the daily maximum criterion of 18˚C and the 7-DADM criterion of 17.5˚C were observed at all three locations (ML1, ML2, and ML3). Flow was measured by Ecology between 1986 and 1991 at a station off Audubon Way.

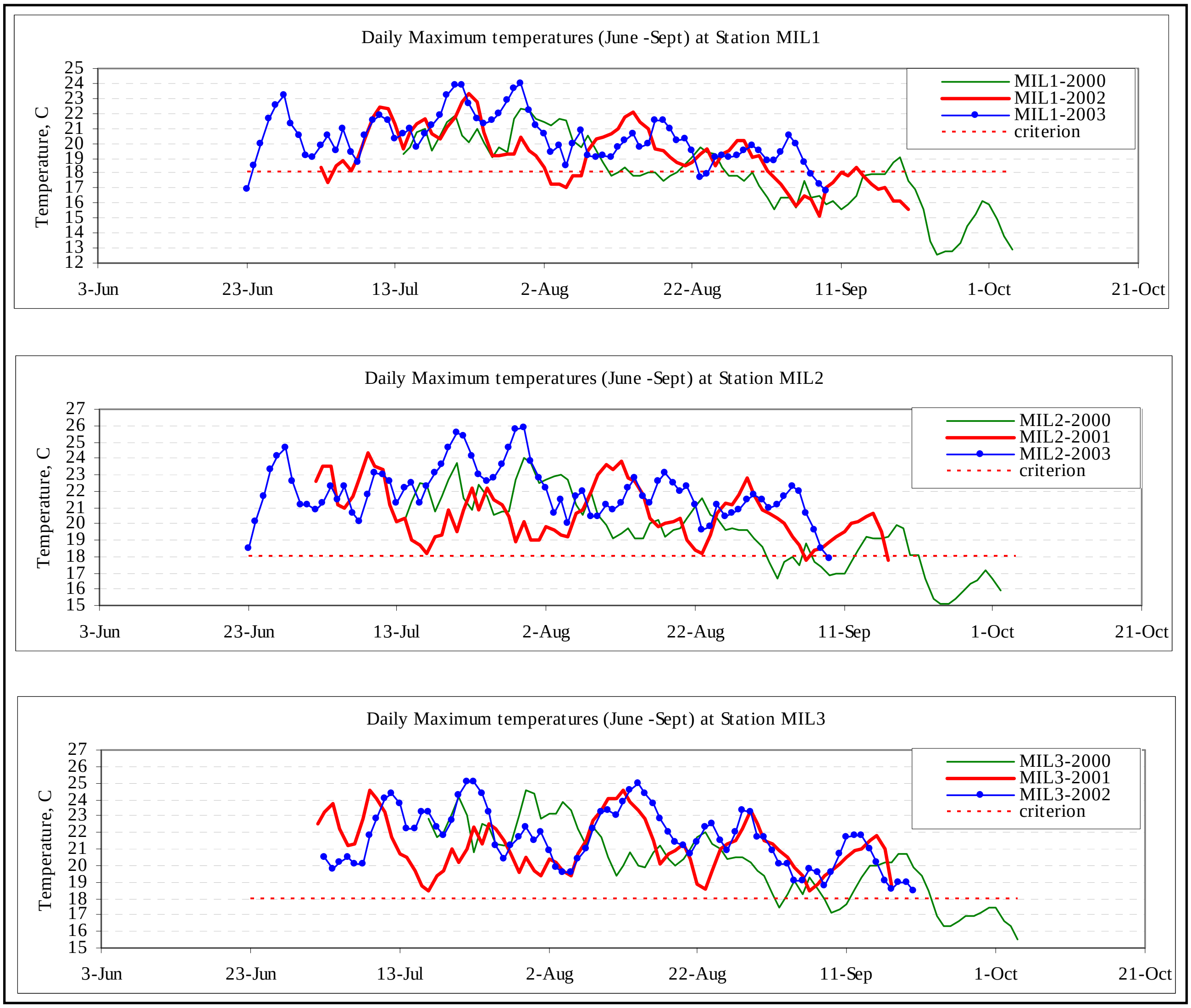


Figure 3. Daily Maximum Temperatures in Mill Creek at Three Stations (MIL1, MIL2, and MIL3).

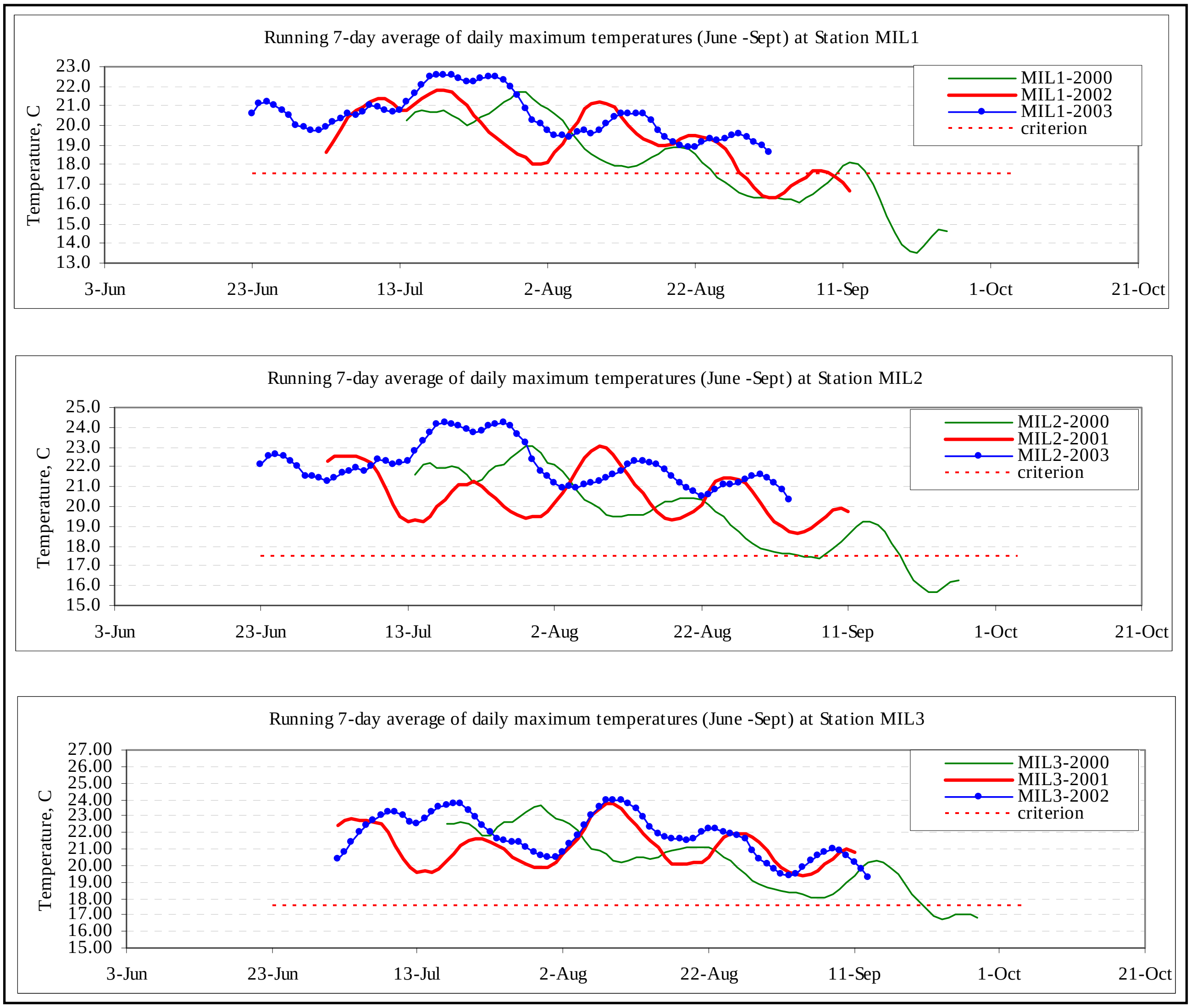


Figure 4. Running 7-DADM Temperatures in Mill Creek (Stations MIL1, MIL2, and MIL3).

The Squaxin Tribe also measured water temperature in Gosnell Creek that feeds into Lake Isabella. Temperatures measured at Station MIL4, upstream of Lake Isabella, were found to be much cooler compared to all downstream stations (MIL1, MIL2, and MIL3). Figure 5 shows the temperature profile at station MIL4. Temperature profiles for all years were below the water quality standards.

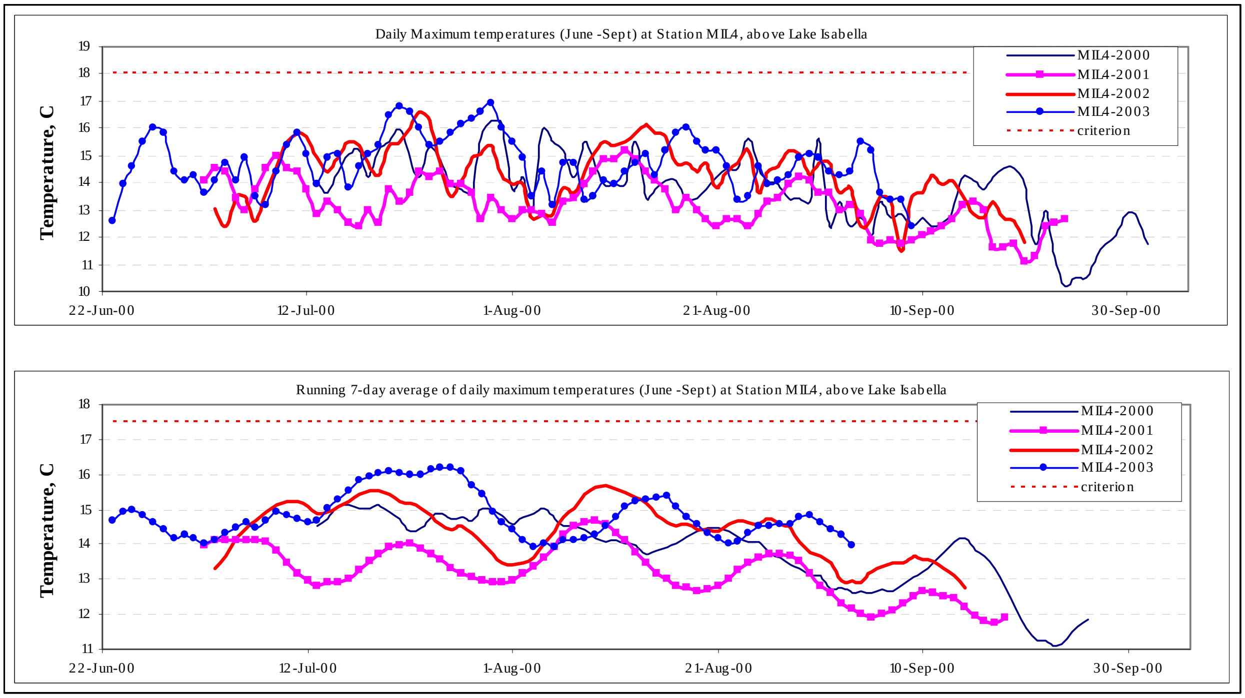


Figure 5. Maximum Daily and Running 7-Day Average of Daily Maximum Temperatures at Station MIL4 above Lake Isabella.

Lake Isabella Temperatures

Figure 6 shows the temperature profiles near the outlet of Lake Isabella. Strong stratification is observed in late summer/early fall period with temperatures as high as 23 ˚C at the surface. Observed temperatures in Gosnell Creek (Figure 5), as it discharges to Lake Isabella, were relatively low compared to temperatures measured at the lake outlet (Figure 6).

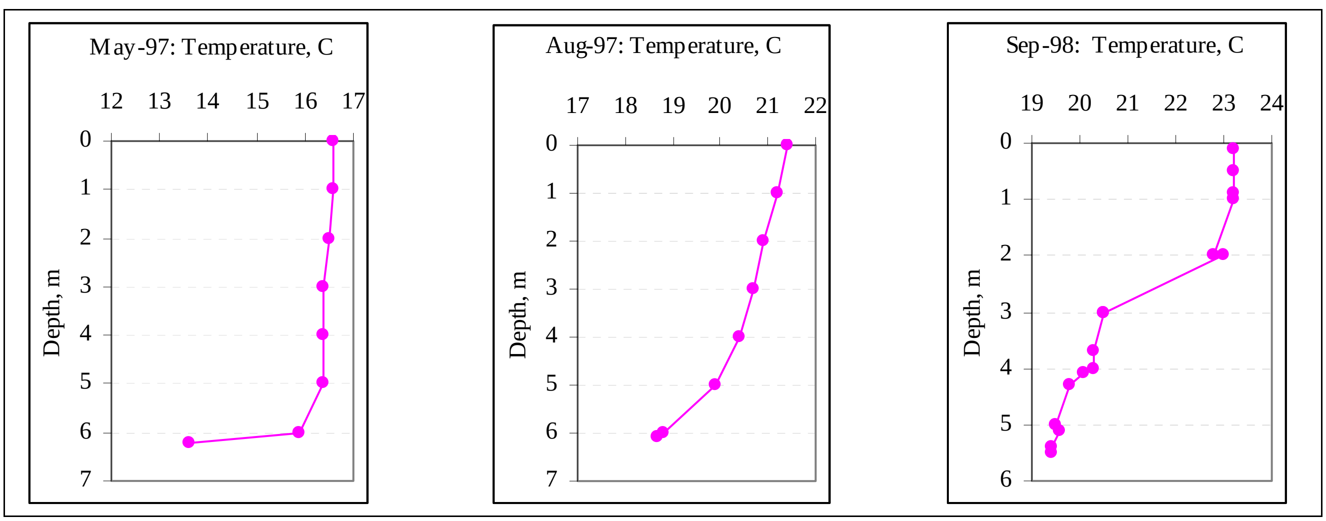


Figure 6. Temperature Profiles Near the Outlet of Lake Isabella.

Thermal Infrared (TIR) Survey

The Squaxin Island Tribe completed the TIR survey for Mill Creek in August 2003. Visual temperature and riparian vegetation profiles are available from this survey at http://www.ecy.wa.gov/apps/watersheds/temperature/tir/oakland_bay/index.html. Figure 7 shows a longitudinal temperature profile from the TIR survey. There is an approximate 3˚C drop in water temperature from the outlet at Lake Isabella to the mouth of Mill Creek at Hammersley Inlet. The cooling may be due to riparian shade and/or cooler groundwater inflow. Figure 8 shows a plan view of the TIR survey with cooling temperatures towards the mouth of the creek.

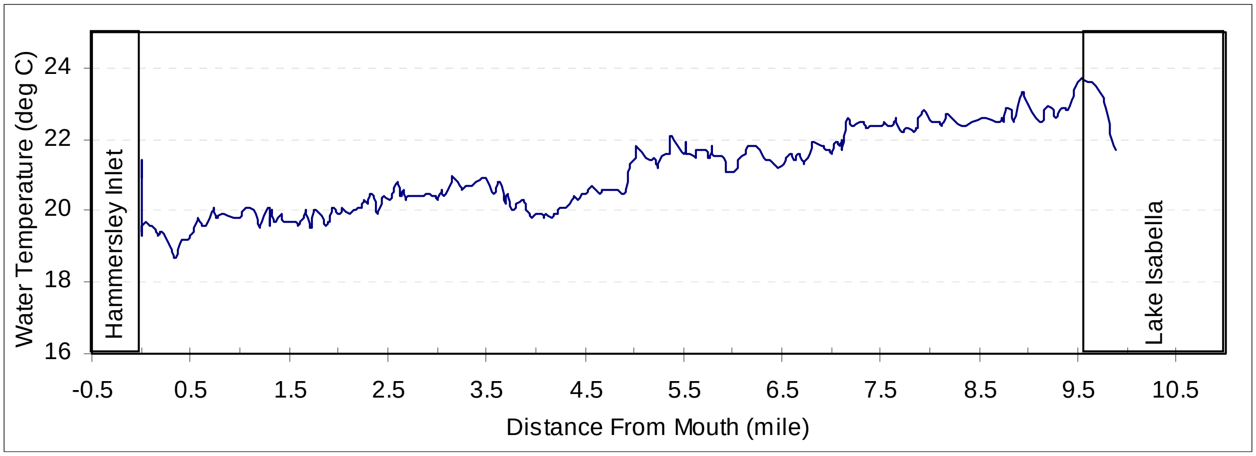


Figure 7. Longitudinal Temperature Profile in Mill Creek from Mouth at Hammersley Inlet to Lake Isabella Outlet. August 2003.

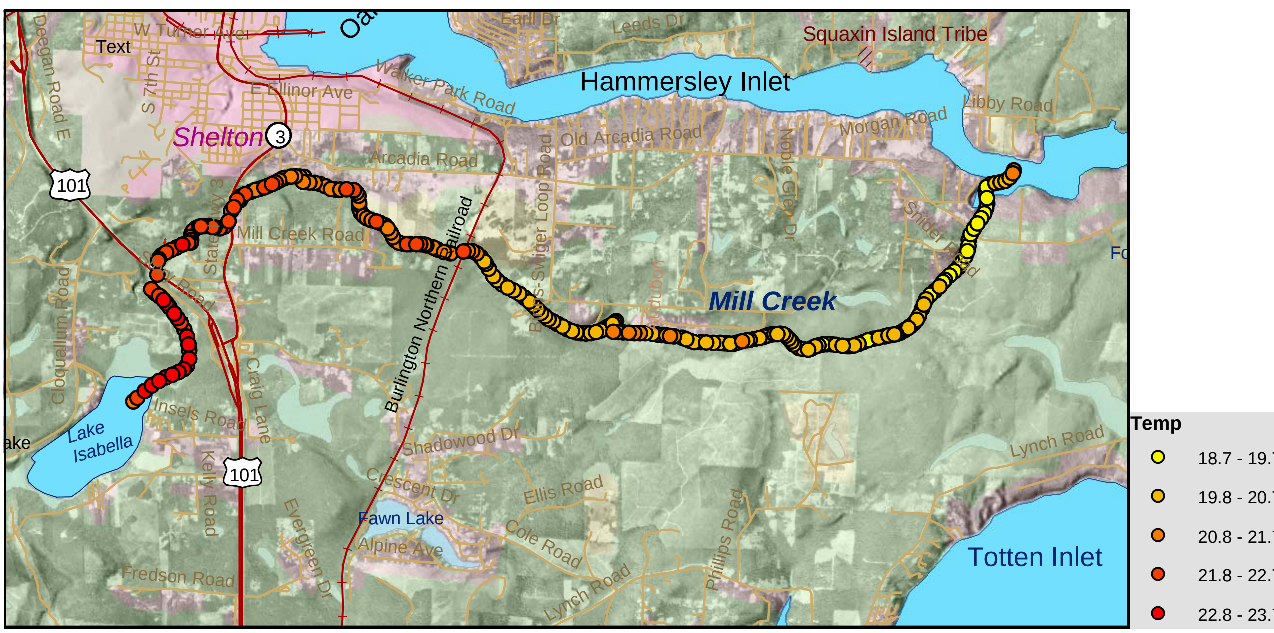


Figure 8. TIR Survey of Mill Creek Showing Decreasing Temperatures Towards the Mouth of the Creek.

Flow

Historical flows were measured at an old USGS gage (No. 12077500) on Highway 3 near Shelton in 1943 and 1951. Ecology measured flows in Mill Creek near Audubon Way in 1986-1991. Figure 9 shows the monthly average flow at the Audubon Way location. Flows were the highest in March and lowest in August. The months of January and February were not monitored. In addition, the Squaxin Tribe maintains a flow gage in Mill Creek. Data is not yet available from this gage.

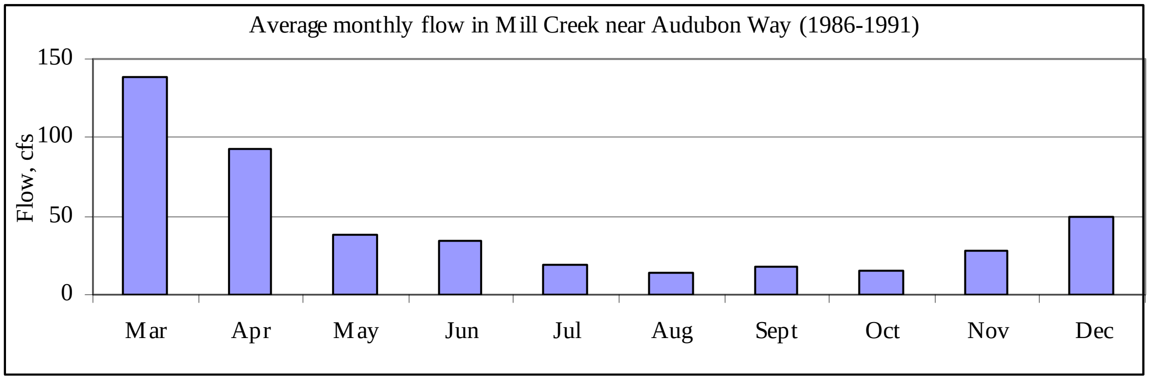


Figure 9. Average Monthly Flows in Mill Creek Near Audubon Way (1986-1991).

Cranberry Creek

Continuous temperature monitoring data were gathered by the Squaxin Island Tribe (SIT) in June-September 2003, at three locations (Figure 10) in Cranberry Creek downstream of Lake Limerick. Station CRA3 is below Lake Limerick, at Mason Lake Road Bridge; station CRA2 is at Mickelson Road Bridge; and station CRA1 is near the mouth of Cranberry Creek at Highway 3 Bridge. The SIT also monitored temperature and flow at station CRA4 just above Lake Limerick (Figure 10).

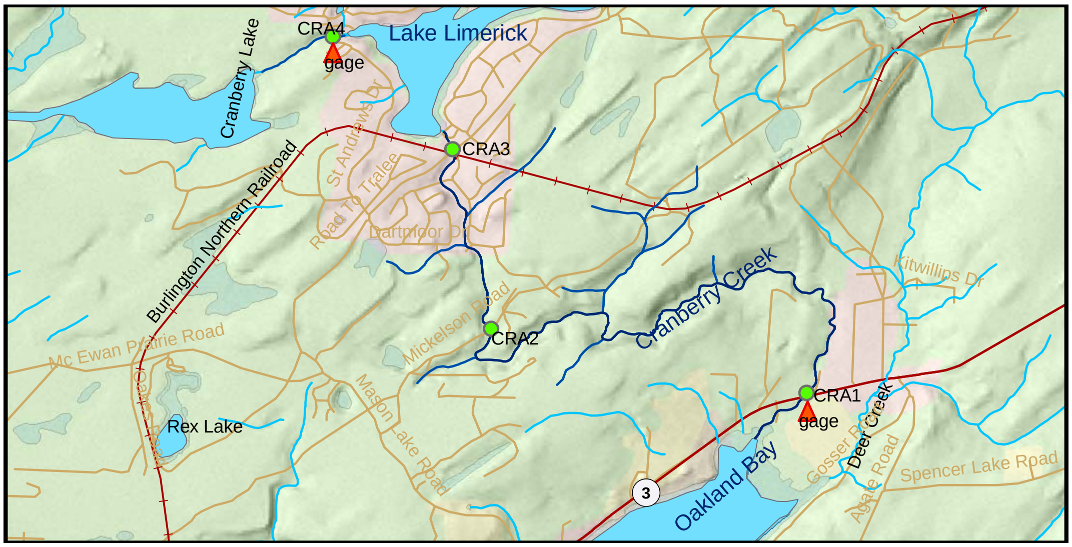


Figure 10. Cranberry Creek Reach Between Cranberry Lake and Oakland Bay.

Flow

Figure 11 shows flow measured by the Squaxin Island Tribe at three stations along Cranberry Creek in the summer of 2002. Flow at station CRA4 represents flows coming out of Cranberry Lake and going into Lake Limerick. Flow at station CRA3 represents discharge from Lake Limerick. The increased flow at CRA1 compared to CRA3 is presumed to be due to groundwater inflow within this reach. The small tributaries (Figure 10) between these two monitoring stations likely go dry during the summer season. Field survey will be conducted to verify this assumption. The average groundwater inflow between July and September in the 3.5 mile reach from Station CRA3 to station CRA1 is approximately 1 cfs/mile (Konovsky, 2004).

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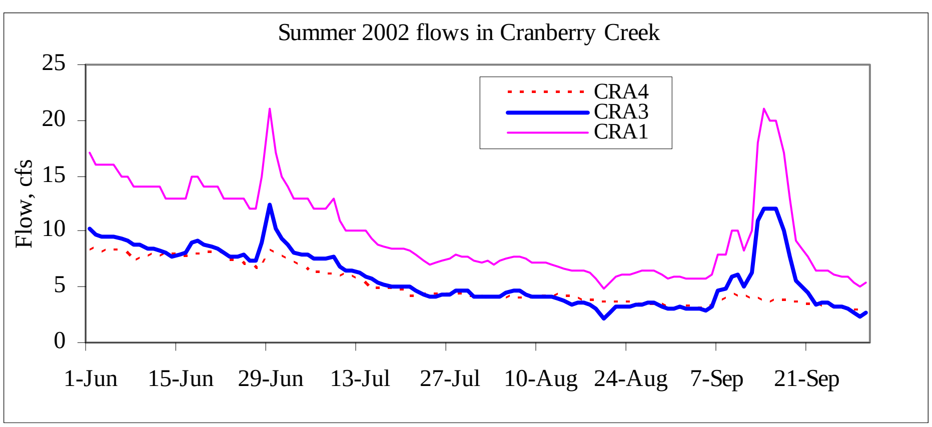

Figure 11. Flows in Cranberry Creek in Summer 2002.

Figure 12 shows that there is a good relationship between flows at station CRA3 (below Lake Limerick) and station CRA1 (at the mouth of Cranberry Creek) for data collected between June and September, 2002. This relationship should be used with caution for dry years when groundwater contribution is relatively low. This relationship will be verified and enhanced with additional data gathered during this project.

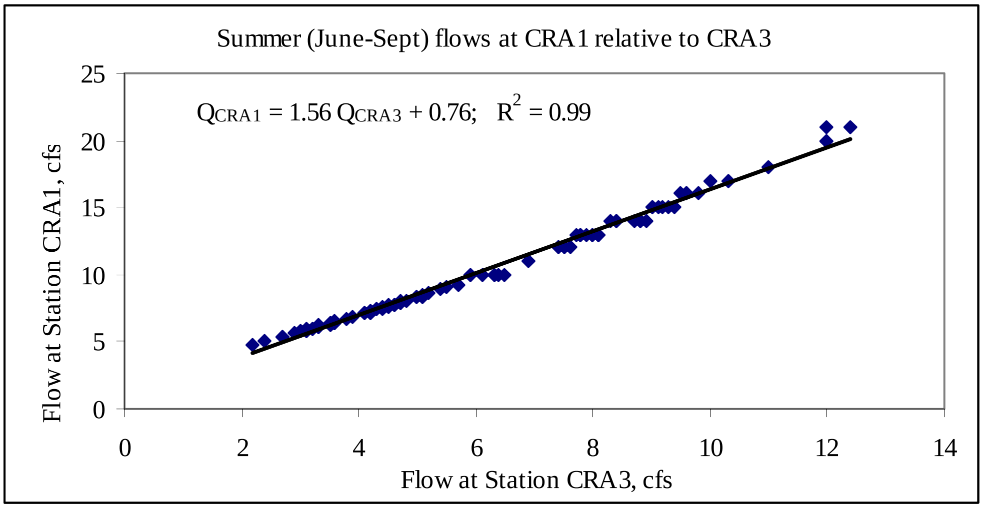

Figure 12. Relationship Between Flow at Station CRA3 and Station CRA1, June-September, 2002.

Channel Hydraulics

Cross-sectional measurements were made, by SIT, several times during the 2002 summer-fall seasons at stations CRA1, CRA3, and CRA4. However, sufficient data were only available for station CRA3 to develop relationship between flow, and the width of stream and velocity as shown in Figure 13. Thus, flow data obtained from the gage at CRA3 can be used to estimate the average velocity and average stream cross-section based on the following relationships.

Velocity, V (fps) = $0.5633\ Q^{0.3909}$; Stream Width, W (ft) = $12.6\ Q^{0.1758}$

Stream Cross-Sectional Area, A (ft^2) = Q/V; Stream Depth, D (ft) = A/W

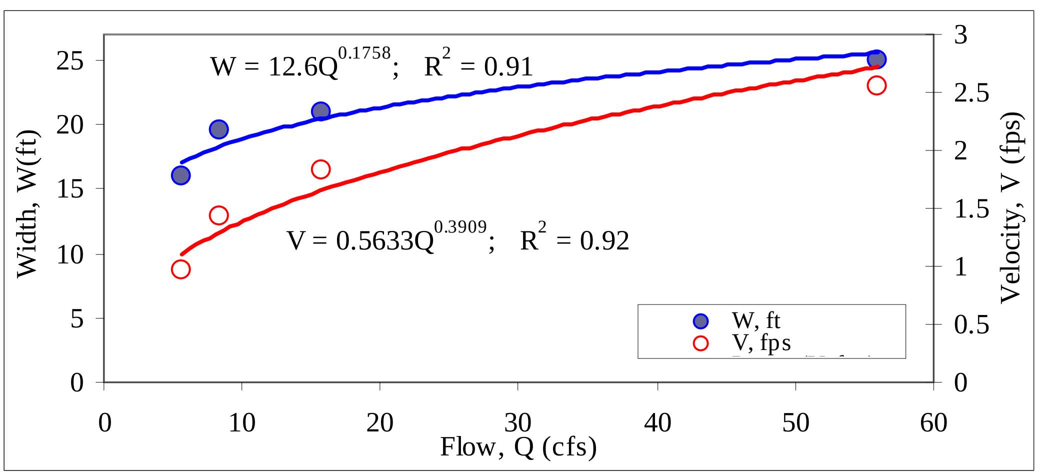

Figure 13. Stream Flow, Velocity and Width Relationships at Station CRA1 (June-December, 2002).

Groundwater Flow

Several flow measurements were made during the summer (2001-2002) by the Squaxin Island Tribe at two stations: CRA1 (near the mouth of the creek) and CRA3 (below Lake Limerick). The difference in flow between the two stations was assumed to represent groundwater contribution. The reach between CRA1 and CRA3 is 3.5 miles long. Table 3 shows the groundwater gain in the creek. There is approximately 1 cfs gain per mile due to groundwater inflow from station CRA1 to station CRA3.

Table 3. Groundwater Gain in Cranberry Creek.

Month	CRA 1	CRA 3	Canyon Gain	GW Gain/Mile
Jul 01	6.6	3.9	2.7	0.8
Aug 01	7.8	4.7	3.1	0.9
Sep 01	8.4	5.5	2.9	0.8
Jul 02	10.0	6.0	4.0	1.1
Aug 02	6.6	3.7	2.9	0.8
Sep 02	9.2	5.3	3.9	1.1

The 3.5 mile reach between station CRA1 and CRA3 contains small sub-tributaries that likely go dry during the summer/early fall dry period. This will be confirmed during the field survey conducted in 2005. If tributary flows are present, then the groundwater contribution between stations CRA1 and CRA3 will be re-estimated through additional seepage runs in this reach.

Stream Temperature

Continuous temperature monitoring data (2002-2003) were gathered by the Squaxin Island Tribe at Stations CRA1, CRA2, CRA3, and CRA4 (see Figure 10).

The daily maximum temperatures in the mainstem locations are shown in Figure 14. Temperature excursions of the daily maximum criterion of 18˚C were observed at all stations. However, a decreasing temperature was observed at the downstream stations.

The running 7-day average of daily maximum (7-DADMax) temperatures in the mainstem locations are shown in Figure 15. Temperature excursions of the 7-DADMax criterion of 17.5˚C were observed at all stations. Again, a decreasing temperature was observed at the downstream stations.

These temperature profiles will be used for QUAL2Kw model calibration along with the associated stream and ground flows. Groundwater temperatures were not specifically measured by the Squaxin Island Tribe. However, ground temperatures were measured during the TIR survey and will be used in the model.

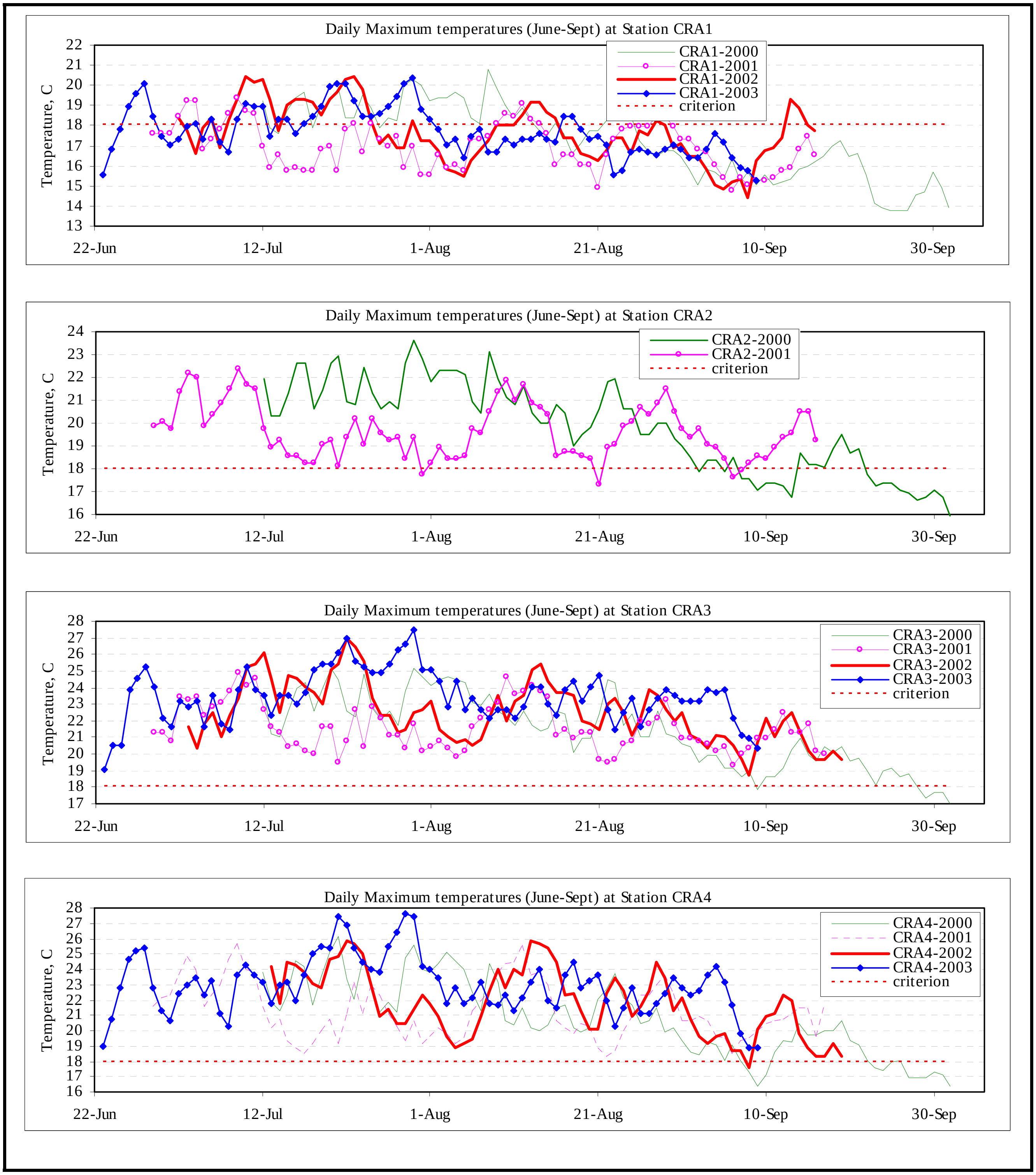

Figure 14. Daily Maximum Temperatures in Cranberry Creek at Four Stations (CRA1, CRA2, CRA3, and CRA4).

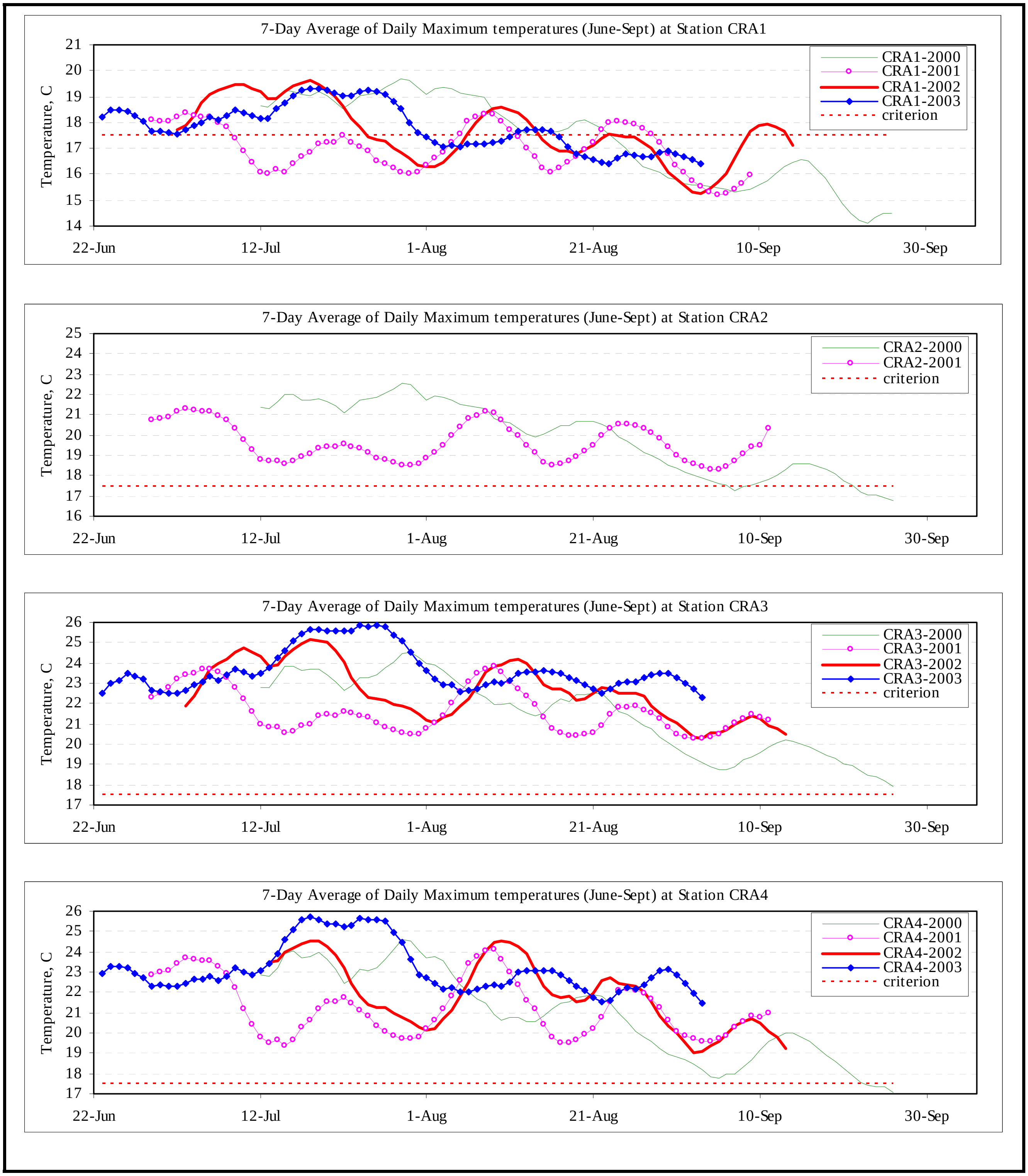

Figure 15. Running 7-DADMax Temperatures in Cranberry Creek at Four Stations (CRA1, CRA2, CRA3, and CRA4).

Lake Temperature

Lake Limerick drains into Cranberry Creek at the headwaters of the lower reach near Station CRA3, approximately 3.5 miles upstream from the mouth of the creek. Figure 16 shows temperatures measured by Ecology at the outlet of Lake Limerick in summer months between 1990 and 1998. High temperatures were observed during all summer months (May-September). Temperatures were the highest near the lake surface and coolest at the bottom. Since Lake Limerick is at the headwaters of the lower reach of Cranberry Creek, it may be assumed that the high temperatures observed in the creek just below the lake are a direct result of the lake discharge.

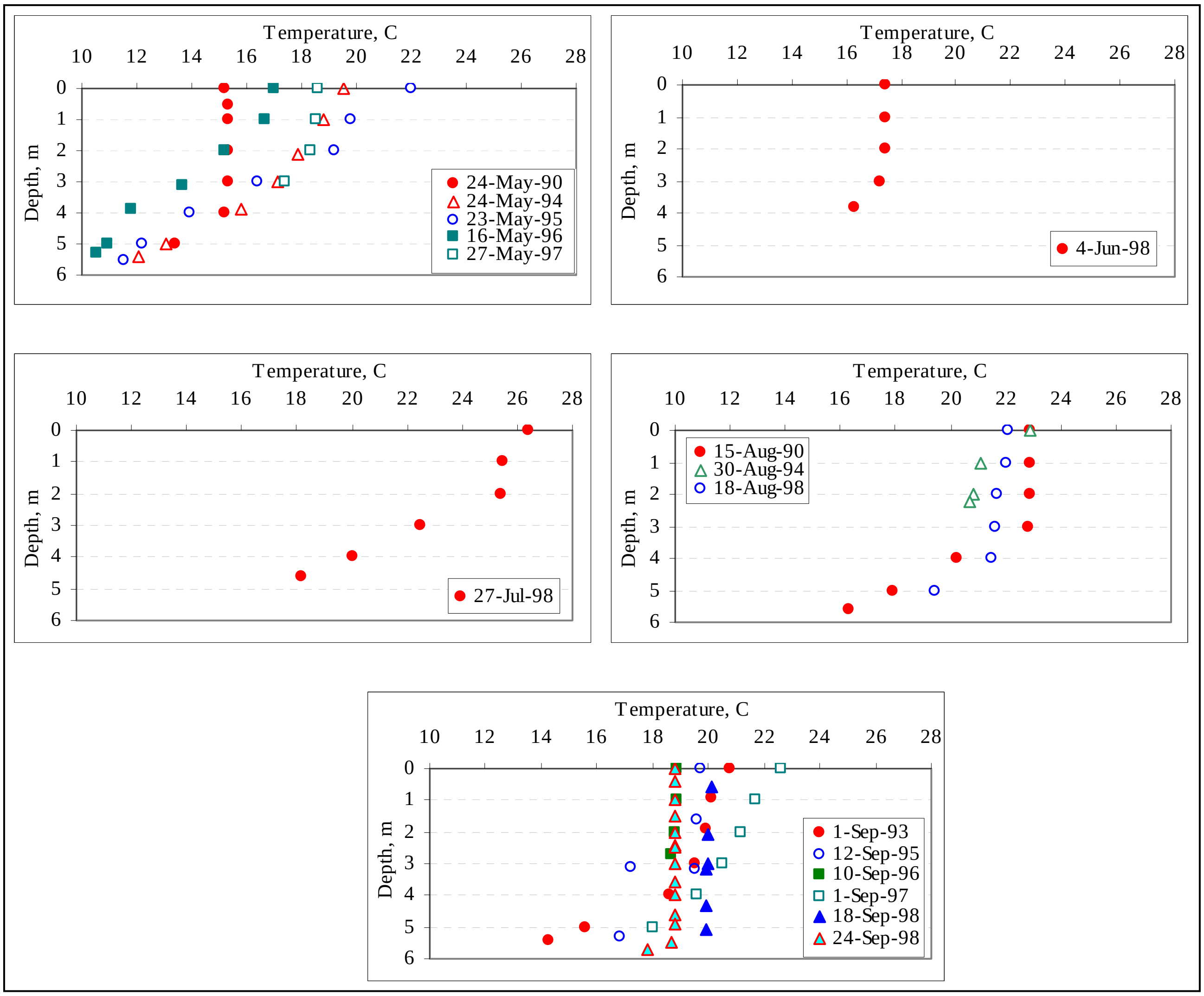

Figure 16. Water Temperatures Near the Outlet of Lake Limerick During Various Summer Months.

Thermal Infrared (TIR) Surveys

The Squaxin Island Tribe completed the TIR survey for Cranberry Creek on August 18, 2003. Visual temperature and riparian vegetation profiles are available from this survey at http://www.ecy.wa.gov/apps/watersheds/temperature/tir/oakland_bay/index.html. Figure 17 shows a longitudinal temperature profile from the TIR survey. There is almost an 8˚C drop in water temperature from the outlet at Lake Limerick to the mouth of Cranberry Creek at Oakland Bay. The cooling may be due to riparian shade and/or cooler groundwater inflow. Cooling also takes place in the 2100 feet of stream stretch between Cranberry and Limerick Lakes. Figure 18 shows a plan view of the TIR survey with cooling temperatures towards the mouth of the creek.

The flow at station CRA1, at the mouth of the creek, on the day of the TIR survey was 4.7 cfs. This is below the August 18, 2002 flow of 6.3 cfs.

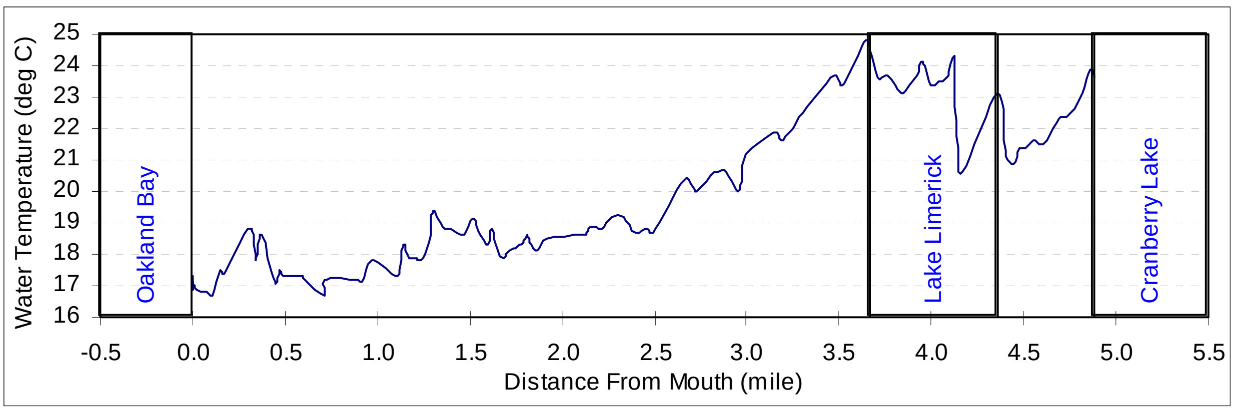

Figure 17. Longitudinal Temperature Profile in Cranberry Creek from Mouth at Oakland Bay to Lake Limerick and Cranberry Lake Outlets. August 2003.

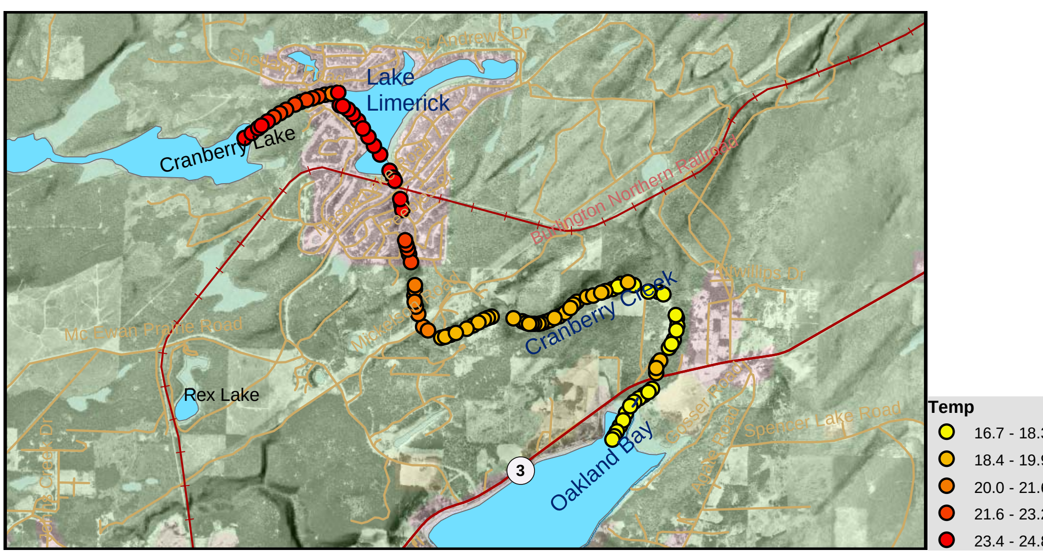

Figure 18. TIR Survey of Cranberry Creek Showing Decreasing Temperatures Towards the Mouth of the Creek.

Stream Characteristics

Some data on stream canopy and channel morphology is available from the Squaxin Island Tribe as shown in Table 4. Additional stream cross-sectional data was measured at stations CRA1 and CRA3 by the Squaxin Island Tribe during groundwater seepage evaluation.

Table 4. Stream Characteristics for Cranberry Creek.

		Canopy Closure				Channel Morphology (ft)				
Station	Year	Upstream	Left Bank	Downstream	Right Bank	Wetted Width	Bank-full Width	Bank-full Mean Depth	Width/ Depth Ratio	*D_{50} (mm)
CRA 1	2002	94%	96%	96%	95%	13.3	41.3			
CRA 2	2002					20.6	23.0	1.3	17.7	33
CRA 3	2002	64%	89%	86%	84%	25.0	32.4			
CRA 4	2002	64%	90%	89%	95%	52.0	64.2			

* D_{50} = 50% of stream bed material size greater than and 50% less than 33 mm.

Johns Creek

The Squaxin Island Tribe gathered continuous temperature data in June –September, 2000-2003, at several locations along Johns Creek (Figure 19). Station JOH1 is at the Bayshore Country Golf Course off Highway 3. JOH2 is at Johns Creek Drive. This station also has a flow gage. JOH3 is at Jensen Road culvert. This station also has a flow gage but will be moved to station JOH1 by April 2005. JOH3.5 is at Brockdale Road culvert. No continuous temperature was measured at this station. JOH4 is under the power lines.

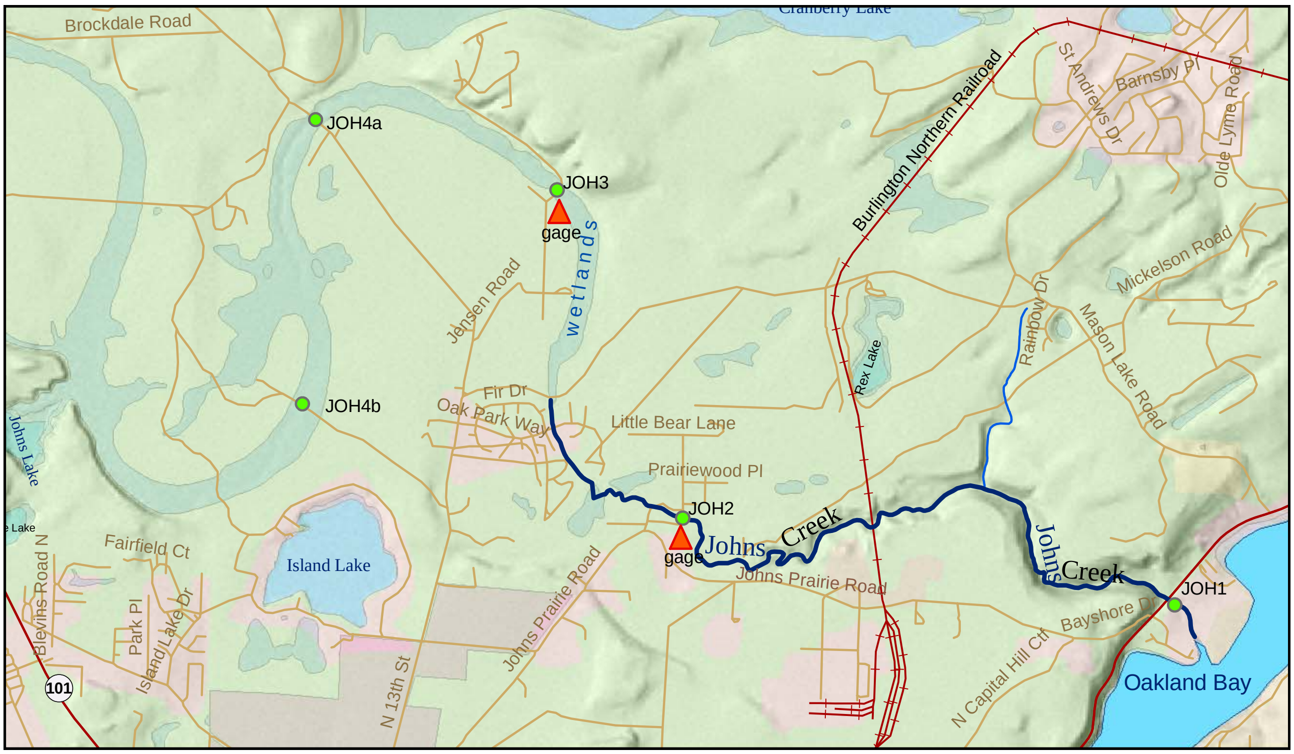

Figure 19.   Map of Johns Creek Showing Wetland at Headwaters and Squaxin Island Tribe Monitoring Stations.

Stream Temperature

Continuous temperature monitoring data (2000-2003) are available for mainstem Johns Creek stations at Stations JOH1, JOH2, JOH3, and JOH4 (see Figure 19). Temperatures at stations JOH3 and JOH4 represents temperatures in the wetland.

The daily maximum temperatures in the mainstem locations are shown in Figure 20. Temperature excursions of the daily maximum criterion of 18˚C were observed at all stations, although there is a general trend of decreasing temperature as the water moves down stream.

The running 7-day average of daily maximum (7-DADMax) temperatures in the mainstem locations are shown in Figure 21. Temperature excursions of the 7-DADMax criterion of 17.5 C were observed at all stations. Again, temperatures were cooler in the lower watershed than they were in the wetland dominated upper watershed.

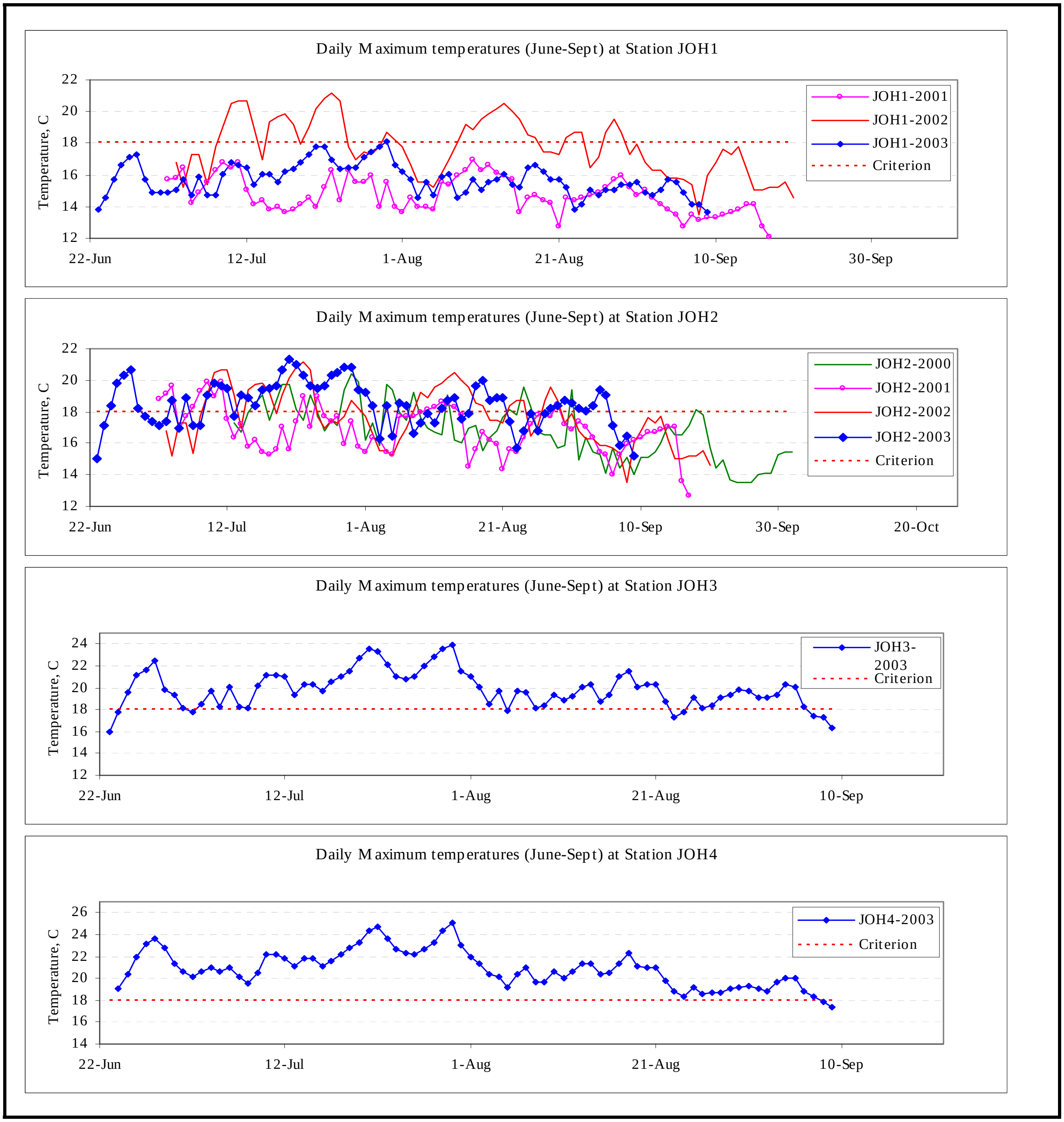

Figure 20. Daily Maximum Temperatures in Johns Creek at Four Stations (CRA1, CRA2, CRA3, and CRA4).

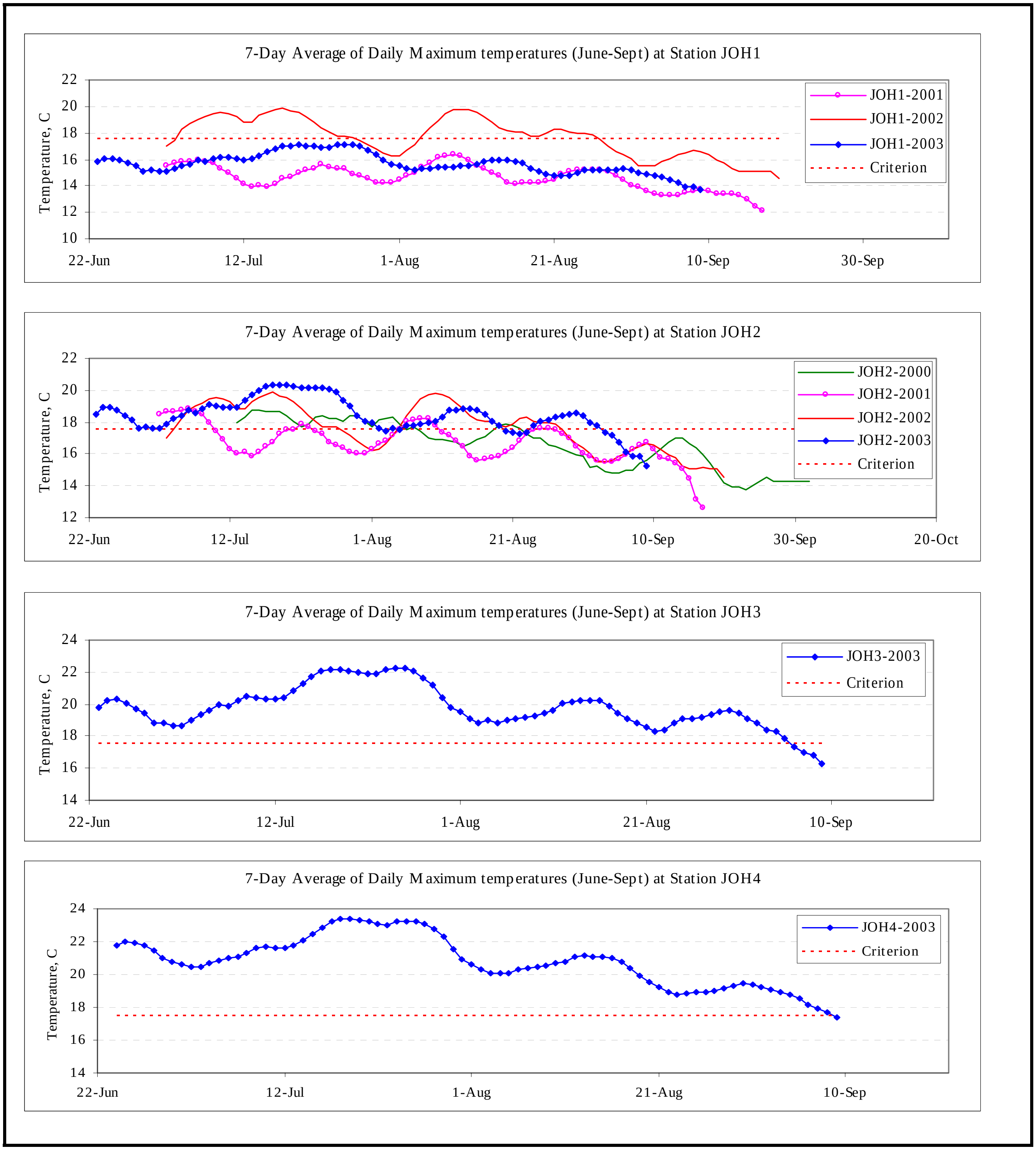

Figure 21. Running 7-DADMax Temperatures in Johns Creek at Four Stations (JOH1, JOH2, JOH3, and JOH4).

These temperature profiles will be used for QUAL2Kw model calibration along with the associated stream and ground flows. Groundwater temperatures were not specifically measured by the Squaxin Island Tribe. However, ground temperatures were measured during the TIR survey and will be used in the model.

Thermal Infrared (TIR) Surveys

The Squaxin Island Tribe completed the TIR survey for Johns Creek in August 2003. Visual temperature and riparian vegetation profiles are available from this survey at http://www.ecy.wa.gov/apps/watersheds/temperature/tir/oakland_bay/index.html. Figure 22 shows a longitudinal temperature profile from the TIR survey. There is an average of a 4˚C drop in water temperature from the downstream end of the wetlands at McEwan Prairie Road to the mouth of Johns Creek at Oakland Bay. The cooling may be due to riparian shade and/or cooler groundwater inflow. Significant cooling (6˚C) also takes place in the wetland from river mile 6.9 to the mouth of the wetland at river mile 4.6. Stream temperatures rise slightly after leaving the wetland and then start a significant cooling trend to about river mile 1 that results in a 6˚C temperature reduction. Stream temperatures rise by roughly two degrees between river mile 0.8 and the mouth of the stream at Oakland Bay. Figure 23 shows a plan view of the TIR survey.

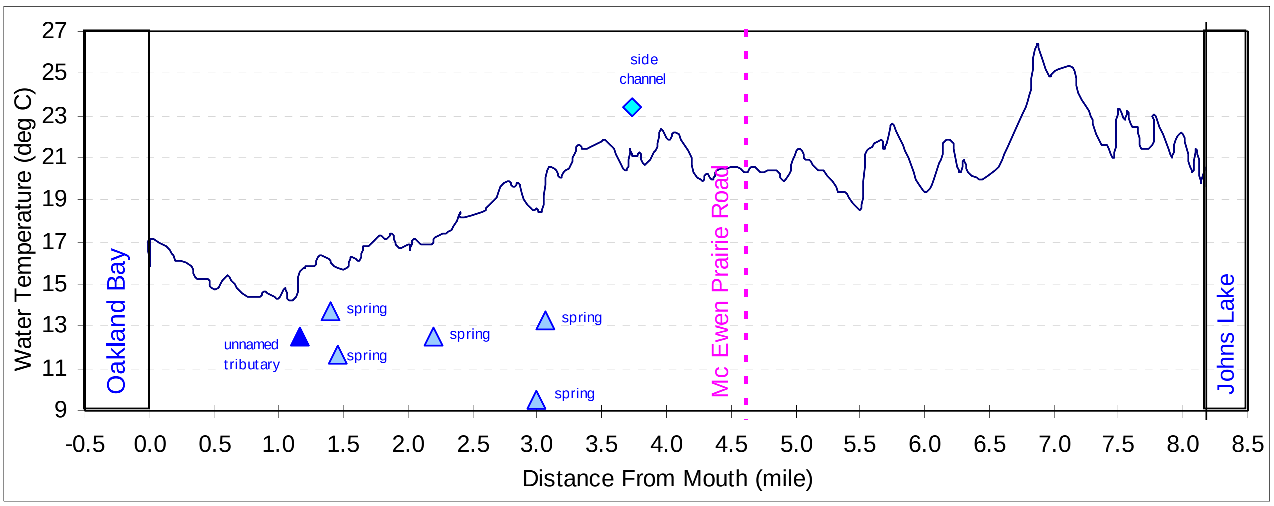

Figure 22. Longitudinal Temperature Profile in Johns Creek. August 2003.

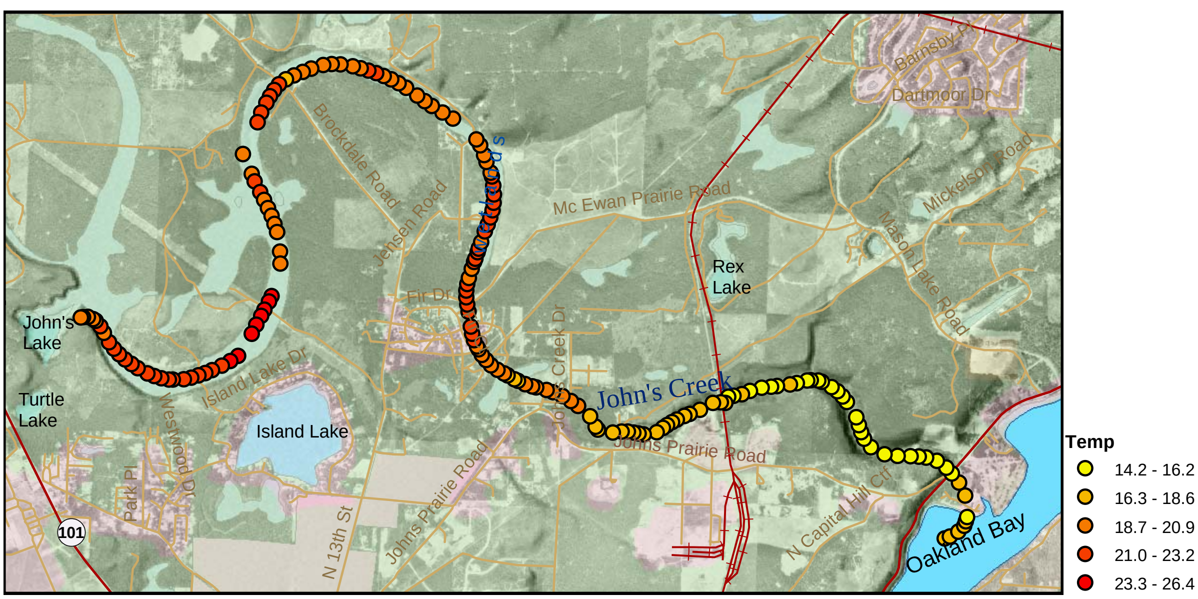

Figure 23. TIR Survey of Johns Creek Showing Decreasing Temperatures Towards the Mouth of the Creek.

Stream Flow

The Squaxin Island Tribe operates a stream gage in Johns Creek at JOH2 (at Johns Creek Drive) and at JOH 3 (Jensen Road culvert). The gage at JOH3 will be moved to station JOH1 by April 2005. Flow data were not available from the Squaxin Island Tribe at the time of completion of this report. Summer flows in Johns Creek, as measured by Ecology between 1986 and 1991, are shown in Figure 24. Lowest flows were observed in September.

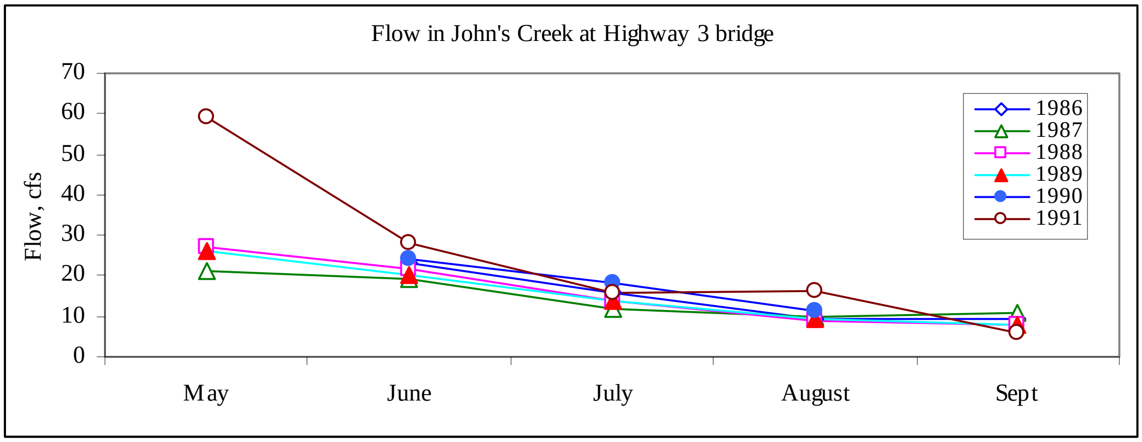

Figure 24. Flow in Johns Creek at Highway 3 Bridge for Selected Months.

Groundwater Flow

Seepage runs were completed during the summers of 2001 and 2003. During the 2001 seepage run, conducted by the Pacific Groundwater Group, flows were measured at JOH1 (at Highway 3, near the mouth of the creek), at unnamed tributary, at the Burlington Northern Rail Road crossing (lower watershed), at JOH2 (at Johns Creek Drive), and at JOH3 (in the lower portion of the wetland). The difference in flow between the stations was assumed to represent groundwater contribution. There was approximately 1 cfs of groundwater gain per mile in Johns Creek below the wetland (Table 5).

Table 5. Groundwater Gain in Johns Creek (cfs).

Date	JOH1	Unnamed Tributary	Railroad Crossing	JOH2	JOH3	JOH4	Total Gain	Wetland Gain	Canyon Gain	GW Gain/Mile in Wetland	GW Gain/Mile in Canyon
8/16/2001	5.4	1.4	3.4	2.7	1.2				2.7		1
7/22/2003				5.5	4.2	3.5		2		0.7	
8/14/2003	9.1			5.2	3.1	3.1	5.9	2	3.9	0.7	1.5
8/19/2003	8.4			4.7	4.2	3.9	4.4	0.8	3.6	0.3	1.4
9/4/2003	7.6			3.6	3.2	3.2	4.4	0.5	4	0.2	1.5

During the 2003 summer seepage runs, conducted by the Squaxin Island Tribe, stream flows were measured at JOH1, JOH2, JOH3, and JOH4 (Table 5). The unnamed tributary between JOH1 and JOH2 was not dry during these events and the flow in this tributary was not measured. However, this tributary is short and likely fed by groundwater. These seepage runs investigated groundwater gains both in the canyon and in the wetland. Total groundwater gains for Johns Creek ranged from 4.4 cfs to 5.9 cfs during these seepage runs. Groundwater gains in the wetland ranged from 0.5 cfs to 2 cfs, while canyon gains ranged from 3.6 cfs to 4 cfs. The groundwater gain per mile in the canyon ranged from 1.4 to 1.5 cfs during these flow monitoring events.

Stream Characteristics

The Squaxin Island Tribe collected canopy closure data for Johns Creek during 2002 at JOH1 and JOH2, and during 2003 at JOH4 (Table 6). Canopy closure at JOH1 was greater than 90% on the left bank, right bank, downstream, and upstream, indicating highly intact streamside vegetation. All canopy closure measurements were also over 90% at JOH2, again, indicating highly intact streamside vegetation. Canopy closure percentages at JOH4 were 12% for the upstream measurement and 0% for the downstream, left bank, and right bank measurements. JOH4 is located where Brockdale Road crosses the large upstream wetland. The lack of canopy closure over the wetland, as well as the relatively slow movement of water, leads to significant heat loading that is reflected in the stream temperature measurements at JOH4 and JOH3 (see Figures 20 and 21). In 2002, the stream cross section was measured at station JOH2 in August at a flow of 5.8 cfs.

Table 6. Stream Characteristics for Johns Creek.

		Canopy Closure				Channel Morphology (ft)				
Stations	Year	Upstream	Leftbank	Downstream	Rightbank	Wetted Width	Bank-full Width	Bank-full Mean Depth	Width/ Depth Ratio	D_{50} (mm)
JOH 1	2002	93%	95%	96%	91%	13.2	24.6			
JOH 2	2002	96%	95%	96%	94%	18.8	32.3	2.4	13.0	45.0
JOH 4	2003	12%	0%	0%	0%					

* D_{50} = 50% of stream bed material size greater than and 50% less than 33 mm

Data Needs

Since temperature is a measure of heat content, the TMDL will be developed for heat. Processes that impact heat content of water column are (Chapra, 1997):

- Heat input from point and non-point sources.
- Solar radiation: (i) shortwave solar radiation.
  (ii) longwave radiation exchange between air and water.
- Convection: exchange between air and water due to temperature differential.
- Conduction: exchange between water and sediment due to temperature differential.
- Evaporation: when vapor pressure is less than the dew point.
- Wind: impacts both convection and evaporation.
- Groundwater: (i) inflow groundwater will cool stream temperatures and increase flow.
  (ii) outflow of warmer stream water will increase temperatures due to reduced depth of flow.

Temperature is an indication of heat content of the material. So, if heat accumulates in the waterbody due to the processes discussed above, there will be a net increase in temperature of the water column and vice versa.

In addition to point and nonpoint sources of thermal pollution, other causes of increased stream temperature are:

- Channel widening increases surface area exposed to solar radiation.
- Reduced riparian vegetation reduces surface shading and increases exposure to solar radiation.
- Reduced summer base flows resulting from increased water rights, land development, and timber harvesting (less groundwater recharge from rain and, therefore, less late-summer groundwater contributions to stream flow) reduces heat-holding capacity of the stream.
- Presence of stratified lakes in upstream locations may increase stream temperatures if lake outlets draw water from the upper layers of the water column.

Stream temperatures will be modeled using QUAL2Kw, a stream water quality model based on the QUAL2E model (Brown and Barnwell, 1987) and developed by Dr. Steven Chapra (Chapra, 2001). QUAL2Kw is a one dimensional (completely-mixed vertically and laterally) model with steady state hydraulics and diurnal water quality simulation capabilities.

Effective shade produced by current riparian vegetation will be estimated using Ecology's Shade-model (Ecology, 2003). Shade is a spreadsheet model that calculates effective shade either by using the HeatSource model developed by Oregon Department of Environmental Quality (ODEQ, 2000) or the HSPF SHADE model developed by Chen (1996).

Data needs for temperature modeling are listed in Table 7 below.

Table 7. Data Needs for Modeling Stream Temperatures.

	Parameter	Model: Shade	Model: QUAL2Kw	Data Collected By: Squaxin Island Tribe	Data Estimated/ Selected By: Ecology	Comment
Flow	discharge - tributary		x	x		
	discharge (upstream & downstream)		x	x		
	flow regression constants		x		x	Calculated from field data
	flow velocity		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	USGS or GIS Maps
	elevation - upstream	x	x		x	USGS or GIS Maps
	elevation/altitude	x	x		x	USGS or GIS Maps
	latitude	x	x		x	USGS or GIS Maps
	longitude	x	x		x	USGS or GIS Maps
	time zone	x			x	
Physical	channel azimuth/stream aspect	x			x	
	cross-sectional area	x	x	x		
	Manning's n value	x	x		x	Calculated from flow data
	Pebble count	x	x	x		
	reach length	x	x	x		
	stream bank slope	x		x		
	stream bed gradient	x	x		x	USGS or GIS Maps
	width - bankfull	x		x		
	width - stream	x	x	x		
	Width – flood prone			x		For information only
Temperature	temperature - ground	x	x	x		
	temperature - groundwater		x	x		
	temperature – water downstream		x	x		
	temperatures - water upstream		x	x		
	temperature - air		x	x		
Vegetation	vegetation overhang	x		x		
	canopy density	x		x	x	Hemispherical photography or densiometer at representative sites and Orthophotos for remaining reaches
	distance to shading vegetation	x		x	x	
	topographic shade angle	x			x	
	vegetation height	x			x	
	vegetation shade angle	x			x	
	vegetation width	x			x	
Weather	relative humidity		x	RH meters	x	weather station*
	% possible sun/cloud cover		x		x	weather station*
	solar radiation		x		x	weather station*
	temperature - air		x		x	weather station*
	wind speed/velocity		x		x	weather station*

*** The Sanderson airfield in Shelton has a weather station.**

TMDL Approach

Mill Creek

The temperature plots of the main stem Mill Creek (see Figures 3 and 4) suggests that temperature standards were not met at any of the stations monitored below Lake Isabella. However, temperatures decreased consistently between Lake Isabella and the mouth of the creek at Hammersley Inlet. Continuous temperature data is lacking for the reach between station ML2 and ML1 and below station ML1. Proposed additional station locations for water/air temperature, relative humidity, and flow measurements are shown in Figure 25.

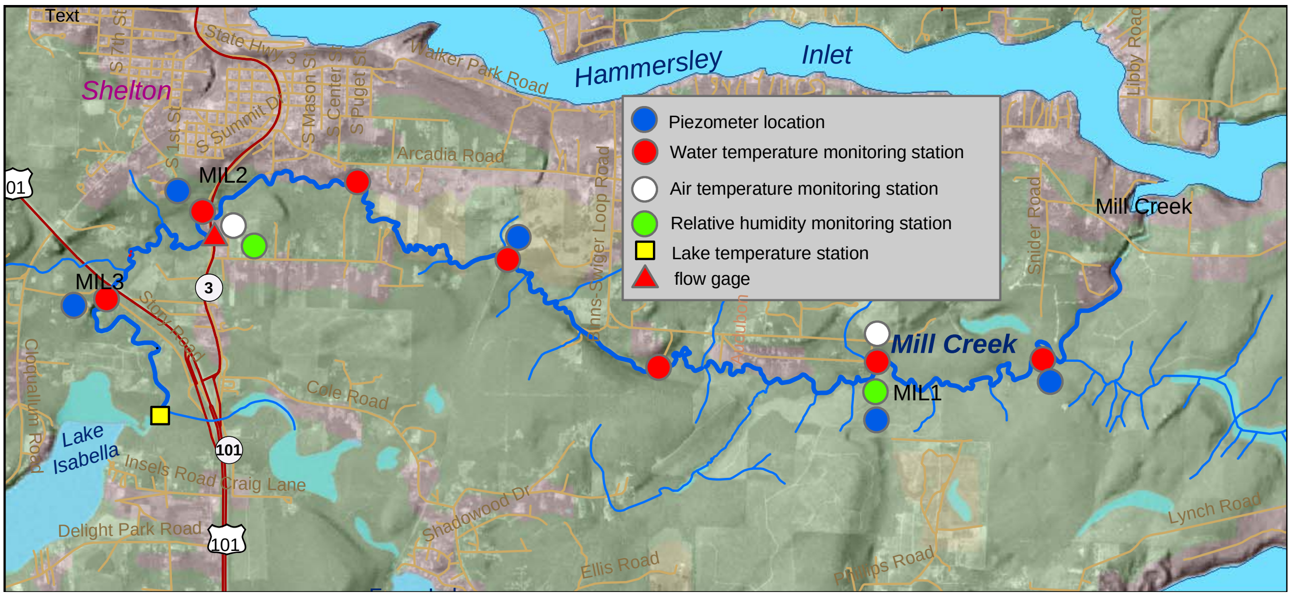

Figure 25. Map Showing Proposed Monitoring Locations in Mill Creek.

The Squaxin Island Tribe will lead the field study for the Mill Creek temperature TMDL. The reach of the creek that will be addressed in this TMDL extends from the outlet of Lake Isabella to the mouth of the creek in Hammersley Inlet.

Continuous water temperature monitoring sites will be established at 7 locations (red dots in Figure 25) in the mainstem and tributaries to Mill Creek. A continuous temperature monitoring device will also be installed at the outlet of Lake Isabella. Air temperatures and relative humidity will be monitored at two mainstem sites (white and green dots, respectively, Figure 25). Water and air temperature will be measured with Onset Stowaway temperature data loggers or equivalent. Relative humidity will be measured with an Onset H8 Pro RH/temperature data logger or equivalent. The air temperature data loggers will be installed in a location in the stream or riparian forest which is shaded from direct sunlight. They will be placed in an area representative of the surrounding environment. The water temperature logger will be installed at approximately one half of the water depth and as close to the center of the thalweg as possible. The installation site will be located where there is obvious water mixing and at a depth that will not become exposed if the water level drops but will not be affected by groundwater inflow or stratification. The air temperature data loggers will be installed adjacent to the water temperature probe about one to three meters into the riparian zone from the edge of the bank-full channel and about one meter off the ground.

Riparian Stream and Habitat Surveys

Timber-Fish-Wildlife Stream Temperature Survey methods will be followed for the collection of data during thermal reach surveys (Schuett-Hames et al., 1999). The surveys will be conducted July to August 2005 at the mainstem temperature sites established in the previous section. Field measurements will be taken at 6 to 10 locations over a 300-meter thermal reach and will consist of bank-full 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. Hemispherical photography or densiometer will be used to measure effective shade and canopy density at all water temperature stations, and at additional selected locations as necessary, to ground-truth the range of vegetation classes digitized from inspection of digital orthophotos.

Groundwater Survey

Mini in-stream piezometers will be installed along the seepage run locations (blue dots in Figure 25) to define the vertical hydraulic gradient between area streams and the water-table aquifer. The piezometers consist of a seven-foot length of ½ inch diameter galvanized pipe, one end of which is crimped and slotted. The piezometers will be hand driven into the stream bed to a depth of approximately five feet. If in any stream reach (area between blue dots in Figure 25) hard pan is encountered, piezometers will not be installed and the groundwater-stream interaction will be assumed to be negligible.

Water levels in the piezometers will be measured monthly between June and September, 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, ground-water 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. Surface water temperature, groundwater temperature, and conductivity will be measured during each of the monthly piezometer surveys. Stream reaches with significant groundwater input (especially during low flow periods) should have similar water chemistry to area groundwater. Measurements will be made with properly-maintained and calibrated field meters in accordance with standard USGS methodology.

Synoptic Surveys

Four field synoptic surveys will be conducted during summer 2005 low flow season: one each in June, July, August, and September. Each survey will be completed in one day. The monitoring locations are shown in Figure 25. The following measurements will be made during each survey.

- Stream cross-sectional dimensions: width (bank-full, and wetted), depth, and stream bank slope.
- Velocity (*in situ*) and estimated flow.
- Temperature (*in situ*).
- Piezometer water level.
- Associated creek stage.
- Conductivity – both piezometer and creek.

Data Collection Timeline

The schedule for field work is as follows.

May 3-7	Reconnaissance survey of the creek to locate areas of least riparian vegetation and inputs from un-named tributaries, culverts, storm drains, and ditches, etc.
May 24-28	Temperature, humidity data logger, and peizometers installed at critical locations.
June 1-15	First synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
June 15-30	Download temperature and humidity data from data loggers.
July 1-15	Second synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
July 30-Aug 30	Stream and habitat surveys.
Aug 1-15	Third synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
Aug 15-30	Download temperature and humidity data from data loggers.
Sept 1-15	Fourth synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
Sept 30-Oct 15	Download final temperature data, remove tidbits.

*Timeline may change due to irregularities in stream discharge and/or weather to ensure data quality.

Cranberry Creek

Cranberry Creek can be divided into two segments, the reach between Cranberry and Limerick Lakes and the reach below Lake Limerick.

Reach Between Cranberry and Limerick Lakes

This segment of Cranberry Creek between the two lakes is approximately 0.52 miles. Figure 26 shows that the riparian vegetation is pretty much intact. The high temperatures observed at Station CRA4 just above Lake Limerick are likely due to warm water discharged from Cranberry Lake. The longitudinal temperature profile measured in August 2003 (see Figure 17) indicates that temperature of water at station CRA4 was almost 3^{o}C cooler than the temperature of water leaving Cranberry Lake in August 2003. The cooling of water is likely a combination of cool groundwater inflow and riparian shade.

Canopy data collected by the Squaxin Island Tribe at Station CRA4, above the mouth of Lake Limerick, shows an average of 85% canopy closure at this site (see Table 4). Nearshore vegetation near the mouth of Lake Limerick could be improved.

Currently, water from Cranberry Lake flows into a shallow ponded area where it overflows into the Cranberry Creek segment via a dam-culvert structure. The riparian vegetation at the shallow ponded area is visibly thin and could potentially be improved.

The objective of a modeling effort for this segment would be to establish the affects of lower temperature in Cranberry Lake discharge on temperature of the water in this segment. However, to withdraw water at a lower depth, where temperatures are potentially lower, would entail construction of an outlet structure in the lake with ability to withdraw water at lower depths. Whether this is feasible must be studied in relation to existence of stratification during summer season, volume of water present in the hypolimnium, the effect of hypolimnetic withdrawal on lake stratification and temperature, and cost of an engineered system with the ability to withdraw water at different depths. This study will only address the stratification in the lake and evaluate if temperatures can be improved through selective withdrawal of lake water. A sensitivity analysis will be done to address potential higher lake temperature from hypolimnetic water withdrawal.

To complete the modeling work, the following minimum additional data needs to be gathered.

1. Lake temperature profile near outlet.
2. Temperature and flow of water in the culvert discharging into the creek.
3. Stream cross-sectional data at two locations within this reach including CRA4.
4. Quantify groundwater inflow/outflow through seepage runs at two locations.

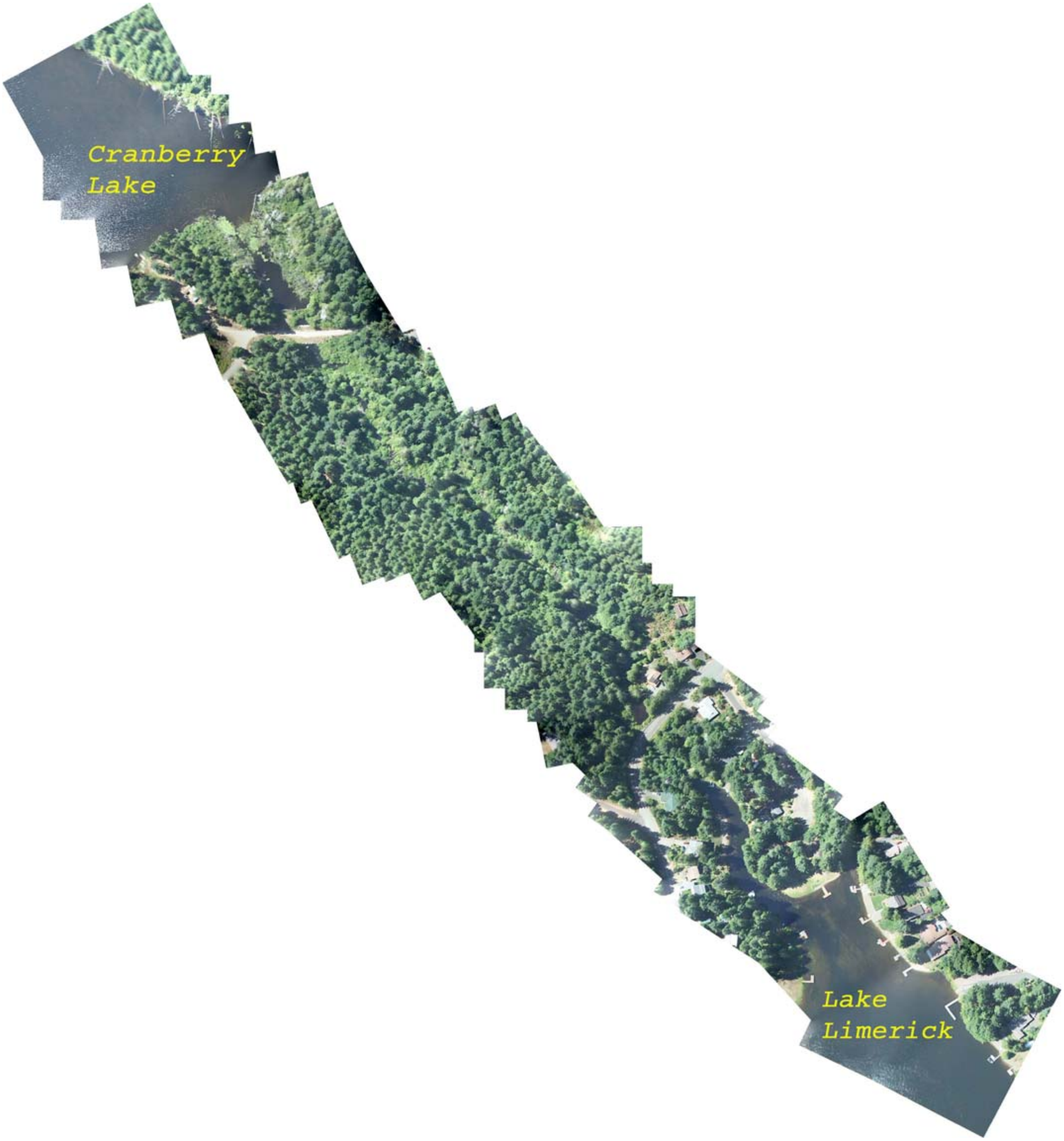

Figure 26. Aerial Photograph of Cranberry Creek Segment Between Cranberry and Limerick Lakes.

Reach Between Lake Limerick and Oakland Bay

Although continuous temperature data exists for this reach at three stations, stream hydraulic characteristics are not well defined for the whole reach. It is proposed that velocity, flow, and cross-sectional measurements be made for several flow regimes (representative of summer flows) at various locations along this Cranberry reach. These measurements should be made in July and August on a bi-weekly basis so that sufficient data is available for conducting regression analysis and establishing power coefficients for velocity and stream width for various summer flows. Piezometers will be installed at several stations to establish the groundwater flow pattern. Seepage runs will be undertaken to quantify the groundwater contribution within the reach.

In addition, to provide contiguous temperature data, several continuous temperature measuring devices will be installed in Lake Limerick at the intake structure so that temperature measurements can be made at depths at every water intake location.

The QUAL2Kw model will be first calibrated to observed flows and temperatures. Air temperatures and relative humidity will also be measured at selected locations.

The Squaxin Island Tribe will lead the field study for Cranberry Creek temperature TMDL.

Field Monitoring

Continuous water temperature monitoring sites will be established at 6 locations (red dots in Figures 27 and 28) in the Mainstem Cranberry Creek and 2 locations (yellow squares in Figures 27 and 28) at the outlets of Cranberry Lake and Lake Limerick. Air temperatures will be monitored at 2 mainstem sites (white dots in Figures 27 and 28). Relative Humidity will be measured at 2 stations (green dots in Figures 27 and 28). Water and air temperature will be measured with Onset Stowaway temperature data loggers or equivalent. Relative humidity will be measured with an Onset H8 Pro RH/temperature data logger or equivalent. The air temperature data loggers will be installed in a location in the stream or riparian forest which is shaded from direct sunlight. They will be placed in an area representative of the surrounding environment. The water temperature logger will be installed at approximately one-half of the water depth and as close to the center of the thalweg as possible. The installation site will be located where there is obvious water mixing and at a depth that will not become exposed if the water level drops, but also will not be affected by groundwater inflow or stratification. The air temperature data loggers will be installed adjacent to the water temperature probe about one to three meters into the riparian zone from the edge of the bank-full channel and about one meter off the ground.

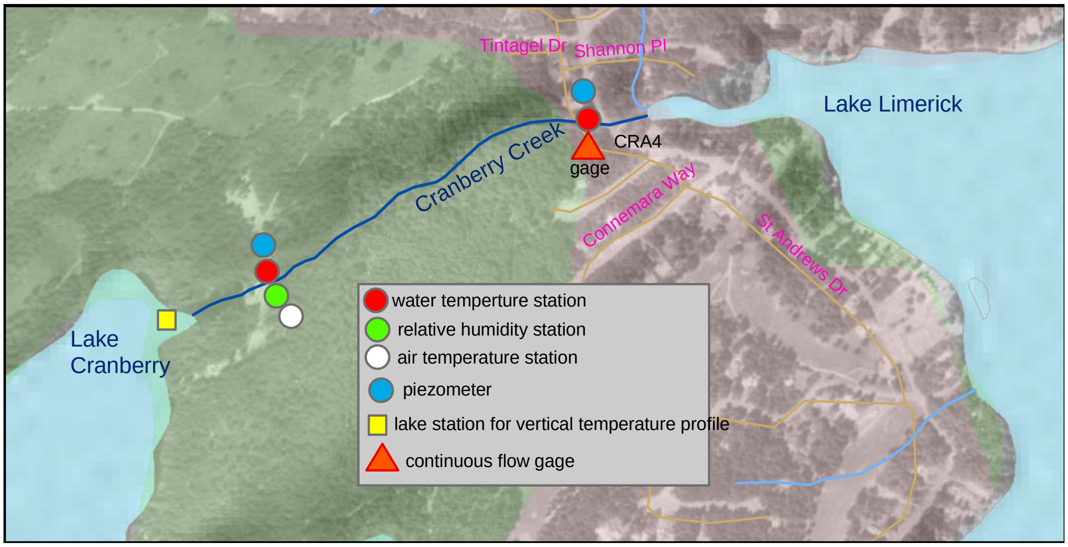

Figure 27. Proposed Stations for Measurement of Flows, Cross Sections, and Temperatures in Cranberry Creek Reach Between Cranberry and Limerick Lakes.

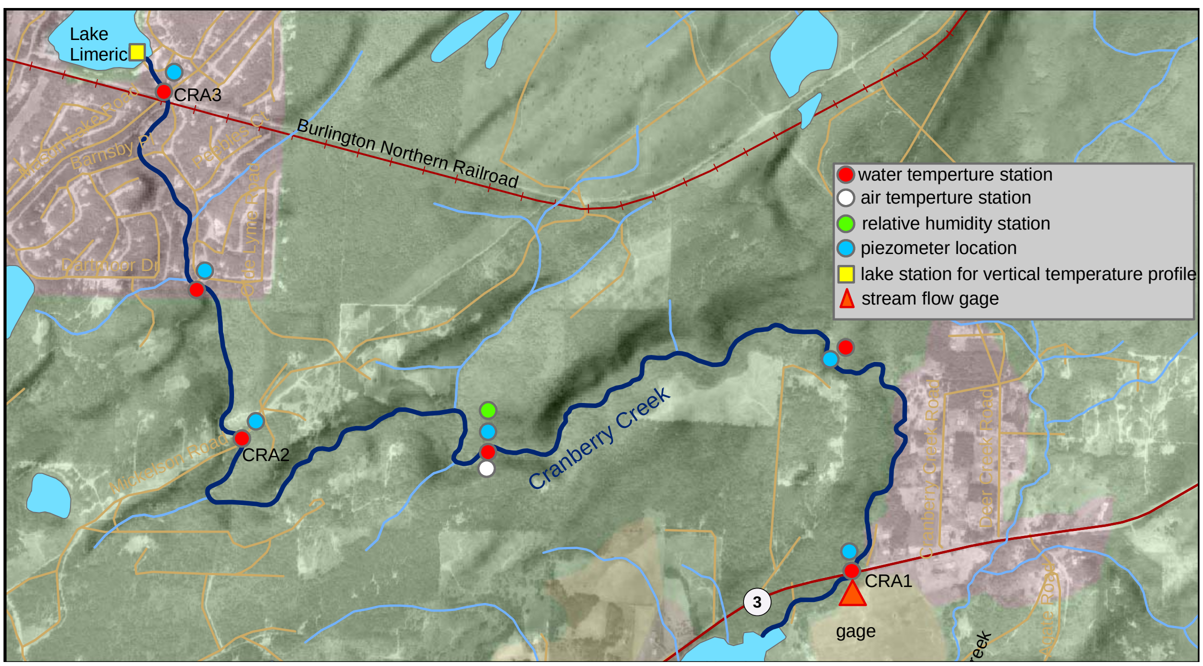

Figure 28. Proposed Stations for Measurement of Flows, Cross Sections, and Temperatures in Cranberry Creek Reach below Lake Limerick.

Riparian Stream and Habitat Surveys

Timber-Fish-Wildlife Stream Temperature Survey methods will be followed for the collection of data during thermal reach surveys (Schuett-Hames et al., 1999). The surveys will be conducted July to August 2005 at the mainstem temperature sites established in the previous section. Field measurements will be taken at 6 to 10 locations over a 300-meter thermal reach and will consist of bank-full 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. Hemispherical photography or densiometer will be used to measure effective shade and canopy density at all water temperature stations, and at additional selected locations as necessary, to ground-truth the range of vegetation classes digitized from inspection of digital orthophotos.

Groundwater Survey

Mini in-stream piezometers will be installed along the seepage run locations (blue dots in Figures 27 and 28) to define the vertical hydraulic gradient between area streams and the water-table aquifer. The piezometers consist of a seven-foot length of ½ inch diameter galvanized pipe, one end of which is crimped and slotted. The piezometers will be hand driven into the stream bed to a depth of approximately five feet. If in any stream reach (area between blue dots in Figures 27 and 28) hard pan is encountered, piezometers will not be installed and the groundwater-stream interaction will be assumed to be negligible.

Water levels in the piezometers will be measured monthly between June and September, 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, ground-water 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. Surface water temperature, groundwater temperature, and conductivity will be measured during each of the monthly piezometer surveys. Stream reaches with significant groundwater input (especially during low flow periods) should have similar water chemistry to area groundwater. Measurements will be made with properly-maintained and calibrated field meters in accordance with standard USGS methodology.

Synoptic Surveys

Four field synoptic surveys will be conducted during the summer 2005 low flow season: one each in June, July, August, and September. Each survey will be completed in one day.
The monitoring locations are shown in Figures 27 and 28. The following measurements will be made during each survey:

- Stream cross-sectional dimensions: width (bank-full, and wetted), depth, and stream bank slope.
- Velocity (*in situ*) and estimated flow.
- Temperature (*in situ*).
- Piezometer water level.
- Associated creek stage.
- Conductivity - both piezometer and creek.

Data Collection Timeline

The schedule for field work is as follows.

May 3-7	Reconnaissance survey of the creek to locate areas of least riparian vegetation and inputs from un-named tributaries, culverts, storm drains, and ditches, etc.
May 24-28	Temperature, humidity data logger, and peizometers installed at critical locations.
June 1-15	First synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
June 15-30	Download temperature and humidity data from data loggers.
July1-15	Second synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
July 3-Aug 30	Stream and habitat surveys.
Aug 1-15	Third synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
Aug 15-30	Download temperature and humidity data from data loggers.
Sept 1-15	Fourth synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
Sept 30-Oct 15	Download final temperature data, remove tidbits.

*Timeline may change due to irregularities in stream discharge and/or weather to ensure data quality.

Johns Creek

Although continuous temperature data is available for two locations in Johns Creek, additional data on temperature, flow, groundwater contribution, and stream cross section is deemed necessary to model the creek. Unlike Mill and Cranberry creeks, there are no lakes at headwaters, but instead a large wetland that drains into Johns Creek. The temperatures in Johns Creek can only be improved through improved riparian vegetation cover and increased groundwater flow. However, the riparian vegetation is more or less intact (see Table 6).

The most important factor in lowering of temperature in Johns Creek is likely inflow of cooler groundwater. Although the riparian vegetation offers additional cooling, any further cooling in the stream can only be accomplished through increasing the inflow of cooler groundwater. On the other hand, increased groundwater flow, if at all possible, will be limited in its ability to lower stream temperatures if the wetland were to continue to increase in surface area, resulting in a rise in water temperature at the headwaters. The QUAL2Kw model can be used to predict how much additional groundwater inflow would be necessary to lower the stream temperatures to within water quality standards. This quantity, if within reason, can then be used as a target for evaluating alternatives for increasing the groundwater inflow. The Squaxin Island Tribe is currently studying the regional groundwater hydrology under a grant from EPA. Increasing stream sinuosity, particularly above the canyon area, may potentially increase groundwater inflow. However, the magnitude of increased groundwater inflow through increased stream sinuosity must first be established. An inventory of water withdrawals from Johns Creek should also be made and evaluated for possible reductions. Other alternatives, like stormwater management, low impact development practices, water conservation, etc. should also be explored.

Continuous water temperature monitoring sites will be established at 8 locations (red dots in Figure 29) in the mainstem and tributaries to Johns Creek. Air temperatures and relative humidity will each be monitored at 2 mainstem sites (white and green dots, respectively in Figure 29). Water and air temperature will be measured with Onset Stowaway temperature data loggers or equivalent. Relative humidity will be measured with an Onset H8 Pro RH/temperature data logger or equivalent. The air temperature data loggers will be installed in a location in the stream or riparian forest which is shaded from direct sunlight. They will be placed in an area representative of the surrounding environment. The water temperature logger will be installed at approximately one-half of the water depth and as close to the center of the thalweg as possible. The installation site will be located where there is obvious water mixing and at a depth that will not become exposed if the water level drops but will not be affected by groundwater inflow or stratification. The air temperature data loggers will be installed adjacent to the water temperature probe about one to three meters into the riparian zone from the edge of the bank-full channel and about one meter off the ground.

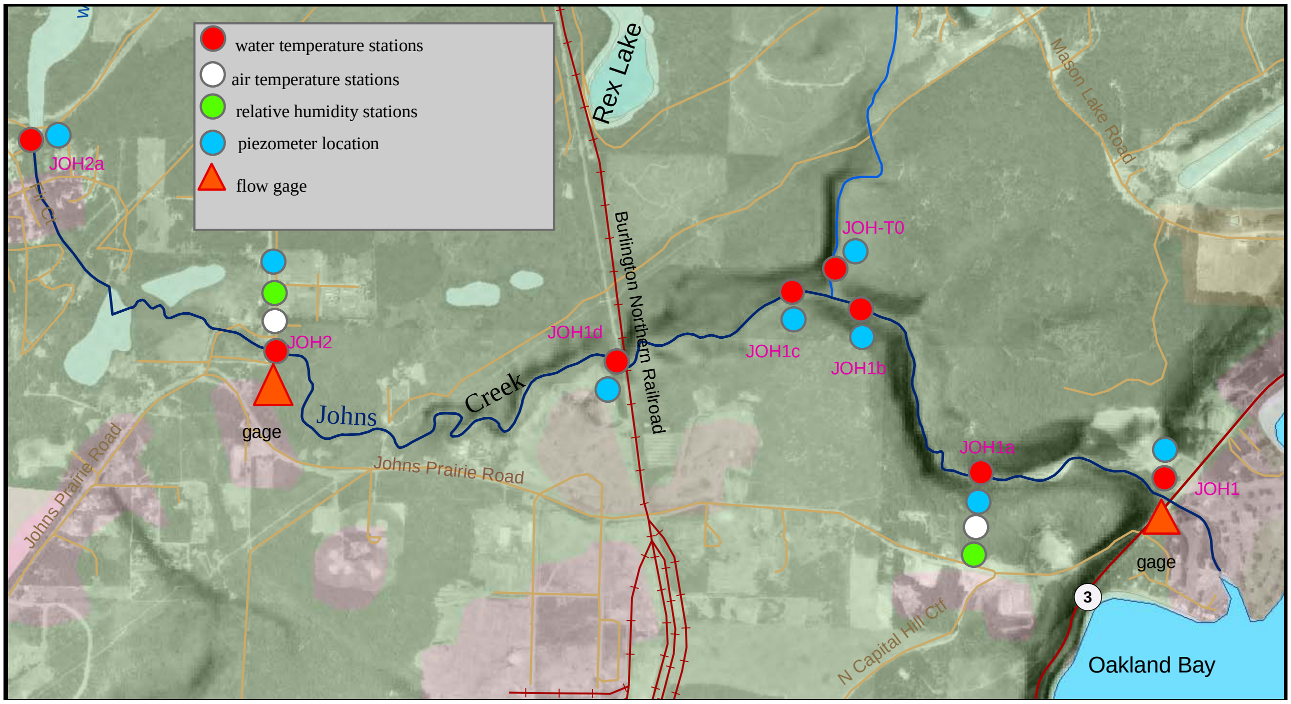

Figure 29. Proposed Stations for Measurement of Flows, Cross Sections, and Temperatures in Johns Creek.

Riparian Stream and Habitat Surveys

Timber-Fish-Wildlife Stream Temperature Survey methods will be followed for the collection of data during thermal reach surveys (Schuett-Hames et al., 1999). The surveys will be conducted July to August, 2005, at the mainstem temperature sites established in the previous section. Field measurements will be taken at 6 to 10 locations over a 300-meter thermal reach and will consist of bank-full 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. Hemispherical photography or densiometer will be used to measure effective shade and canopy density at all water temperature stations and at additional selected locations, as necessary, to ground-truth the range of vegetation classes digitized from inspection of digital orthophotos.

Groundwater Survey

Mini in-stream piezometers will be installed along the seepage run locations (blue dots in Figure 29) to define the vertical hydraulic gradient between area streams and the water-table aquifer. The piezometers consist of a seven-foot length of ½ inch diameter galvanized pipe, one end of which is crimped and slotted. The piezometers will be hand driven into the stream bed to a depth of approximately five feet. If in any stream reach (area between blue dots in Figure 29) hard pan is encountered, piezometers will not be installed and the groundwater-stream interaction will be assumed to be negligible.

Water levels in the piezometers will be measured monthly between June and September, 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. Surface water temperature, groundwater temperature, and conductivity will be measured during each of the monthly piezometer surveys. Stream reaches with significant groundwater input (especially during low flow periods) should have similar water chemistry to area groundwater. Measurements will be made with properly-maintained and calibrated field meters in accordance with standard USGS methodology.

Synoptic Surveys

Four field synoptic surveys will be conducted during the summer 2005 low flow season: one each in June, July, August, and September. Each survey will be completed in one day. The monitoring locations are shown in Figure 29. The following measurements will be made during each survey.

- Stream cross-sectional dimensions: width (bank-full, and wetted), depth, and stream bank slope.
- Velocity (*in situ*) and estimated flow.
- Temperature (*in situ*).
- Piezometer water level.
- Associated creek stage.
- Conductivity – both piezometer and creek.

Data Collection Timeline

The schedule for field work is as follows.

May 3-7	Reconnaissance survey of the creek to locate areas of least riparian vegetation and inputs from un-named tributaries, culverts, storm drains, and ditches, etc.
May 24-28	Temperature, humidity data logger and peizometers installed at critical locations.
June 1-15	First synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
June 15-30	Download temperature and humidity data from data loggers.
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July 30-Aug 30	Stream and habitat surveys.
Aug 1-15	Third synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
Aug 15-30	Download temperature and humidity data from data loggers.
Sept 1-15	Fourth synoptic flow and temperature measurements taken on tributaries and mainstem and groundwater monitoring.
Sept 30-Oct 15	Download final temperature data, remove tidbits.

*Timeline may change due to irregularities in stream discharge and/or weather to ensure data quality.

Monitoring Protocols for Additional Data

Data Quality Objectives

Accuracy objectives for field measurements are presented in Table 5. Experience at Ecology has shown that duplicate field thermometer readings consistently show a high level of precision, rarely varying by more than 0.2°C. Therefore, replicate field thermometer readings were not deemed to be necessary and will not be taken. Accuracy of the thermograph data loggers and the field thermometers will be maintained through pre- and post-calibration in accordance with Timber-Fish-Wildlife (TFW) Stream Temperature Survey Manual (Schuett-Hames et al., 1999) to document instrument bias and performance at representative temperatures. A certified reference thermometer will be used for the calibration. The certified reference thermometer, manufactured by HB Instrument Co. (Part No. 61099-035, Serial No. 2L2087) is certified to meet ISO9000 standards and calibrated against National Institute of Standards and Technology (NIST) traceable equipment. The field thermometer is a Brooklyn Alcohol Thermometer (Model No. 67857). If there is a temperature difference of greater than 0.2°C, the field thermometer's temperature readings will be adjusted by the mean difference.

Table 8. Summary of Field Measurements, Target Accuracy or Reporting Values, and Methods.

Parameter	Accuracy or Reporting Values	Method
Air Temperature Water Temperature	± 0.4°C ± 0.2°C	Onset Stowaway Onset Stowaway
Relative Humidity	± 3 %	Onset RH
Velocity	± 2 % of reading	AquaCalc Pro with Pigmy meter

Manufacturer specifications report an accuracy of ±0.2 °C for the Onset Stowaway (-5°C to +37°C) and ±0.4°C for the Onset Stowaway (-20°C to +50°C). If the mean difference between the NIST thermometer and the thermal data loggers differs by more than the manufacturer's reported specifications, the thermal data logger will not be used during field work.

Accuracy of the Onset Stowaway will be evaluated by comparing the downloaded data to reference temperature readings taken with a calibrated field thermometer during site visits throughout the sampling season. The mean difference between the downloaded data and the reference thermometer readings will be calculated. Data are only acceptable if they do not exceed a maximum mean difference of 0.2 °C.

Representativeness of the data is achieved by a sampling scheme that accounts for land practices, flow contribution of tributaries, and seasonal variation of in-stream flow and temperatures in the basin. Extra calibrated field thermometers and thermograph data loggers 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 TFW Stream Temperature Survey Manual (Schuett-Hames et al., 1999) and the Watershed Assessment Section (WAS) Protocol Manual (WAS, 1993). Temperature recorders 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 bank-full 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).

Quality Control Procedures

Variation for field sampling will be addressed with a field check of the instruments with a handheld thermometer at all thermograph sites upon deployment, retrieval, and also once during the sampling season (mid-August). Field sampling and measurements will follow quality control protocols described in the WAS Protocol Manual (WAS, 1993) and the TFW Stream Temperature Manual (Schuett-Hames et al., 1999). The Onset Stowaway Tidbits will be pre- and post-calibrated in accordance with TFW stream temperature survey protocol to document instrument bias and performance at representative temperatures. A certified reference thermometer will be used for the calibration.

Data Analysis and Modeling Procedures

From the raw data collected at each monitoring location for temperature, the maximum, minimum, and daily average will be determined. The data will be used to characterize the water temperature regime of the basin and to determine periods when the water temperatures are above the state numeric water quality standard. Estimates of groundwater inflow will be calculated by constructing a water mass balance from continuous and instantaneous stream flow data and piezometer studies.

A model will be developed for observed and critical conditions. Critical conditions for temperature are characterized by a period of low-flow and high-water temperatures. The model will be used to develop load allocations for heat energy to the stream. Sensitivity analysis will be run to assess the reliability of the model results.

GIS coverage of riparian vegetation in the study area will be created from information collected during the 2004 temperature field study and analysis of the most current digital orthophotos. Riparian forest coverage will be created by qualifying four attributes: tree height, species and/or combinations of species, percent vegetation overhang, and the average canopy density of the riparian forest. All four attributes of vegetation in the riparian zone on the right and left bank will be sampled from GIS coverage of the riparian vegetation along the stream at 30-meter to 100-meter intervals using the Ttools extension for Arcview that was developed by the Oregon Department of Environmental Quality (ODEQ, 2001). Other spatial data that will be estimated at each transect location include stream aspect, elevation within the riparian area, and topographic shade angles to the west, south, and east.

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

- ODEQ's Ttools extension for Arcview (ODEQ, 2001) will be used to sample and process GIS data for input to the HeatSource/Shadealator and QUAL2Kw models.
- Ecology's shade calculator (Ecology, 2003) will be used to estimate effective shade along the mainstem Mill Creek. 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 (Pelletier and Chapra, 2004) 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 that are described in Chapra (1997). Diurnally varying water temperatures at 500- to 1000-meter intervals along the Mainstem Mill Creek will be simulated using a finite difference numerical method.

At this point, QUAL2Kw and HeatSource are the preferred tools to model temperature. HeatSource has a proven history in calculating effective shade in both Oregon and Washington temperature TMDLs. QUAL2Kw can model various water quality parameters thus incorporating temperature modeling with other TMDL efforts. This will be advantageous for Ecology's efforts for the "one entry TMDL."

Reporting Schedule

The reporting schedule for this project is as follows:

March 2006	Draft report due to Unit Supervisor.
April 2006	Draft report due to Ecology's Southwest Regional Office and the Squaxin Island Tribe.
June 2006	Draft report out for external review.
September 2006	Final report to printer.
March 2006	EIM data entry completed.

Project Organization

The roles and responsibilities of Ecology staff involved in this project are provided below.

Anise Ahmed, Project Manager, Watershed Ecology Section, Environmental Assessment Program.
Responsible for overall project management. Defines project objectives, scope, and study design. Responsible for writing the project Quality Assurance (QA) Project Plan and final technical report. Manages data collection program. Oversees and coordinates field sampling by the Squaxin Island Tribe. Writes TMDL technical study report.

LawrenceSullivan, Principal Investigator, Water Quality Studies Unit, Environmental Assessment Program.
Assists in defining project objectives and scope. Responsible for writing sections of the QA Project Plan, data collection, data entry to the EIM system, and sections of technical report related to data collection, field methods, and data quality review.

John Konovsky, Squaxin Island Tribe.
Temperature Study Lead Field Investigator. Responsible for review and approval of the QA Project Plan. Coordinates and conducts all field investigations.

Christine Hempleman, TMDL Lead, Water Quality Program, Southwest Regional Office (SWRO).
Reviews and comments on QA Project Plans and reports. Coordinates local outreach and information exchange about the technical study and local development of implementation and monitoring plans between Ecology and local planning groups. Supports data collection as part of the TMDL implementation monitoring.

Kim McKee, Unit Supervisor, Water Cleanup Unit, Water Quality Program, Southwest Regional Office (SWRO).
Responsible for review and approval of the QA Project Plan and final report.

Kelly Susewind, Section Manager, Water Quality Program, SWRO.
Responsible for approval of TMDL submittal to EPA.

Will Kendra, Section Manager, Watershed Ecology Section, Environmental Assessment Program.
Responsible for approval of the QA Project Plan and final report.

Karol Erickson, Unit Supervisor, Water Quality Studies Unit, Environmental Assessment Program.
Responsible for review and approval of the QA Project Plan and final report.

Cliff Kirchmer, Quality Assurance Officer, Environmental Assessment Program.
Responsible for review and approval of QA Project Plan. Available for technical assistance on quality assurance issues and problems during the implementation and assessment phases of the project.

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