Long-Term Temperature and Shade Monitoring of Whatcom Creek

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EXECUTIVE SUMMARY

In accordance with Ecology Grant No. G0800132, the City of Bellingham (COB) completed temperature and shade monitoring in Whatcom Creek during 2011. Data generated from this first year of a long-term monitoring program will be used to support the implementation of temperature Total Maximum Daily Loads (TMDL) wasteload allocations in the creek. To ensure high data quality and repeatable monitoring efforts, the City prepared a Quality Assurance Project Plan (QAPP) that controls monitoring implementation.

This long-term temperature and shade monitoring report is designed to document the first year of the monitoring program. The methods employed, the quality control procedures implemented, the monitoring results, and recommendation for future data collection are summarized into one source for comparison with future collected data.

Temperature data were collected using continuous recording Tidbit temperature loggers. Ten temperature loggers recorded air and water temperatures on Whatcom Creek from May 23 through October 14, 2011 between the control dam at Lake Whatcom and Dupont Street near the mouth of Whatcom Creek at Bellingham Bay. Stream shade data were collected using hemispherical photography in combination with computer analysis of digital photographs. Fifty hemispherical shade photographs were taken between July 11 and 27, 2011. Computer shade analysis was conducted in cooperation with Ecology using the proprietary HemiView© software to ensure database compatibility with other TMDL studies in the region.

The summer 2011 7-DADmax water temperatures ranged between 19.9°C and 22.7°C. The highest recorded water temperatures in Whatcom Creek during the summer months were located immediately downstream of the Control Dam at the outlet of Lake Whatcom. 7-DADmax water temperatures decreased nearly 3°C from the Control Dam to Valencia Street as the creek flows 1.2 miles while dropping 245 feet through the canyon reach within Whatcom Falls Park. Downstream from Valencia Street, thermal warming added approximately 0.2°C to the 7-DADmax value by the time the creek reached Dupont Street. During 2011, all seven of the monitoring sites exceeded the summer state water quality criterion of 16°C designed to protect core fish rearing and migration habitat. Temperature criterion exceedances were common at all stations by mid-July and the thermal regime generally remained above the biological criterion until early October. In addition, the supplemental spawning and incubation biological criterion of 13°C between February 15th and June 15th, applicable to water temperature stations at Valencia, Racine, James, and State streets, was exceeded at all four of these stations at the onset of the 2011 measurements in May through mid-June. This thermal pattern is typical for

Whatcom Creek. Waters routinely run warm as a function of the initial water temperatures released at the lake outlet and the lack of considerable groundwater inputs through the lower creek. The temperature data collected during 2011 confirm water temperatures in the creek are dominated by the initial temperature and volume of surface lake water released at the Control Dam.

Consistent with the TMDL, the City of Bellingham used effective shade as the metric to describe the radiation blocking effect of the vegetative canopy. Effective shade is defined as the percent total solar radiation penetrating the riparian canopy and striking the surface below. Riparian canopies derived from hemispherical photography varied along Whatcom Creek from relatively open conditions downstream of Racine Street to dense closures throughout Whatcom Falls Park. Effective shade values at the various sites ranged between 6 and 91 percent, while averaging 53 percent. The greatest frequency of high shade levels occurred in Whatcom Falls Park and the lowest shade levels between Racine and James streets.

The vegetative stand attributes of effective shade, canopy cover, and leaf area index calculated from hemispherical photos via HemiView© are highly correlated factors. Effective shade is a direct factor of the amount of canopy intercepting the sunlight and the areal extent and shape of the leaf surfaces. Regression equations were developed to quantify the relationships between the various stand attributes.

Ecology established TMDL wasteload allocations as a function of effective shade levels for Whatcom Creek based on channel widths and stream aspect (orientation). The load allocations were defined as the potential maximum achievable effective shade for the watershed. The allocations for the mainstem of Whatcom Creek are quantified for specific reaches from the Control Dam to the mouth at Bellingham Bay. Ecology established the target wasteload allocations based on effective shade levels from mature riparian vegetation along flowing streams. The intent of this approach was to generate future water temperatures equivalent to thermal regimes present under natural conditions. However, Hood et al. (2011) recognized the system potential temperatures in Whatcom Creek resulting from mature vegetation are predicted to be higher than the 16°C water quality criterion during the hottest period of the year. Washington Administrative Code (WAC) 173-201A-200(1)(c)(i) states:

> *"When a water body's temperature is warmer than the criteria in Table 200 (1)(c) (or within 0.3°C (0.54°F) of the criteria) and that condition is due to natural conditions, then human actions, considered cumulatively, may not cause the 7-DADmax temperature of that water body to increase more than 0.3°C (0.54°F)"*

As a result, Hood et al. (2011) implied the warm water outflow from Lake Whatcom was a natural condition.

A comparison of the 2011 shade results with the wasteload allocations indicate current shade levels along Whatcom Creek are relatively consistent with target shade allocations near the Control Dam downstream through Whatcom Falls Park to a location near the confluence of Hanna Creek. Effective shade levels in 2011 had the largest departures from the load allocations in the reaches between Valencia and James streets where effective shade values ranged between 23 and 66 percentage points lower than target shade levels. Shade increased between State Street and Dupont Street in downtown Bellingham with 2011 effective shade values exceeding the allocated shade targets.

The longitudinal distribution of shade in Whatcom Creek does not show a strong relationship with either water or air temperatures recorded during the 2011 monitoring period. Warm water released from the lake is the primary factor influencing water temperatures in the creek and may mask any shade and temperature relationship.

1. INTRODUCTION

1.1 MONITORING GOALS AND OBJECTIVES

The goal of the City of Bellingham's long-term temperature and shade monitoring effort is to provide periodic feedback regarding the adequacy of temperature load allocations in Whatcom Creek over the next 50 years. The monitoring results will be used to track reach-scale changes in shading and temperature over time. The City of Bellingham and Ecology will use the results in evaluating the effectiveness of Total Maximum Daily Load (TMDL) wasteload allocations.

The objective of the monitoring funded under Ecology Grant No. G0800132 is to provide the first season of temperature and shade monitoring. Because this effort is the beginning of a long-term monitoring program, it is unlikely any decisions will be made regarding wasteload allocations. The data will help establish an initial baseline of information.

This report is designed to document the first year of the monitoring program. It summarizes the methods employed, the quality control procedures implemented, the monitoring results, and recommendation for future data collection into one source for comparison with future collected data.

1.2 BACKGROUND

Whatcom Creek, located in the northwest corner of Washington State, runs from east to west from Lake Whatcom to Bellingham Bay. Lake Whatcom supplies drinking water for more than 82,000 residents in Bellingham and Whatcom County. The City of Bellingham (COB) diverts water from River Mile (RM) 7.0 of the Middle Fork Nooksack River to Lake Whatcom to increase water availability to the city. Water in Lake Whatcom is released at the northwest end of the lake into Whatcom Creek.

Whatcom Creek is 4.3 miles long with an 8.9 square mile (5,700 acre) drainage basin. Besides the outlet at Lake Whatcom, the creek is fed by four tributaries: Hanna, Cemetery, Fever, and Lincoln creeks (Figure 1). The COB regulates flow in Whatcom creek using a control dam located at the outflow of Lake Whatcom. Flow regulation creates water storage in the lake for municipal supply and minimizes downstream flooding. The City does not restrict the outflow of the lake when the lake elevation is above 314.5 mean feet above sea level to protect lakefront properties against flooding.

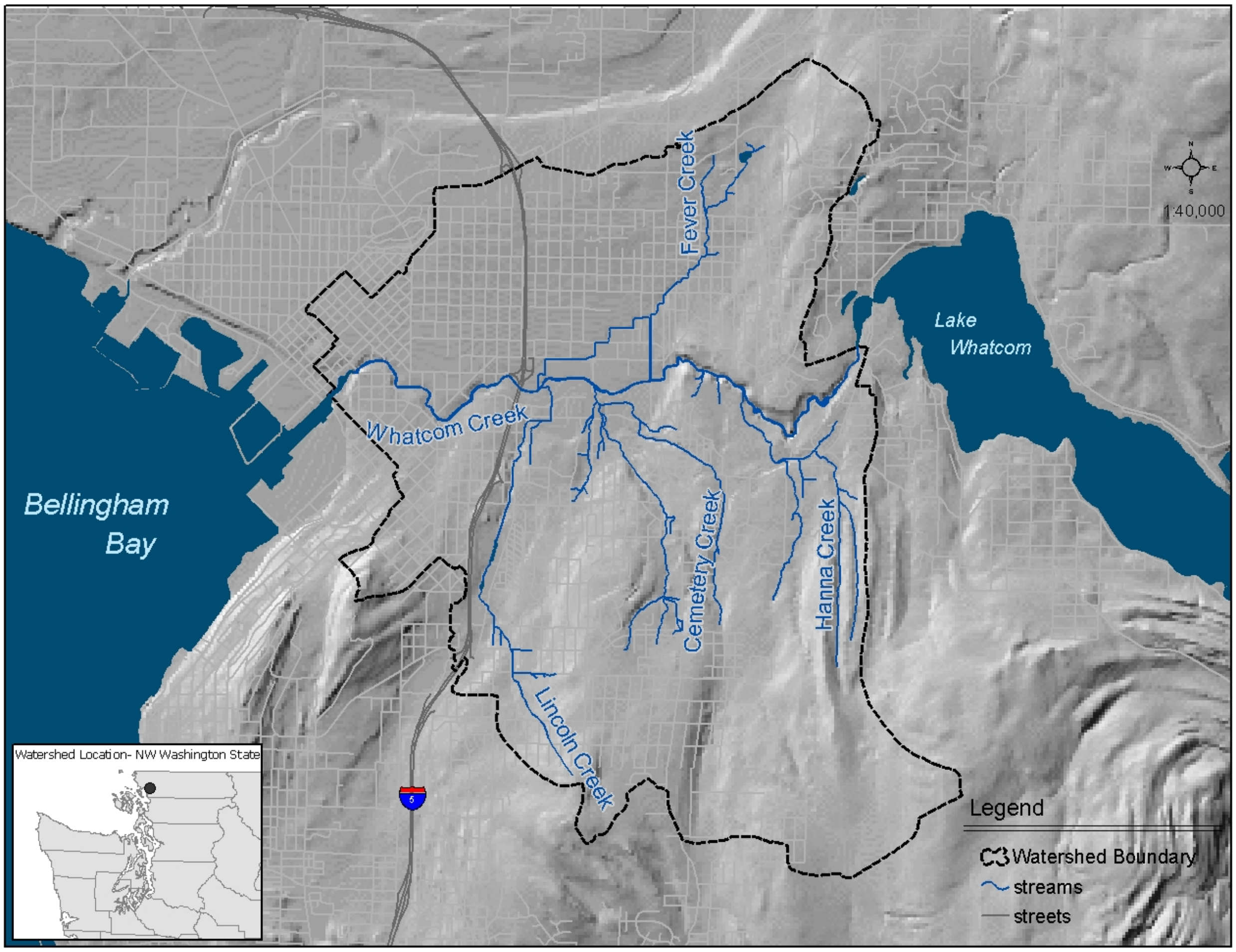

Figure 1. Whatcom Creek watershed boundary.
Source: City of Bellingham (2012).

Downstream of the lake, Whatcom Creek enters Whatcom Falls Park, an undeveloped, mature forested area with an abundance of large Douglas-fir and western red cedar. Hanna Creek joins the mainstem as Whatcom Creek enters a deeply incised bedrock gorge. This section of Whatcom Creek is the only freshwater shoreline in Bellingham designated as "Natural" under the City's Shoreline Management Master Program. Downstream of the gorge, Whatcom Creek flows over Middle Falls, a natural barrier to the migration of adult and juvenile salmonid fishes. Below Middle Falls, the creek flows through residential and light industrial areas and is joined by Cemetery, Fever, and Lincoln creeks before flowing into the urbanized downtown area of Bellingham, and eventually into Bellingham Bay. The section from Middle Falls to the mouth of Whatcom Creek provides habitat for cutthroat trout (*Oncorhynchus clarki*), Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), chum salmon (*O. nerka*), pink salmon (*O. gorbuscha*), steelhead and rainbow trout (*O. mykiss*). A longitudinal profile of Whatcom Creek stream gradients from Lake Whatcom to Bellingham Bay is shown in Figure 2.

The climate of the area is typical of the maritime Pacific Northwest with cool wet winters and mild summers. Precipitation and streamflows are highest in winter as a result of rainstorms and drainage from Lake Whatcom. The lowest flows typically occur from July through September during the summer dry season.

Water quality in Whatcom Creek reflects the influence of urban development, with documented exceedances of Washington State water quality criteria for fecal coliform, water temperature, and dissolved oxygen. Water quality within Whatcom Creek and its tributaries is regulated by the state water quality standards for surface water (WAC 173-201A-602). These water quality standards establish beneficial uses of water using specific criteria for parameters such as water temperature. The criteria are intended to define the level of protection necessary to support the beneficial uses, defined by the City of Bellingham (2012) as:

- *Recreation* – Fishing and swimming (designated as primary contact).

- *Fish* – Core summer habitat designation for aquatic life include anadromous salmonid species [native cuthroat trout, Chinook, coho, chum and pink salmon, and steelhead trout (*Onchohynchus* spp.)] as well as petromyzontid species [native Pacific lamprey and river lamprey (*Entosphenus* and *Lampetra* sp., respectively)].

- *Water Supply* – Whatcom Creek supplies water to two hatcheries in the watershed, one at each end of the creek. The Washington State Department of Fish and Wildlife hatchery is located in Whatcom Falls Park and the Maritime Heritage Fish Hatchery is near the mouth of Whatcom Creek above the estuary. The use of Whatcom Creek by the Whatcom Falls Hatchery is limited, since they take water directly from Lake Whatcom most of the time, while the Maritime Heritage Hatchery relies solely on Whatcom Creek for its water supply.

- *Wildlife Habitat* – Whatcom Falls Park and the Cemetery Creek and Salmon Park restoration sites provide habitat for a diverse community of wildlife including riparian areas where many species are dependent on stream flows for habitat. Whatcom Creek and its tributaries support riparian habitat for a variety of wildlife species.

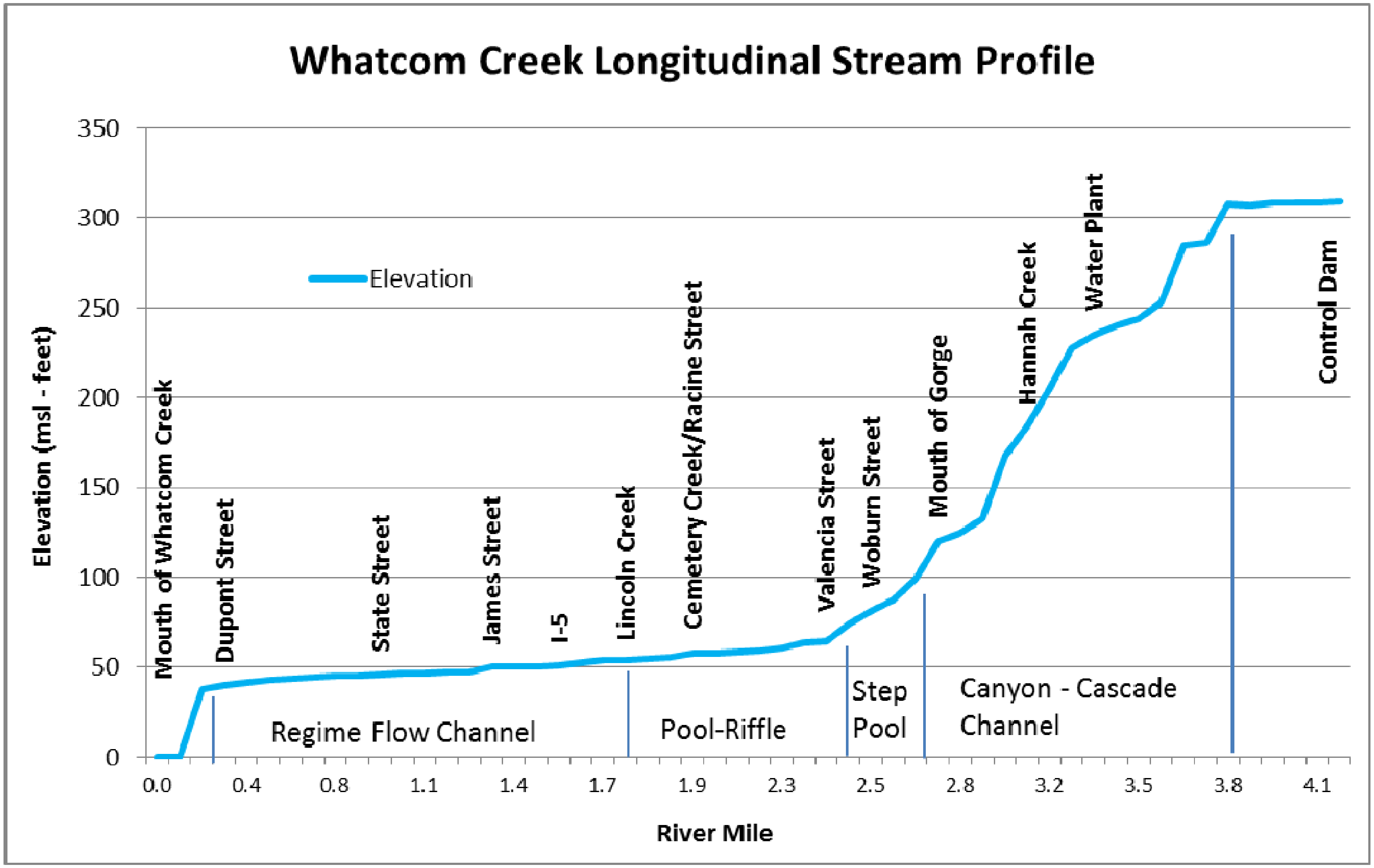

Figure 2. Whatcom Creek longitudinal stream profile.
[Channel classification from Montgomery and Buffington (1993)].

The maximum Washington State Department of Ecology (Ecology) aquatic life temperature criterion for core summer rearing habitat applicable to Whatcom Creek, based on the 7-day average of the recorded daily maximum values (7-DADmax), is 16.0°C (60.8ºF) (WAC 173-201A-200 (1)(c)). A portion of Whatcom Creek between Whatcom Falls Park and State Street also falls under Ecology's requirement for supplemental spawning and incubation protection of 13°C between February 15th and June 15th, annually (Payne 2011). As a function of current water quality data, Ecology designated Whatcom Creek as a Category 5, water temperature-limited stream (Ecology 2009).

Washington State uses the criteria described above to ensure, where a water body is naturally capable of providing full support for its designated aquatic life uses, that thermal conditions will be maintained. The standards recognize, however, that not all waters are naturally capable of remaining below the temperature criteria. When a water body is naturally warmer than the biological criteria, the state provides an allowance for additional warming due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.3°C increase above the naturally high temperature condition (WAC 173-201A-200(1)(c)(i))."

Water temperature is a concern in Whatcom Creek and its tributaries due to the presence of several species of salmon and trout using the system as a migration corridor and for spawning and rearing habitat. Elevated stream temperatures are thought to limit the available spawning and rearing habitat for resident and anadromous fishes.

Sources of nonpoint thermal loading in the Whatcom Creek watershed include:

1. Riparian vegetation disturbance and loss of shade:
   a. Removal of trees and shrubs for development.
   b. Conversion of land from forest to residential/industrial uses.
   c. The Whatcom Creek fuel spill and fire; June 10, 1999.
2. Channel morphologhy impacts that generate wider and shallower streambeds than normal:
   a. Increased sediment loading from urban development.
   b. Bank instability/erosion and sedimentation caused by removal of trees and root structures.

3. Hydrologic Changes:
    a. Urbanized areas with large impervious surfaces increase wet season runoff and decrease summer base flows.
    b. Engineered flood control structures such as regional detention facilities and flood control berms that alter natural flow regimes.
    c. Altered hydrologic regime due to operation and management of Lake Whatcom Control Dam. Current flow releases are not reflective of the natural flow regime. Management of the Control Dam considers the needs of Lake Whatcom, but not Whatcom Creek. Flow management of Whatcom Creek is not optimized to reduce high stream temperatures.
4. Heating of Water:
    a. Altered stream flow patterns from urbanized areas with increases in impervious surfaces.
    b. Stormwater runoff.
    c. Solar heating of water along the shallow west end of Lake Whatcom in Basin 1 and Scudder Pond.
    d. Altered hydrologic regime and increased water particle residence time in Basin 1 and Scudder Pond from engineered lake level management structures.

Ecology completed a Temperature TMDL Water Quality Improvement Report for Whatcom, Squalicum, and Padden Creeks (Hood et al. 2011). Riparian restoration to increase shade and manage stormwater runoff and flows was the primary means recommended to meet temperature load and wasteload allocations (Hood et al. 2011). The COB has been actively acquiring and restoring riparian habitats along Whatcom Creek since 1999 (City of Bellingham 2012).

1.3 PROJECT DESCRIPTION

This project consists of the first year (2011) of data collection for a long-term monitoring effort initiated by the COB. Contingent upon funding, the monitoring is designed to occur at 5-year intervals and will be used to track reach-scale changes in stream shading and surface water temperature over time. The COB prepared a Quality Assurance Project Plan (QAPP) that controls the implementation of this study (City of Bellingham 2012).

Temperature data were collected using continuous recording Tidbit temperature loggers. Ten temperature loggers recorded air and water temperatures on Whatcom Creek from May 23 through October 14, 2011 between the control dam at Lake Whatcom and Dupont Street near the mouth of Whatcom Creek at Bellingham Bay (Table 1).

Stream shade data were collected using hemispherical photography in combination with computer analysis of digital photographs. Fifty hemispherical shade photographs were taken between July 11 and 27, 2011. Computer shade analysis was conducted in cooperation with Ecology using the proprietary HemiView© software to ensure database compatibility.

A map of temperature logger and shade station locations is presented in Figure 3. Field coordinates are provided in Tables 1 and 2 and Station Location ID Photos are included in Appendix A.

Table 1. Location information for temperature loggers in Whatcom Creek (NAD 83).

Location	Type	ID	Longitude	Latitude	Elevation (ft)
Dupont	Water	Dupont_Wat	-122.481112117	48.755248276	38
Dupont	Air	Dupont_Air	-122.480268240	48.755646591	40
State	Water	State_Wat	-122.471075413	48.751369833	46
James	Water	James_Wat	-122.465153996	48.754259301	50
Racine	Water	Racine_Wat	-122.462572540	48.753887512	58
Racine	Air	Racine_Air	-122.453054059	48.754338346	58
Valencia	Water	Valencia_Wat	-122.446402554	48.754940142	64
Water Plant	Water	Plant_Wat	-122.433039681	48.752058639	228
Control Dam	Water	Dam_Wat	-122.422426804	48.757667528	309
Control Dam	Air	Dam_Air	-122.422367508	48.757608439	309

Figure 3. Map of temperature logger and shade monitoring stations in Whatcom Creek.
[**Source**: City of Bellingham (2012)].

Table 2. Location information for shade stations in Whatcom Creek (NAD83).
Source: City of Bellingham (2012).

Station ID	Latitude	Longitude	Station ID	Latitude	Longitude
1	48.755271	-122.481170	26	48.754752	-122.447519
2	48.755805	-122.479968	27	48.754878	-122.446399
3	48.755632	-122.477604	28	48.755742	-122.445118
4	48.755013	-122.476898	29	48.756108	-122.443642
5	48.753911	-122.476426	30	48.756481	-122.443106
6	48.753900	-122.474777	31	48.756153	-122.441552
7	48.753743	-122.473179	32	48.755701	-122.440085
8	48.752718	-122.473079	33	48.755104	-122.438797
9	48.751677	-122.471943	34	48.754902	-122.437452
10	48.751438	-122.470468	35	48.754505	-122.435931
11	48.752238	-122.469406	36	48.753585	-122.435409
12	48.752949	-122.468000	37	48.752722	-122.434389
13	48.754058	-122.467052	38	48.752039	-122.433338
14	48.754238	-122.465156	39	48.751707	-122.432074
15	48.754755	-122.464277	40	48.751132	-122.430688
16	48.754586	-122.462885	41	48.750932	-122.429768
17	48.753833	-122.461581	42	48.751921	-122.429262
18	48.753973	-122.459909	43	48.752703	-122.428155
19	48.754831	-122.458780	44	48.753713	-122.427993
20	48.754783	-122.457054	45	48.753478	-122.426689
21	48.754868	-122.455301	46	48.753912	-122.425314
22	48.754629	-122.453836	47	48.754892	-122.424353
23	48.754008	-122.452662	48	48.755905	-122.423555
24	48.753813	-122.450702	49	48.756766	-122.422410
25	48.754361	-122.449162	50	48.757666	-122.422500

2. MONITORING METHODS

2.1 TEMPERATURE

Collection of temperature data generally followed the procedures outlined in Schuett-Hames et al. (1999) and Bilhimer and Stohr (2009). Onset StowAway 'Tidbit' temperature loggers were used to collect water and air temperature in a continuous fashion. Field loggers were programmed to record water temperatures every 30 minutes. Field loggers were deployed on May 23 and retrieved on October 14, 2011. A summary of performance specifications for temperature loggers and field thermometers is presented in Table 3.

Table 3. Instrument performance specifications.
Source: City of Bellingham (2012).

Instrument	Range	Accuracy	Resolution
Onset Stowaway Tidbit Temperature Logger	-5°C to +37°C	±0.20°C	0.16°C
Handheld Spirit-Filled Field Thermometers	-1°C to +51°C	±0.20°C	0.10°C

2.1.1 Temperature Field Procedures

Temperature loggers were attached to the interior cavity of a concrete masonry block, secured with cable, and tethered to a stable object. The block serves as an anchor and the placement of the logger inside the block's cavity shades the gage from direct sunlight. The openings of the block were oriented with the holes facing into the flow to allow stream flow to move past the data logger.

Air temperature loggers were installed in shaded locations in the riparian zone adjacent to the in-stream water temperature loggers. The air temperature gages were installed with cables to trees or shrub branches.

Field logs using write-in-the-rain paper were employed to record site-specific maintenance, calibration, and downloading information at each of the air and water gage locations for each field visit. Equipment calibration details are provided in Appendix B and information collected during the field visits is included in Appendix C.

2.1.2 Temperature Station Location/Sampling Frequency

Logger locations were based on previous temperature monitoring conducted in Whatcom Creek as part of the temperature TMDL study (City of Bellingham 2003). The continuous data loggers were set to record temperatures every 30 minutes. Every effort was made to avoid data loss. Potential data gaps for continuous temperature monitoring were minimized as a result of two week frequency for gage maintenance and data downloading. Whenever possible, field visits for gage maintenance were scheduled to occur in the morning or late afternoon hours to avoid disturbance during peak temperature hours.

2.1.3 Temperature Quality Assurance and Control

Temperature loggers and field thermometers were checked for accuracy before and after deployment (pre- and post-season) using standard calibration methods (presented in Appendix B of QAPP; City of Bellingham 2012). Handheld spirit-filled field thermometers were used for quality control checks in the field and any temperature logger failing to meet the quality control limits were exchanged with a calibrated logger and the data flagged for review. Data were downloaded from temperature loggers approximately every two weeks. At each download, air and water temperature loggers were checked against field thermometers as part of quality control procedures (detailed in Appendix B of QAPP; City of Bellingham 2012). Protocols for calibration and quality control checks followed Schuett-Hames et al. (1999) and Bilhimer and Stohr (2009) and are described in Appendices A and B of the QAPP (City of Bellingham 2012). A summary of measurement quality objectives is included in Tables 4 and 5.

Table 4. Measurement quality objectives for pre- and post-season calibration checks.
Source: City of Bellingham (2012).

Instrument	Pre-Season Calibration Check		Post-Season Calibration Check	
	Method	Limits	Method	Limits
Onset StowAway Tidbit Temperature Logger	Calibration checked (ice and room temperature) against an NIST-traceable thermometer	Correction factor applied if difference is greater than ± 0.2°C	Calibration checked (ice and room temperature) against an NIST-traceable thermometer	Correction factor applied if difference is greater than ± 0.2°C
Handheld Spirit-filled Field Thermometers	Calibration checked (ice and room temperature) against an NIST-traceable thermometer	Correction factor applied if difference is greater than ± 0.5°C *	Calibration checked (ice and room temperature) against an NIST-traceable thermometer	Correction factor applied if difference is greater than ± 0.5°C

* Field thermometers were discarded if the correction factor differed more than 1°C from reference thermometer.

Table 5. *In situ* temperature logger quality control requirements for site visits.
Source: City of Bellingham (2012).

Quality Control Procedures			
Instrument	**Method**	**Frequency**	**Limits**
Onset Stowaway Tidbit Temperature Logger	Compare against field thermometer	At every download (approx. every 2 weeks)	Water: ±0.3°C Air: ±2.0°C

2.1.4 Temperature Data Analysis

Temperature data were downloaded onsite from the loggers approximately every two weeks with the use of a StowAway interrogator software program. Downloaded data were reviewed in the field to assess drifting, spiking, or exposure of the water logger to air. Documentation was provided to explain the reason for any data excluded from the record (Appendix G).

The approved data were organized in an Excel spreadsheet with recordings for date, time, and associated water temperature. The daily maximum, mean, and minimum temperatures were tallied over the sampling period and graphed for each station. The 7-day running average of the daily maximum values were also calculated and plotted on the graph with the daily ranges (Appendix D). The maximum 7-DADmax value was determined and reported for each station for comparative purposes. All temperature data collected will be submitted to the Department of Ecology's Environmental Information Management System (EIM).

2.2 SHADE

Fifty hemispherical shade photographs were taken between July 11 and 27, 2011 (Figure 4). The summer time frame for stream shade photography was necessary to ensure full leaf expansion of deciduous trees. Computer shade analysis was conducted in cooperation with Ecology using the proprietary HemiView© software to ensure database compatibility. In an assessment of various shade monitoring methods, Moore et al. (2005) indicate that hemispherical photography offers an approach less prone to operator error than ocular methods. HemiView© also allows computation of a range of parameters that are strongly related to solar radiation exposure (Ringold et al. 2003). Diffuse, direct, and total radiation values both above and below the canopy were used to calculate effective shade values.

2.2.1 Shade Field Procedures

Station ID photos were also taken at each photo point prior to each canopy photo; one facing the right bank and one facing the left bank. Where possible the ID photos included landscape features that are more likely to persist through time (e.g., rooftops, utility poles, etc.). ID photos also included the date, station ID number, and stream bank orientations. ID photos help maintain organization and proper labeling of the canopy photos, and also assist in locating these identical photo point locations during future surveys.

Figure 4. Example of hemispherical photograph.
Source: Stohr and Bilhimer (2008)

2.2.2 Shade Station Location/Sampling Frequency

Photos were taken 425 feet apart throughout the study area. Some stations were moved slightly in the field to ensure clear view of the canopy. A Trimble GPS unit was used to locate the stations in longitude/latitude coordinates.

Hemispherical digital photographs were taken looking upwards from the middle of the stream channel using a Nikon Coolpix 4500 digital camera with a Nikon converter FC-E8 180º fish-eye lens (focal range of 7.85 to 32 mm). The height of the camera platform above the channel was 1.3 m at most sites and up to 1.5 m at some deeper water sites as itemized in field log books (Appendix C). Image resolution settings were documented during the 2011 surveys to ensure the settings were repeatable in the future. Photographs were oriented north using the red marker on the camera platform.

2.2.3 Shade Quality Assurance and Control

Quality control and assurance for the collection of hemispherical digital photographs followed the procedures outlined by Stohr and Bilhimer (2008). These procedures include viewing each photograph in the camera display before moving on to the next location. Camera display viewing allows field staff to check for problems such as obscured images. In addition, duplicate hemispherical photos were taken at each site to help ensure at least one usable photo per site. Pre-processing of photos and data analysis was conducted according to quality control and assurance procedures outlined in Stohr (2008). Adobe Photoshop processing is used to correct color, brightness, glare (sunflares, hotspots), and inappropriate or transient objects influencing the shade assessment in the original images if they are not correctly classified in HemiView©. Photoshop is also used to mask the north/south orientation markers so that they do not impact the classified image.

2.2.4 Shade Data Analysis

The photos were processed for HemiView© software analysis of effective shade. The original hemispherical photographs were stored in their raw electronic form in a specific folder. Copies used for image analysis were kept in a separate folder. The HemiView© software application was used with these images to determine total solar radiation, canopy cover, leaf area index (LAI), and effective shade for the sampling time period. To perform the analysis, HemiView© converts the full color hemispherical photo to a two-color image where black pixels represent shading vegetation and topography, and white pixels represent sky pixels (Figure 5).

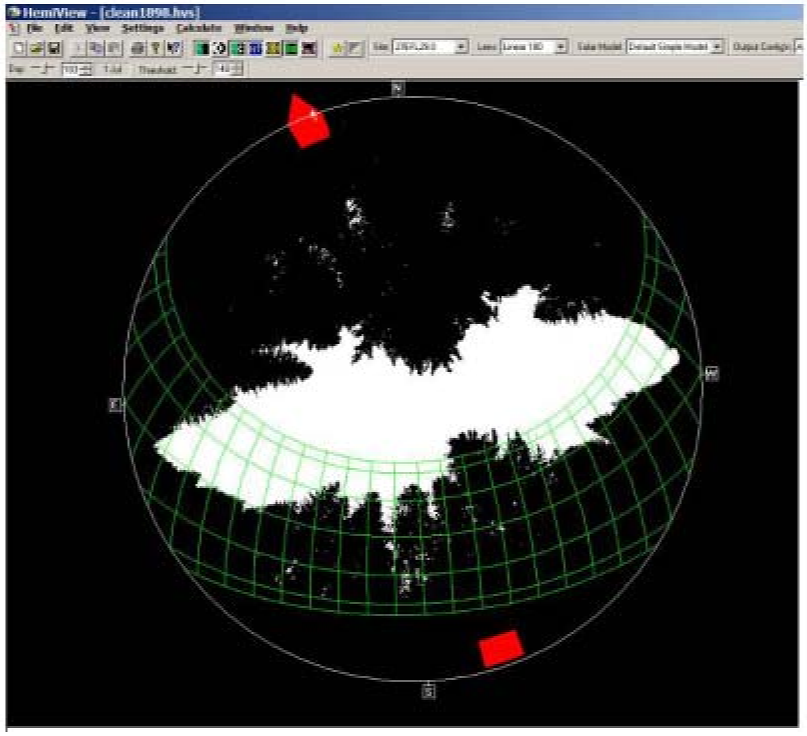

Figure 5. Hemispherical photo classified with the HemiView software.
Source: Stohr (2008)

Effective shade is radiation blocking effect of the vegetative canopy and topography defined as the total radiation below the canopy divided by the total solar radiation above the canopy summed over a full day. Total radiation includes the sum of direct and diffuse radiation sources. Diffuse, direct, and total radiation both above and below the canopy were used to calculate effective shade values for each of the 50 photos in the HemiView software as shown below:

Eqn. 1: $(S_{eff}) = (R_{be}/R_{ab})$

Where:

S_{eff} = Effective shade

R_{ab} = Total solar radiation above the canopy ($DIR_{ab} + DIF_{ab}$)

R_{be} = Total solar radiation below the canopy ($DIR_{be} + DIF_{be}$)

DIR_{ab} = Direct Radiation above the canopy

DIF_{ab} = Diffuse Radiation above the canopy

DIR_{be} = Direct Radiation below the canopy

DIF_{be} = Diffuse Radiation below the canopy

Such That: $(S_{eff}) = (DIR_{be} + DIF_{be}) / (DIR_{ab} + DIF_{ab})$

All of these factors were corrected for the orientation of the intercepting surfaces in the final calculation of effective shade.

Canopy cover, or the percentage of sky blocked by vegetation or topography, within the individual photos was calculated as:

Eqn. 2: $C_c = [1 - \text{VisSky}(\beta)]$

Where: C_c = Canopy Cover

β = The overall fraction of visible sky **(VisSky)** within the digital photo as shown below in Figure 6:

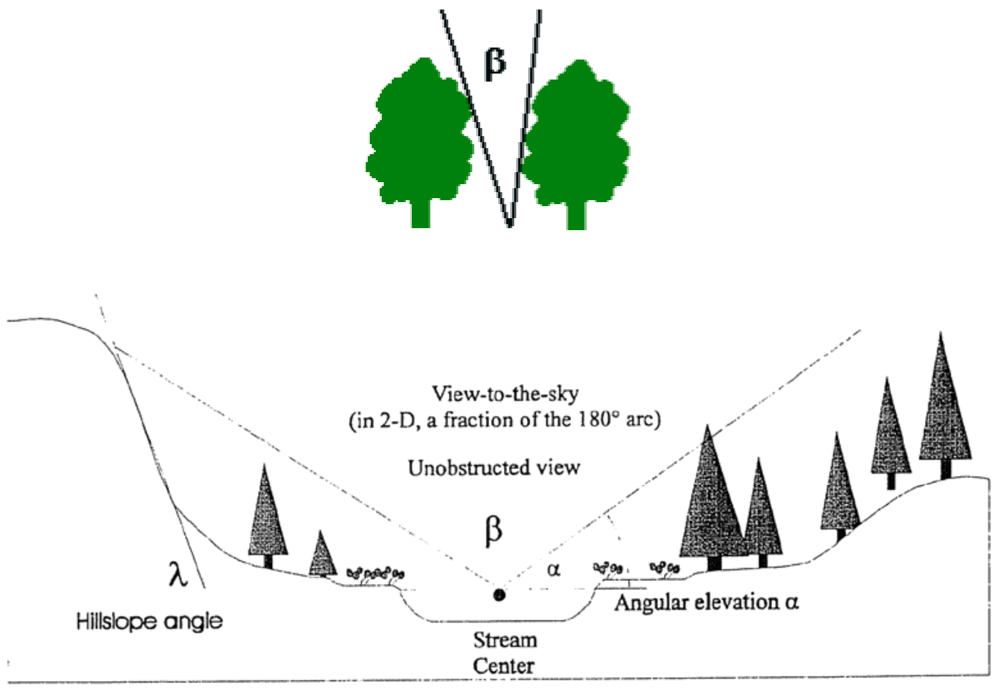

Figure 6. The overall fraction of visible sky (VisSky) and canopy cover calculated in HemiView© software.
Source: WFPB (1997); Rich et al. (1999)

Leaf Area Index (LAI) is a method of forest measurement of leaf area calculated using Beer's Law as the surface area of leaves per unit ground area. Only the upper surface area is counted for broad leaf vegetation. For conifers or other non-flat leaves, LAI is calculated as the total leaf surface area (all sides) divided by two per unit ground area. LAI is widely used in models that examine the influence of shade since the interception of solar radiation is generally proportional to the surface area of leaves (Rich et al. 1999).

2.3 DATA QUALITY

Pre- and post-season instrument calibration and quality control checks were used to assess the quality of the data as part of data validation (Appendices B and G). In addition *in situ* quality control checks of the temperature data loggers using spirit-filled thermometers were performed during routine maintenance procedures. Field staff ensured the methods and protocols specified in the QAPP (City of Bellingham 2012) were followed, including instrument calibration and quality control checks. Evaluation criteria itemized in the QAPP including the acceptability of instrument calibrations, post-calibration and post-sampling calibration checks, and results from *in situ* field checks per Tables 4 and 5 above, were assessed. The data were reviewed to determine if the results met measurement quality objectives and the data output was consistent, correct, and complete. Based on these assessments the data were either accepted, accepted with appropriate qualifications, or rejected as described in Section 3.0 *Results*, below.

3. RESULTS

3.1 TEMPERATURE

Water temperature data at seven stations and air temperature data at three associated stations are summarized in Table 6 and shown graphically for the air and water temperature stations in Appendix D.

Table 6. Maximum water and air temperatures recorded in Whatcom Creek during 2011.

Station	Water Temperature 7-DADmax (°C)[1]	Air Temperature 1-Dmax (°C)[2]
Dupont	20.03	26.70
State	20.02	
James	19.87	
Racine	19.92	26.65
Valencia	19.87	
Water Plant	20.22	
Control Dam	22.73	24.22

1) Highest weekly average of the daily maximum temperature values over the recording period in degrees Celsius.
2) Instantaneous daily maximum temperature in degrees Celsius.

The distribution of 2011 water temperatures at seven longitudinal stations in Whatcom creek is shown over time in Figure 7. Graphs of the daily fluctuations and 7-day running average for monitoring stations are provided in Appendix D. The 2011 7-DADmax water temperatures ranged between 19.9°C and 22.7°C. The highest recorded water temperatures in Whatcom Creek during the summer months were located immediately downstream of the Control Dam at the outlet of Lake Whatcom. 7-DADmax water temperatures decreased nearly 3°C from the Control Dam to Valencia Street as the creek flows 1.2 miles while dropping 245 feet through the canyon reach within Whatcom Falls Park (Figure 2).

Downstream from Valencia Street, thermal warming added approximately 0.2°C to the 7-DADmax value by the time the creek reached Dupont Street (-26 feet in elevation change over 2.0 miles). This thermal warming equates to an increase of approximately +0.10°C per mile through the city.

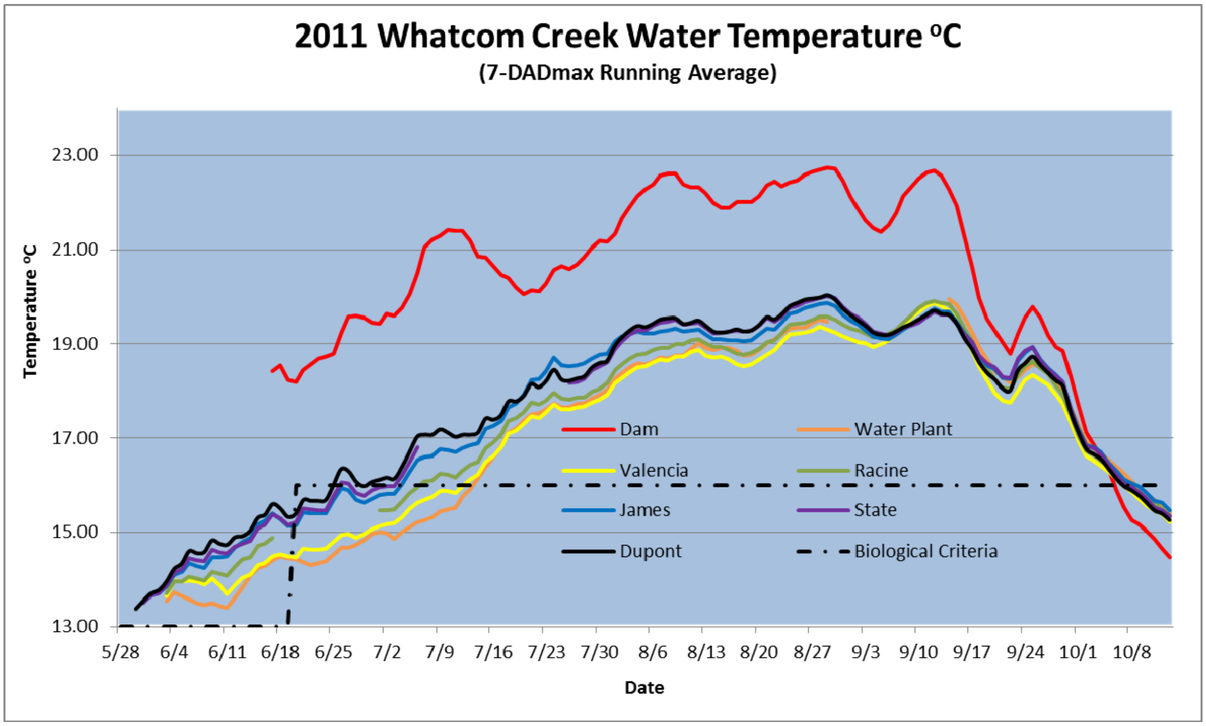

Figure 7. Distribution of 2011 surface water temperatures at seven monitoring stations in Whatcom Creek. (Refer to Section 1.2 *Background* in the text for the water quality standard designations).

3.2 SHADE

Copies of the digital HemiView photos are provided for 50 photo stations in Appendix E. Effective shade results from the digital photographs are included in Appendix F and shown discretely for each of the sites in Figure 8. The longitudinal distribution of survey stations is also shown for reference in this figure.

Summer 2011 effective shade levels in Whatcom Creek ranged from 6 to 91 percent, while averaging 53 ± 25 percent. The greatest frequency of high shade levels occurred in Whatcom Falls Park and the lowest shade levels between Racine and James streets. Effective shade values ranged between 15 and 109 percent and averaged 72 ± 25 percent of the canopy closure levels.

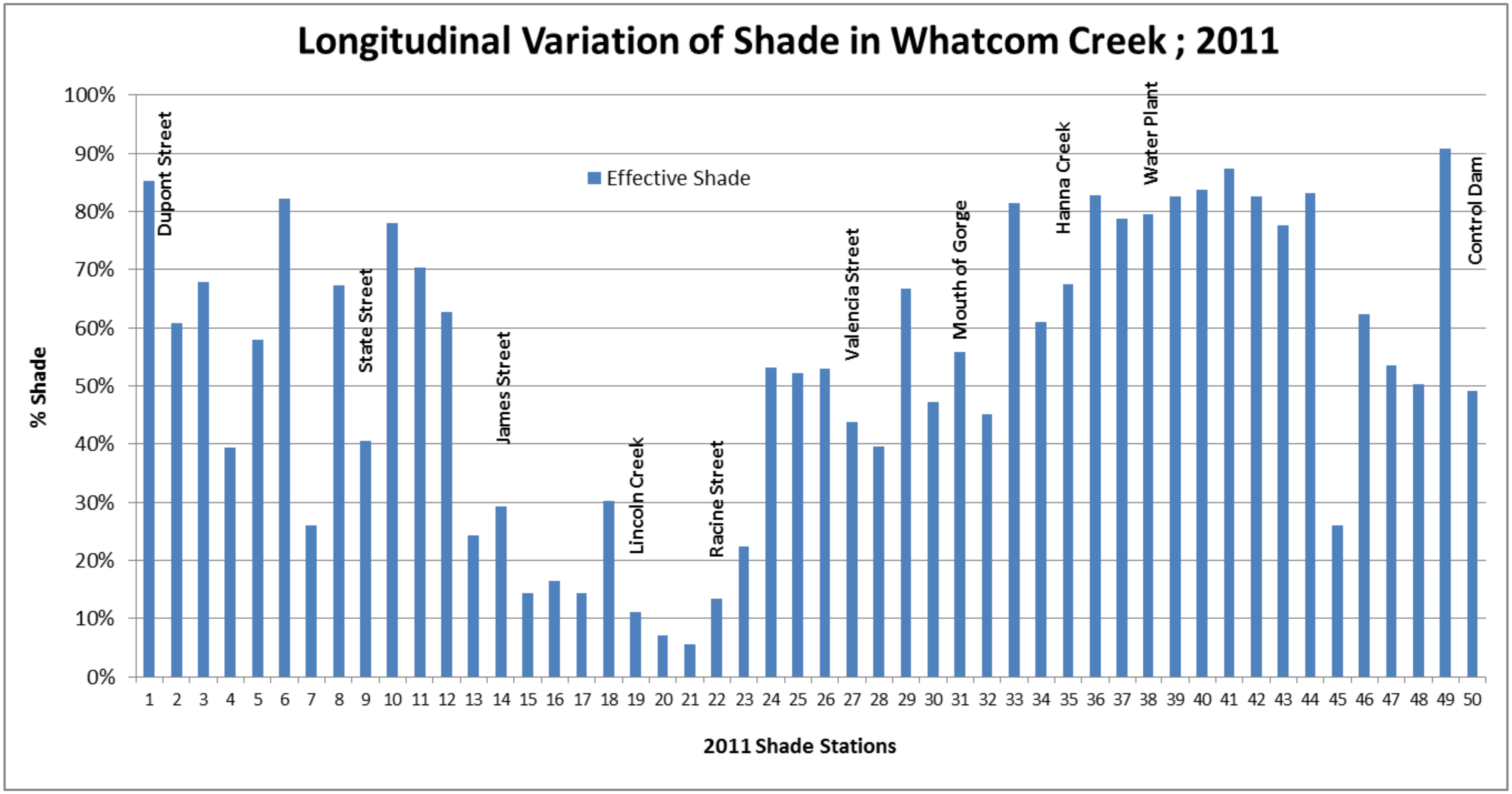

Figure 8. Distribution of 2011 effective shade levels at fifty photo-monitoring sites in Whatcom Creek.

4. DISCUSSION

4.1 TEMPERATURE PATTERNS

The distribution of water temperatures shows the warm water outflow from Lake Whatcom that establishes the base thermal regime in Whatcom Creek. Surface water cools as the stream falls from the outlet through the canyon section of the creek, losing up to 3°C in the first 1.2 miles to Valencia Street. The waters begin a slow, low-level heating process between Valencia and Dupont streets adding, on average, nearly 0.2°C to the peak 7-DADmax value prior to discharging into Bellingham Bay. During 2011, all seven of the monitoring sites exceeded the summer state biological criterion of 16°C designed to protect core fish rearing and migration habitat. Temperature criterion exceedances were common at all stations by mid-July and the thermal regime generally remained above the biological criterion until early October. In addition, the supplemental spawning and incubation biological criterion of 13°C between February 15th and June 15th, applicable to water temperature stations at Valencia, Racine, James, and State streets, was exceeded at all four of these stations at the onset of the 2011 measurements in May through mid-June (Figure 4).

This thermal pattern is typical for Whatcom Creek. Waters routinely run warm as a function of the initial water temperatures released at the lake outlet and the lack of considerable groundwater inputs through the lower creek (Polaris Applied Sciences et al. 2000). The temperature data collected during 2011 confirm water temperatures in the creek are dominated by the initial temperature and volume of surface lake water released at the Control Dam.

4.2 SHADE PATTERNS

Riparian canopies derived from hemispherical photography varied along Whatcom Creek from relatively open conditions downstream of Valencia Street to dense closures throughout Whatcom Falls Park. Effective shade values at the various sites ranged between 6 and 91 percent. Generally, the effective shade percentages were less than canopy closure levels at each station. On average, the ratio of effective shade to canopy closure (S_e/C_c) was approximately 0.72 ± 0.25. However, the relationship was highly variable between the individual photographs with the effective shade factor ranging between 0.15 and 1.09 times canopy closure. In cases where the shade values exceeded canopy closure levels, the canopy routinely supported high leaf area index (LAI) values, typical of dense coniferous forests. In other words, shade values were on the order of 75 percent of canopy closure levels and vegetative stands with high leaf area indices supported higher than average shade values.

The strong correlations between shade, canopy cover, and LAI in Whatcom Creek are shown in linear regression calculations in Figures 9 and 10. The corresponding best-fit regression equation is a linear relationship between effective shade and canopy closure as follows:

Eqn. 3. $y = 1.4284x - 0.4418$; $R^2 = 0.8681$

Where:
y = Effective Shade percent.
x = Canopy Closure levels.
R^2 = the proportion of the variation of y explained by x.

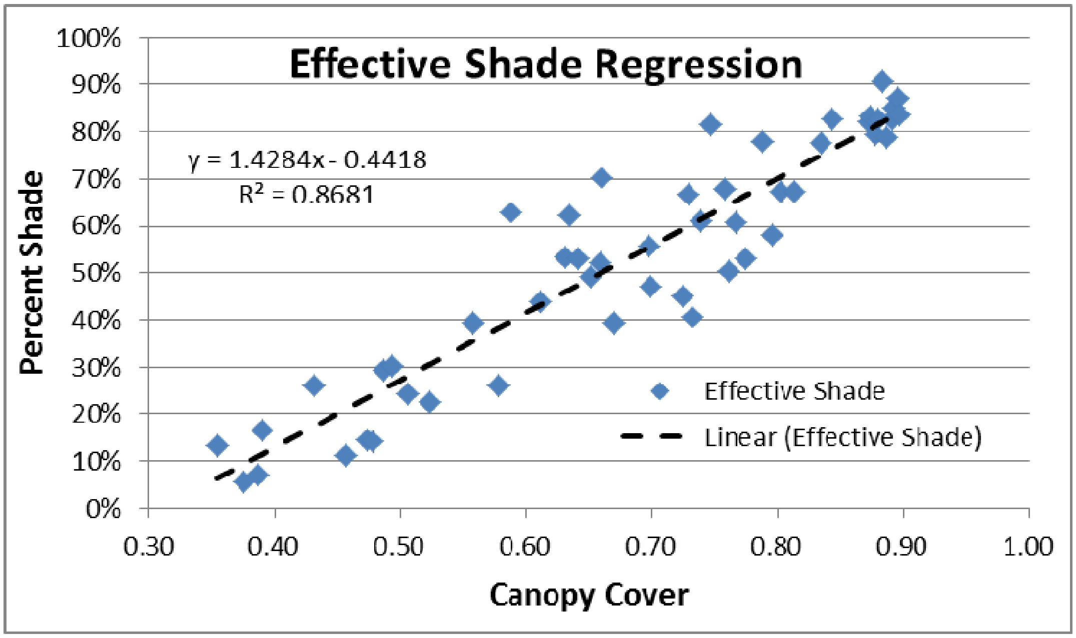

Figure 9. Linear relationship between effective shade and canopy cover in Whatcom Creek riparian zones during 2011 monitoring.

Conversely, a logarithmic expression fits the data best in explaining relationship between effective shade and LAI as follows:

Eqn. 4. $y = 0.351 \ln(x) + 0.4774$ $R^2 = 0.8684$

Where:
y = Effective Shade percent.
x = Leaf Area Index (LAI)
ln = natural log
R^2 = the proportion of the variation of y explained by x

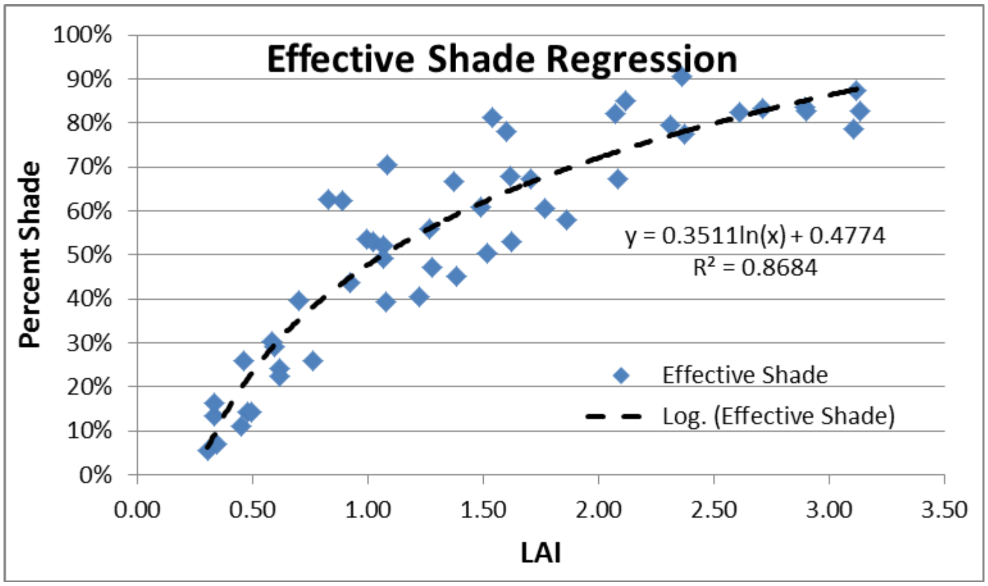

Figure 10. Logarithmetric relationship between effective shade and leaf area index (LAI) in Whatcom Creek riparian zones during 2011 monitoring.

The above discussion indicates the vegetative stand attributes of effective shade, canopy cover, and leaf area index calculated from hemispherical photos via HemiView© are highly correlated factors. Effective shade, or the proportion of total solar radiation penetrating to the ground, is a direct factor of the amount of canopy intercepting the sunlight and the area of the leaf surfaces. The aforementioned regression equations quantify the relationships between the stand attributes and can help in the design of riparian restoration efforts.

In Ecology's TMDL study, Hood et al. 2011 established wasteload allocations as a function of effective shade levels for Whatcom Creek based on channel widths and stream aspect (orientation). The load allocations were defined as the potential maximum achievable effective shade for the watershed. The allocations for the mainstem of Whatcom Creek are quantified for specific reaches of approximately 0.25 miles in length from the Control Dam to the mouth at Bellingham Bay (Table 7). A comparison of the 2011 shade results with the wasteload

Table 7. Effective shade load allocations for Whatcom Creek.

Source: developed from Hood et al. (2011)

Downstream Segment Boundary (RM)	Upstream Segment Boundary (RM)	2011 Photo Site ID	Load Allocation for Effective Shade on August 1 (%)	Effective Shade 2011 (%)	Difference (%)	Landmarks/Comments
4.00	4.20	49 - 50	69%	70%	+01%	0.2 mi segment with the Control Dam as the upper boundary
3.75	4.00	46 - 48	57%	55%	-02%	Derby Dam at the downstream end of this segment
3.50	3.75	43 - 45	77%	62%	-15%	
3.25	3.50	40 -42	81%	85%	+04%	Water Plant at the downstream end of this segment
3.00	3.25	37 - 39	79%	80%	+01%	
2.75	3.00	34 - 36	84%	70%	-14%	Hanna Creek Confluence
2.50	2.75	31 - 33	81%	61%	-20%	Mouth of the Gorge
2.25	2.50	27 - 30	76%	49%	-27%	Valencia Street
2.00	2.25	24 - 26	76%	53%	-23%	
1.75	2.00	21 - 23	76%	24%	-52%	Racine Street
1.50	1.75	18 - 20	67%	16%	-51%	
1.25	1.50	15 - 17	81%	15%	-66%	James Street
1.00	1.25	12 - 14	75%	39%	-36%	
0.75	1.00	9 - 11	46%	63%	+17%	State Street
0.50	0.75	5 - 8	37%	58%	+21%	
0.25	0.50	1 - 4	68%	63%	-05%	Dupont Street at downstream end of segment
0.00	0.25		59%	-	-	No 2011 data

allocations indicate current shade levels along Whatcom Creek are relatively consistent with target shade allocations near the Control Dam downstream through Whatcom Falls Park to a location near the confluence of Hanna Creek (Table 7). Effective shade levels in 2011 had the largest departures from the load allocations in the reaches between Valencia and James streets. Individual reaches through this 1.25 mile portion of the creek supported effective shade values ranging between 23 and 66 percentage points lower than target shade levels. Maturation of riparian restoration projects at Salmon Park, Cemetery Creek, and Red Tail Reach may improve shade levels in this section of Whatcom Creek in the future. Shade levels increased between State Street and Dupont Street in downtown Bellingham with 2011 effective shade values exceeding the allocated shade targets.

Ecology established the target wasteload allocations based on effective shade levels from mature riparian vegetation along flowing streams. The intent of this approach was to generate future water temperatures equivalent to thermal regimes present under natural conditions (Hood et al. 2011). The allocations did not specifically address the warm water contribution from Lake Whatcom as a natural condition, however Hood et al. (2011) recognized Whatcom Creek may not comply with the biological criterion to protect core fish rearing and migration habitat during the warmest periods of summer even under fully mature riparian conditions.

4.3 SHADE/WATER TEMPERATURE RELATIONSHIP

The longitudinal distribution of shade in Whatcom Creek does not show a strong relationship with water temperatures recorded during the 2011 monitoring period (Figure 11). Shade levels in the figure represent the average of all photo stations 2,000 feet upstream of each temperature gage to approximate a typical thermal response distance for streams of this nature (Sullivan et al. 1990). Warm water released from the lake cools in the downstream direction as it cascades through the Park and gorge area. Closed riparian canopies and good shade levels assist in the cooling trend in this section of the creek. However, there is little to no increase in water temperature along the open riparian canopy section between Valencia and James streets. Conversely, there is a small increase in Whatcom Creek temperatures in the State and Dupont reaches where canopy cover and effective shade levels exceeded the TMDL effective shade allocation targets. The average summer 2011 increase in the 7-DADmax of 0.02°C between Valencia and Dupont streets is less than the allowable cumulative increase under state water quality regulations of WAC 173-201A-200(1)(c)(i) and it is less than a typical natural thermal increase as streams move in a downstream direction (Theurer et al. 1984; Adams and Sullivan 1989, Sullivan et al. 1990; Zwieniecki and Newton 1999). According to the State Department of Natural Resources’ (DNR) temperature/shade/ elevation screen [WFPB 2000; WAC 222-30-

040(2)], a change in elevation similar to the difference between Valencia and Dupont streets of -26 ft msl should add approximately 0.04°C to the natural temperature regime.

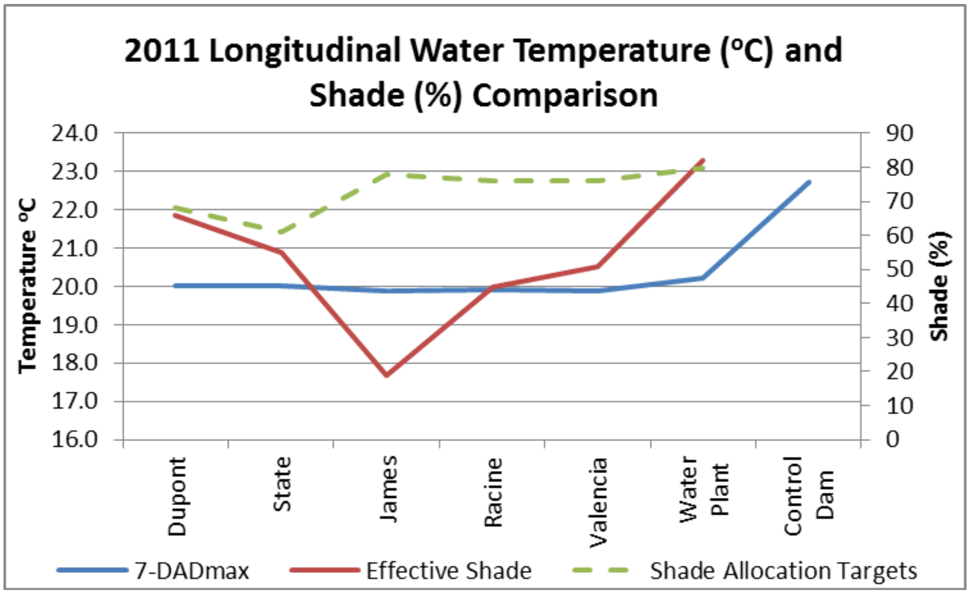

Figure 11. Longitudinal water temperature and shade comparison in Whatcom Creek during 2011.

Note: Shade levels represent average of all photo stations 2,000 feet upstream of temperature gauges. Shade allocation targets represent average of all wasteload allocation segments (Hood et al. 2011) 2,000 feet upstream of temperature gauges.

According to the physics of stream heating, water temperatures move toward a fixed equilibrium with the surrounding ambient conditions as a function of riparian canopy, stream width and depth, local air temperature (including effects of elevation), and groundwater inflow (Theurer et al. 1984; Adams and Sullivan 1989, Sullivan and Adams, 1990; Sullivan et al. 1990). The rate a parcel of water adjusts to changes in the thermal environment depends on a channel's width, depth, and flow characteristics (Sullivan et al. 1990; Caldwell et al. 1991; Moore et al. 2005). Shallow streams adjust relatively quickly to changes in energy inputs compared to deep streams with greater water volumes. Given the small (approximately 30-ft bankfull width) and relatively shallow (0.7 to 2.4 feet deep) nature of Whatcom Creek (Polaris Applied Sciences et al. 2000), the stream should respond quickly to changes in effective shade levels and one would expect only a short lag period between energy input and thermal response.

Water velocity determines the distance water can travel over a given amount of time and the subsequent amount of solar exposure. Sullivan et al. (1990) calculated that temperature equilibrium was established typically within 2,000 feet or less for moderately-sized streams (less than 2 feet deep and less than 75 feet wide) comparable to Whatcom Creek. Releasing a consistent 10 to 20 cfs of flow into Whatcom Creek during the summer months would increase water volumes, stream depths, and velocities (Polaris Applied Sciences et al. 2000) compared to current conditions making the creek less vulnerable to temperature changes from thermal loading (Theurer et al. 1984; Adams and Sullivan 1989). Conversely, the rate of cooling currently experienced downstream of the control dam through Whatcom Falls Park and the gorge may decrease with higher creek discharges.

Narrow or discontinuous riparian zones may allow streams to remain exposed to solar radiation (Jackson et al. 2001). Temperature increases reported in the scientific literature have been found to be related to the canopy cover conditions in the riparian areas. According to the Northwest Forest TMDL Implementation Plan, maintaining a minimum continuous 80 percent effective shade in the nearest 60 feet to the streambank should protect stream temperatures (USFS and BLM 2005). Riparian openings that expose a stream surface to direct solar radiation can result in a temporary temperature rise until the stream re-enters closed canopy conditions (Zwieniecki and Newton 1999). Over any stream length, heat will be retained as it flows downstream in the water column only if the heat inputs are greater than the heat losses (Theurer et al. 1984). Downstream shade prevents further heating of the stream so that other processes (e.g., evaporation; groundwater mixing; convection) have a chance to cool the stream. Zwieniecki and Newton (1999) concluded modest riparian buffers and/or gaps, lead to little accumulation of heat persisting further than 1,000 feet below an opening to a greater degree than expected from natural downstream warming.

4.4 SHADE/AIR TEMPERATURE RELATIONSHIP

Similar to water temperatures, the effective shade distributions in Whatcom Creek does not show an obvious influence on air temperature regimes. Researchers have observed a general reduction in the daily fluctuations and maximum air mass temperatures as riparian canopies increase (Sullivan et al. 1990; Moore et al. 2005). Sullivan et al. (1990) also describe a strong equilibrium relationship between air mass and associated water temperatures in open riparian canopies. The authors note the divergence of water and air temperatures when riparian canopies increase. Three stations collected continuous air temperature records during 2011 in Whatcom Creek. Two stations were located in relatively open riparian areas near the Control Dam and at Racine Street, while the most downstream station at Dupont Street was located in a heavily shaded section of the stream. Maximum daily water temperatures fluctuated widely as a function of weather conditions with the range of fluctuations and maximum daily temperatures increasing in the downstream direction (Appendix D). There was no observable relationship between effective shade levels and air temperature extremes. Except for vegetative conditions in Whatcom Falls Park, the riparian zones along Whatcom Creek may not be of sufficient size to trap air masses and influence near-stream air temperatures (Chen et al. 2003, Moore et al. 2005).

5. RECOMMENDATIONS

Recommendations based on the first year of data results follow:

5.1 SHADE AND TEMPERATURE LEVELS

The shade values observed in Whatcom Creek during 2011 were low and furthest from the TMDL effective shade allocation targets between Valencia and James streets. Nevertheless, temperature recorders did not show a measurable increase in surface water temperatures downstream of Valencia Street. Following cooling of water released from Lake Whatcom through the gorge, surface water temperatures maintained a consistent 7-DADmax level of 19.9 ± 0.07°C for the 6,600-ft (1.25 mi.) section between Valencia and Dupont Street. Water temperatures did not show an influence from open riparian canopy conditions through this section of the creek.

Riparian shade levels will increase over time as vegetation communities grow and mature within a zone of approximately 60 to 75 feet from the stream. However in the near-term, based on TMDL waste load allocation targets, shade levels should be increased in the section of Whatcom Creek between Valencia and James streets. Continued plantings and enhancement of riparian conditions with high leaf-area index (LAI) vegetative compositions (like conifer species) similar to ongoing restoration efforts at Salmon Park, Cemetery Creek, and Red Tail Reach are encouraged.

To minimize the influence of below target shade levels on stream temperatures, water in the range of 10 to 20 cfs could be released in the future from the control dam on a consistent basis during the summer months to increase water depths, volumes, and stream velocities. Such a measure would increase water depths and decrease the water particle travel time of surface waters exposed to open riparian shade levels between Valencia and James streets. The change in stream volume compared to current conditions would minimize the vulnerability of the stream to temperature changes from the potential for increased thermal loading. Nevertheless, the effects of increased stream discharge on the potential to slow the rate of cooling currently experienced between Lake Whatcom and the mouth of the gorge needs to be assessed. Temperature monitoring is recommended during fixed increments of controlled flow releases at the control dam as a form of hypothesis testing.

The following recommendations are offered based on field data collection experience during 2011:

5.2 TEMPERATURE DATA COLLECTION

The primary challenge encountered in this first season of temperature monitoring in Whatcom Creek was vandalism and/or tampering of the monitoring equipment. To minimize data loss, site visits for maintenance and data downloads are recommended at least once every two weeks. In future years, it is also recommended field staff take extra care to conceal loggers while situating the units in a safe, accessible spot. Tethering the blocks to a nearby post or tree is the stipulated technique to provide some assurance the loggers may be recovered following periods of high flow or when blocks begin to naturalize and blend in with the creek bottom. Nevertheless, in this highly urbanized setting with considerable foot traffic in and around Whatcom Creek, the tethered cables may increase visibility and/or cause a tripping hazard. In two locations (Control Dam and State Street) water temperature loggers were eventually deployed without tethered cables to avoid tampering. Neither block appeared to shift downstream nor were they difficult to locate or retrieve. Therefore, field staff should consider deploying concrete blocks in the future without a tethering cable in locations with high public visibility and foot traffic (see Appendix Table C-1, "*2011 Temperature Monitoring Field Notes Summary*.").

5.3 SHADE DATA COLLECTION

A few challenges were encountered while collecting hemispherical photos on Whatcom Creek in 2011. The creek provided some obstacles, especially where it flows through the gorge, a deeply incised bedrock canyon reach below Hannah Creek. For safety reasons, all stations within this reach should be accessed by walking upstream or downstream from either end of the gorge, since adjacent shorelines consist of precipitous drops and related safety hazards. In addition, a pole-mounted Hurricane antenna was required to determine the Trimble GPS locations within the steeply-sided gorge. A minimum crew of two individuals is required while surveying this reach.

Some of the original shade stations were located in deep water or near other hazards such as waterfalls. These stations were shifted to enable access with the hemispherical photo equipment. Other stations were re-positioned to minimize the interference of overhead bridges and other built structures (see Attachment B for a summary of field notes relating to the field collection of shade monitoring photos). All updated station locations were provided in Table 2.

Another challenge was presented by the field equipment borrowed from Ecology's Environmental Assessment Program. The camera was a COOLPIX 4500 and the lens was the Nikon converter FC-E8 "Fish-eye" lens (focal range of 7.85 to 32 mm). The point of connection between the large and relatively heavy fish-eye lens with the compact digital camera was weak and required extra care and patience to keep the camera and lens safely connected while capturing photos in the field. For future surveys, more robust equipment is recommended.

The collection of photos within the allotted time frame was also challenging as a function of the large number of shade stations spaced throughout the stream. In future years the density and total number of photo points should be re-evaluated to determine if fewer photo points may yield data sufficient to meet the goals of this project.

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Appendices

A Shade and Temperature Station Location ID Photos

B Equipment Calibration

C Field/Maintenance Logs

D 2011 Temperature Recordings

E 2011 Canopy Photographs

F Summary Spreadsheet of 2011 Shade Levels Based on HemiView© Software Analysis of Hemispherical Photographs

G Data Verification

Appendix A

Shade and Temperature Station Location ID Photos

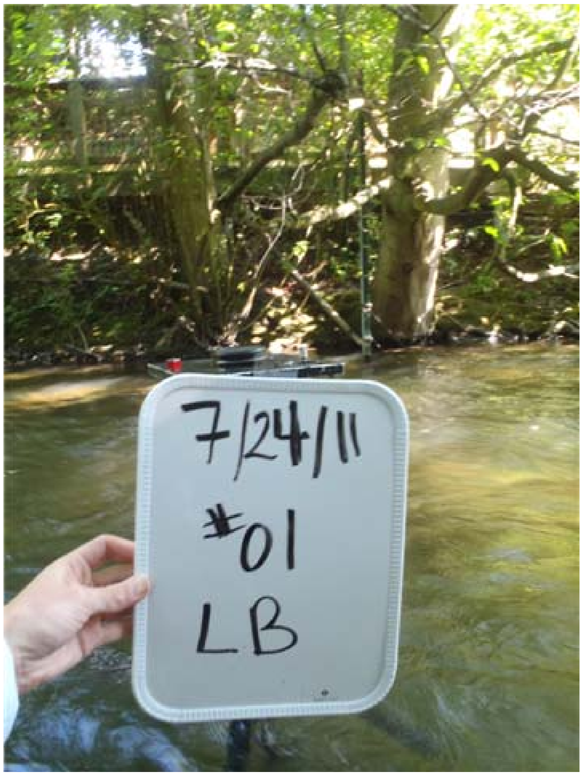

Figure A-1. Shade Photo Site 01 left bank.

Figure A-2. Shade Photo Site 01 right bank.

Figure A-3. Shade Photo Site 02 left bank.

Figure A-4. Shade Photo Site 02 right bank.

Figure A-5. Shade Photo Site 03 left bank.

Figure A-6. Shade Photo Site 03 right bank.

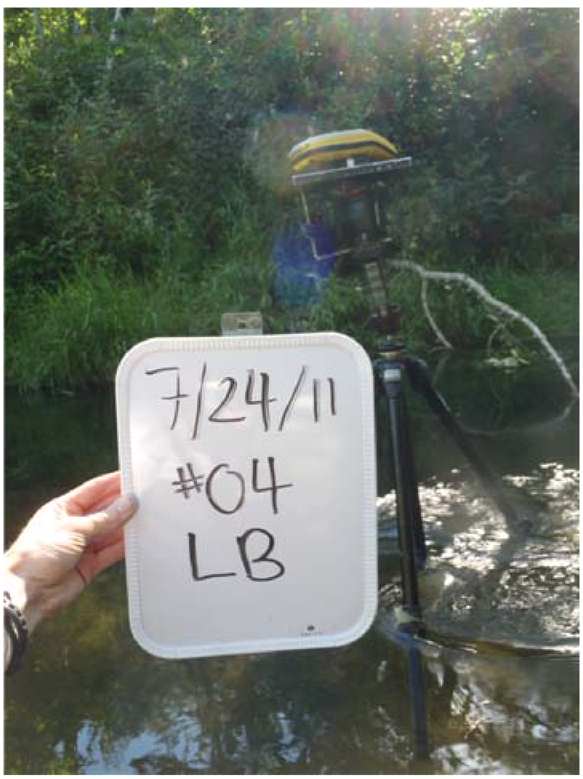

Figure A-7. Shade Photo Site 04 left bank.

Figure A-8. Shade Photo Site 04 right bank.

Figure A-9. Shade Photo Site 05 left bank.

Figure A-10. Shade Photo Site 05 right bank.

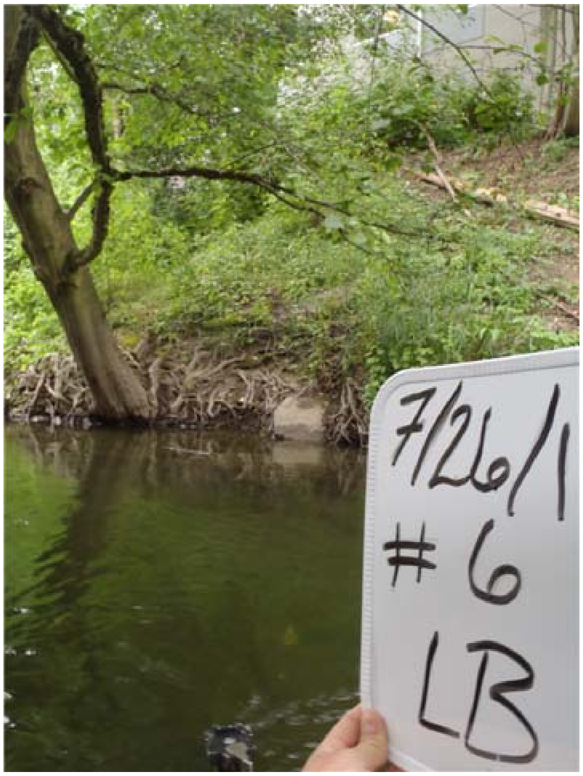

Figure A-11. Shade Photo Site 06 left bank.

Figure A-12. Shade Photo Site 06 right bank.

Figure A-13. Shade Photo Site 06 downstream.

Figure A-14. Shade Photo Site 06 upstream.

Figure A-15. Shade Photo Site 07 left bank.

Figure A-16. Shade Photo Site 07 right bank.

Figure A-17. Shade Photo Site 08 left bank.

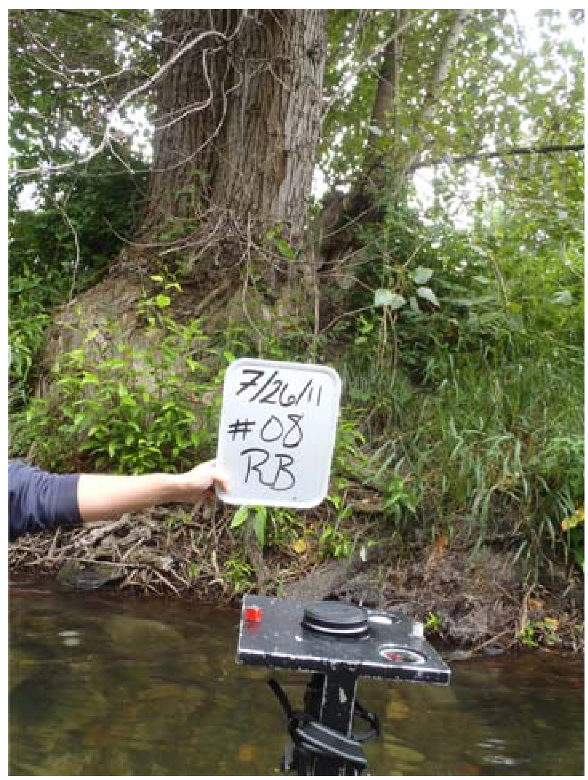

Figure A-18. Shade Photo Site 08 right bank.

Figure A-19. Shade Photo Site 09 left bank.

Figure A-20. Shade Photo Site 09 right bank.

Figure A-21. Shade Photo Site 10 left bank.

Figure A-22. Shade Photo Site 10 right bank.

Figure A-23. Shade Photo Site 11 left bank.

Figure A-24. Shade Photo Site 11 right bank.

Figure A-25. Shade Photo Site 12 left bank.

Figure A-26. Shade Photo Site 12 right bank.

Figure A-27. Shade Photo Site 13 left bank.

Figure A-28. Shade Photo Site 13 right bank.

Figure A-29. Shade Photo Site 14 left bank.

Figure A-30. Shade Photo Site 14 right bank.

Figure A-31. Shade Photo Site 15 left bank.

Figure A-32. Shade Photo Site 15 right bank.

Figure A-33. Shade Photo Site 16 left bank.

Figure A-34. Shade Photo Site 16 right bank.

Figure A-35. Shade Photo Site 17 left bank.

Figure A-36. Shade Photo Site 17 right bank.

Figure A-37. Shade Photo Site 18 left bank.

Figure A-38. Shade Photo Site 18 right bank.

Figure A-39. Shade Photo Site 19 left bank.

Figure A-40. Shade Photo Site 19 right bank.

Figure A-41. Shade Photo Site 20 left bank.

Figure A-42. Shade Photo Site 20 right bank.

Figure A-43. Shade Photo Site 21 left bank.

Figure A-44. Shade Photo Site 21 right bank.

Figure A-45. Shade Photo Site 22 left bank.

Figure A-46. Shade Photo Site 22 right bank.

Figure A-47. Shade Photo Site 23 left bank.

Figure A-48. Shade Photo Site 23 right bank.

Figure A-49. Shade Photo Site 24 left bank.

Figure A-50. Shade Photo Site 24 right bank.

Figure A-51. Shade Photo Site 25 left bank.

Figure A-52. Shade Photo Site 25 right bank.

Figure A-53. Shade Photo Site 26 left bank.

Figure A-54. Shade Photo Site 26 right bank.

Figure A-55. Shade Photo Site 27 left bank.

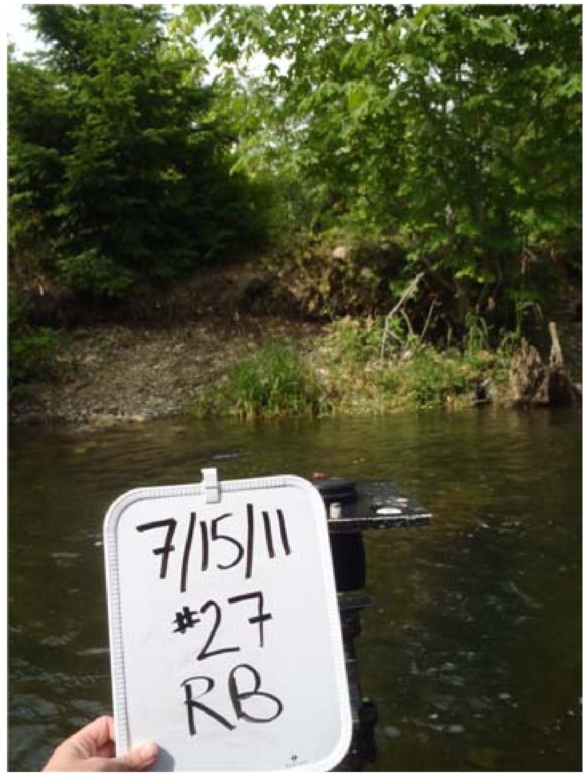

Figure A-56. Shade Photo Site 27 right bank.

Figure A-57. Shade Photo Site 28 left bank.

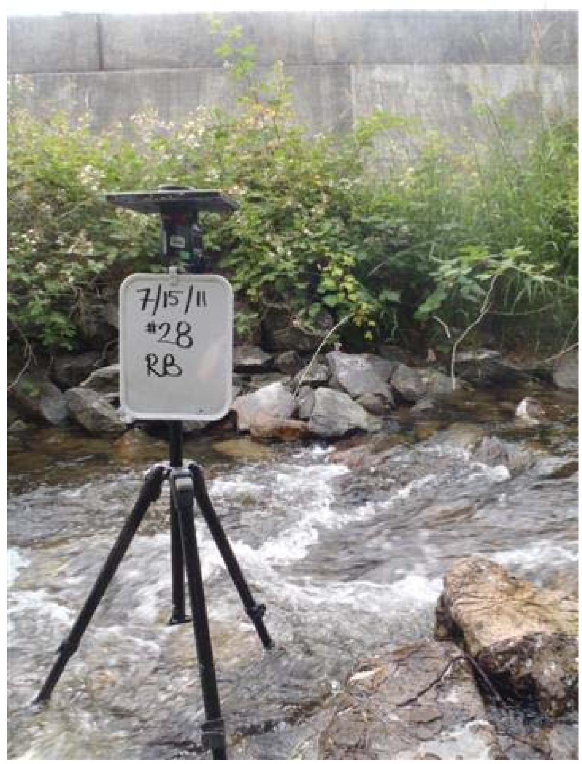

Figure A-58. Shade Photo Site 28 right bank.

Figure A-59. Shade Photo Site 29 left bank.

Figure A-60. Shade Photo Site 29 right bank.

Figure A-61. Shade Photo Site 30 left bank.

Figure A-62. Shade Photo Site 30 right bank.

Figure A-63. Shade Photo Site 30 downstream.

Figure A-64. Shade Photo Site 30 upstream.

Figure A-65. Shade Photo Site 31 left bank.

Figure A-66. Shade Photo Site 31 right bank.

Figure A-67. Shade Photo Site 31 downstream.

Figure A-68. Shade Photo Site 31 upstream.

Figure A-69. Shade Photo Site 32 left bank.

Figure A-70. Shade Photo Site 32 right bank.

Figure A-71. Shade Photo Site 32 downstream.

Figure A-72. Shade Photo Site 32 upstream.

Figure A-73. Shade Photo Site 33 left bank.

Figure A-74. Shade Photo Site 33 right bank.

Figure A-75. Shade Photo Site 33 downstream.

Figure A-76. Shade Photo Site 33 upstream.

Figure A-77. Shade Photo Site 34 left bank.

Figure A-78. Shade Photo Site 34 right bank.

Figure A-79. Shade Photo Site 34 downstream.

Figure A-80. Shade Photo Site 34 upstream.

Figure A-81. Shade Photo Site 35 left bank.

Figure A-82. Shade Photo Site 35 right bank.

Figure A-83. Shade Photo Site 35 downstream.

Figure A-84. Shade Photo Site 35 upstream.

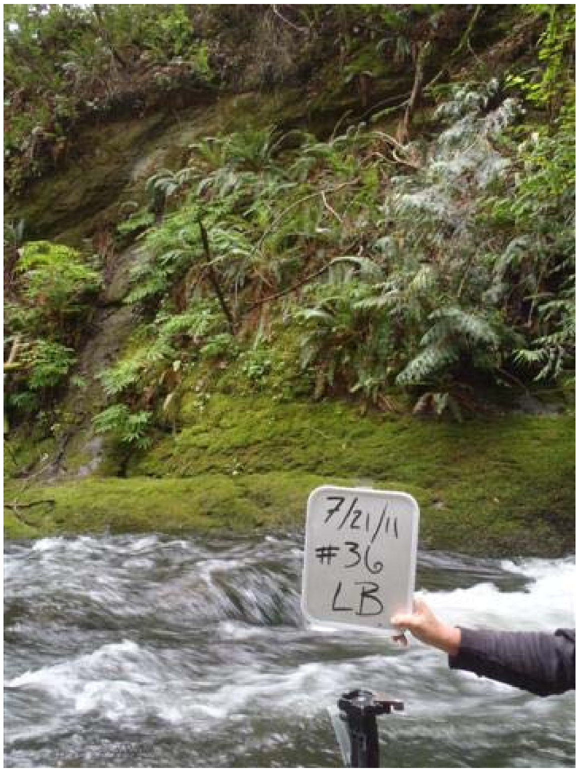

Figure A-85. Shade Photo Site 36 left bank.

Figure A-86. Shade Photo Site 36 right bank.

Figure A-87. Shade Photo Site 36 downstream.

Figure A-88. Shade Photo Site 36 upstream.

Figure A-89. Shade Photo Site 37 left bank.


Figure A-90. Shade Photo Site 37 right bank.

Figure A-91. Shade Photo Site 37 downstream.

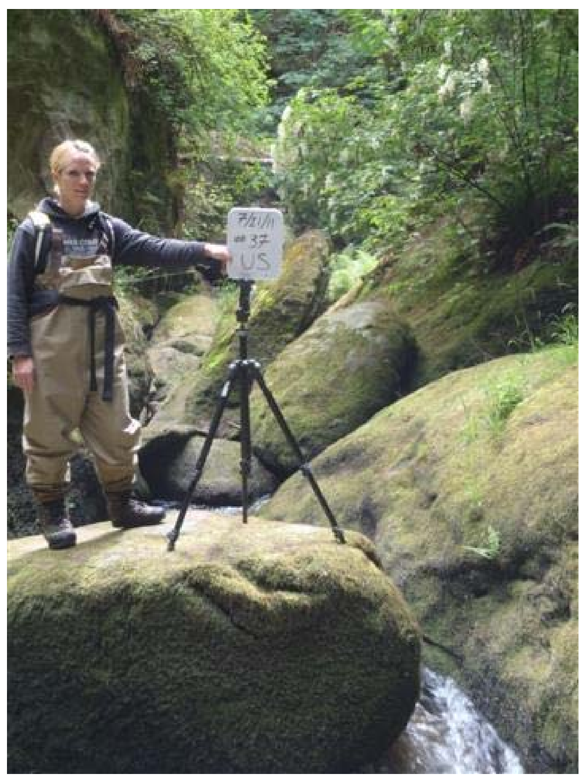
Figure A-92. Shade Photo Site 37 upstream.

Figure A-93. Shade Photo Site 38 left bank.

Figure A-94. Shade Photo Site 38 right bank.

Figure A-95. Shade Photo Site 38 downstream.

Figure A-96. Shade Photo Site 38 upstream.

Figure A-97. Shade Photo Site 39 left bank.

Figure A-98. Shade Photo Site 39 right bank.

Figure A-99. Shade Photo Site 39 downstream.

Figure A-100. Shade Photo Site 39 upstream.

Figure A-101. Shade Photo Site 40 left bank.

Figure A-102. Shade Photo Site 40 right bank.

Figure A-103. Shade Photo Site 40 downstream.

Figure A-104. Shade Photo Site 40 upstream.

Figure A-105. Shade Photo Site 41 left bank.

Figure A-106. Shade Photo Site 41 right bank.

Figure A-107. Shade Photo Site 41 downstream.

Figure A-108. Shade Photo Site 41 upstream.

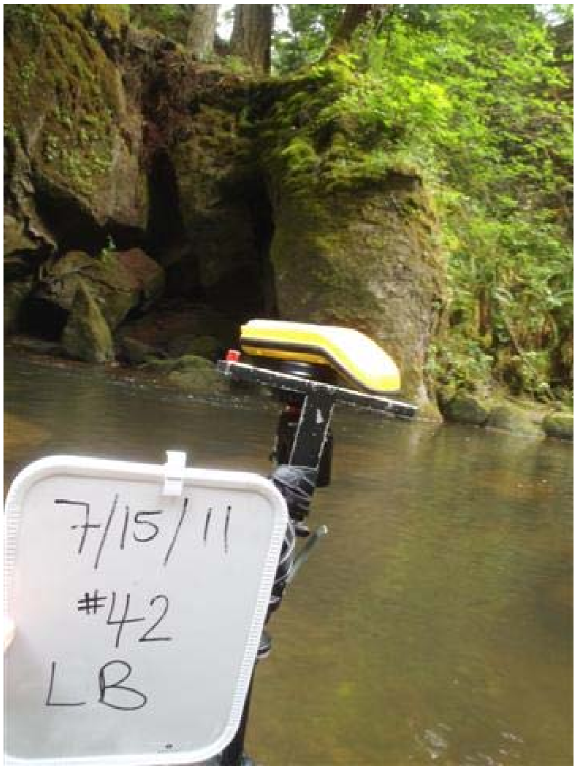

Figure A-109. Shade Photo Site 42 left bank.

Figure A-110. Shade Photo Site 42 right bank.

Figure A-111. Shade Photo Site 42 downstream.

Figure A-112. Shade Photo Site 42 upstream.

Figure A-113. Shade Photo Site 43 left bank.

Figure A-114. Shade Photo Site 43 right bank.

Figure A-115. Shade Photo Site 43 downstream.

Figure A-116. Shade Photo Site 43 upstream.

Figure A-117. Shade Photo Site 44 left bank.

Figure A-118. Shade Photo Site 44 right bank.

Figure A-119. Shade Photo Site 45 left bank.

Figure A-120. Shade Photo Site 45 right bank.

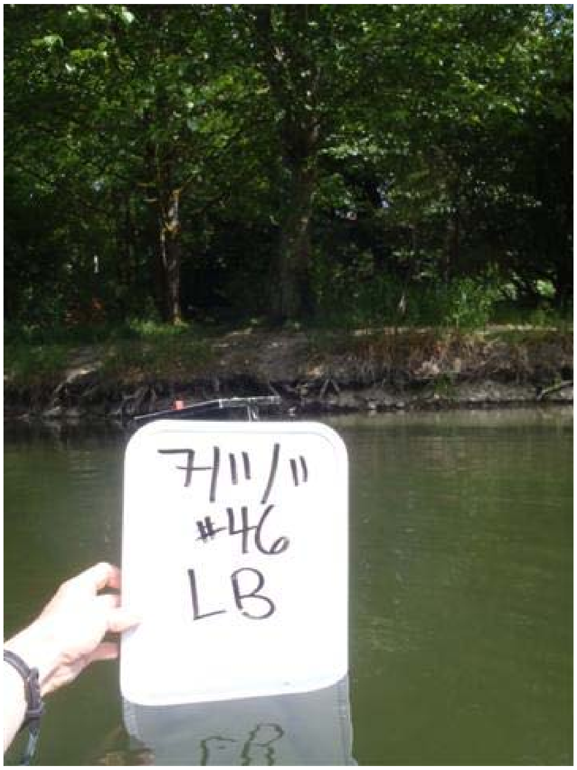

Figure A-121. Shade Photo Site 46 left bank.

Figure A-122. Shade Photo Site 46 right bank.

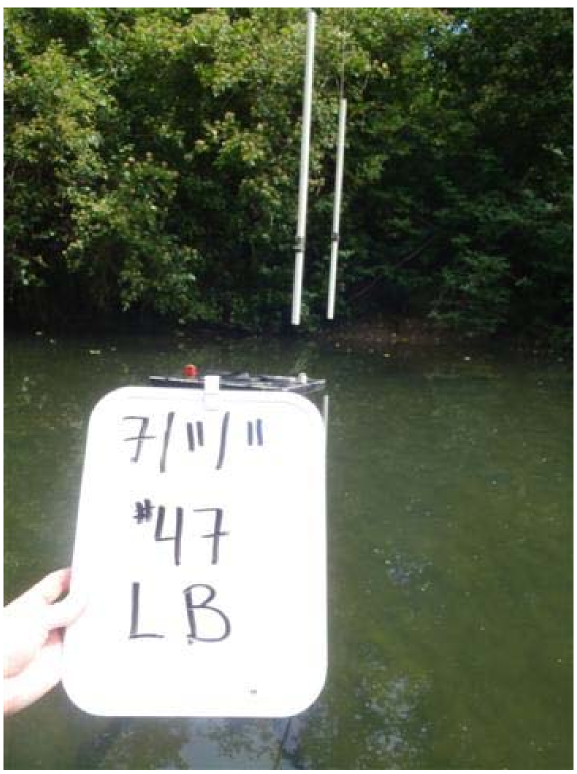

Figure A-123. Shade Photo Site 47 left bank.

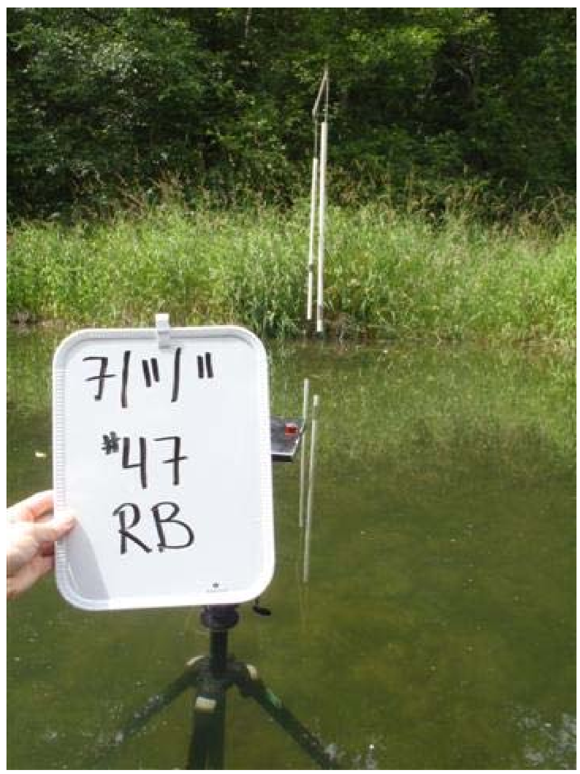

Figure A-124. Shade Photo Site 47 right bank.

Figure A-125. Shade Photo Site 48 left bank.

Figure A-126. Shade Photo Site 48 right bank.

Figure A-127. Shade Photo Site 49 left bank.

Figure A-128. Shade Photo Site 49 right bank.

Figure A-129. Shade Photo Site 50 left bank.

Figure A-130. Shade Photo Site 50 right bank.

Appendix B

Equipment Calibration

Table B-1. Summary of pre- and post-season calibration check results.

Spring 2011: Pre-season Calibrations			Fall 2011: Post-season Calibrations		
Spirit-filled Field Thermometers					
Therm #	**Difference***	**Calibration Factor**	**Therm #**	**Difference***	**Calibration Factor**
Calibration factor applied if difference is greater than +/- 0.5°C for spirit-filled therms.					
HA00588	0.08	none	HB A00588	Broken in field on 6/10/11. No post-season accuracy check.	
HA00538	0.11	none	HB A00538	0.05	none
001	0.03	none	001	0.05	none
002	0.24	none	002	NOT deployed into the field in 2011.	
003	0.35	none	003	NOT deployed into the field in 2011.	
004	0.60	**CF=.60**	004	NOT deployed into the field in 2011.	
005	0.77	**CF=.77**	005	NOT deployed into the field in 2011.	
006	0.23	none	006	NOT deployed into the field in 2011.	
007	0.33	none	007	NOT deployed into the field in 2011.	
008	0.16	none	008	0.05	none
009	0.02	none	009	0.06	none
010	**0.52**	**CF=.52**	010	NOT deployed into the field in 2011.	
			1577†	0.13	none
			8483†	0.01	none
Tidbit Temploggers					
Tidbit #	**Difference***	**Calibration Factor**	**Tidbit #**	**Difference***	**Calibration Factor**
Calibration factor applied if difference is greater than +/- 0.2°C for tidbits.					
2311774	0.18	none	2311774	0.14	none
2311775	0.10	none	2311775	0.01	none
2311776	0.12	none	2311776	0.17	none
2311777	0.03	none	2311777	0.03	none
2311778	0.11	none	2311778	0.06	none
2311779	0.06	none	2311779	0.09	none
2311780	0.12	none	2311780	0.09	none
2311781	0.10	none	2311781	0.03	none
2311782	0.13	none	2311782	NOT deployed into the field in 2011.	
2311783	0.11	none	2311783	NOT deployed into the field in 2011.	
9794425	0.11	none	9794425	0.04	none
9794426	0.00	none	9794426	0.01	none
9794427	0.03	none	9794427	0.07	none
9794428	0.01	none	9794428	0.04	none
9794429	0.16	none	9794429	0.03	none
9794430	0.10	none	9794430	0.04	none
9794431	0.00	none	9794431	0.07	none
9794432	0.07	none	9794432	0.00	none
9794433	0.07	none	9794433	Stolen from Control Dam; replaced with #2311779 on 6/10/11. No post-season accuracy check.	
9794434	0.06	none	9794434	Stolen from Control Dam; replaced with #2311777 on 6/10/11. No post-season accuracy check.	

* Absolute average difference of all accepted readings.

Table B-2. Summary of *in situ* quality control results for site visits.

For Water tidbits, absolute difference >0.3°C flagged in pink.
For Air tidbits, absolute difference >2.0°C flagged in pink.

Date of Site Visit	Tidbit Time	Tidbit Temp (°C)	Field Therm Temp (°C)	Difference*
Dupont Water- Tidbit # 9794425				
6/10/2011	10:30	13.44	13.40	0.04
6/24/2011	14:30	15.48	15.20	0.28
7/7/2011	10:30	14.69	14.40	0.29
7/19/2011	11:00	16.75	16.60	0.15
8/4/2011	9:00	17.39	17.35	0.04
8/19/2011	9:00	17.87	17.70	0.17
9/8/2011	8:30	18.03	17.97	0.06
9/19/2011	11:00	16.28	16.20	0.08
10/6/2011	10:30	14.85	14.90	0.05
10/14/2011	12:30	13.44	13.60	0.16
Dupont Air - Tidbit # 9794426				
6/10/2011	11:00	14.47	14.20	0.27
6/24/2011	15:00	17.01	16.55	0.46
7/7/2011	11:00	14.94	15.20	0.26
7/19/2011	11:00	14.78	15.28	0.50
8/4/2011	9:30	16.37	16.55	0.18
8/19/2011	9:30	13.69	13.80	0.11
9/8/2011	9:00	15.89	15.80	0.09
9/19/2011	11:00	15.42	15.00	0.42
10/6/2011	10:30	11.52	11.95	0.43
10/14/2011	13:00	11.52	11.05	0.47
State Water- Tidbit # 9794427				
6/10/2011	12:00	13.33	13.20	0.13
6/24/2011	15:30	15.68	15.55	0.13
7/7/2011	11:30	14.89	14.70	0.19
8/4/2011	10:00	17.92	17.85	0.07
8/19/2011	9:30	17.76	17.67	0.09
9/8/2011	9:00	18.08	18.10	0.02
9/19/2011	11:30	16.48	16.50	0.02
10/6/2011	11:30	15.04	15.17	0.13
10/14/2011	14:00	14.26	14.35	0.09
James Water- Tidbit # 9794428				
6/10/2011	12:30	13.35	13.25	0.10
6/24/2011	16:30	15.38	15.10	0.28
7/7/2011	13:00	14.90	14.60	0.30
7/19/2011	12:00	16.97	17.10	0.13
8/4/2011	10:30	18.25	18.23	0.02
8/19/2011	10:00	17.93	17.95	0.02
9/8/2011	9:30	18.25	18.25	0.00
9/19/2011	12:00	17.77	17.70	0.07
10/6/2011	12:00	15.22	15.45	0.23
10/14/2011	14:30	14.58	14.65	0.07
Racine Water- Tidbit # 9794429				
6/10/2011	12:30	13.76	13.40	0.36
7/7/2011	14:00	15.49	15.50	0.01
7/19/2011	12:30	17.24	17.00	0.24
8/4/2011	11:00	18.38	18.30	0.08
8/19/2011	10:30	18.21	18.15	0.06
9/8/2011	10:00	18.38	18.30	0.08
9/19/2011	12:30	17.57	17.48	0.09
10/6/2011	14:00	15.65	15.70	0.05
10/14/2011	15:30	14.54	14.40	0.14

Date of Site Visit	Tidbit Time	Tidbit Temp (°C)	Field Therm Temp (°C)	Difference*
Racine Air- Tidbit # 9794430				
6/10/2011	13:30	16.47	14.99	1.48
6/24/2011	17:30	18.88	17.65	1.23
7/7/2011	14:00	19.20	18.57	0.63
7/19/2011	13:00	17.27	17.05	0.22
8/4/2011	11:00	20.50	19.93	0.57
8/19/2011	10:30	15.51	15.90	0.39
9/8/2011	10:30	19.69	20.50	0.81
9/19/2011	12:30	17.58	16.70	0.88
10/6/2011	13:30	13.63	13.40	0.23
10/14/2011	15:30	13.63	13.10	0.53
Valencia Water- Tidbit # 9794431				
6/10/2011	15:00	13.64	13.35	0.29
6/24/2011	18:00	14.57	14.28	0.29
7/7/2011	17:00	15.53	15.20	0.33
7/19/2011	15:00	17.43	17.39	0.04
8/4/2011	13:00	18.40	18.30	0.10
8/19/2011	12:30	18.57	18.53	0.04
9/8/2011	13:30	18.89	18.80	0.09
9/19/2011	14:30	17.59	17.51	0.08
10/6/2011	14:30	15.53	15.73	0.20
10/14/2011	16:00	14.26	14.35	0.09
Plant Water- Tidbit # 9794432				
6/10/2011	14:00	13.44	13.15	0.29
6/24/2011	18:00	13.74	13.49	0.25
7/7/2011	17:30	15.00	14.65	0.35
7/19/2011	16:00	17.22	17.20	0.02
8/4/2011	13:30	17.87	17.87	0.00
8/19/2011	13:00	18.35	18.45	0.10
9/19/2011	15:30	18.03	18.07	0.04
10/6/2011	15:00	15.79	15.80	0.01
10/14/2011	17:00	14.68	14.70	0.02
Dam Water- Tidbit # 2311779				
6/24/2011	19:00	19.16	18.90	0.26
7/7/2011	18:00	20.62	20.30	0.32
7/19/2011	16:30	19.81	19.72	0.09
8/19/2011	14:00	21.61	21.55	0.06
9/8/2011	15:00	22.11	22.17	0.06
10/6/2011	16:00	14.54	14.78	0.24
Dam Air- Tidbit # 2311777				
6/24/2011	18:30	15.08	14.40	0.68
7/7/2011	18:00	16.03	15.10	0.93
7/19/2011	16:30	17.78	17.78	0.00
8/4/2011	14:00	21.02	21.60	0.58
8/19/2011	14:00	19.08	19.57	0.49
9/8/2011	15:00	22.19	22.60	0.41
9/19/2011	16:00	16.82	15.60	1.22
10/6/2011	16:00	13.22	12.40	0.82
10/14/2011	17:30	11.04	9.90	1.14

*Absolute difference between last recorded Tidbit temperature reading and spirit-filled field thermometer temperature

Appendix C

Field/Maintenance Logs

Table C-1. 2011 Temperature Monitoring Field Notes Summary.

Tidbit Download Event Notes				
Download Date	**Arrival Time**	**Personnel**	**Weather**	**Notes**
5/23/2011	19:00	SBB & Keith Doran	-	Initial/test deployments.
5/27/2011	11:35	SBB & Keith Doran	Overcast, intermittent rain	First deployments. Depth of logger will always be between 0.19 and 0.48 ft above the bottom i.e. within the cavity of the concrete block.
6/10/2011	10:40	SBB & Keith Doran	Overcast, cool	Therm 588 broken in field. Will use 538 for both Air and Water.
"	"	"	"	James_Wat: Vegetative material stranding along cable & around tidbit itself. Removed from tidbit.
"	"	"	"	Racine_Wat: Discard temp at 13:00-- tidbit in air. QC failed but close. 39 minute time diff. btwn. Tidbit at 12:30 and field therm at 13:09.
"	"	"	"	Valencia_Wat: Block found mis-oriented with hole facing up. Barely passed QC check.
"	"	"	"	Plant_Wat: Block found mis-oriented with hole facing up.
"	"	"	"	**Dam_Wat and Dam_Air: Cables cut and tidbits 9794433 & 9794434 missing. Replaced with tidbits 2311779 & 2311777. Deployed water tidbit in a larger, double cavity, algae-covered block w/o a cable to conceal it better.**
6/24/2011	14:40	SBB	-	Therm 8483 may need calibration factor, temporary replacement for broken therm. (8483 checked after field season-- no CF needed).
"	"	"	"	James_Wat: Use tidbit temp at 16:30 instead-- closer to 16:25. Passed QC when compared with 15.38°C at 16:30.
"	"	"	"	**Racine_Wat: Tidbit found on bank, out of water. :(But not stolen! :) probably removed AM of 6/17/11.**
"	"	"	"	Racine_Air: Failed first QC check with therm 538, passed second check with therm 8483-- tidbit at 17:30 and field therm at 17:22.
"	"	"	"	Valencia_Wat: Compare with temp at 18:00 instead of 17:30-- closer point in time. Also note different looking diurnal pattern for this download-- wonder why?
7/7/2011	10:40	SBB	Overcast (very warm/clear prev. day)	James_Wat: Deployment too close in time to 12:30. Use 13:00 instead but note that 12:27 and 13:00 are 33 minutes apart, making this QC failure reasonable. No need to swap tidbits.
7/19/2011	10:45	SBB	Overcast, breezy	**State_Wat: Tidbit and brick found on bank w/ cable cut. Returned to water w/o a cable in hopes of decreasing tampering. Also moved to DS side of bridge.**
8/4/2011	9:00	SBB	Clear	James_Wat: ~10 beaver-chewed sticks caught on wire to tidbit/block. Extra shading from this snaggged wood?
"	"	"	"	Plant_Wat: Block found mis-oriented with hole facing up. Location unchanged.
"	"	"	"	Dam_Wat: Missing field therm temp.
8/19/2011	9:00	SBB	Overcast	
9/8/2011	8:30	SBB	Clear, sunny	Racine_Wat: Thalweg shifted so block location just outside of it. Moved brick back toward thalweg.
"	"	"	"	**Plant_Wat: Block/Tidbit found on bank, in air.**
9/9/2011	10:45	SBB	Partial clouds	Jamews_Wat: Red light blinking "out." Indicates that logger is out of user pre-set range. Check to see if any "alarms" were set on this tidbit at launch by accident.
"	"	"	"	Valencia_Wat: Photographed 2 juv. bullfrogs ~1.5".
"	"	"	"	Dam_Water: Neglected to record field therm temp. No QC on this day.
10/6/2011	10:30	SBB	Overcast, recent rains	James_Wat: Block found mis-oriented with hole facing up. Red light blinking again. Found high/low alarm set to 25.26°C, multiple sampling set to maximum. Re-set both to "off."
"	"	"	"	Racine_Wat: Redd adjacent to temp logger. Walked around.
10/14/2011	12:00	SBB	Overcast	***Last Tidbit Download Event for 2011***
"	"	"	"	Dam_Wat: Missing field therm temp and time.

Table C-1 (Cont). 2011 Temperature Monitoring Field Notes Summary.

Spirit-filled Field Therm Notes
Pre-season calibration check included handheld field therms: HB A00588, HB A00538,and blue therms #001 thru #010. All therms used in field were within the 0.20°C MQO.
On 6/10/11 therm #588 was used for Dupont_Wat only and then broken. Therm #538 was used for both air and water tidbit QC check for remainder of day (air before water in each case).
On 6/24/11 therm #538 was used for all water tidbits and #8483 was used for all air tidbits (except at Racine where field therm #538 was used for Air-- water tidbit found on bank).
Note: Replacement therm #8483 did not receive a pre-season calibration check.
On 7/7/11 therm #538 was used for all water tidbits and #8483 was used for all air tidbits.
On 7/19/11 new total immersion therms #1623 and #1577 were used for all water and air tidbits, respectively. These new replacement therms did not receive pre-season calibration checks.
On 8/4/11, 8/19/11, and 9/8/11 the same (above) therms #1623 and #1577 were used for all water and air tidbits, respectively.
On 9/19/11 (during Cemetery Creek downloads), therm #1623 was broken after NP Air tidbit. #1577 used for remainder of that day.
On 10/6/11, 10/7/11 and 10/14/11 therm #1577 was used for both air and water (air first, with 20min+ acclimation time between water sites).
On 10/14/11 brand new therm w/ nickel armoring was STOLEN from walkway railing at Dupont St. bridge while I was retrieving tidbit only ~10 ft away!!! Never used or calibrated this therm.
Post-season calibration check included handheld field therms: HB A00538, #1577, #8483, and blue therms #001, #008 and #009. All therms used in field were within the 0.20°C MQO.

Tidbit Location Descriptions
Dupont_Wat: Next year, do NOT cable block to staff gauge as per Michelle Evans' request.
Dupont_Air: Brand new, never used field therm just STOLEN! It was hanging from the walkway railing and I was <10 ft away! Crazy.
State-Wat: Block is tucked into rip-rap on LB under State St. bridge on DS end.
James_Wat: Block is on LB attached to DS piling.
Racine_Wat: Cabled to young cottonwood tree on LB. Redd near tidbit location (US from block).Did not disturb. Good to take tidbits out now. Early October maybe even better in future.
Racine_Air: Also cabled to young cottonwood tree on LB.
Valencia_Wat: Block cabled to big willow w/ multiple trunks on RB.
Plant_Wat: Site is just US of a sharp R-hand bend in the creek. There is a spur trail to the promontory at the bend. Descend steep bank w/ care on US side. Tidbit cabled to tall maple tree.
Dam_Wat: Block is double cavity & is not cabled to anything. Left it in the water, mid-channel, below the dam.
Dam_Air: Air location is on a root on the upper slope of the RB, near the concrete structure.

1) **SBB = Sara Brooke Benjamin**
2) **RB= Right bank, facing downstream**
3) **LB= Left bank, facing downstream**
4) **DS= Downstream**
5) **US= Upstream**

Table C-2. 2011 Shade Monitoring Field Note Summary.

Hemispherical Photos

Date Photos Taken	7/11/2011
Arrival Time	13:26
Personnel	SBB
Weather	Overcast
Platform Height	1.3m

Station ID	Right Bank ID photo?	Left Bank ID Photo?	Platform level/Red peg oriented North?	Notes
50	Y	Y	Y	At control dam.
49	Y	Y	Y	
48	Y	Y	Y	
47	Y	Y	Y	Deep water.
46	Y	Y	Y	Deep water--> platform height increased to 1.5m (below chin).
45	Y	Y	Y	Derby Pond. B/c of deep water in pond, moved point to shore of RB (at point of bend). [New lat/lon: 48.753498, 122.426689. NAD 83 Conus, 8 satellites.]

Date Photos Taken	7/15/2011
Arrival Time	13:58
Personnel	SBB
Weather	Overcast
Platform Height	1.3m

Station ID	Right Bank ID photo?	Left Bank ID Photo?	Platform level/Red peg oriented North?	Notes
44	Y	Y	Y	
43	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken.
42	Y	Y	Y	Moved ~10ft US to get out from under bridge. No new lat/lon b/c satellites not visible from within the gorge reach.
27	Y	Y	Y	Good satellite coverage.
28	Y	Y	Y	
29	Y	Y	Y	

Date Photos Taken	7/20/2011
Arrival Time	13:45
Personnel	SBB
Weather	Partial Clouds
Platform Height	1.3m

Station ID	Right Bank ID photo?	Left Bank ID Photo?	Platform level/Red peg oriented North?	Notes
26	Y	Y	Y	
25	Y	Y	Y	
24	Y	Y	Y	
23	Y	Y	Y	Original point located in a now abandoned side channel. [Re-located to: 48.75401, 122.45266. -- "51_shade stations" on Trimble.]
22	Y	Y	Y	Just DS of Racine St. footbridge. Updated so point is not under bridge. [New lat/lon: 48.75462850, 122.45383595-- "29_shade stations on Trimble.]
21	Y	Y	Y	
20	Y	Y	Y	
19	Y	Y	Y	

Date Photos Taken	7/22/2011
Arrival Time	9:30
Personnel	SBB & Sarah Manley (WCC)
Weather	Partial Clouds
Platform Height	1.3m

Station ID	Right Bank ID photo?	Left Bank ID Photo?	Platform level/Red peg oriented North?	Notes
41	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken.
40	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken.
39	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken.
38	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken. New point created DS from orig. point due to waterfalls (safety issue). Also a better split of distance between stations 39 & 37. ["53_shade stations"]
37	Y	Y	Y	On rock in middle of channel.
36	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken.
35	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken.
30	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken.
31	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken.

Table C-2 (Cont). 2011 Shade Monitoring Field Note Summary.

Date Photos Taken	7/24/2011
Arrival Time	10:00
Personnel	SBB
Weather	Sunny, clear.
Platform Height	1.3m

Station ID	Right Bank ID photo?	Left Bank ID Photo?	Platform level/Red peg oriented North?	Notes
1	Y	Y	Y	Point is directly adjacent to staff gauge ~ 50 ft US from Dupont St. Bridge.
2	Y	Y	Y	Moved point DS and out from under bridge/vegetated overpass.
3	Y	Y	Y	Moved point out from under road [New lat/lon: 48.75563224, 122.47760414--"55_shade stations on Trimble.]
4	Y	Y	Y	
5	Y	Y	Y	Updated and moved out of deep pool-- too deep o access. ["46_shade stations" on Trimble.]

Date Photos Taken	7/26/2011
Arrival Time	9:30
Personnel	SBB & Sarah Manley (WCC)
Weather	Overcast
Height of Platform	1.3m

Station ID	Right Bank ID photo?	Left Bank ID Photo?	Platform level/Red peg oriented North?	Notes
34	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken.
33	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken. LWD to SE of photopoint may be contributing some shade. Could not discern from photo on camera in the field.
32	Y	Y	Y	Upstream (US) and downstream (DS) photos also taken.
6	Y	Y	Y	Bridge to W visible but low on horizon.
7	Y	Y	Y	Moved and updated point ["44_shade stations" on Trimble.] Dogwood plantings on LB are new. Bike + dog may be visible on bridge.
8	Y	Y	Y	Building in photo.
9	Y	Y	Y	Updated/moved point from under bridges. New point in triangle between State, James & Ellis.
10	Y	Y	Y	Moved point to just DS from concrete slab/waterfall.
11	Y	Y	Y	
12	Y	Y	Y	{Access #13 from bridge at Bellingham Fitness.}
14	Y	Y	Y	

Date Photos Taken	7/27/2011
Arrival Time	13:30
Personnel	SBB
Weather	Partial clouds, intermittent sun.
Height of Platform	1.3m

Station ID	Right Bank ID photo?	Left Bank ID Photo?	Platform level/Red peg oriented North?	Notes
18	Y	Y	Y	
17	Y	Y	Y	
16	Y	Y	Y	
15	Y	Y	Y	
13	Y	Y	Y	Moved point US to equalize distance between points. Sunspot in photo.

Table C-3. 2011 Temperature Field Form.

Tidbit Temperature Loggers - Field Sheet

Date: Personnel:

Weather: Project/Stream:

Equipment: Fully CHARGED laptop, Tidbit shuttle w/ cable, field therms x2,
phone, field sheets, pencil(s), rag/hand towel, stadia rod, chest waders.

Air Therm #: Water Therm #:

Tidbit Info	**p. 1 of _____**

Site:	**No.**
Water depth=	Tidbit depth=
Therm in @	
Tidbit out @	
Download @	
Last Temp @	=
Delayed Start @	
Green light? ☐	Redeployed @
Therm Temp @	=
QC?	

Site:	**No.**
Water depth=	Tidbit depth=
Therm in @	
Tidbit out @	
Download @	
Last Temp @	=
Delayed Start @	
Green light? ☐	Redeployed @
Therm Temp @	=
QC?	

Table C-3(Cont). 2011 Temperature Field Form.

Date:	**p. _____ of _____**

Site:	**No.**
Water depth=	Tidbit depth=
Therm in @	
Tidbit out @	
Download @	
Last Temp @	=
Delayed Start @	
Green light? ☐	Redeployed @
Therm Temp @	=
QC?	

Site:	**No.**
Water depth=	Tidbit depth=
Therm in @	
Tidbit out @	
Download @	
Last Temp @	=
Delayed Start @	
Green light? ☐	Redeployed @
Therm Temp @	=
QC?	

Notes:

Appendix D

2011 Temperature Recordings

(Temperature Metric Definitions are included in Section 1.2 *Background* of the Report Text).

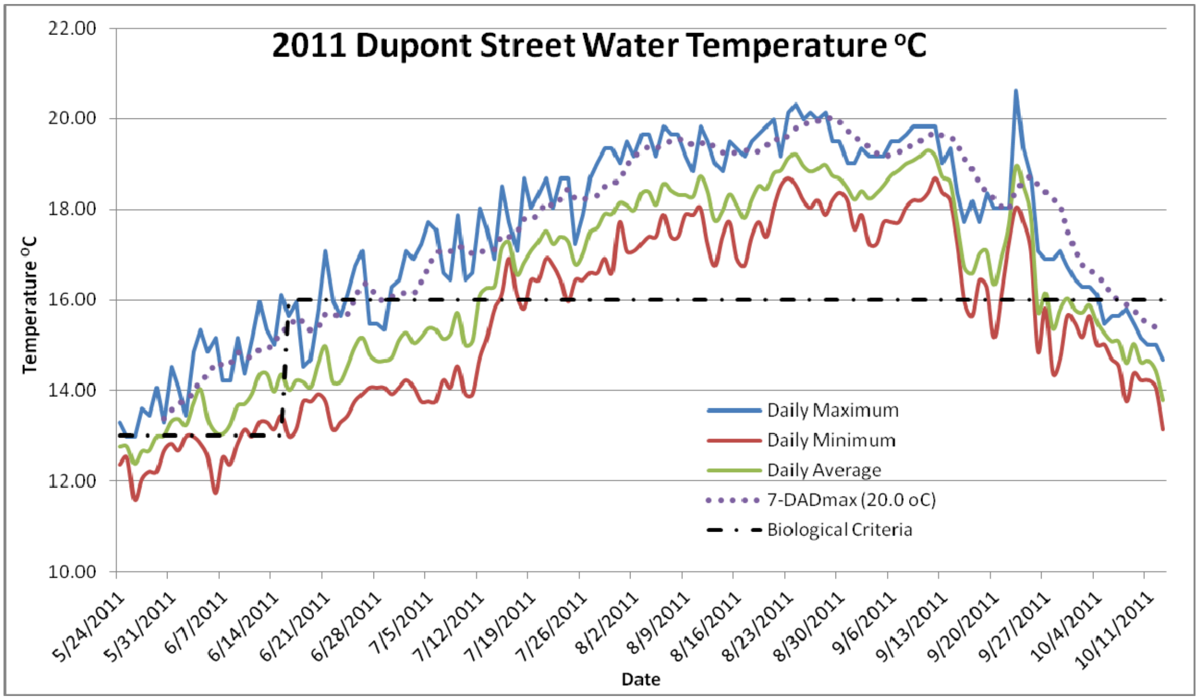

Figure D-1. 2011 surface water temperatures at Dupont Street monitoring station in Whatcom Creek. The highest 7-DADmax at this station was 20.0°C.

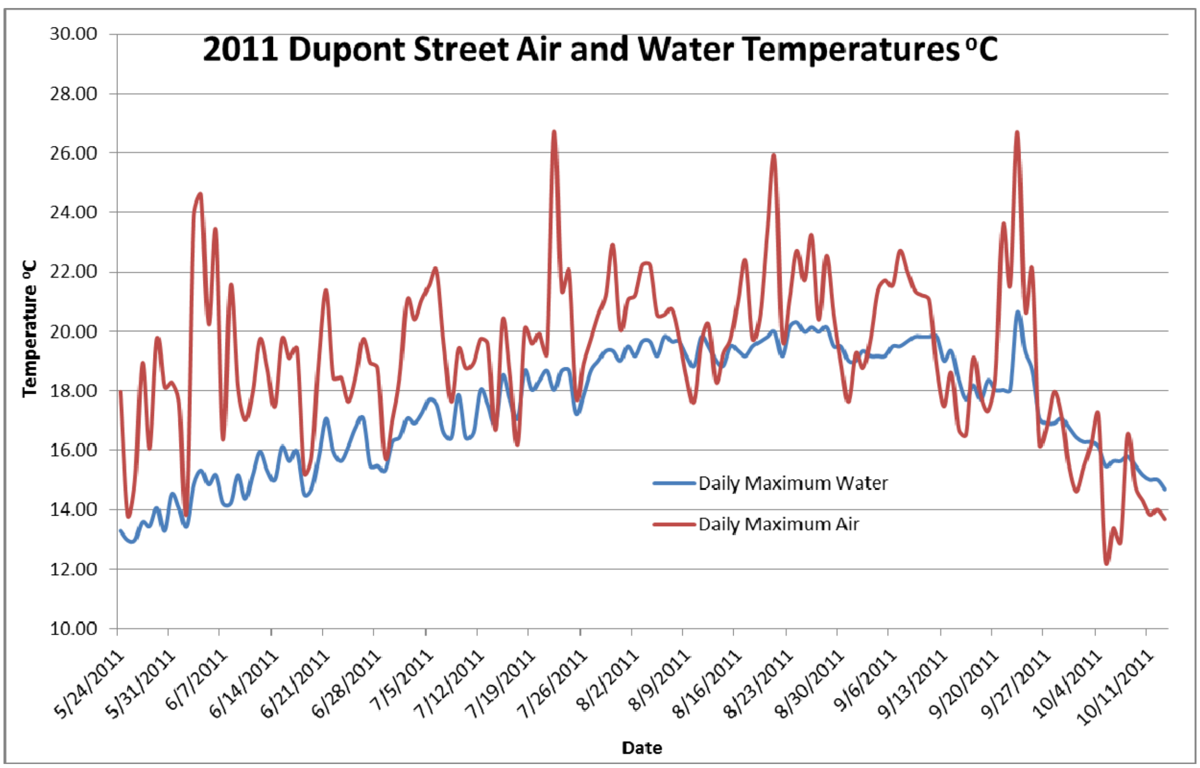

Figure D-2. 2011 daily maximum air and water temperatures at Dupont Street.

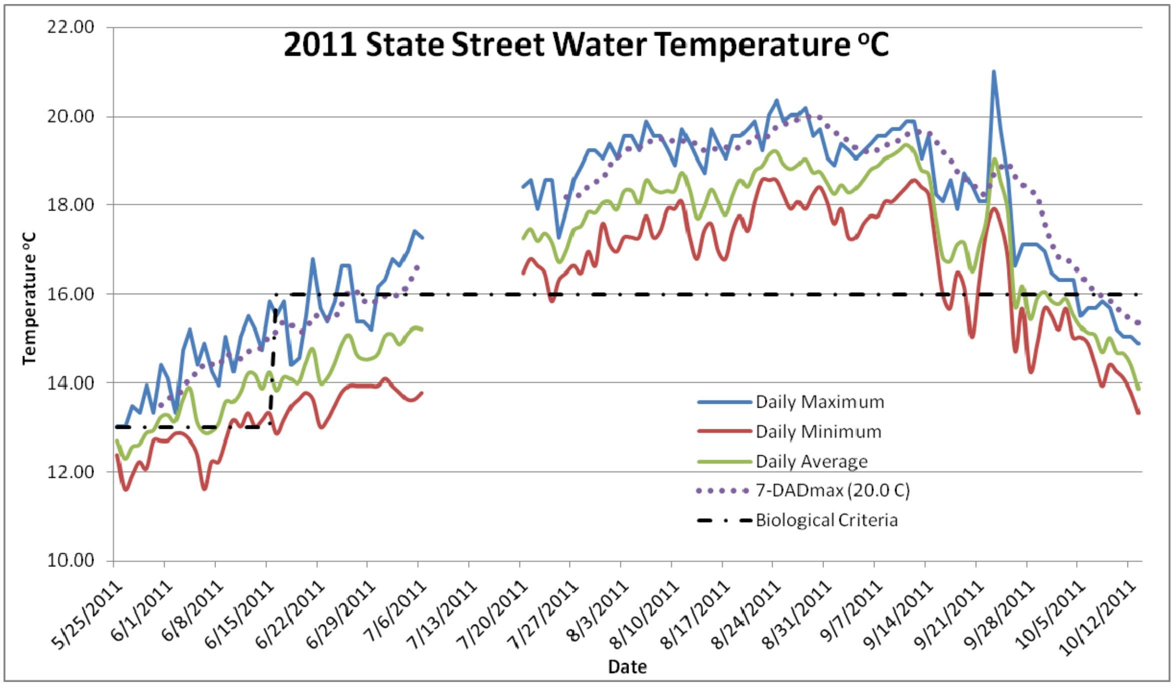

Figure D-3. 2011 surface water temperatures at State Street monitoring station in Whatcom Creek. The highest 7-DADmax at this station was 20.0°C.

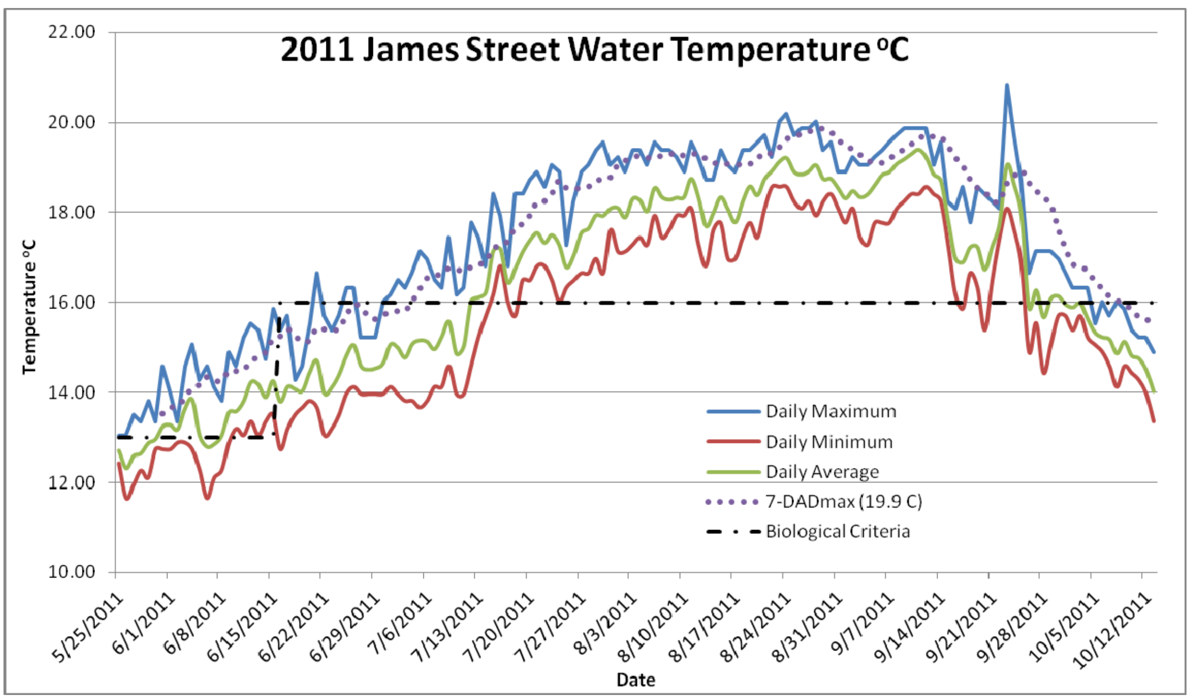

Figure D-4. 2011 surface water temperatures at James Street monitoring station in Whatcom Creek. The highest 7-DADmax at this station was 19.9°C.

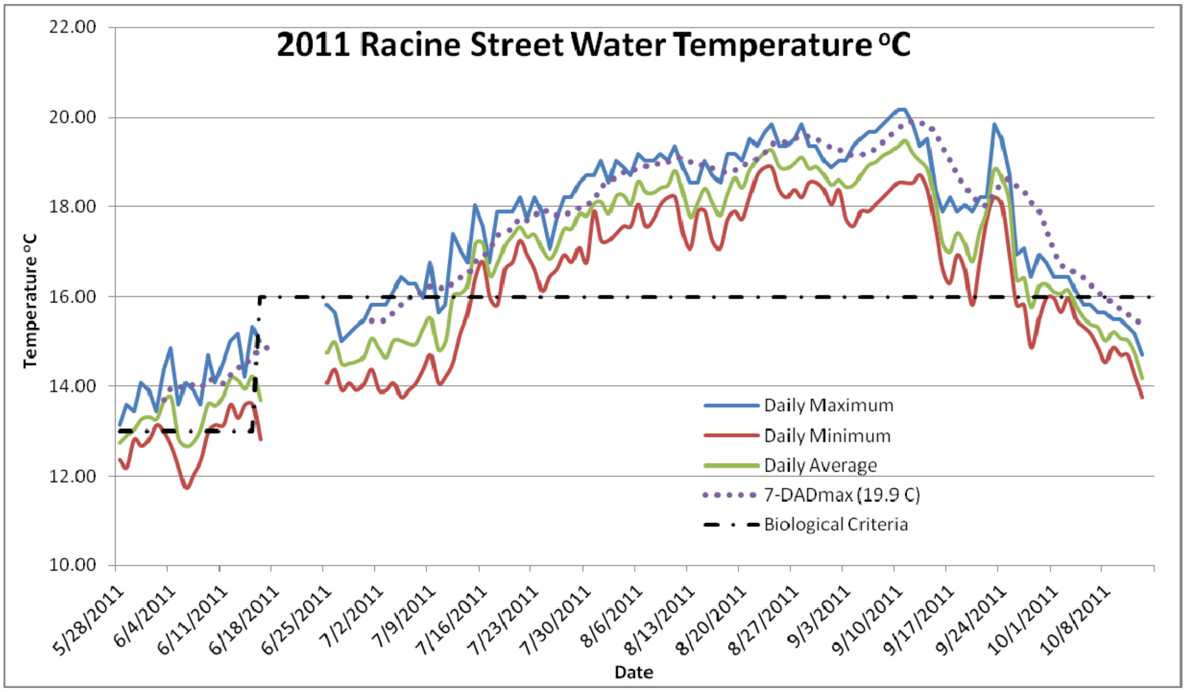

Figure D-5. 2011 surface water temperatures at Racine Street monitoring station in Whatcom Creek. The highest 7-DADmax at this station was 19.9°C.

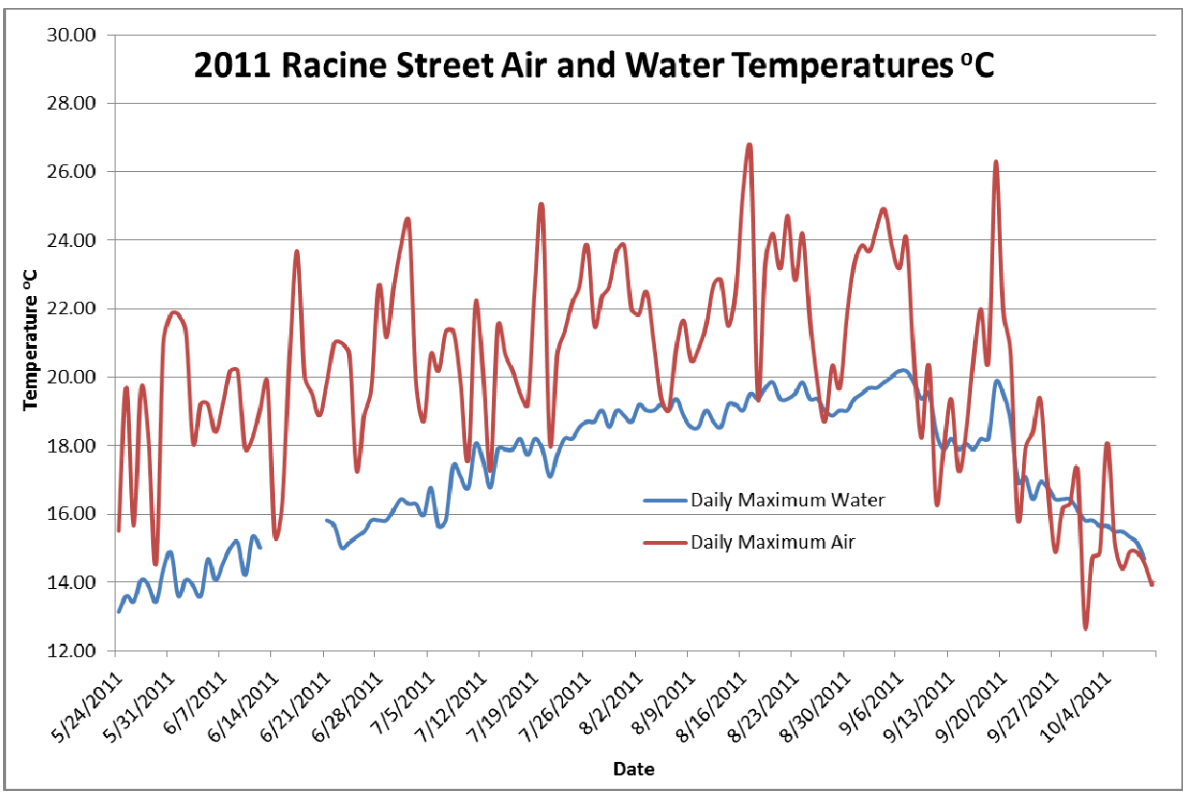

Figure D-6. 2011 daily maximum air and water temperatures at Racine Street.

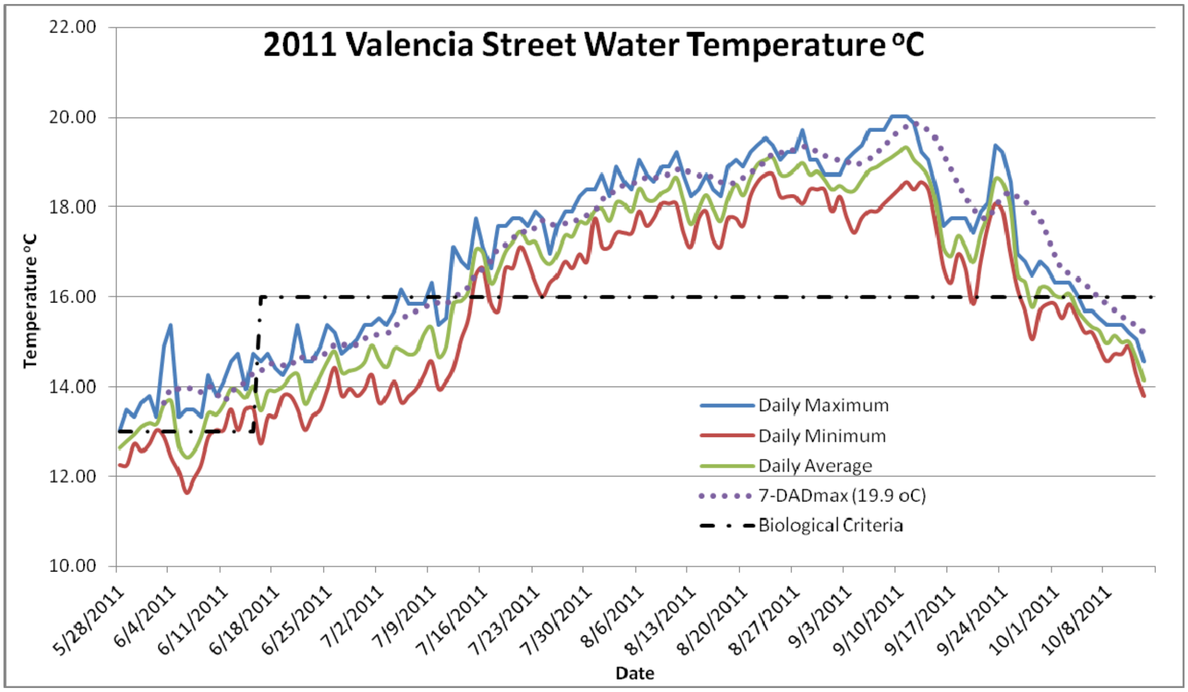

Figure D-7. 2011 surface water temperatures at Valencia Street monitoring station in Whatcom Creek. The highest 7-DADmax at this station was 19.9°C.

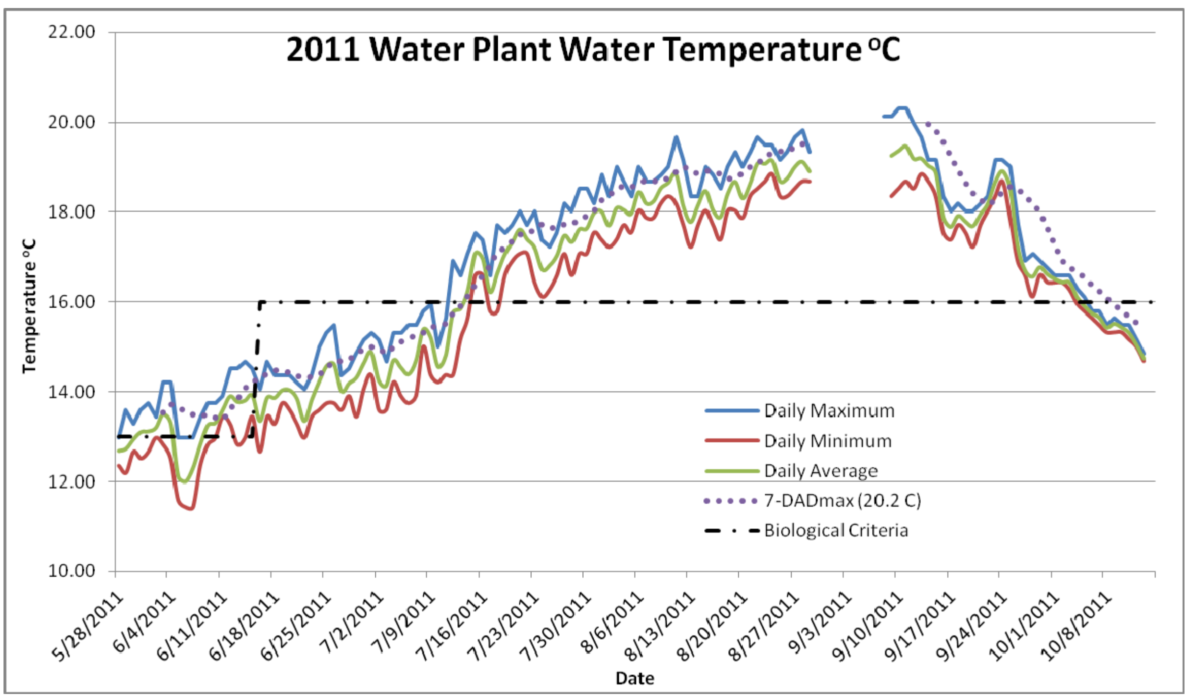

Figure D-8. 2011 surface water temperatures at the Water Plant monitoring station in Whatcom Creek. The highest 7-DADmax at this station was 20.2°C.

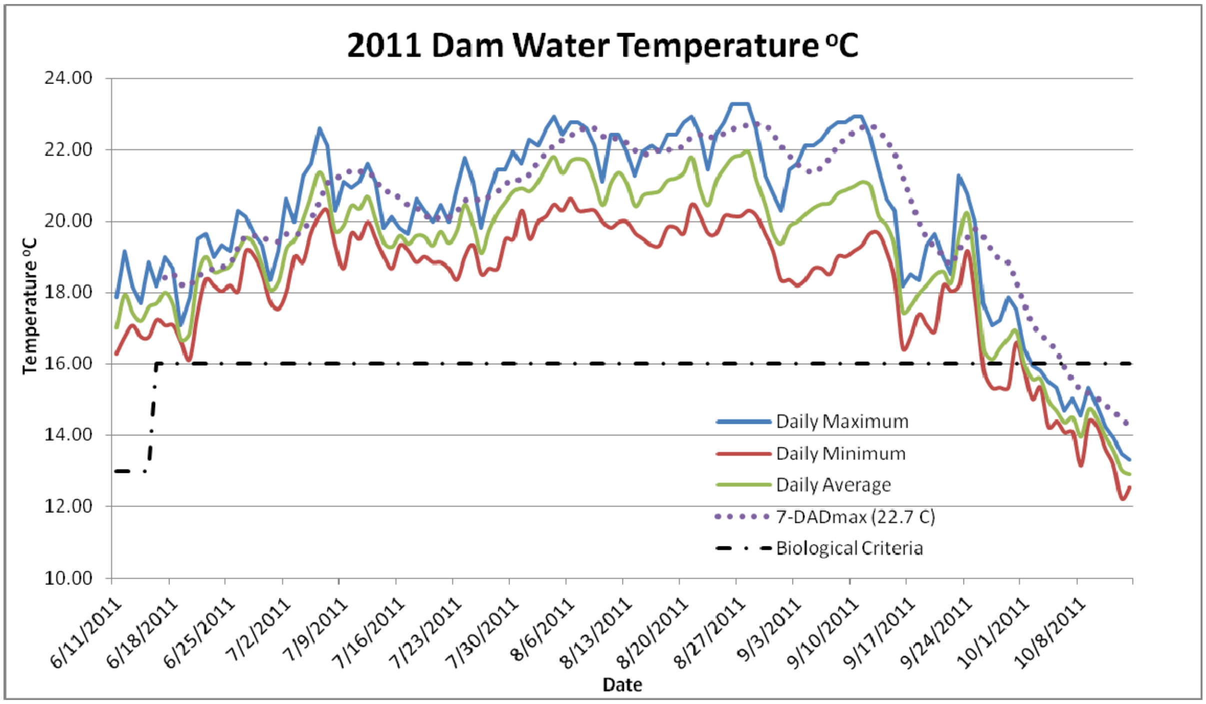

Figure D-9. 2011 surface water temperatures at the Control Dam monitoring station in Whatcom Creek. The highest 7-DADmax at this station was 22.7°C.

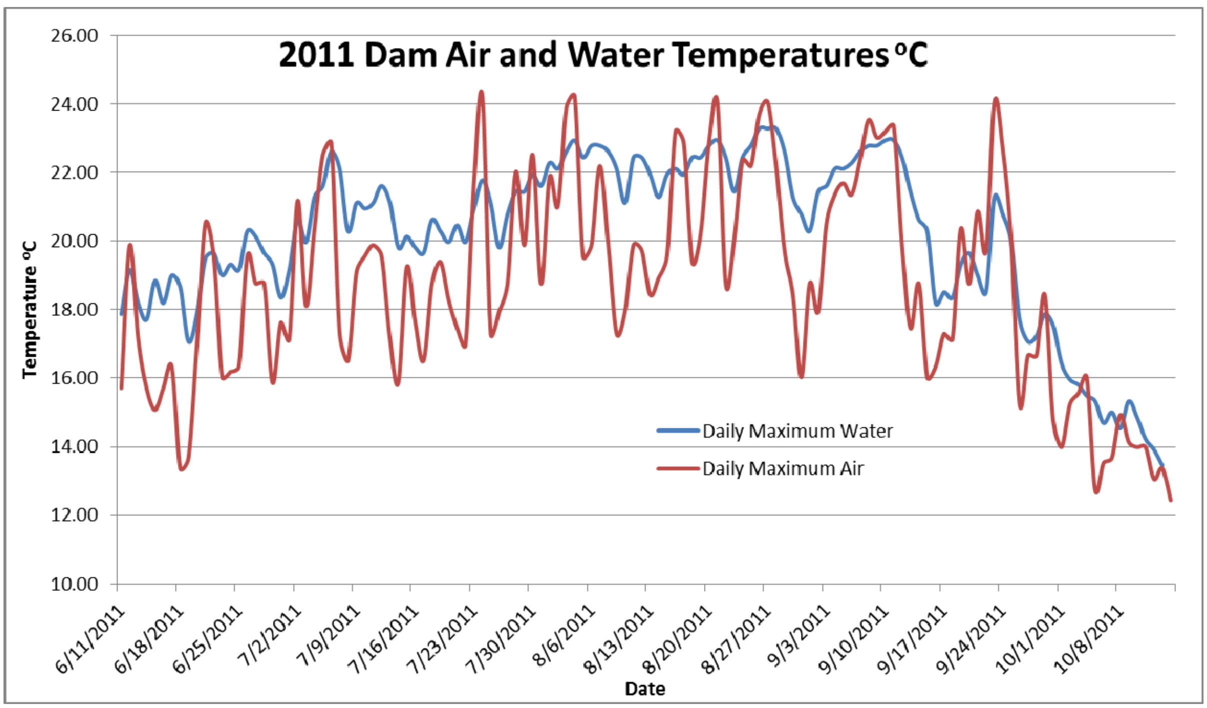

Figure D-10. 2011 daily maximum air and water temperatures at the Control Dam.

Appendix E

2011 Canopy Photographs

Figure E-1. Canopy Photo Site 01.

Figure E-2. Canopy Photo Site 02.

Figure E-3. Canopy Photo Site 03.

Figure E-4. Canopy Photo Site 04.

Figure E-5. Canopy Photo Site 05.

Figure E-6. Canopy Photo Site 06.

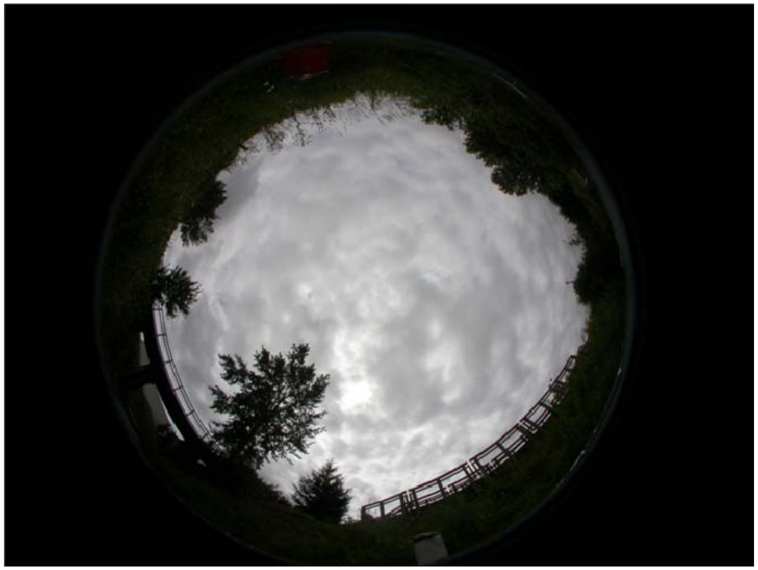

Figure E-7. Canopy Photo Site 07.

Figure E-8. Canopy Photo Site 08.

Figure E-9. Canopy Photo Site 09.

Figure E-10. Canopy Photo Site 10.

Figure E-11. Canopy Photo Site 11.

Figure E-12. Canopy Photo Site 12.

Figure E-13. Canopy Photo Site 13.

Figure E-14. Canopy Photo Site 14.

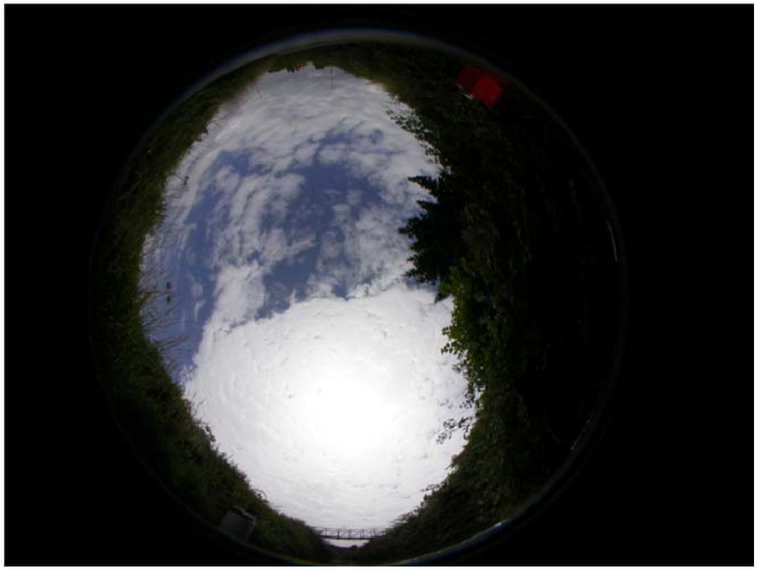

Figure E-15. Canopy Photo Site 15.

Figure E-16. Canopy Photo Site 16.

Figure E-17. Canopy Photo Site 17.

Figure E-18. Canopy Photo Site 18.

Figure E-19. Canopy Photo Site 19.

Figure E-20. Canopy Photo Site 20.

Figure E-21. Canopy Photo Site 21.

Figure E-22. Canopy Photo Site 22.

Figure E-23. Canopy Photo Site 23.

Figure E-24. Canopy Photo Site 24.

Figure E-25. Canopy Photo Site 25.

Figure E-26. Canopy Photo Site 26.

Figure E-27. Canopy Photo Site 27.

Figure E-28. Canopy Photo Site 28.

Figure E-29. Canopy Photo Site 29.

Figure E-30. Canopy Photo Site 30.

Figure E-31. Canopy Photo Site 31.

Figure E-32. Canopy Photo Site 32.

Figure E-33. Canopy Photo Site 33.

Figure E-34. Canopy Photo Site 34.

Figure E-35. Canopy Photo Site 35.

Figure E-36. Canopy Photo Site 36.

Figure E-37. Canopy Photo Site 37.

Figure E-38. Canopy Photo Site 38.

Figure E-39. Canopy Photo Site 39.

Figure E-40. Canopy Photo Site 40.

Figure E-41. Canopy Photo Site 41.

Figure E-42. Canopy Photo Site 42.

Figure E-43. Canopy Photo Site 43.

Figure E-44. Canopy Photo Site 44.

Figure E-45. Canopy Photo Site 45.

Figure E-46. Canopy Photo Site 46.

Figure E-47. Canopy Photo Site 47.

Figure E-48. Canopy Photo Site 48.

Figure E-49. Canopy Photo Site 49.

Figure E-50. Canopy Photo Site 50.

Appendix F

Summary Spreadsheet of 2011 Shade Levels Based on HemiView© Software Analysis of Hemispherical Photographs

Source: Ecology (2012)

Table F-1. Effective shade, canopy cover, and leaf area index values from hemispherical photographs in Whatcom Creek during 2011.

Overall Values		*Overall fraction of visible sky*	*Canopy Cover (fraction) = 1 - VisSky*	*Overall indirect site factor, corrected for intercepting surface orientation*	*Overall direct site factor, corrected for intercepting surface orientation*	*Overall global site factor, corrected for intercepting surface orientation*	*Diffuse radiation above canopy corrected for intercepting surface orientation*	*Diffuse radiation below canopy corrected for intercepting surface orientation*	*Direct radiation above canopy corrected for intercepting surface orientation*	*Direct radiation below canopy corrected for intercepting surface orientation*	*Effective Shade = 1 - ((DirBe + DifBe) / (DirAB + DifAb))*	*Overall leaf area index for the canopy*
SeqNo	**Label**	**VisSky**	**CANOPY COVER**	**ISF**	**DSF**	**GSF**	**DifAb**	**DifBe**	**DirAb**	**DirBe**	**EFFECTIVE SHADE**	**LAI**
1	Site01	0.108	0.892	0.137	0.150	0.148	1082	148	5935	892	85%	2.120
2	Site02	0.233	0.767	0.359	0.399	0.393	1072	385	5886	2350	61%	1.766
3	Site03	0.242	0.758	0.408	0.305	0.321	1083	442	5941	1810	68%	1.616
4	Site04	0.329	0.671	0.496	0.627	0.607	1083	537	5939	3723	39%	1.078
5	Site05	0.204	0.796	0.334	0.436	0.420	1082	361	5940	2588	58%	1.862
6	Site06	0.127	0.873	0.178	0.178	0.178	1060	188	5728	1021	82%	2.073
7	Site07	0.569	0.431	0.784	0.733	0.741	1068	838	5816	4262	26%	0.464
8	Site08	0.197	0.803	0.305	0.331	0.327	1043	318	5316	1758	67%	1.708
9	Site09	0.267	0.733	0.376	0.635	0.594	1005	378	5292	3362	41%	1.224
10	Site10	0.212	0.788	0.303	0.205	0.220	1082	327	5940	1220	78%	1.603
11	Site11	0.340	0.660	0.506	0.258	0.296	1083	548	5940	1534	70%	1.084
12	Site12	0.412	0.588	0.592	0.333	0.373	1076	637	5919	1973	63%	0.828
13	Site13	0.494	0.506	0.709	0.766	0.758	1082	768	5941	4553	24%	0.619
14	Site14	0.513	0.487	0.717	0.706	0.707	1066	765	5808	4098	29%	0.595
15	Site15	0.526	0.474	0.688	0.886	0.856	1082	744	5936	5262	14%	0.482
16	Site16	0.610	0.390	0.763	0.849	0.836	1077	821	5881	4992	16%	0.334
17	Site17	0.522	0.478	0.677	0.890	0.857	1081	732	5933	5279	14%	0.497
18	Site18	0.507	0.493	0.716	0.694	0.698	1083	775	5941	4124	30%	0.583
19	Site19	0.543	0.457	0.696	0.923	0.888	1083	753	5941	5485	11%	0.449
20	Site20	0.613	0.387	0.737	0.964	0.929	1082	798	5941	5725	7%	0.344
21	Site21	0.624	0.376	0.769	0.976	0.944	1083	833	5941	5797	6%	0.307
22	Site22	0.645	0.355	0.843	0.871	0.866	1083	913	5939	5172	13%	0.332

Overall Values		Overall fraction of visible sky	Canopy Cover (fraction) = 1 - VisSky	Overall indirect site factor, corrected for intercepting surface orientation	Overall direct site factor, corrected for intercepting surface orientation	Overall global site factor, corrected for intercepting surface orientation	Diffuse radiation above canopy corrected for intercepting surface orientation	Diffuse radiation below canopy corrected for intercepting surface orientation	Direct radiation above canopy corrected for intercepting surface orientation	Direct radiation below canopy corrected for intercepting surface orientation	Effective Shade = 1 - ((DirBe + DifBe) / (DirAB + DifAb))	Overall leaf area index for the canopy
SeqNo	Label	VisSky	CANOPY COVER	ISF	DSF	GSF	DifAb	DifBe	DirAb	DirBe	EFFECTIVE SHADE	LAI
23	Site23	0.477	0.523	0.669	0.794	0.775	1083	725	5942	4720	22%	0.620
24	Site24	0.358	0.642	0.551	0.454	0.469	1082	596	5942	2698	53%	1.022
25	Site25	0.341	0.659	0.525	0.469	0.478	1083	568	5942	2789	52%	1.067
26	Site26	0.226	0.774	0.344	0.493	0.470	1083	373	5942	2927	53%	1.623
27	Site27	0.389	0.611	0.589	0.557	0.562	1077	635	5913	3294	44%	0.926
28	Site28	0.442	0.558	0.612	0.604	0.605	1061	649	5849	3532	39%	0.699
29	Site29	0.270	0.730	0.394	0.321	0.332	1083	427	5942	1909	67%	1.371
30	Site30	0.301	0.699	0.491	0.535	0.528	1083	531	5943	3181	47%	1.280
31	Site31	0.302	0.698	0.475	0.436	0.442	1083	515	5944	2589	56%	1.268
32	Site32	0.275	0.725	0.439	0.568	0.548	1083	475	5946	3378	45%	1.383
33	Site33	0.253	0.747	0.425	0.143	0.186	1083	460	5946	848	81%	1.542
34	Site34	0.261	0.739	0.432	0.383	0.391	1082	468	5948	2281	61%	1.491
35	Site35	0.186	0.814	0.312	0.329	0.326	1082	337	5951	1955	67%	2.085
36	Site36	0.108	0.892	0.179	0.172	0.173	1082	194	5953	1026	83%	3.137
37	Site37	0.113	0.887	0.202	0.215	0.213	1082	218	5954	1280	79%	3.110
38	Site38	0.122	0.878	0.184	0.209	0.205	1082	199	5956	1245	79%	2.310
39	Site39	0.156	0.844	0.256	0.160	0.175	1041	266	5724	915	83%	2.614
40	Site40	0.102	0.898	0.167	0.163	0.163	1082	181	5958	968	84%	2.894
41	Site41	0.104	0.896	0.170	0.120	0.127	1082	184	5958	712	87%	3.117
42	Site42	0.119	0.881	0.202	0.168	0.173	1083	219	5959	1002	83%	2.903
43	Site43	0.165	0.835	0.267	0.216	0.224	1083	290	5962	1290	78%	2.376
44	Site44	0.126	0.874	0.205	0.161	0.168	1082	222	5962	962	83%	2.713
45	Site45	0.422	0.578	0.611	0.764	0.740	1083	662	5964	4554	26%	0.762

Overall Values		Overall fraction of visible sky	Canopy Cover (fraction) = 1 - VisSky	Overall indirect site factor, corrected for intercepting surface orientation	Overall direct site factor, corrected for intercepting surface orientation	Overall global site factor, corrected for intercepting surface orientation	Diffuse radiation above canopy corrected for intercepting surface orientation	Diffuse radiation below canopy corrected for intercepting surface orientation	Direct radiation above canopy corrected for intercepting surface orientation	Direct radiation below canopy corrected for intercepting surface orientation	Effective Shade = 1 - ((DirBe + DifBe) / (DirAB + DifAb))	Overall leaf area index for the canopy
SeqNo	**Label**	**VisSky**	**CANOPY COVER**	**ISF**	**DSF**	**GSF**	**DifAb**	**DifBe**	**DirAb**	**DirBe**	**EFFECTIVE SHADE**	**LAI**
46	Site46	0.365	0.635	0.512	0.353	0.378	1083	554	5964	2106	62%	0.893
47	Site47	0.368	0.632	0.560	0.448	0.465	1082	607	5964	2672	53%	0.996
48	Site48	0.238	0.762	0.362	0.521	0.496	1083	392	5962	3105	50%	1.519
49	Site49	0.117	0.883	0.174	0.078	0.093	1083	188	5962	466	91%	2.362
50	Site50	0.349	0.651	0.515	0.508	0.509	1075	553	5932	3013	49%	1.071
	Minimum		0.355								6%	0.307
	Maximum		0.898								91%	3.137
	Mean		0.682								53%	1.422
	St. Deviation		0.208								27%	0.866
	Median		0.712								55%	1.274

KEY

Black Original HemiView® Output

Blue Original HemiView Output used for calculation

Red Ecology calculations using the values in the blue columns as per the formulae provided in the HemiView SOP, sections 6.6.2.1 and 6.6.2.2.

Appendix G

Data Verification

Temperature Data

In situ quality control temperature checks were performed at each monitoring site during site visits. The purpose of the temperature check is to verify that the data loggers are performing according to specifications and to provide a log of verified temperatures that may be used for troubleshooting purposes. Limits for site visit quality control checks are presented in Table G-1.

Table G-1. Temperature logger quality control requirements for site visits.

Quality Control Procedures			
Instrument	Method	Frequency	Limits
Onset StowAway Tidbit Temperature Logger	Compare against field thermometer	At every download (approx. every 2 weeks)	Water: ±0.3 °C Air: ±2.0 °C

Five separate instances of quality control failures occurred during the first three data retrieval visits on 6/10/11, 6/24/11 and 7/7/11 (Table G-2). All of these failures occurred while using the same field thermometer (HA00538) and soon after it was discovered that the accuracy on this thermometer (as well as HA00588) was insufficient for this project. (The *Whatcom Creek Long Term Temperature and Shade Monitoring* QAPP calls for +/- 0.2ºC accuracy and 0.1ºC resolution, whereas thermometers HA00538 and HA00588 are reportedly only accurate to 1ºC). These thermometers were replaced by new, sufficiently accurate and precise field thermometers on 7/19/11 (see details in "Spirit-Filled Therm Notes," Table C-1, p. 2). Thereafter all tidbit temperature loggers successfully met all quality control limits during *in situ* temperature checks. Therefore, these six quality control failures early in the season were likely due to field thermometer inaccuracy rather than any deficiencies on the part of the tidbit temperature loggers. No tidbit failed to meet quality control limits on more than one occasion. All 2011 air and water tidbit temperature recordings were accepted without qualification.

Shade Data

Quality control and assurance for the collection of hemispherical digital photographs followed the procedures outlined by Stohr and Bilhimer 2008. Duplicate hemispherical photos were taken at each site to help ensure at least one usable photo per site. Station ID photos were also taken at each photo point for reference. Pre-processing of photos and data analysis was conducted according to quality control and assurance procedures outlined in Stohr 2008 and summarized in the QAPP (City of Bellingham 2012).

The best riparian canopy image from the duplicate photos at each site was forwarded to Ecology for assessment using the HemiView® software package. All 50 of these photos (Appendix E) were judged acceptable for analysis in the 2011 shade monitoring program.

Table G-2. Summary of Quality Control Results for Site Visits.

Date of Site Visit	Tidbit Time	Tidbit Temp (°C)	Field Therm Temp (°C)	Difference*	Date of Site Visit	Tidbit Time	Tidbit Temp (°C)	Field Therm Temp (°C)	Difference*
For Water tidbits, absolute difference >0.3°C flagged in pink.									
For Air tidbits, absolute difference >2.0°C flagged in pink.									
Dupont Water- Tidbit # 9794425					**Racine Air- Tidbit # 9794430**				
6/10/2011	10:30	13.44	13.40	0.04	6/10/2011	13:30	16.47	14.99	1.48
6/24/2011	14:30	15.48	15.20	0.28	6/24/2011	17:30	18.88	17.65	1.23
7/7/2011	10:30	14.69	14.40	0.29	7/7/2011	14:00	19.20	18.57	0.63
7/19/2011	11:00	16.75	16.60	0.15	7/19/2011	13:00	17.27	17.05	0.22
8/4/2011	9:00	17.39	17.35	0.04	8/4/2011	11:00	20.50	19.93	0.57
8/19/2011	9:00	17.87	17.70	0.17	8/19/2011	10:30	15.51	15.90	0.39
9/8/2011	8:30	18.03	17.97	0.06	9/8/2011	10:30	19.69	20.50	0.81
9/19/2011	11:00	16.28	16.20	0.08	9/19/2011	12:30	17.58	16.70	0.88
10/6/2011	10:30	14.85	14.90	0.05	10/6/2011	13:30	13.63	13.40	0.23
10/14/2011	12:30	13.44	13.60	0.16	10/14/2011	15:30	13.63	13.10	0.53
Dupont Air - Tidbit # 9794426					**Valencia Water- Tidbit # 9794431**				
6/10/2011	11:00	14.47	14.20	0.27	6/10/2011	15:00	13.64	13.35	0.29
6/24/2011	15:00	17.01	16.55	0.46	6/24/2011	18:00	14.57	14.28	0.29
7/7/2011	11:00	14.94	15.20	0.26	7/7/2011	17:00	15.53	15.20	0.33
7/19/2011	11:00	14.78	15.28	0.50	7/19/2011	15:00	17.43	17.39	0.04
8/4/2011	9:30	16.37	16.55	0.18	8/4/2011	13:00	18.40	18.30	0.10
8/19/2011	9:30	13.69	13.80	0.11	8/19/2011	12:30	18.57	18.53	0.04
9/8/2011	9:00	15.89	15.80	0.09	9/8/2011	13:30	18.89	18.80	0.09
9/19/2011	11:00	15.42	15.00	0.42	9/19/2011	14:30	17.59	17.51	0.08
10/6/2011	10:30	11.52	11.95	0.43	10/6/2011	14:30	15.53	15.73	0.20
10/14/2011	13:00	11.52	11.05	0.47	10/14/2011	16:00	14.26	14.35	0.09
State Water- Tidbit # 9794427					**Plant Water- Tidbit # 9794432**				
6/10/2011	12:00	13.33	13.20	0.13	6/10/2011	14:00	13.44	13.15	0.29
6/24/2011	15:30	15.68	15.55	0.13	6/24/2011	18:00	13.74	13.49	0.25
7/7/2011	11:30	14.89	14.70	0.19	7/7/2011	17:30	15.00	14.65	0.35
8/4/2011	10:00	17.92	17.85	0.07	7/19/2011	16:00	17.22	17.20	0.02
8/19/2011	9:30	17.76	17.67	0.09	8/4/2011	13:30	17.87	17.87	0.00
9/8/2011	9:00	18.08	18.10	0.02	8/19/2011	13:00	18.35	18.45	0.10
9/19/2011	11:30	16.48	16.50	0.02	9/19/2011	15:30	18.03	18.07	0.04
10/6/2011	11:30	15.04	15.17	0.13	10/6/2011	15:00	15.79	15.80	0.01
10/14/2011	14:00	14.26	14.35	0.09	10/14/2011	17:00	14.68	14.70	0.02
James Water- Tidbit # 9794428					**Dam Water- Tidbit # 2311779**				
6/10/2011	12:30	13.35	13.25	0.10	6/24/2011	19:00	19.16	18.90	0.26
6/24/2011	16:30	15.38	15.10	0.28	7/7/2011	18:00	20.62	20.30	0.32
7/7/2011	13:00	14.90	14.60	0.30	7/19/2011	16:30	19.81	19.72	0.09
7/19/2011	12:00	16.97	17.10	0.13	8/19/2011	14:00	21.61	21.55	0.06
8/4/2011	10:30	18.25	18.23	0.02	9/8/2011	15:00	22.11	22.17	0.06
8/19/2011	10:00	17.93	17.95	0.02	10/6/2011	16:00	14.54	14.78	0.24
9/8/2011	9:30	18.25	18.25	0.00					
9/19/2011	12:00	17.77	17.70	0.07					
10/6/2011	12:00	15.22	15.45	0.23					
10/14/2011	14:30	14.58	14.65	0.07					
Racine Water- Tidbit # 9794429					6/24/2011	18:30	15.08	14.40	0.68
6/10/2011	12:30	13.76	13.40	0.36	7/7/2011	18:00	16.03	15.10	0.93
7/7/2011	14:00	15.49	15.50	0.01	7/19/2011	16:30	17.78	17.78	0.00
7/19/2011	12:30	17.24	17.00	0.24	8/4/2011	14:00	21.02	21.60	0.58
8/4/2011	11:00	18.38	18.30	0.08	8/19/2011	14:00	19.08	19.57	0.49
8/19/2011	10:30	18.21	18.15	0.06	9/8/2011	15:00	22.19	22.60	0.41
9/8/2011	10:00	18.38	18.30	0.08	9/19/2011	16:00	16.82	15.60	1.22
9/19/2011	12:30	17.57	17.48	0.09	10/6/2011	16:00	13.22	12.40	0.82
10/6/2011	14:00	15.65	15.70	0.05	10/14/2011	17:30	11.04	9.90	1.14
10/14/2011	15:30	14.54	14.40	0.14					

* Absolute difference between last recorded Tidbit temperature recording and spirit-filled field thermometer temperature.