



APPENDIX E

WRIA 30

SWALE CREEK WATER TEMPERATURE STUDY

Prepared for:

Klickitat County Planning Unit

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WPN

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Appendix E

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Appendix E:

Swale Creek Water Temperature Study

1 INTRODUCTION

A water quality study was completed between June and December, 2003 to address the current water temperature situation in Swale Creek, a tributary of the Klickitat River in Washington, and to estimate the potential and natural temperature situation in the lower portion of the creek which runs through a canyon. A segment of Swale Creek in Range 4N, Township 14E, Section 19, is listed on Ecology's proposed 2002 303(d) list¹ and Ecology's current 1998 303(d) list² as impaired due to exceedance of water temperature criteria. This section is located at the mouth of the creek. There was little published data available for Swale Creek water temperature. Ecology's 303(d) list cites data submitted by Carroll Palmer of the Yakama Nation in 1996 and 1997 showing numerous excursions above the state water quality standard.

Continuous water temperature data were collected during the summer of 2003. Data on geomorphology, flow, adjacent riparian conditions, and potential growth situations were also collected. Oregon's Heat Source model was used to estimate water temperature under various shade conditions. Unpublished data collected in previous years by the Yakama Nation and the Klickitat County Conservation District were used to address inter-annual variability in temperature.

An evaluation of land use effects on stream flow was not part of the original scope of work for this project. Stream flow, however, could have a significant effect on riparian vegetation and heating mechanics of the stream. Therefore, an overview of the current hydrologic conditions based on other studies conducted in the area has been provided below. Additionally, cadastral survey maps and notes completed in 1860 to 1872 were reviewed and used to infer historic flow and vegetation conditions.

1.1 HYDROLOGIC OVERVIEW

Swale Creek is a tributary to the Klickitat River and lies entirely within Klickitat County. The creek is characterized by three larger geomorphic areas. These include the headwaters which drain rolling terrain, the Swale Creek valley which is wide and relatively flat, and the lower basin which runs predominantly through a steep canyon (Figure 1).

Most of the surface runoff within the Swale Creek subbasin occurs in numerous small tributaries draining the Columbia Hills that flank the southern edge of the subbasin. Based on field observations completed in April 2003 (Aspect Consulting 2003a), lesser runoff occurs in several small tributaries flowing south from the ridge bordering the Swale Creek valley to the north. Within Swale Canyon, there are fewer tributaries draining High Prairie to the west, but some of

¹ (http://www.ecy.wa.gov/programs/wq/303d/2002/wria_pdfs/wria30.pdf)

² (<http://www.ecy.wa.gov/programs/wq/303d/1998/wrias/wria30.pdf>)

these tributaries appear to convey somewhat greater flows than those entering the Swale Valley east of Warwick.

East of Warwick, the Swale Valley is an alluvium-filled basin within an east-west trending synclinal trough of the Wanapum Basalt. Alluvial deposits have filled the central axis of the valley between approximately Highway 97 on the east and Warwick on the west, with depths to bedrock along the valley axis greater than 200 feet near Centerville. Groundwater in this basin occurs within both the alluvial deposits (Alluvial Aquifer) and the underlying Wanapum and Grande Ronde Basalts. West of Warwick, Swale Creek Canyon is incised deeply within the Wanapum and Grande Ronde Basalts, with little alluvium except along the lowermost 2 miles (Figure 2). Figure 2 is a geologic map of the Swale Creek subbasin (from Washington DNR; November 2000), showing surficial geologic units and alignments of major geologic folds and faults.

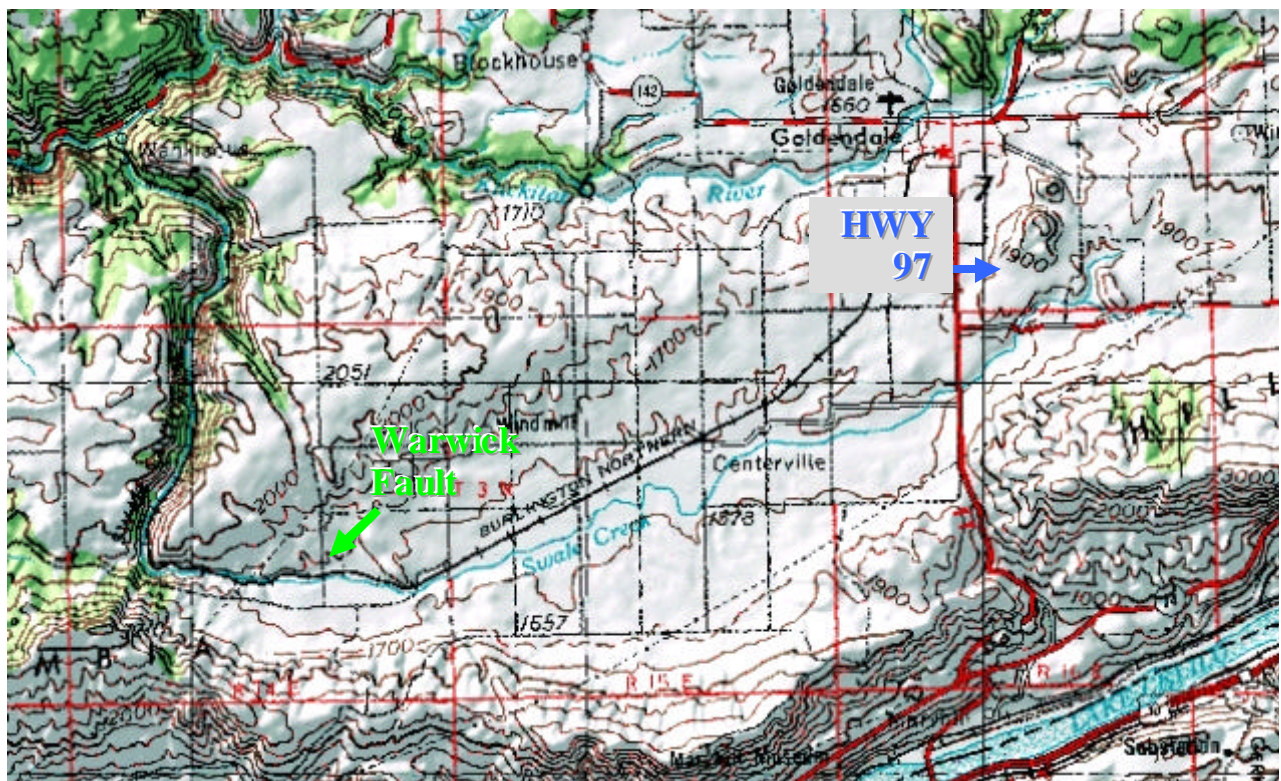
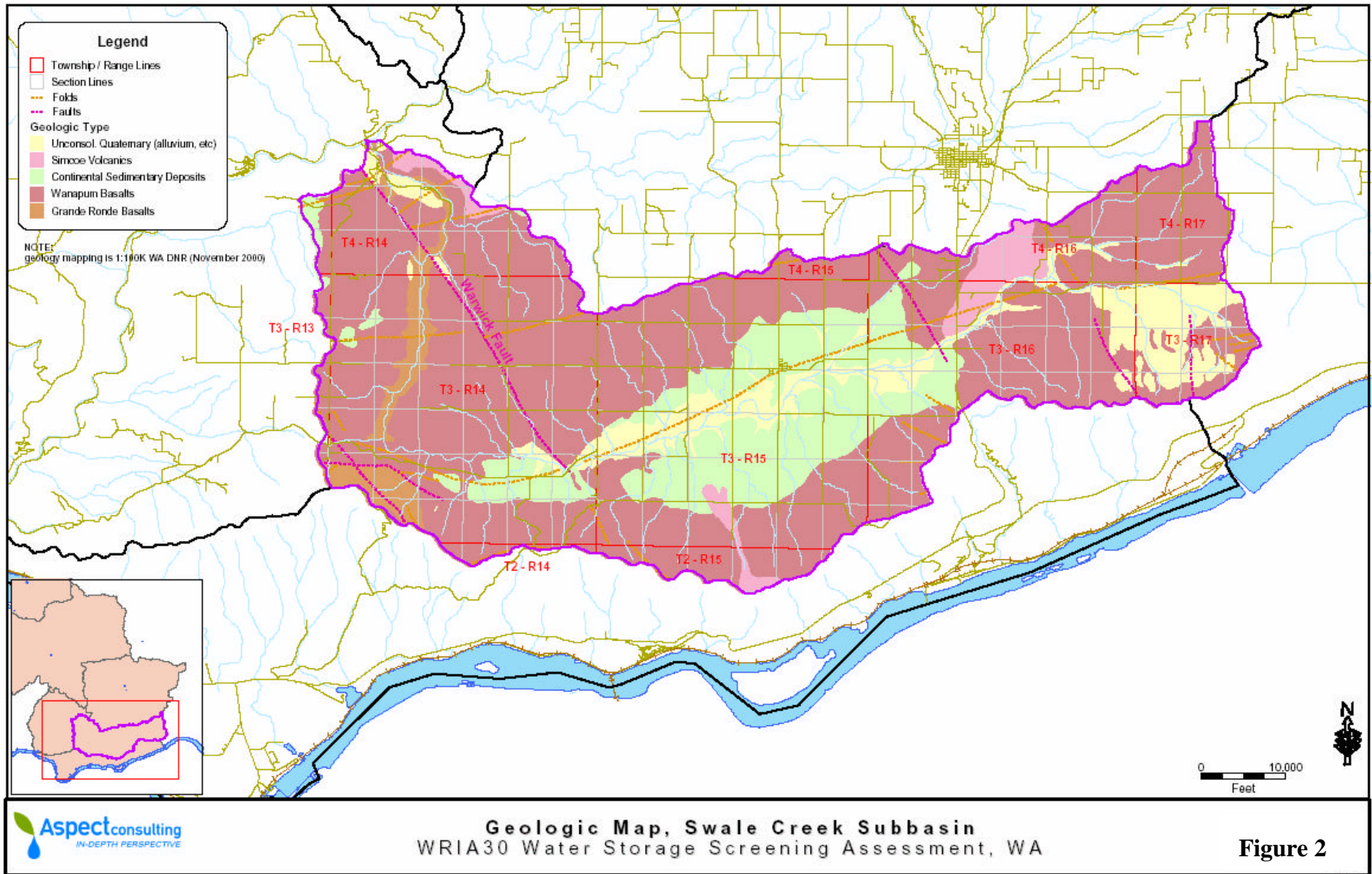


Figure 1. Topographic depiction of the Swale Creek basin. The headwaters of the creek are in the east. The Swale Creek canyon runs largely north to south, turning northwest in the lower 3 miles. The Swale valley extends from Highway 97 to the Warwick fault.



Swale Creek between approximately Highway 97 and Warwick is an expression of the water table in the Alluvial Aquifer. As such, it is ephemeral (seasonal) and directly related to the groundwater level in the alluvium. In early spring, groundwater levels in the alluvium are generally high (shallow depth below the ground surface). Localized flooding of the low-lying areas around Swale Creek has occurred during particularly wet periods in the late winter and early spring. This portion of the creek is generally dry by late spring/early summer and for the balance of the year as groundwater levels in the alluvium decline. In summer, open water is largely limited to a few standing pools. Groundwater level data from the 1960s to present indicate that the groundwater levels recover each spring, with no apparent long-term water level declines in that period.

The Warwick Fault, which bisects the western portion of the Swale Creek valley at Warwick (Figures 1, 3, 4), is an important structural control on groundwater flow in this subbasin, including the interaction of groundwater with Swale Creek. Based on regional assessment of structural controls (folds and faults) in the basalts, Newcomb (1969) concluded that the Warwick Fault forms a structural closure to the Swale Creek valley and thus should create an impoundment of groundwater to the east of the fault. Previous USGS interpretations of regional groundwater flow conditions indicate that the Warwick Fault does impound groundwater in the overlying Wanapum Basalt (Luzier 1969), but there were no specific data to confirm the same for the Grande Ronde Basalt. However, the Yakama Nation recently drilled a 100-foot deep well into the Grande Ronde Basalt near Wahkiacus, just east (upgradient) of the Warwick Fault. The well is flowing artesian, with a flow of 700 gpm and a shut-in pressure of 10 psi. The presence of considerable excess pressure upgradient of the fault suggests that it also impounds groundwater in the Grande Ronde.

Figure 3 depicts regional groundwater elevation contours and inferred groundwater flow directions for the Grande Ronde Basalt as mapped in 1983 (modified from Bauer et al. 1985). Although there are several wells tapping into the Grande Ronde Basalt regionally, only one well is known to produce from this aquifer in the Swale Creek valley.

The Wanapum Basalt is the largest source for groundwater supply for irrigation withdrawals in the Swale Creek subbasin. Figure 4 depicts regional groundwater elevation contours and inferred groundwater flow directions for the Wanapum Basalt, as well as the locations of existing wells completed in this basalt unit as mapped in 1983 (modified from Bauer et al. 1985). Groundwater in the Wanapum regionally flows toward the southwest, but a significant east-west trending groundwater divide occurs along an unnamed anticline separating the Goldendale area (to the north) from the Centerville area (to the south). It is inferred that this groundwater divide is controlled by the anticline and would thus not change position substantively as a result of pumpage in the Swale Creek subbasin. From this groundwater divide, groundwater flows in the basalt northward to the Little Klickitat River and southward to the Swale Creek valley. Groundwater in the Wanapum flows into the Swale Creek valley from the north and south.

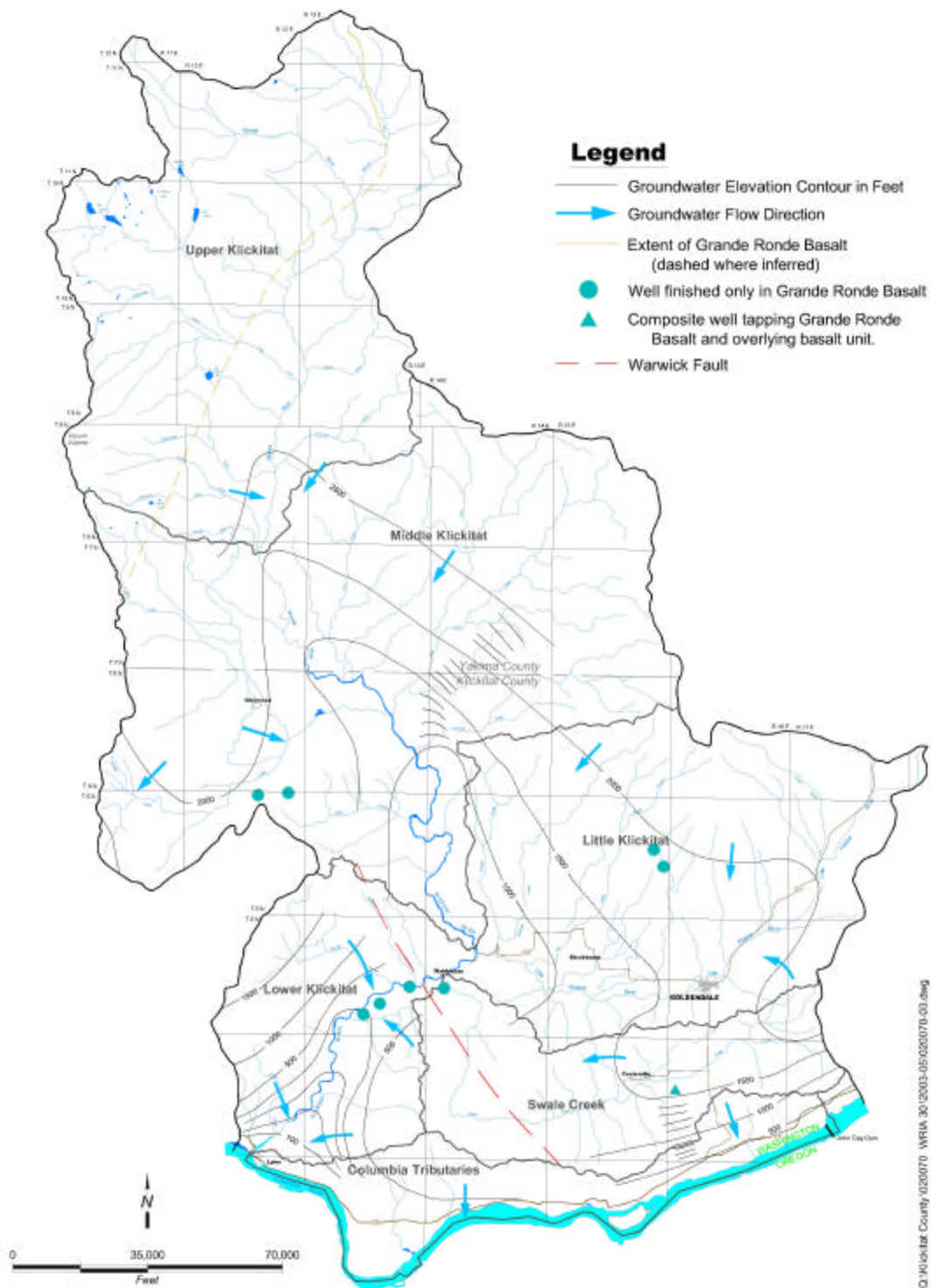


Figure 3. Groundwater contours and flow directions within the Grande Ronde basalt in the Klickitat basin (after Bauer et al, 1985).

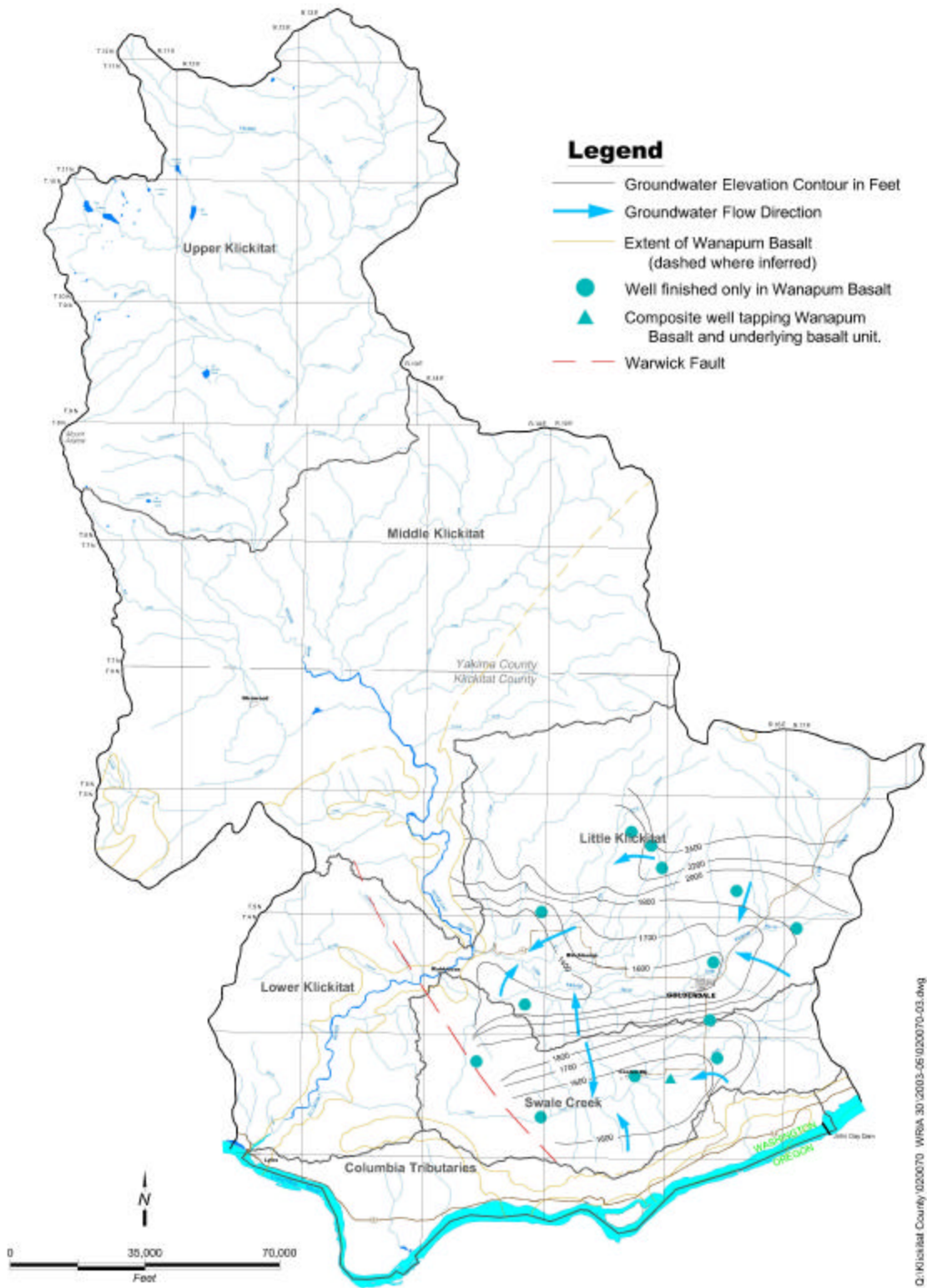


Figure 4. Groundwater contours and flow directions within the Wanapum basalt in the Klickitat basin (after Bauer et al, 1985).

As discussed above for the Grande Ronde, the Warwick Fault creates an impoundment of groundwater in the Wanapum Basalt to the east. This groundwater flow interpretation is consistent with that presented in Luzier (1969).

The presence of the Warwick fault on the western margin of Swale Creek valley, which impedes westerly groundwater flow within the basalts, together with low summer surface water flows within Swale Creek Canyon (west of Warwick), indicate little baseflow contribution of groundwater from the basalts to the creek. The April 2003 field reconnaissance of the entire Swale Creek Canyon (prior to start of irrigation pumping in the region) confirmed very low quantities of spring discharge from the basalts (Aspect Consulting 2003a). None of these observed springs had significant discharge, which is consistent with their lack of mapping in Brown (1979). Anecdotal information from a 40-year resident (Mr. Tony Sareson) of the upper Swale Canyon indicates that, as soon as surface runoff from the Columbia Hills stops, Swale Creek dries up every year that he has lived there, except at Warwick and in scattered pools throughout the canyon. Field observations from a September 2003 field reconnaissance of Swale Creek confirm this. At that time, there was approximately 0.25 cfs entering Swale Creek from Stacker Canyon (presumably spring discharge from a higher elevation) and approximately 0.25 cfs present at the mouth of Swale Creek (Aspect Consulting 2003b). There was no evidence that stream flow had increased as a result of groundwater contribution from the basalt aquifers down the canyon.

Based on the collective information, flows in Swale Creek are supported principally by runoff from numerous small tributaries draining the surrounding uplands downstream of Warwick (e.g., Columbia Hills and High Prairie). Groundwater discharge provides minimal baseflow to Swale Creek. Because geologic structure (the Warwick Fault) limits groundwater discharge to Swale Canyon, the lack of groundwater baseflow into the canyon has existed for geologic time, unchanged by land use change within the subbasin.

1.2 Land Use

Since the early 1900s irrigated agriculture has been, and currently remains, a principal land use in the Swale Valley east of Warwick. However, the amount of irrigated agriculture in the valley is in decline due to economic and market conditions. West of Warwick, land use on the uplands above Swale Canyon is predominantly low-density residential with some pasture land.

In 1902, a railroad grade was constructed along the full length of Swale Canyon. Inter Fluve (2002) completed an assessment of Swale Canyon to evaluate the creek channel's current geomorphic and hydraulic conditions, and identify alternatives and locations for enhancing the current stream channel (by reducing the physical presence of the railroad grade) with the objective of improving fisheries habitat and riparian function. That assessment concluded that construction and long-term maintenance of the existing railroad grade has severely degraded the stream channel, principally by reducing the width of the channel and access of higher flows to the broader floodplain. Narrowing the channel increased the stream's erosive energy, particularly in the upper portion of the canyon, and increased sediment loads delivered to low-energy portions of the channel downstream. Maintenance activities completed to prevent erosion of the railroad grade over 90 years of operation (e.g., removing large rocks from the channel to armor the railroad grade) have reportedly further degraded channel and habitat conditions.

2 STATE WATER TEMPERATURE STANDARDS

The State of Washington temperature standards (Washington Department of Ecology, 2003) define temperature criteria for 6 aquatic life categories for fresh water (Table 1). Each of these pertains to different species and/or life history stages. Waters can also be designated for the beneficial uses of recreational use (exceptional primary contact, primary contact, and/or secondary contact), water supply uses (domestic water, industrial water, agricultural water and/or stock water), and other miscellaneous uses (wildlife habitat, harvesting, commerce/Navigation, boating and/or aesthetics).

Table 1. Aquatic life temperature criteria in fresh water (Washington Department of Ecology, 2003).

Category	Highest 7-DADMax
Char	12°C
Salmon and Trout Spawning. Core Rearing, and Migration	16°C
Salmon and Trout Spawning. Noncore Rearing, and Migration	17.5°C
Salmon and Trout Rearing and Migration Only	17.5°C
Non-anadromous Interior Redband Trout	18°C
Indigenous Warm Water Species	20°C

The specific designated uses applicable to many major water bodies have been specified. These water bodies and their designated uses are listed in Table 602 of WAC 173-201A-600. Swale Creek is not on that list. For those water bodies for which designated uses have not been specified in Table 602 of WAC 173-201A-600, including Swale Creek, the applicable designated uses are quoted from the WAC as follows (the **bolded** language applies to Swale Creek):

“(1) All surface waters of the state not named in Table 602 are to be protected for the designated uses of: Salmon and trout spawning, noncore rearing, and migration; primary contact recreation; domestic, industrial, and agricultural water supply; stock watering; wildlife habitat; harvesting; commerce and navigation; boating; and aesthetic values.

(a) Additionally, the following waters are also to be protected for the designated uses of salmon and trout spawning, core rearing, and migration; and extraordinary primary contact recreation:

(i) All surface waters lying within national parks, national forests, and/or wilderness areas;

(ii) All lakes and all feeder streams to lakes (reservoirs with a mean detention time greater than fifteen days are to be treated as a lake for use designation);

(iii) All surface waters that are tributaries to waters designated salmon and trout spawning, core rearing, and migration; or extraordinary primary contact recreation; and

(iv) All fresh surface waters that are tributaries to extraordinary quality marine waters (WAC 173-201A-610 through 173-201A-612).

(2) The water quality standards for surface waters for the state of Washington do not apply to segments of waters listed in Table 602 that are on Indian reservations.”

Based on these criteria, the designated uses for Swale Creek default to the following:

- Salmon and trout spawning, noncore rearing, and migration;
- Primary contact recreation;
- Domestic, industrial, and agricultural water supply;
- Stock watering;
- Wildlife habitat;
- Harvesting;
- Commerce and navigation;
- Boating; and
- Aesthetic values.

Hence, the aquatic life temperature criteria that applies in Swale Creek is 17.5 °C.

The standards specify provisions regarding these criteria. These provisions are provided below (directly quoted from Washington Department of Ecology, 2003).

“(i) 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).

(ii) When the natural condition of the water is cooler than the criteria in Table 200 (1)(c), the allowable rate of warming up to, but not exceeding, the numeric criteria from human actions is restricted as follows:

(A) Incremental temperature increases resulting from individual point source activities must not, at any time, exceed $28/(T.+5)$ as measured at the edge of a mixing zone boundary (where "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge); and

- (B) *Incremental temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not, at any time, exceed 2.8°C (5.04°F).*
- (iii) *Temperatures are not to exceed the criteria at a probability frequency of more than once every ten years on average.*
- (iv) *Spawning and incubation protection. Where the department determines the temperature criteria established for a water body would likely not result in protective spawning and incubation temperatures, the following criteria apply:*
- *Maximum 7-DADMax temperatures of 9°C (48.2°F) at the initiation of spawning and at fry emergence for char; and*
 - *Maximum 7-DADMax temperatures of 13°C (55.4°F) at the initiation of spawning for salmon and at fry emergence for salmon and trout.*

The two criteria above are protective of incubation as long as human actions do not significantly disrupt the normal patterns of fall cooling and spring warming that provide significantly colder temperatures over the majority of the incubation period. The department will maintain a list of waters where the single-summer maximum criterion is not sufficient to protect spawning and incubation.

- (v) *For lakes, human actions considered cumulatively may not increase the 7-DADMax temperature more than 0.3°C (0.54°F) above natural conditions.*
- (vi) *Temperature measurements should be taken to represent the dominant aquatic habitat of the monitoring site. This typically means samples should:*
- (A) *Be taken from well mixed portions of rivers and streams; and*
 - (B) *Not be taken from shallow stagnant backwater areas, within isolated thermal refuges, at the surface, or at the water's edge.*
- (vii) *The department will incorporate the following guidelines on preventing acute lethality and barriers to migration of salmonids into determinations of compliance with the narrative requirements for use protection established in this chapter (e.g., WAC 173-201A-310(1), 173-201A-400(4), and 173-201A-410 (1)(c)). The following site-level considerations do not, however, override the temperature criteria established for waters in subsection (1)(c) of this section or WAC 173-201A-602:*
- (A) *Moderately acclimated (16-20°C, or 60.8-68°F) adult and juvenile salmonids will generally be protected from acute lethality by discrete human actions maintaining the 7-DADMax temperature at or below 22°C (71.6°F) and the 1-day maximum (1-DMax) temperature at or below 23°C (73.4°F).*

-
- (B) *Lethality to developing fish embryos can be expected to occur at a 1-DMax temperature greater than 17.5°C (63.5°F).*
- (C) *To protect aquatic organisms, discharge plume temperatures must be maintained such that fish could not be entrained (based on plume time of travel) for more than two seconds at temperatures above 33°C (91.4°F) to avoid creating areas that will cause near instantaneous lethality.*
- (D) *Barriers to adult salmonid migration are assumed to exist any time the 1-DMax temperature is greater than 22°C (71.6°F) and the adjacent downstream water temperatures are 3°C (5.4°F) or more cooler.*
- (viii) *Nothing in this chapter shall be interpreted to prohibit the establishment of effluent limitations for the control of the thermal component of any discharge in accordance with 33 U.S.C. 1326 (commonly known as section 316 of the Clean Water Act)."*

3 METHODS

3.1 Data Collection

A survey of the geomorphic and riparian conditions of the creek was completed. The survey included documentation and mapping of existing vegetation, collection of shade information using a densiometer, and documentation of locations where soil and moisture conditions may allow for the development of denser riparian vegetation over time. Areas where current riparian vegetation is impacted by land were also documented and the potential for development of denser vegetation was estimated. Specific details of data collection are provided below.

Temperature Data: Eleven Onset brand continuous water temperature recording devices were deployed in Swale Creek. One was lost. The locations of the sites of the remaining 10 are depicted in Figure 5. Each water temperature monitoring device was deployed in an area where water was deep and securely tethered to the stream bed. Continuous air temperature and humidity devices were also deployed at sites near Warwick and near the mouth of the creek. These instruments were deployed within a housing that allowed for ample flow of air around the instruments, but shaded them from direct sunlight. Instruments were deployed in late July and retrieved in late September to early October (Table 2). Data were downloaded following the instructions provided by the manufacturers.

Late Summer Stream Flow Information: Stream flow data in Swale Creek are sparse and limited to "spot" measurements. Such spot measurements were completed in April by Aspect Consulting (2003a). Late summer estimates of stream flow and groundwater inputs are also needed for the modeling effort. Flows within Swale Creek were too low to measure with any conventional equipment, hence flow was estimated visually.

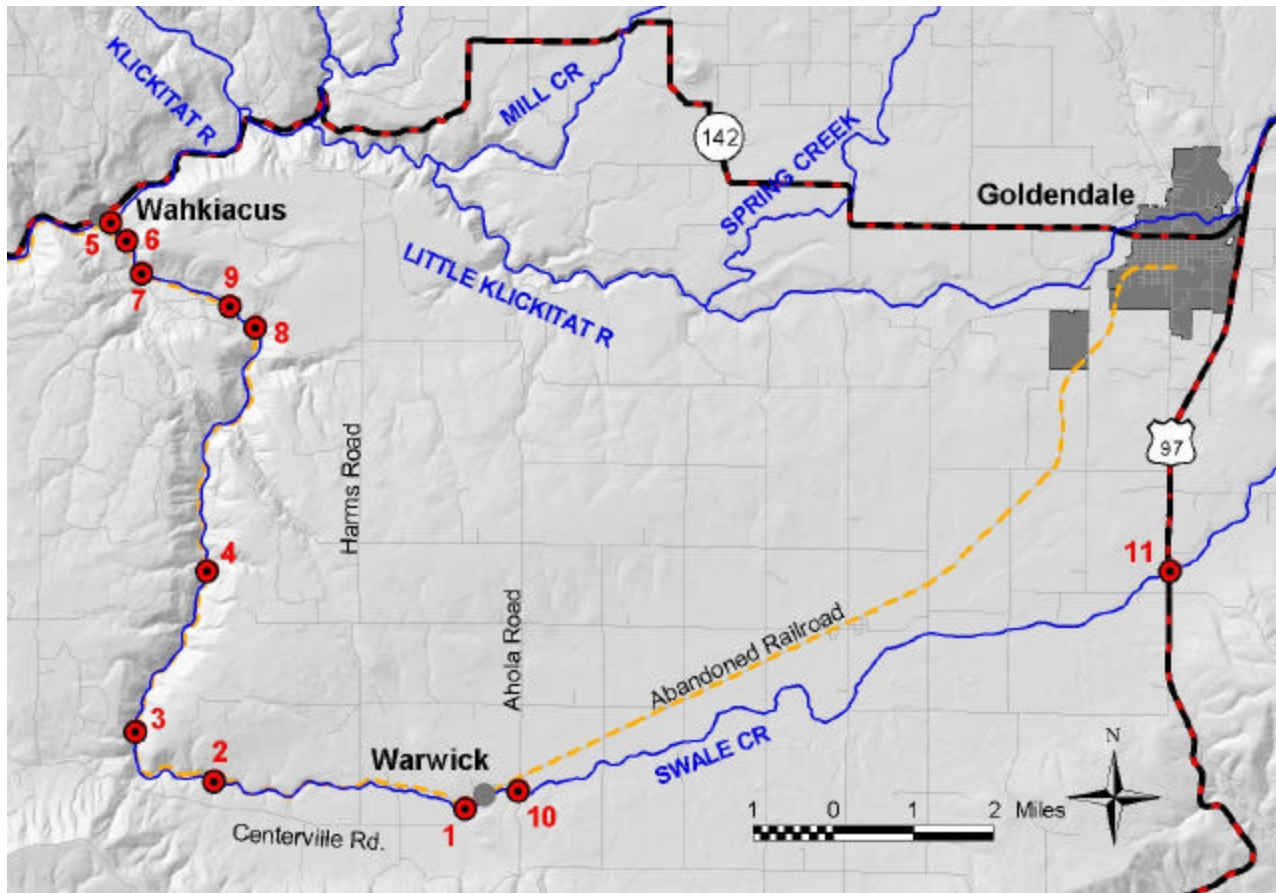


Figure 5. Temperature monitoring locations within the Swale Creek subbasin.

Table 2. Dates when temperature monitoring instruments were deployed and retrieved.

Sample Site	Date Deployed	Date Retrieved
1	7/23/03	9/27/03
2	7/23/03	9/27/03
3	7/23/03	9/30/03
4	7/23/03	10/4/03
5	7/24/03	9/30/03
6	7/24/03	Lost
7	7/24/03	10/3/03
8	7/29/03	9/30/03 ¹
9	7/29/03	9/29/03
10	7/28/03	9/27/03
11	7/28/03	9/27/03
Air Temperature and Humidity Recorders	7/24/03	9/29/03

1/ Instrument only worked until 8/2/03

Prior Years Water Temperature Data: The Central Klickitat Conservation District and the Yakama Nation have collected stream temperature data in Swale Creek over the last few years. This data was gathered and used to address inter-annual variability of temperature in the creek.

Current Vegetation: Current vegetation information was collected using a semi-quantitative relevé technique, which is a walk-through, ocular survey (Barbour 1987). Changes in vegetation species and patterns along the length of the creek were noted. In the canyon reaches, densiometer readings were taken to accurately estimate average shade conditions, and dominant plant species were tracked. Data on shade conditions were averaged using a class system and reported for inclusion in the hydrologic model.

3.2 Data Analysis

3.2.1 Temperature Data: All thermographs were downloaded into computer data files using the manufacturers' software. Daily minimum, average, maximum, and 7-day averages of the daily maximum temperatures were calculated in a Microsoft Excel spreadsheet. Data collected at times that the stream was apparently dry or near dry are included in some of the plots, but were removed from data summaries and analyses.

3.2.2 Potential vegetation: Aerial photographs were located from a variety of sources. The NRCS office in Goldendale provided the aerial photographs from 8-6-1954, 6-25-60, and both 5-22-69 and 6-1-1969. The Washington Department of Natural Resources office in Husum provided aerial photographs dated 6-9-79, and 7-19-91. Digital photos from 7-16-1996 can be found on the Internet at the Terraserver website (<http://www.terraserver.com/>). Availability of older images is limited. Aerial photograph interpretation of the 1954, 1960, 1969, 1979 and 1991 photographs was conducted using stereo-paired photographs and a stereoscope. Photographs were scanned at 600 dots per inch using a computer scanner, with information then overlaid using computer graphics software. The original photographs were used simultaneously for clarification and to adjust for the lower resolution of the scanned images. All available aerial photographs were taken decades following the construction of the railroad. The railroad construction and maintenance affected the condition of the channel; hence the available aerial photographs do not reflect a pre-development condition. They are, however, useful in evaluating the variability of the channel and riparian characteristics under current and recent historical conditions.

There are assumptions and limitations encountered while working with aerial photographs. Focal point, scale, time of day, and season affect the interpretation, as well as the resolution of photography conducted in 2000 versus 1979. These factors were taken into consideration while doing the analysis, and are explained in the text where necessary.

Inquiries were made at the local library and historic society. Two local landowners who have lived near Swale Creek for their whole lives were interviewed. Henry Garner was interviewed on 11/6/03, and Stanley Crocker was interviewed on 11/7/03. Dave Guenther, NRCS, was interviewed on 11/25/2003.

A projection of the potential vegetation conditions of Swale Creek is based on a combination of current and recent historic vegetation information, current climate patterns, soils, geology, and geomorphology. "Potential" vegetation and shade was estimated through a number of approaches. First, within the canyon reach, the mature state of riparian vegetation that is currently becoming re-

established was estimated. Second, areas that are not disturbed by land use and are apparently mature were assumed to reflect the “potential” condition. Lastly, estimates of potential vegetation in the absence of site-specific land use effects were developed based on the geographic location of the stream segments and on available soils and water. These sources of information were combined to develop likely scenarios for potential vegetation under current channel conditions. The cadastral survey notes and maps were used to infer riparian conditions present prior to the construction of the railroad. These maps and notes only provide a general description and could not be used to develop precise estimates of riparian density or shade prior to the railroad construction.

3.2.3 “Potential” Stream Temperature: The potential stream temperature was bounded by utilizing the information on existing conditions and estimates of potential vegetation. Estimates were generated using Oregon’s Heat Source model. The modeling effort incorporated stream flow data and stream and air temperature data collected within the basin, humidity data collected in the basin, the results of previous investigations on groundwater inputs into the canyon reach, and the results of previous studies on groundwater and geology as they affect stream flow in the Swale Creek subbasin.

The *Heat Source* model was developed at Oregon State University as a tool for analyzing stream temperature data (Boyd, 1996). The model is used to predict effects on stream temperatures resulting from changes in various stream parameters, and allows evaluation of variations due to different management scenarios. The *Heat Source* model has been described in detail by ODEQ (1999). The code is written in Visual Basic, with an Excel spreadsheet input/output interface. *Heat Source* uses the same fundamental physical and thermodynamic concepts as many other process-based models. The fundamental premise of the model is that the water temperature at any given time and location in the stream is the result of the physical heat transfer processes between the stream and its surrounding environment. As a reach-based model, *Heat Source* predicts water temperatures at a downstream location based on some known water temperatures at an upstream location.

The model itself requires four basic types of input:

- Stream characteristics - location, aspect, wetted width, flow, etc.
- Riparian characteristics - buffer height, width, density, overhang, etc.
- Atmospheric conditions - air temperature, humidity, wind speed
- Hourly water temperatures at the upstream end of the reach through the course of a day

Based on these inputs, the model predicts the hourly water temperatures at the downstream end of the reach, and displays the results in tabular and graphic formats.

The most sensitive input parameters (in terms of effect on output temperatures) are primarily (in approximate order of importance) air temperature, relative humidity, buffer height, stream depth, buffer density, and wind speed. Other input parameters, such as buffer width, stream width, stream flow, and stream aspect, also influence output temperatures, but their effect is relatively smaller.

The lowest 3.4 miles of stream was divided into 8 reaches for modeling, with reach breaks taken at significant changes in stream aspect. In addition, two other reaches located somewhat upstream

were modeled individually, because they were isolated reaches above the point where flow in the stream is continuous, and because they had temperature sensors located within them in the summer of 2003. The complete set of input parameters used for the *Heat Source* model is shown in Addendum B. The date of July 29, 2003 was used to calibrate the model, because that was the date that the warmest temperatures were recorded by air temperature monitors in the watershed in 2003. August 14, 2003 was chosen for model prediction validation, because that was the warmest day recorded in the watershed in August, 2003. Once the model was calibrated, the model was run using maximum potential shade estimates to evaluate potential stream temperature in the canyon reach of Swale Creek.

Average stream flows, wetted width, and depth were estimated from field measurements taken at various locations in September/October, 2003. Average flow velocity was then calculated from flow, width, and depth. Latitude, longitude, stream aspect, stream elevations, and topographic shade angles were estimated for each reach from topographic maps. Height and density of riparian vegetation along each reach was estimated from field observations.

Minimum and maximum air temperatures and relative humidity values were obtained from temperature monitors placed in the watershed during the summer of 2003. Groundwater temperature was initially assumed to be 12°C, but groundwater temperature was one of the parameters used for calibration of the model. (No lapse rate adjustments were made in air temperatures or groundwater temperatures, because the elevation change of the creek is only about 300 feet within the modeled section.)

3.2.4 Historic Conditions in Swale Creek. The General Land Office (GLO) cadastral survey maps and notes were reviewed to determine what information was available regarding stream flow and vegetation conditions in the Swale Creek basin. The surveys were completed in October 1860 for the portion of Swale Creek extending from the eastern edge of Township 3N, Range 16E (present day Miller Road) to the western edge of Township 3N, Range 15E (present day Uecker Road). Township 3N, Range 14E (present day Uecker Road to Schilling Road) was surveyed in September, 1861. The lower 5 miles of Swale Creek (Township 4N, Range 14E) were surveyed in April, 1872 and the upper headwaters of the drainage (Township 3N, Range 17E) were surveyed in April of 1868. The survey maps and notes provide a depiction of conditions during the dry season for the Swale Creek valley and most of the creek downstream of Warwick. The lower sections of the creek and the headwaters were surveyed at high flow and do not reflect summer flows.

The GLO surveys were conducted following section lines. Survey markers were placed at section corners. Markers included a wood stake where trees were available, rocks where trees were absent, or mounds of dirt where neither rocks nor trees were available. At each section corner, the distance and direction to nearby trees (witness trees) were documented when trees were present. The size of the witness tree was also recorded. Features such as trees, channels, streams, ponds, et cetera were noted along each transect. Hence, information regarding water bodies is provided at locations where the section lines intersect those water bodies.

The maps and notes generated during the surveys were reviewed to identify information regarding channel presence/absence, stream size, water depth, and locations of other features. Notes on vegetation, including specific information as well as notes on marker types used at section corners

and size of survey trees, were also reviewed. Water features and comments in the notes were transferred to a current day topographic map.

No climate data were available at the time the surveys were completed, however the National Climate Data Center has reconstructed drought indices from tree rings for the period from 1840 to 2003 (Garfin and Hughes, 1996 with data expanded to 2003; <ftp://ftp.ncdc.noaa.gov/pub/data/paleo/treering/reconstructions>). General climate patterns at the time the surveys were conducted were inferred from this data.

4 RESULTS

4.1 Stream Temperature

4.1.1 2003 Monitoring Data

Eleven continuous water temperature recorders were deployed in Swale Creek in the summer of 2003 (Figures 6 through 14). One of these was lost. The recorder at station 8 (near the bend in the creek where it turns to the west, roughly 4 stream miles from the mouth) quit working after 3 days of recording. Data from this site were disregarded. Stations 1, 2, and 10 were all dry when the temperature monitors were retrieved. These sites include the two near Warwick and a third roughly 1.8 stream miles downstream of Warwick. The patterns observed in the data suggest that Station 1 went dry on August 2nd, Station 2 went dry on September 12th, and Station 10 went dry on August 20th (Figures 6, 7, and 13). In mid-season, stream temperatures at Station 4 also suggest that the creek was dry at that location from August 15th through September 8th (Figure 9). The station was wetted when the monitoring device was retrieved; therefore, we cannot confirm that the station was dry at any time.

In general, water temperatures declined slowly from the time that the monitoring devices were deployed until they were retrieved. This suggests that the peak summer temperature may have been missed. Peak recorded temperatures ranged from 23.4 to 32.5 °C (Figures 6-14, Table 3). The state water quality standards for temperature are based on a 7-day average of the daily maximum temperatures. This 7-day average ranged from 22.9 to 30.7 °C (Figure 15, Table 3). These temperatures exceed all of the Department of Ecology's aquatic life temperature criteria for fresh water.

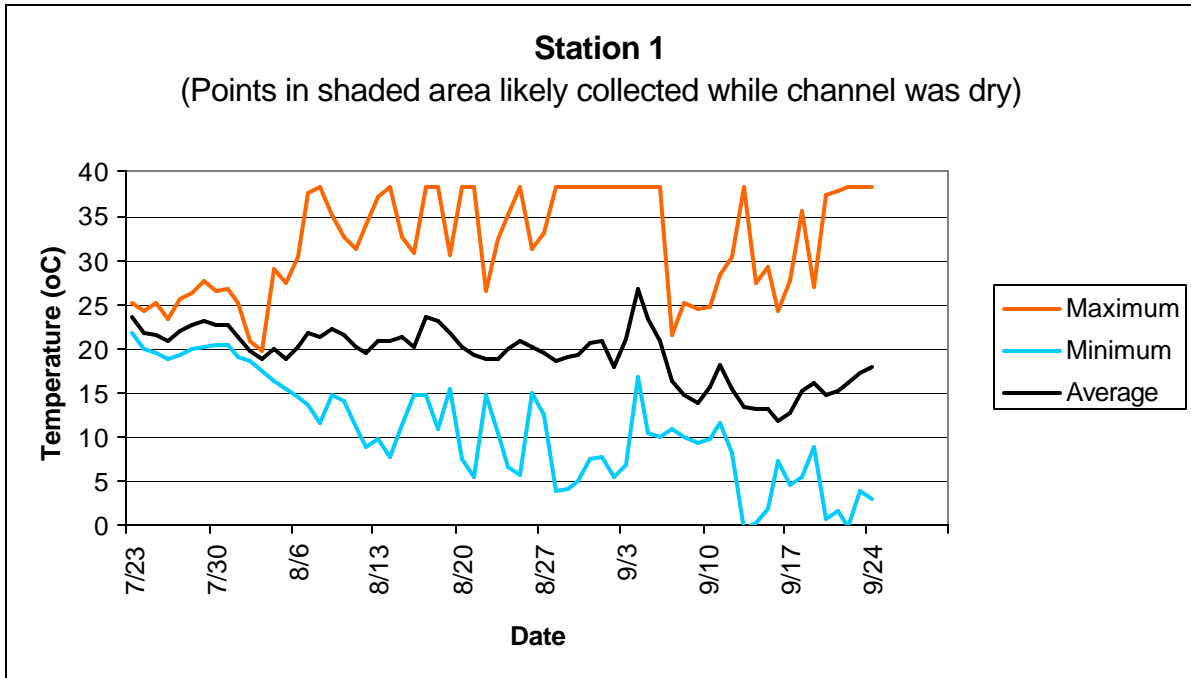


Figure 6. Water temperature recorded at Station 1 (just downstream of Warwick). Station was dry when the recording device was retrieved. Shaded area indicates period when site was likely dry.

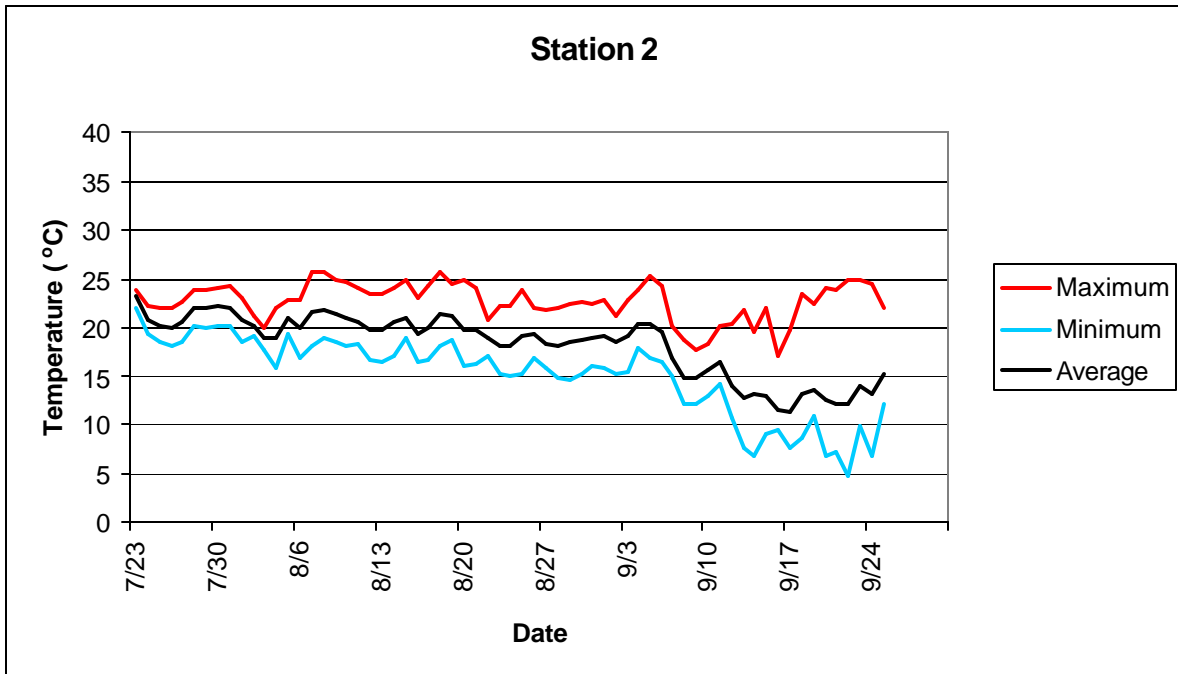


Figure 7. Water temperature recorded at Station 2 (approximately 1.8 miles downstream from Warwick). The site was dry when the device was retrieved. The shaded area on the plot indicates the likely period during which the site was dry.

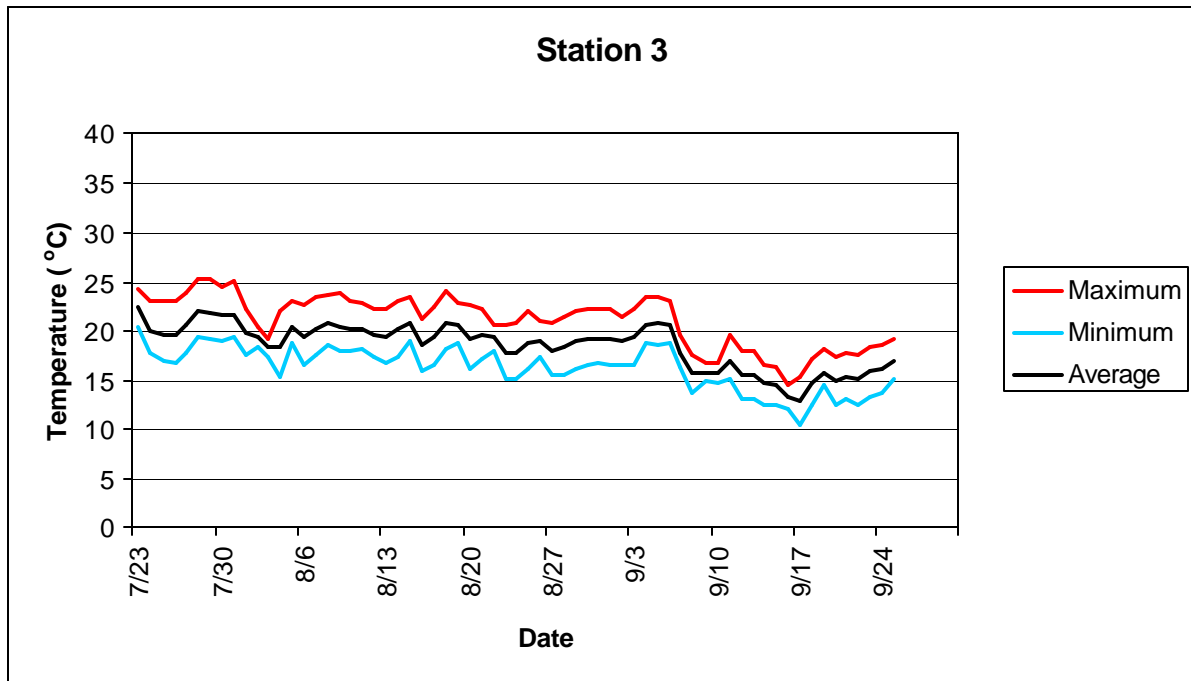


Figure 8. Water Temperature recorded at Station 3 (approximately ½ mile downstream of Stacker Canyon).

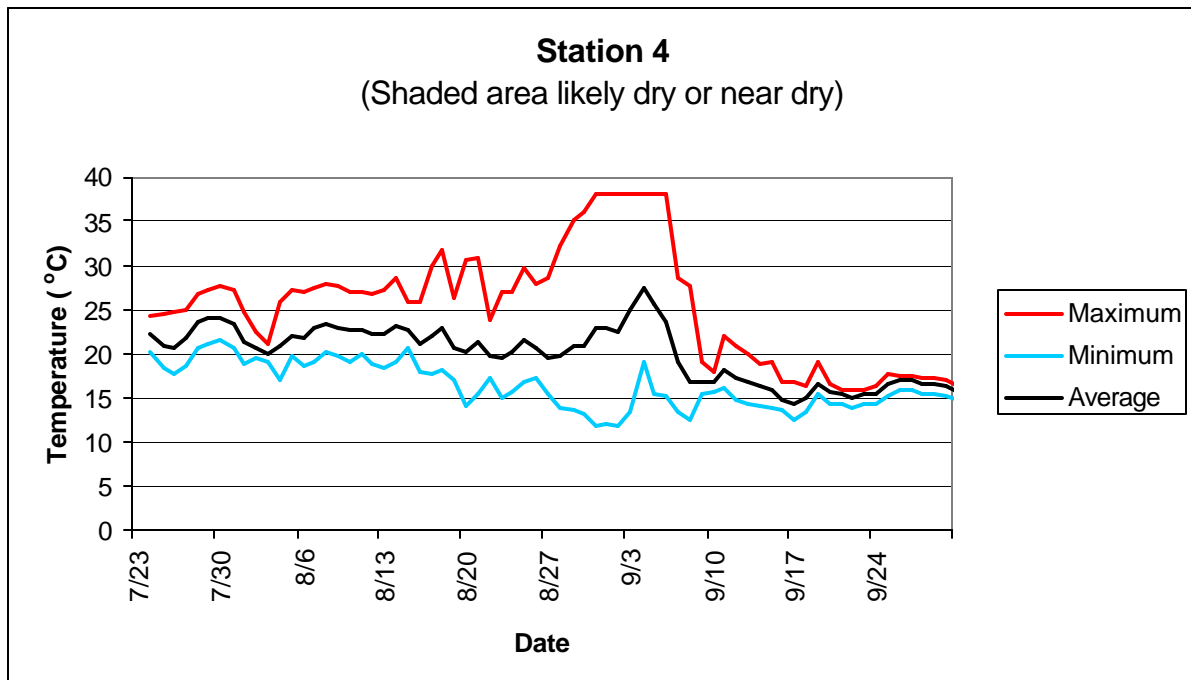


Figure 9. Water temperature recorded at Station 4 (approximately 3 miles downstream of Stack Canyon). Site was wetted when device was retrieved, however data suggest the site may have been dry for a period in late August (shaded area).

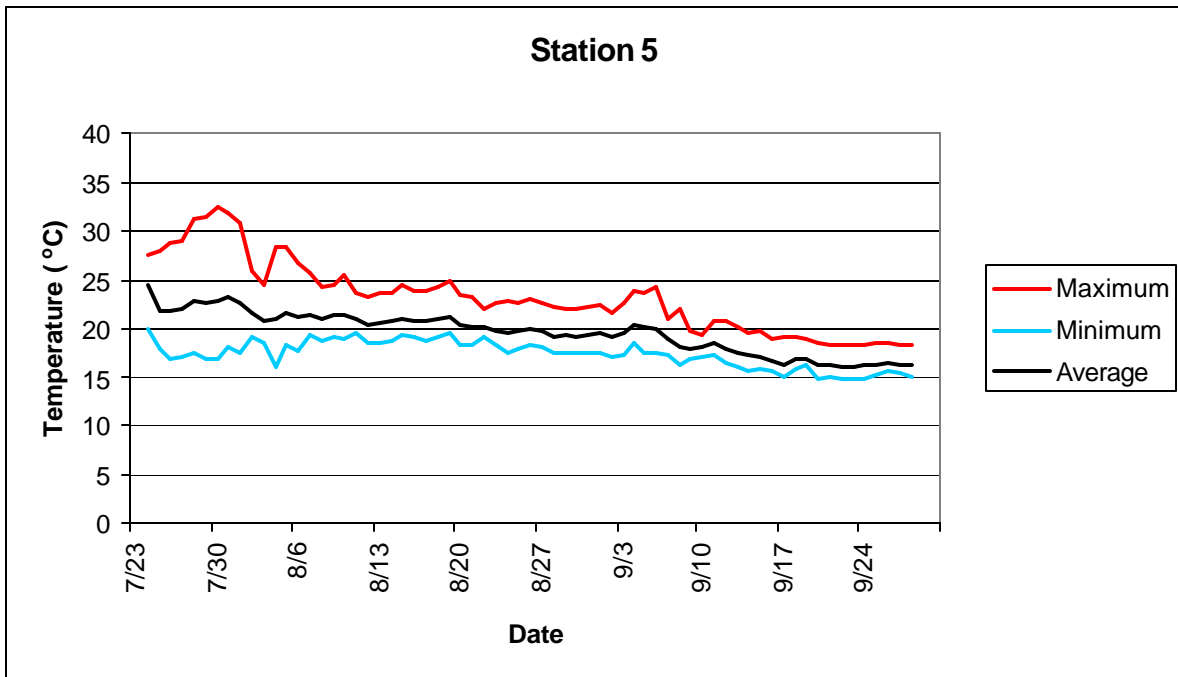


Figure 10. Water temperature recorded at Station 5 (near mouth of Swale Creek). The wide fluctuation in temperature during the first 2 weeks of deployment is unexplained.

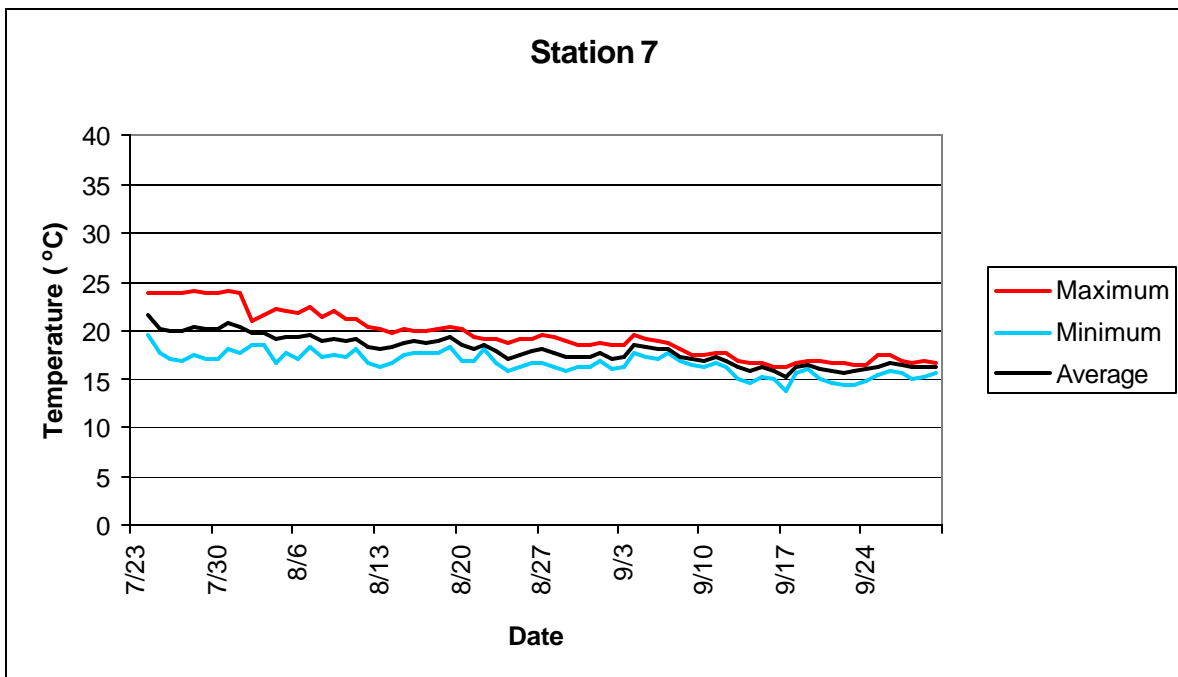


Figure 11. Water temperature recorded at Station 7 (roughly 1.5 stream miles upstream of mouth).

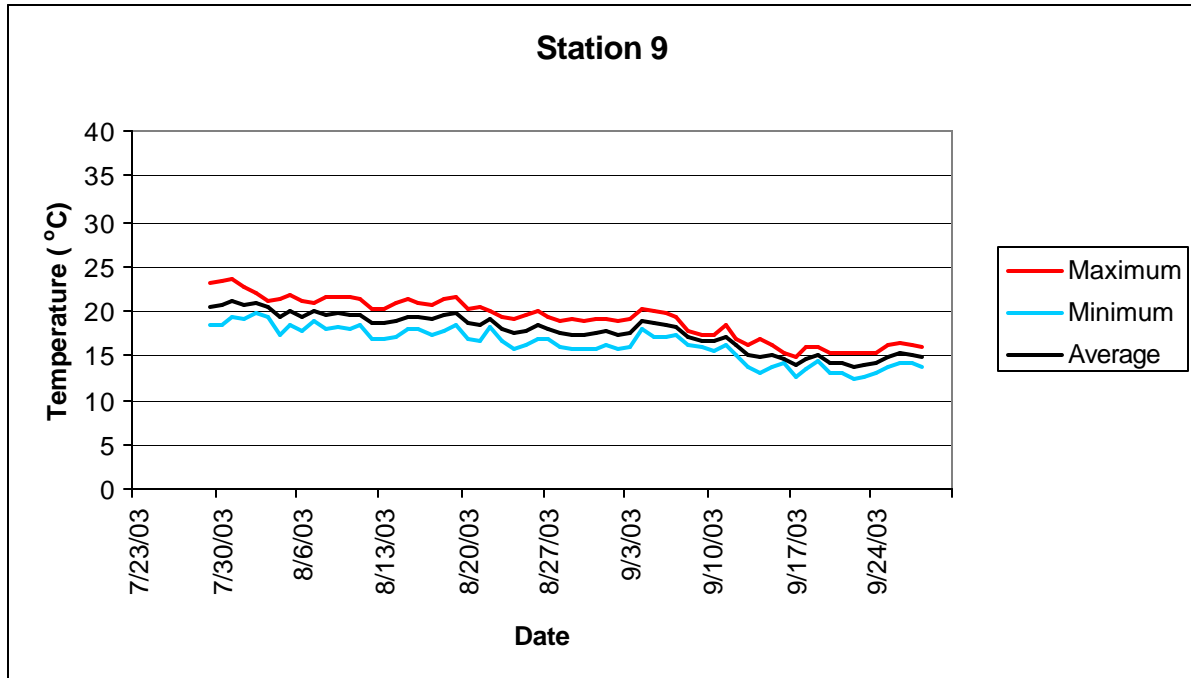


Figure 12. Water temperature recorded at Station 9 (approximately ½ mile downstream of bend in creek where creek turns west and runs toward the confluence with the Klickitat River).

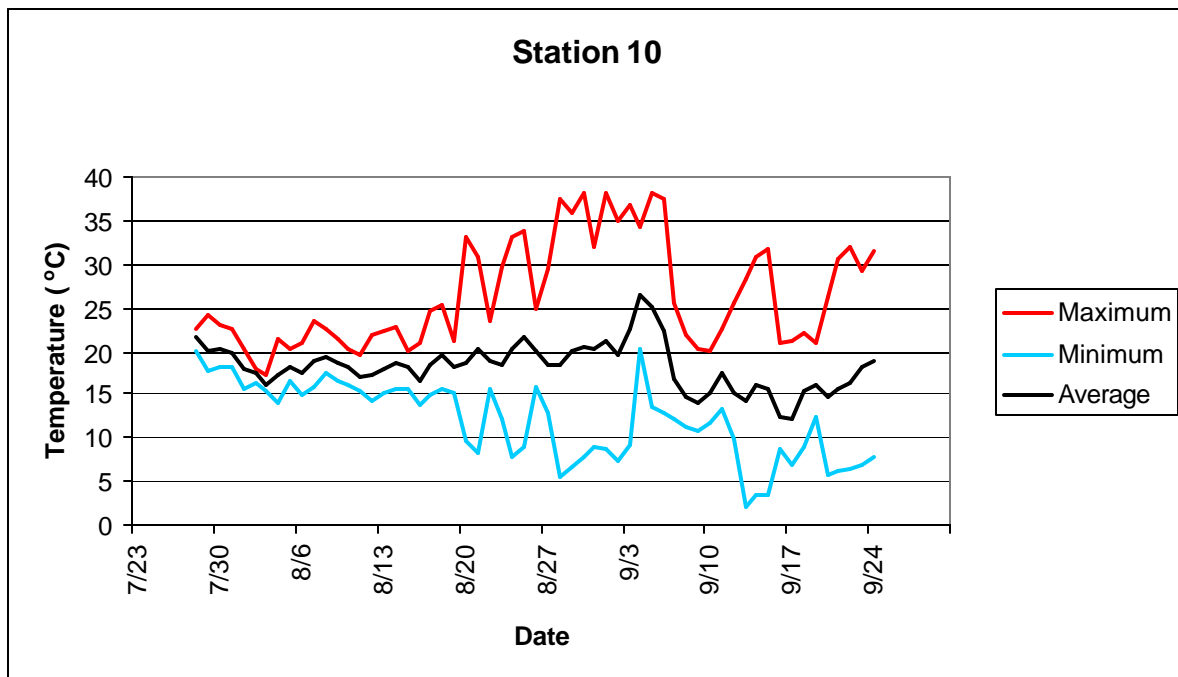


Figure 13. Water temperature recorded at Station 10 (just upstream of Warwick). Stream was dry when monitoring device was retrieved. Shaded area indicates duration of time during which the stream was likely dry.

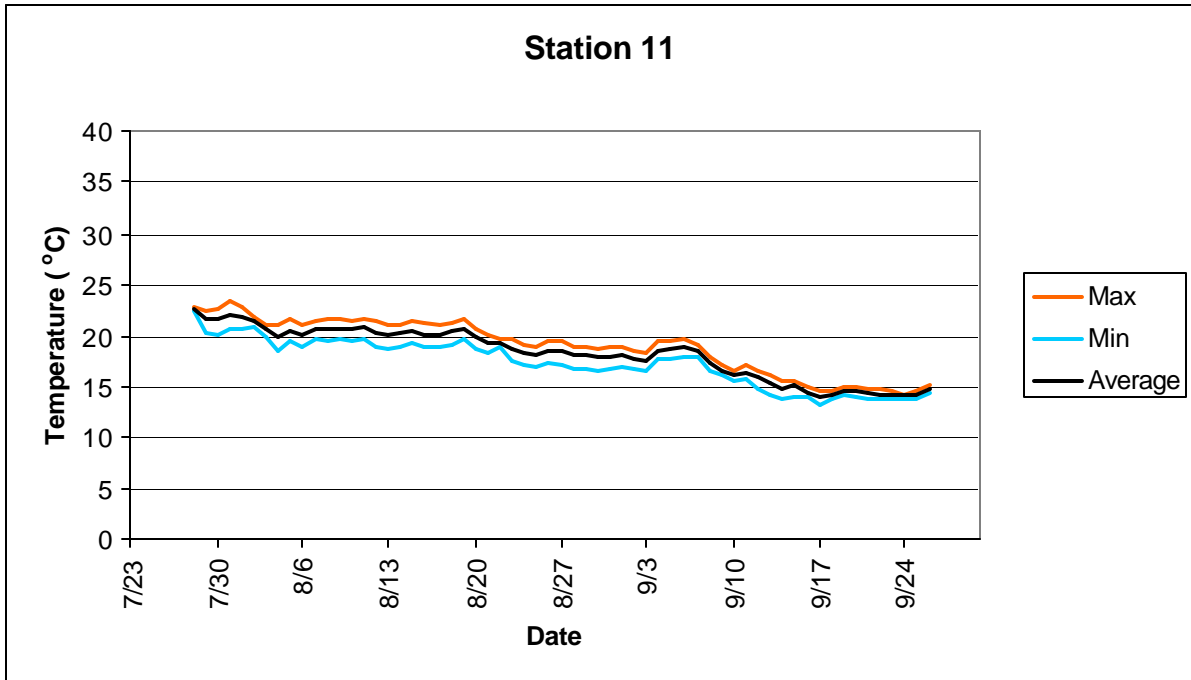


Figure 14. Water temperature recorded at Station 11 (just upstream of Highway 97 Bridge).

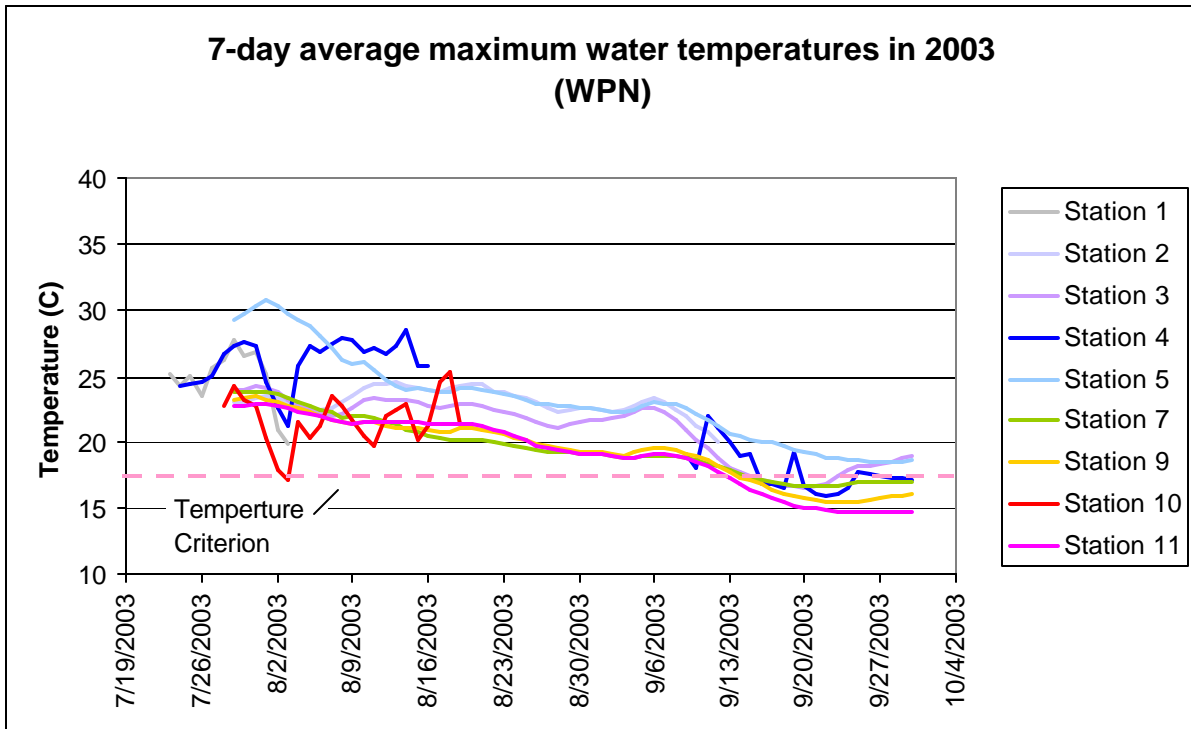


Figure 15. Seven day average maximum water temperature at locations on Swale Creek monitored by this project in 2003.

Table 3. Instantaneous maximum recorded stream temperatures and 7-day average of daily maximum temperatures (C) at the various Swale Creek monitoring stations.

Station Number	Maximum Recorded Stream Temperature (C)	Maximum of the 7-day average of daily maximum temperatures (C)	General Reach of Swale Creek
1	27.8	26.0	Warwick to Stacker Canyon
2	25.7	24.6	Warwick to Stacker Canyon
3	25.2	24.3	Stacker Canyon to RM 3.0
4	28.6	27.5	Stacker Canyon to RM 3.0
5	32.5	30.7	RM 3.0 to mouth
7	24.1	23.9	RM 3.0 to mouth
9	23.7	23.4	RM 3.0 to mouth
10	25.3	23.5	Warwick to Stacker Canyon
11	23.4	22.9	Highway 97

4.1.2 Central Klickitat Conservation District and Yakama Nation Water Temperature Data

The Central Klickitat Conservation District (CKCD) has collected water temperature data at three sites in the Swale Creek basin between 1995 and 2003. CKCD's Site 1 is located at Highway 97. Site 2 is at Harms Road and Site 3 is just downstream of the Horseshoe Bend Bridge near Wahkiacus. Data were collected at Site 1 in 1995 only. Data were collected at site 2 for 7 years between 1995 and 2003 (Table 4). Eight years of data are available for Site 3; however one of these years is missing data for mid-summer. The 1995 data collected at Site 3 do not display the normal diel (day to night) variability or the typical within season trends (warmer in mid-summer than in spring and fall). We suspect that the instrument used to collect the 1995 data was not functioning correctly. Hence, data collected by this instrument were not used in any analyses.

Some of the CKCD water temperature data sets included short periods of time when the diel variability in temperature was unusually broad and appeared to be more typical of the variability seen in air temperature than in water temperature. It is possible that the recording instruments were out of water or in very shallow water during these periods. This cannot be confirmed. The unusual data points were plotted but were not retained for data analysis. Plots of minimum, average, and maximum temperature recorded at each site during each year are provided in Addendum A. The unusual data points are shaded gray on these plots.

The Yakama Nation also collected data at two sites for a period of 8 years (Table 4). These sites included a location near Harms Road and a location near the mouth of the creek. The Yakama Nation conducted a rigid quality assurance process on their temperature data. In this process, data points collected when the device was suspected to be out of water were removed. Plots of minimum, average, and maximum temperature recorded at each site during each year are provided in Addendum A.

Table 4. Years and sites represented in the Central Klickitat Conservation District and Yakama Nation temperature data sets.

Year	CKCD			YAKAMA NATION	
	Site 1 Hwy 97	Site 2 Harms Road	Site 3 Horseshoe Bend Bridge	Harms Road	Mouth
1995	X	X	Malfunction?		
1997		X	X	X	X
1998		X	X	X	X
1999		X	X	X	X
2000		X	X	X	X
2001		X	X	X	X
2002			Partial	X	X
2003		X	X	X	X
2004				Through June	Through early May

It should be noted that the three sets of data collected at Harms Road, near the mouth of Swale Creek and at Highway 97 (2 sets) were not all collected at precisely the same point. Hence, there are differences in the datasets for similar locations (e.g. Figure 16). These differences likely reflect differences in site characteristics such as water depth, wind speed, and shade. The CKCD site and the plot for this study plotted in Figure 16 were roughly 0.75 miles apart. The Yakama Nation site was further downstream than the other two sites.

Temperature peaks in late July or early August in all years at CKCD Sites 2 and 3 and at both of the sites monitored by the Yakama Nation (Figures 17 through 20). Mid-summer 7-day averages of the daily maximum temperatures typically range from 19 to 26 °C near Harms Road and range from 21 to 30 °C near the mouth of the creek. Generally, the inter-annual variability at each site was smaller than the within year variability in temperature (Figures 17 through 20). The year 2003 was very similar to the average of all years of data collected by CKCD near Harms Road and was slightly cooler than 1995 to 2003 average of the CKCD near the mouth of the creek (Figures 21 and 22).

On average, the state temperature criterion of 17.5 °C is exceeded from early to mid May through the end of September near Harms Road and from mid-May through late September or early October at the Horseshoe Bend Bridge (Figures 17 through 20). In all years, the criterion was exceeded for at least 2.5 months near Harms Road and 4 to 5 months near the mouth of the creek.

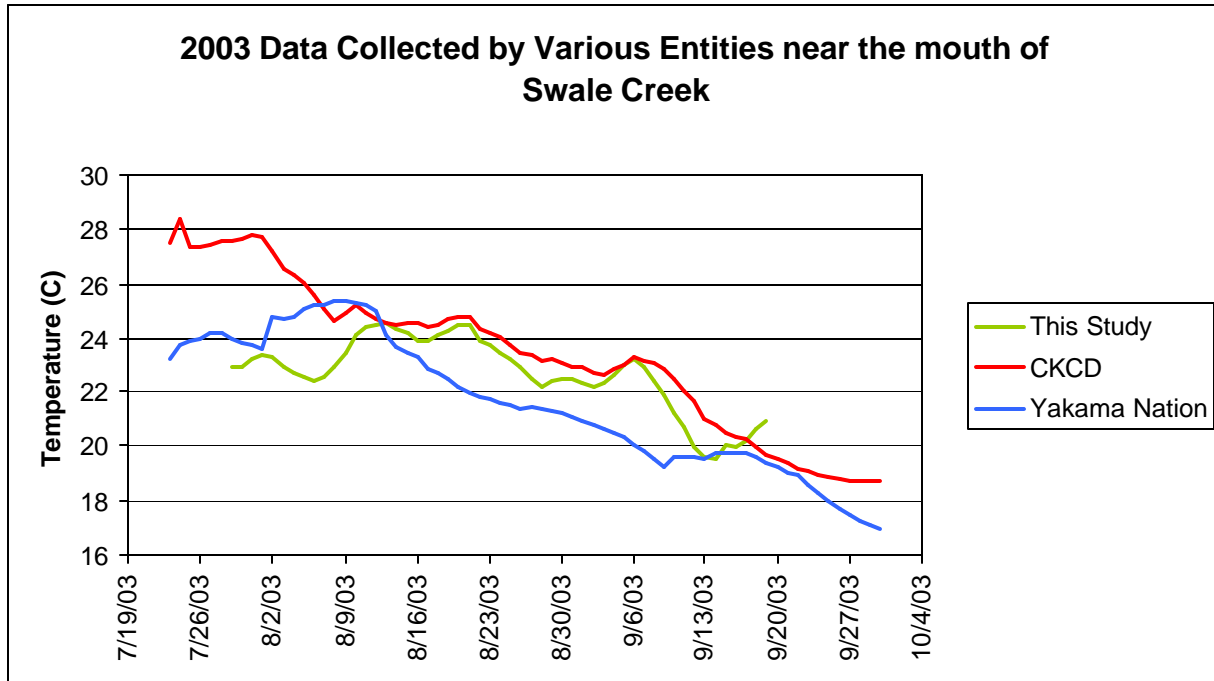


Figure 16. Comparison of data collected in 2003 near the mouth of Swale Creek by this study, the Yakama Nation, and CKCD.

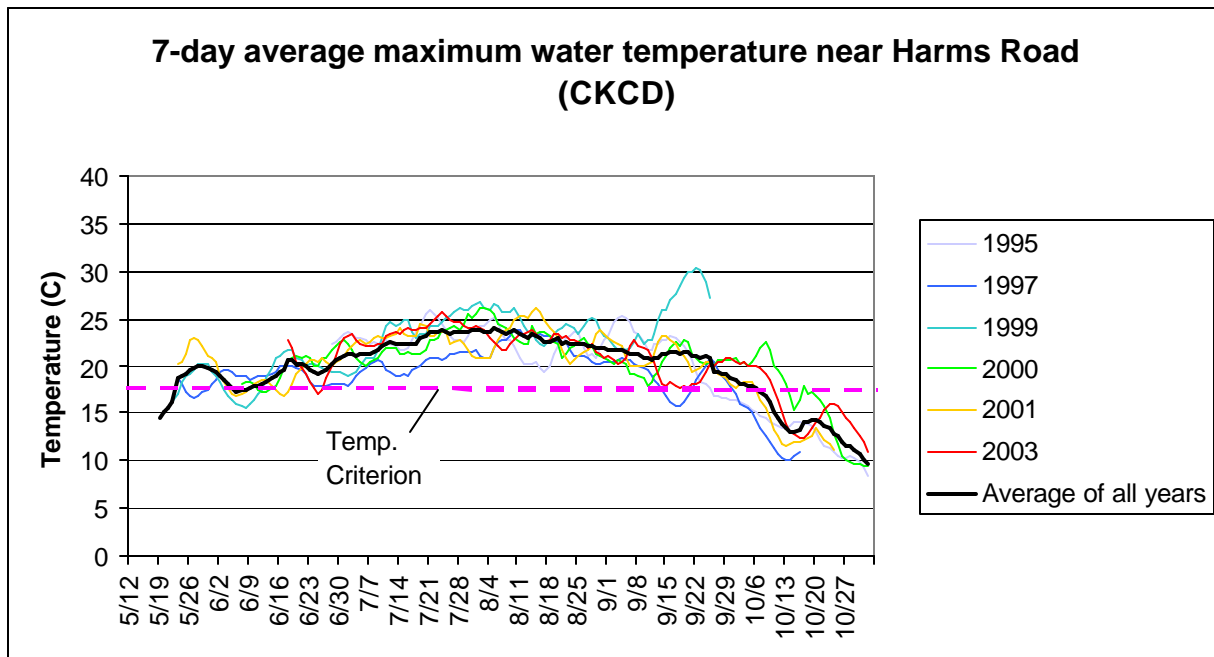


Figure 17. Six years of 7-day averages of the daily maximum temperatures recorded by CKCD at Site 2 (Harms Road).

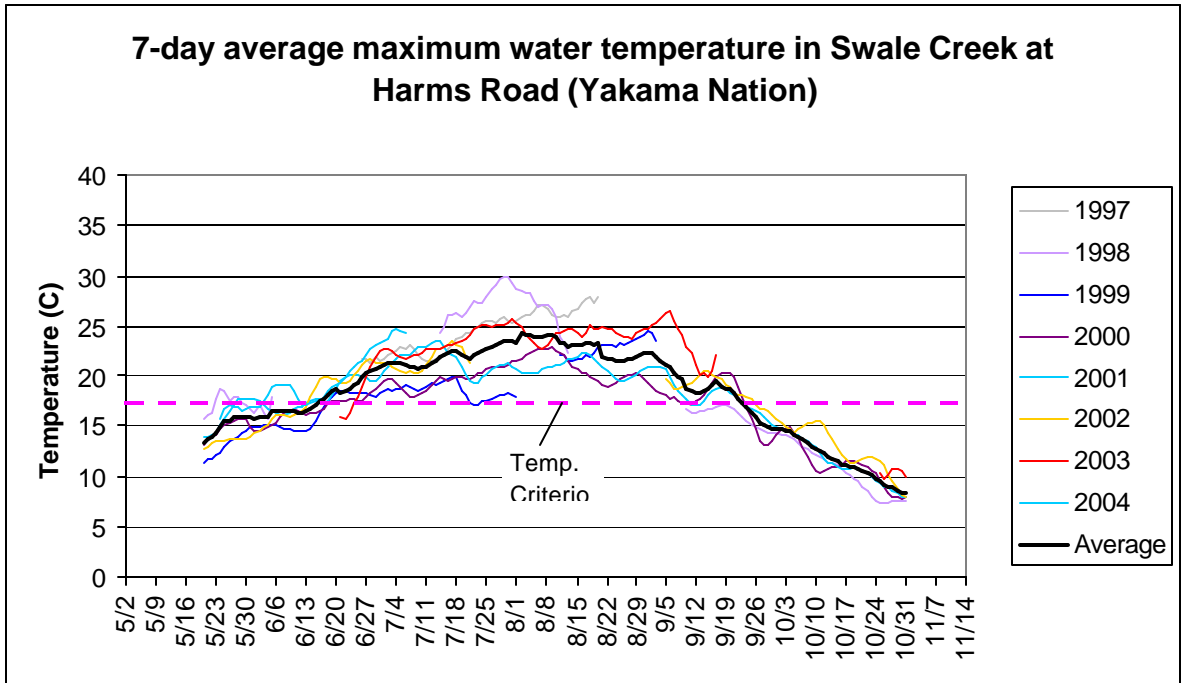


Figure 18. Eight years of 7-day averages of the daily maximum temperatures recorded by the Yakama Nation at Harms Road

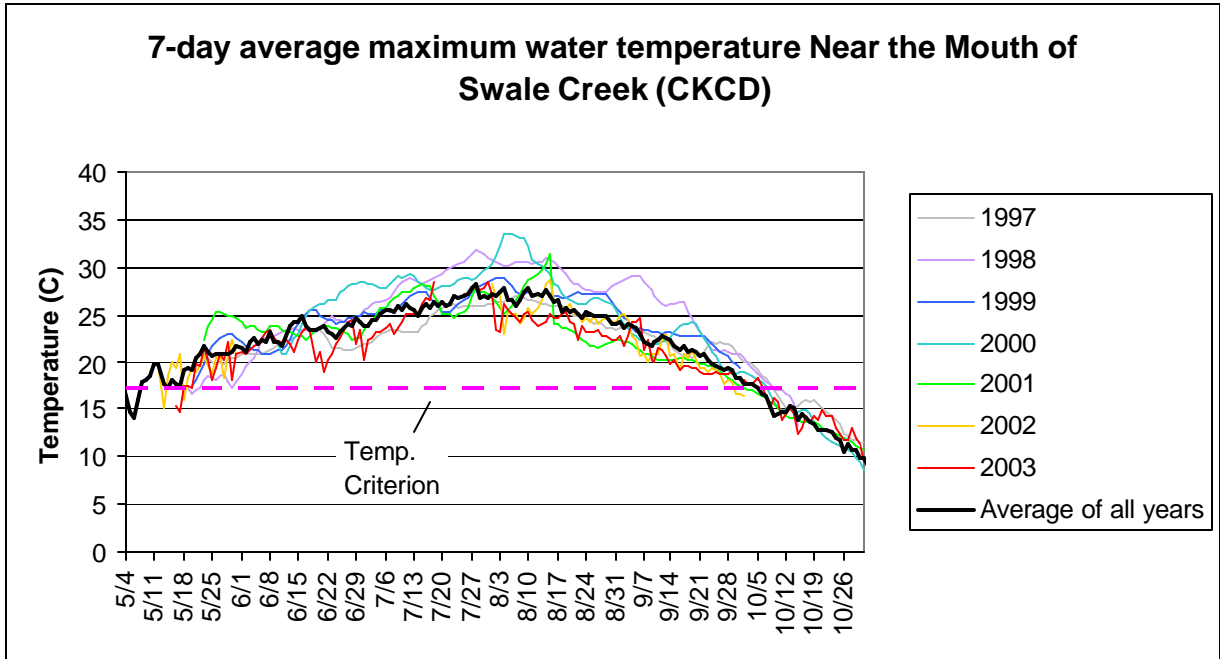


Figure 19. Seven years of 7-day averages of the daily maximum temperatures recorded by CKCD at Site 3.

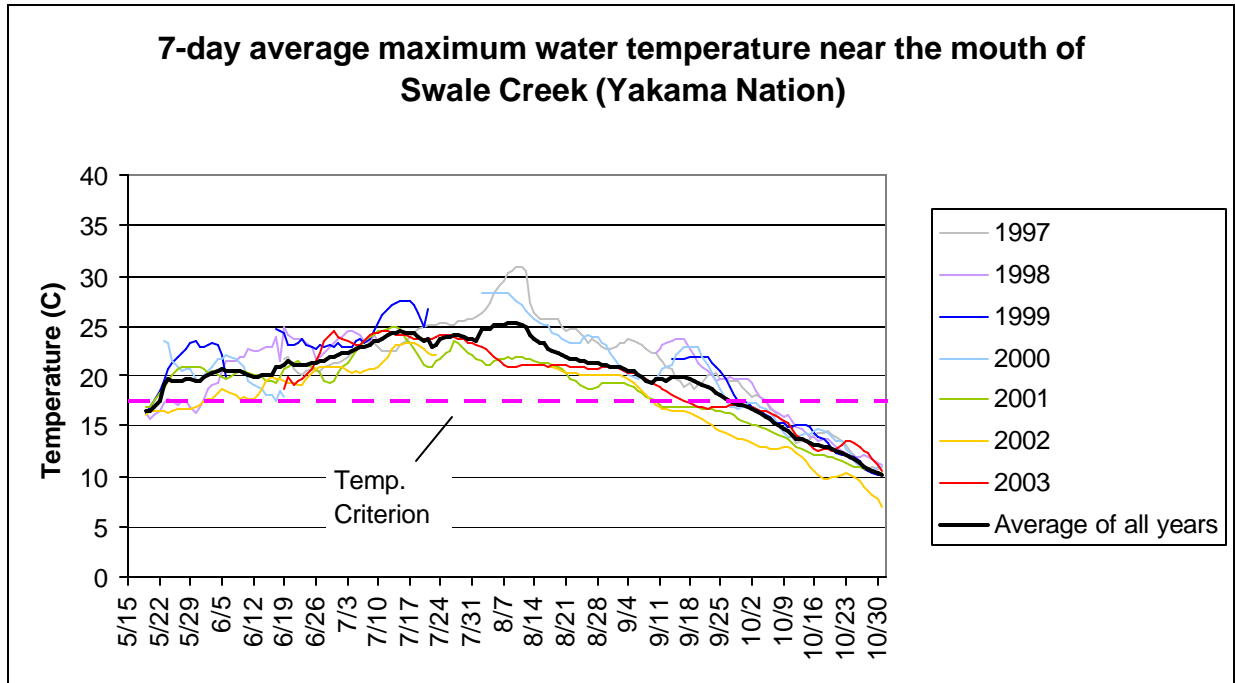


Figure 20. Seven years of 7-day averages of the daily maximum temperatures recorded by the Yakama Nation at the mouth of Swale Creek.

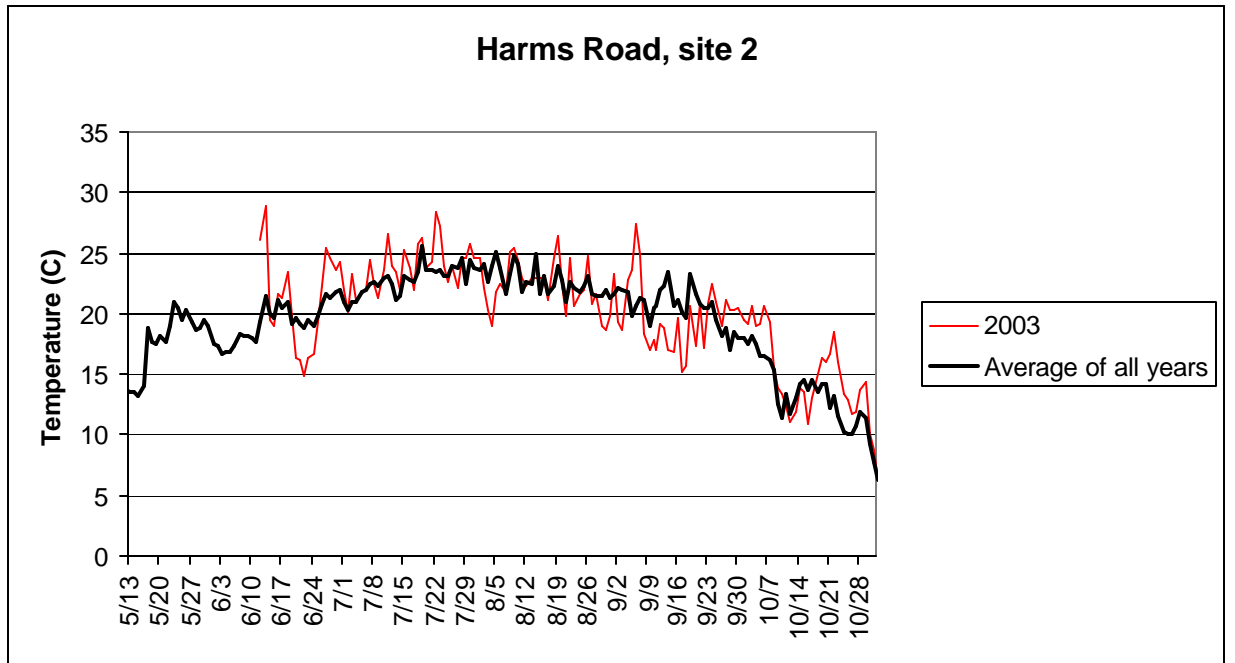


Figure 21. Comparison of 2003 daily maximum water temperature with the average daily maximum temperature from 1995 through 2003 at CKCD's Site 2 (Harms Road).

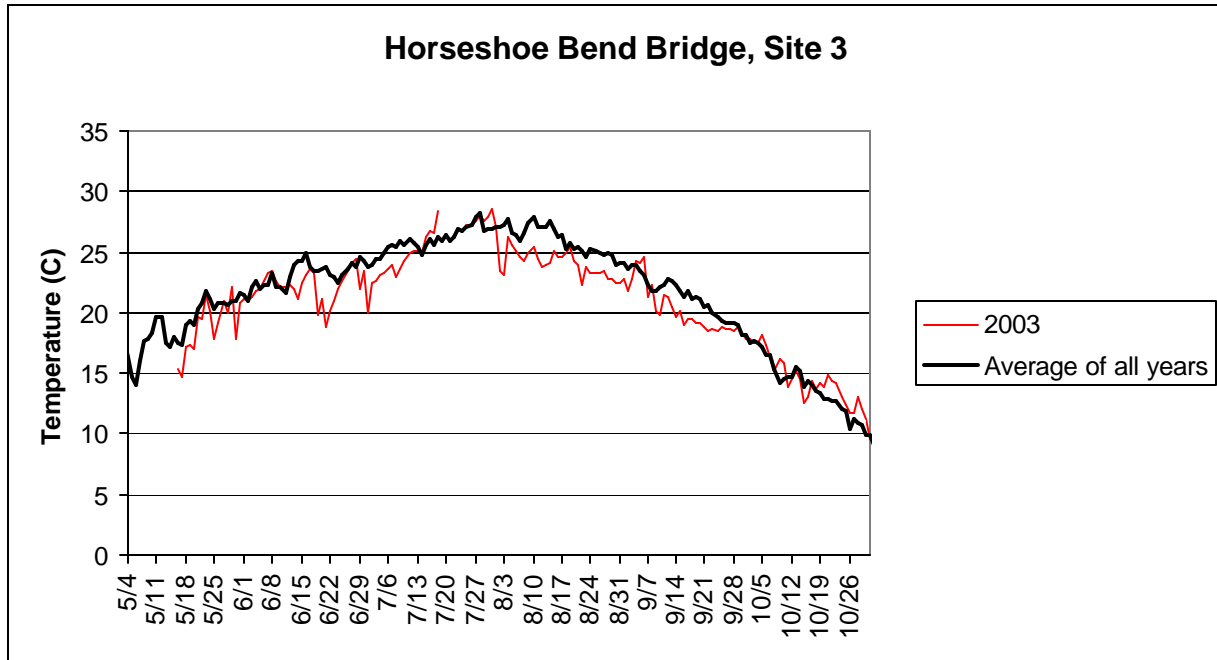


Figure 22. Comparison of 2003 daily maximum water temperature with the average daily maximum temperature from 1995 through 2003 at CKCD's Site 3 (Horseshoe Bend Bridge).

4.2 Stream Flow

In September, Swale Creek was dry or stagnant upstream (east) of Harms Road, at river mile (RM) 12.2. Downstream of Harms Road, flows in Swale Canyon were not measured because flows were small; instead Swale Canyon flows were estimated visually. Flow in Swale Canyon began at the confluence with Stacker Canyon (approximately at the bend to the North at RM 9.2) which provided approximately 0.25-0.5 cfs to Swale Creek. Downstream of this point, Swale Creek would interchange back and forth from flowing, to pooled, to dry (on the surface) multiple times. The lower 3.0 miles of the stream were continually wetted. Surface flow was typically observed in bedrock constrained reaches of Swale Creek but was not present in alluvial reaches. As a rough estimate, 40 percent of Swale Creek downstream of Harms Road had flowing water, 20 percent had pooled water, and the remainder was dry. The springs observed emanating from the east wall of the Canyon did not contribute much flow to the creek in fall which was consistent with observations in April. Discharge at the downstream end of Swale Canyon was approximately equal to the input from Stacker Canyon, further indicating limited input from groundwater discharge.

4.3 Air Temperature and Humidity

Air temperature and humidity was monitored at Stations 3 and 4. A third monitoring device malfunctioned and no data were retrieved. Air temperatures decreased gradually throughout the summer (Figures 23 and 24) and ranged between roughly 5 and 40 °C. No seasonal pattern was apparent in the humidity data (Figures 25 and 26). Humidity varied from close to 0 to 90%.

Both air temperature and humidity vary considerably over the day. Air temperature and humidity tend to be inversely correlated. Humidity increases at night as air temperatures decrease and then decreases in day as the air warms (Figures 27 and 28).

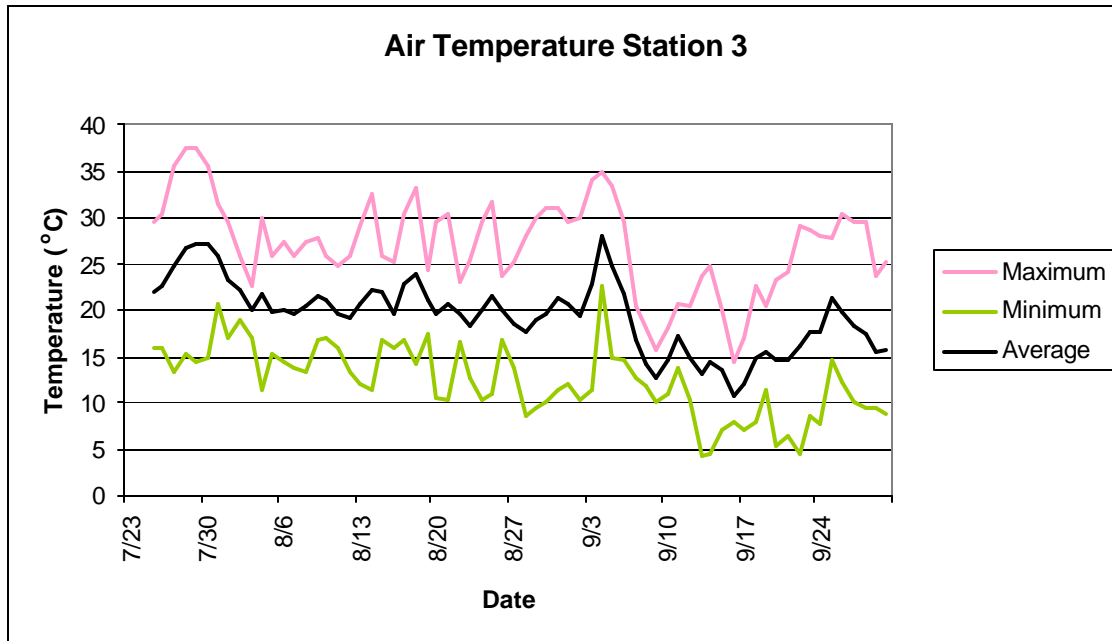


Figure 23. Air temperature recorded in 2003 at water temperature monitoring station 3.

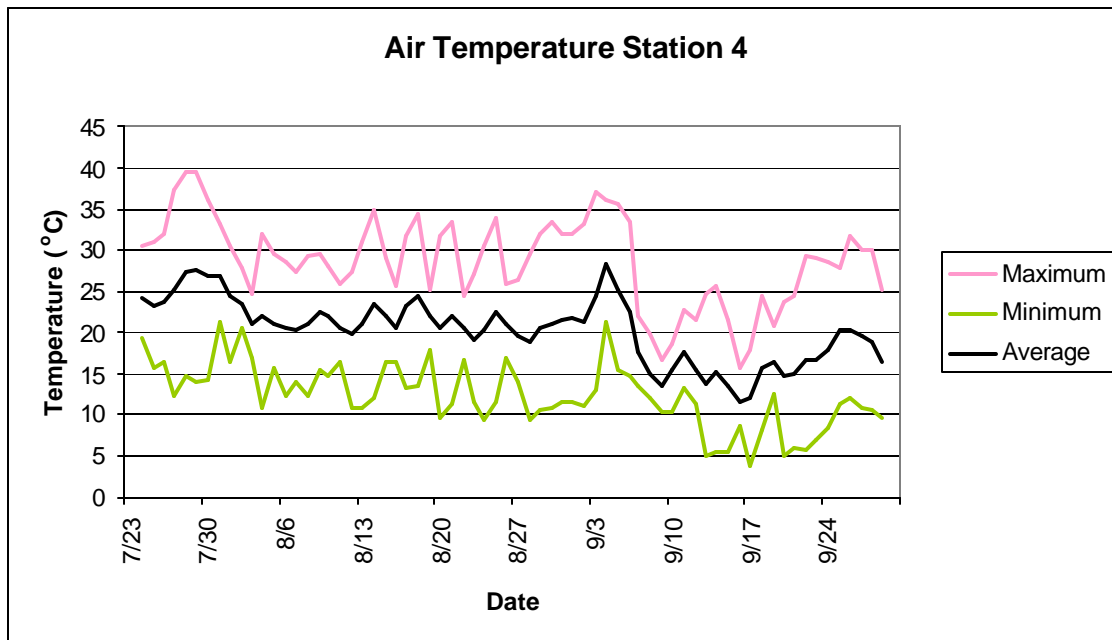


Figure 24. Air temperature recorded in 2003 at water temperature monitoring station 4.

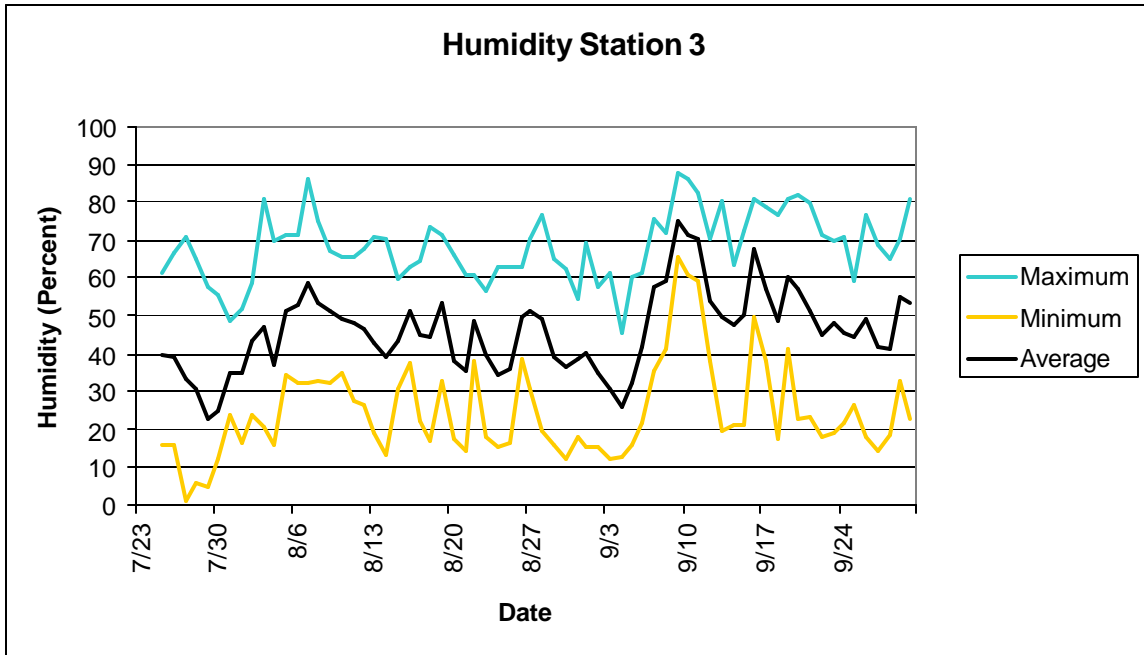


Figure 25. Humidity recorded in 2003 at water temperature monitoring station 3.

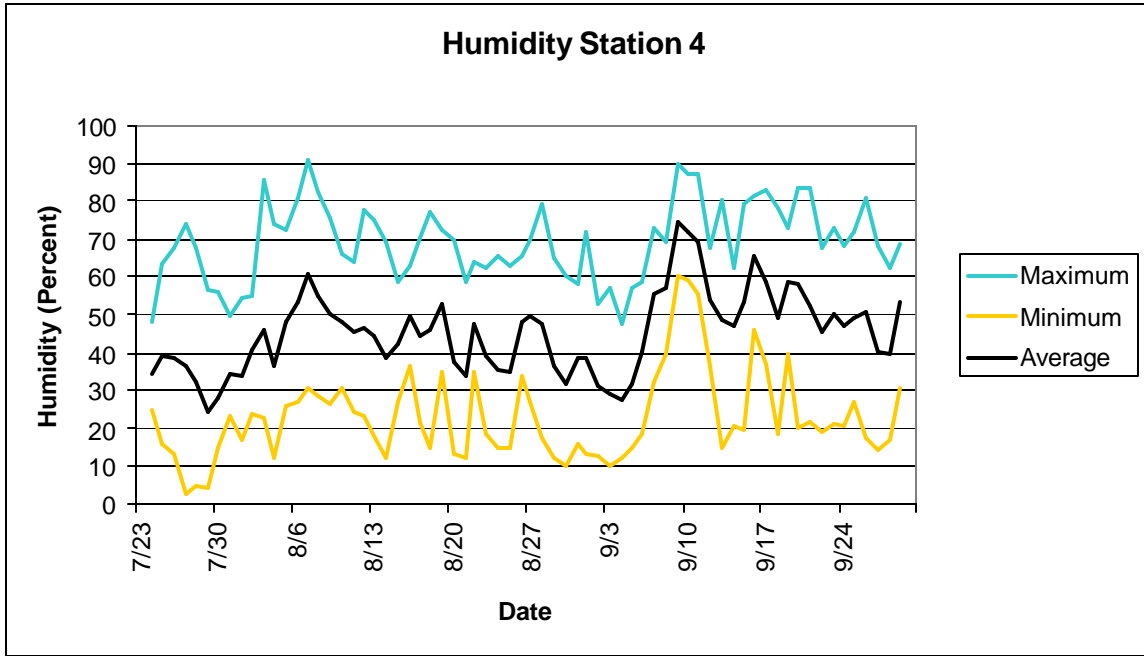


Figure 26. Humidity recorded in 2003 at water temperature monitoring station 4.

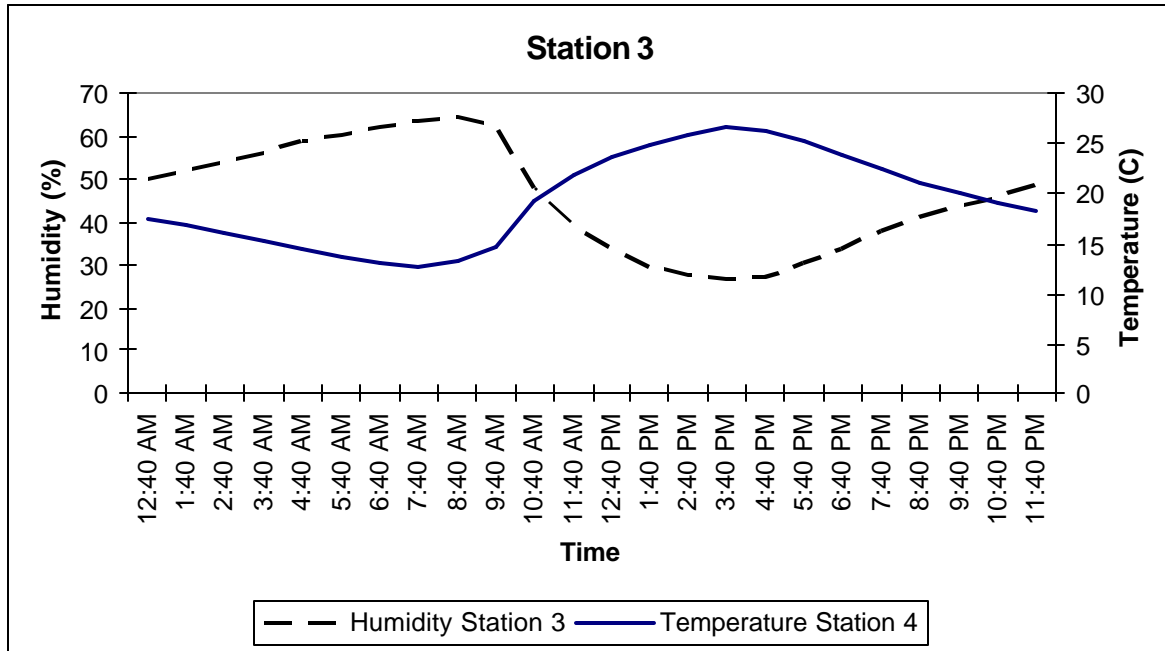


Figure 27. Average diel (day to night) air temperature and humidity patterns at Station 3.

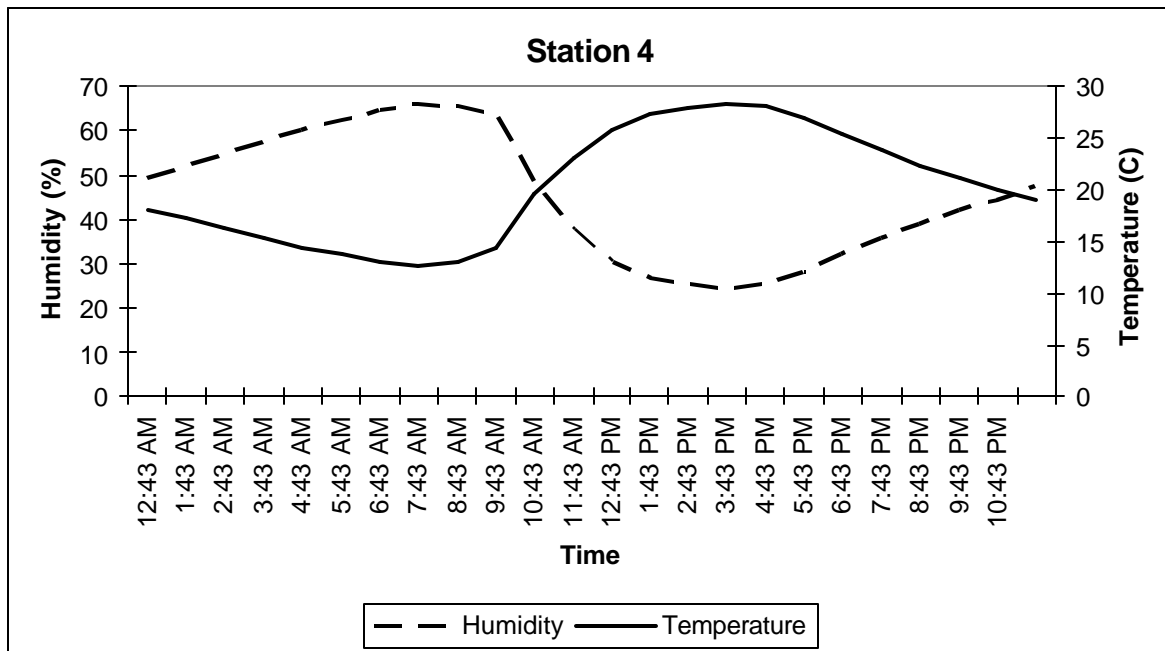


Figure 28. Average diel (day to night) air temperature and humidity patterns at Station 4.

The data presented here were collected on the bank adjacent to the stream and roughly 4 feet above the water surface. Nearer the interface between the water and the air, the influence of water tends to decrease air temperature and increase humidity (Reif 1965). Therefore, these data are useful in guiding the selection of temperature and humidity values used to estimate heating and cooling processes at the water surface, but they do not precisely represent the situation occurring at the air/water interface.

4.4. Historic Flow and Vegetation

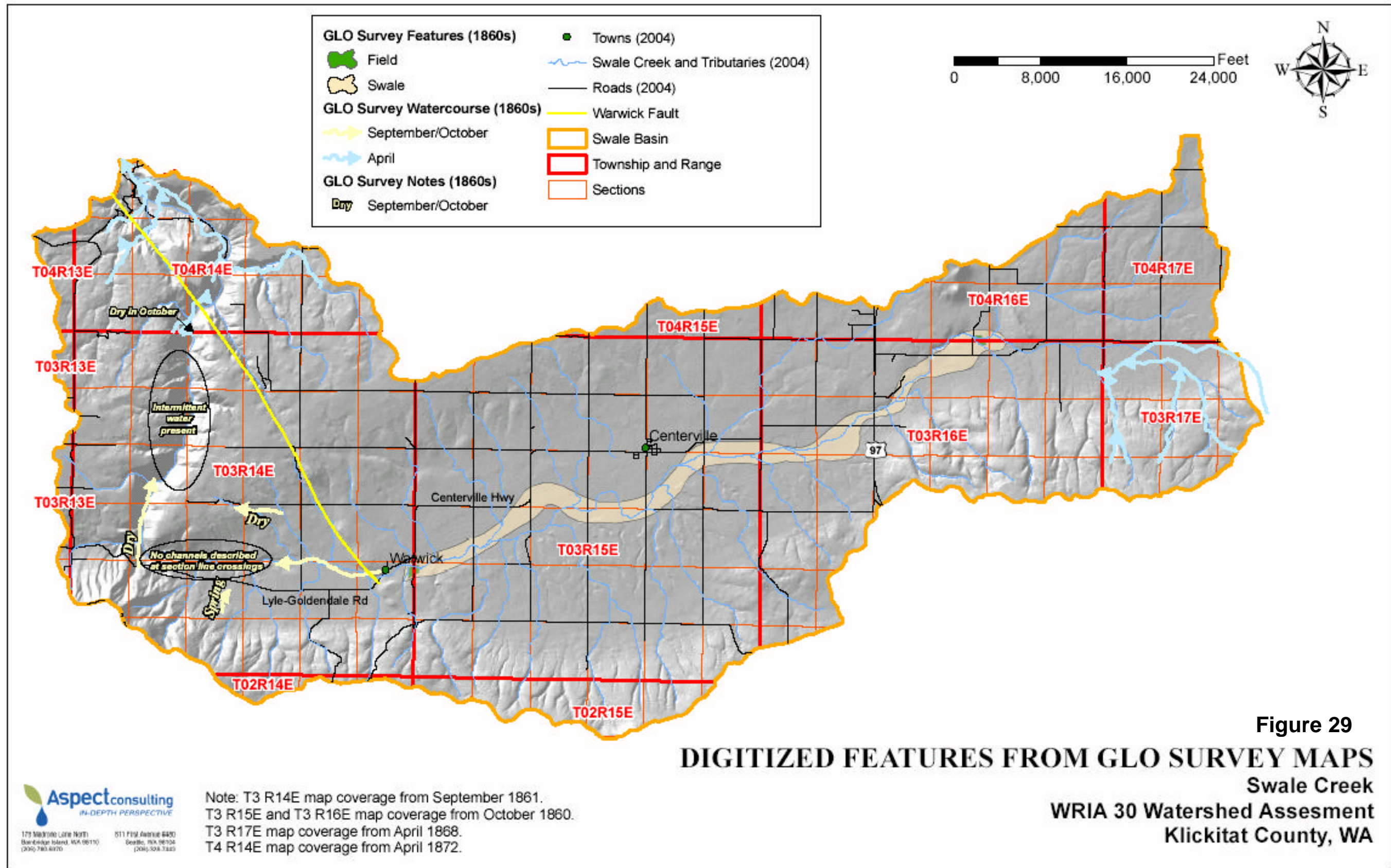
The National Climate Data Center reconstructed drought indices (Garfin and Hughes, 1996) suggests that 1860, 1861, and 1868 were relatively wet years and 1872 was just a little drier than average (Table 5). Therefore, it appears the survey notes and maps represent the situation in relatively wet years for all portions of the basin except the lower 5 miles (which were surveyed in April).

Table 5. Drought index (Garfin and Hughes, 1996) and percent of the 164 year period for which the drought index was constructed that was drier for each of the years that the cadastral surveys were completed in the Swale Creek basin.

Year	Drought Index Value	% of Years that Were Drier	Area Surveyed	Month Surveyed
1860	2.117	81%	Miller Rd to Uecker Rd	October
1861	3.46	91%	Uecker Rd to Shilling Rd	September
1868	2.069	80%	Upstream of Miller Rd	April
1872	-0.406	47%	Lower 5 miles of Swale Cr	April

The information gathered in the cadastral surveys conducted between 1860 and 1872 in the basin was reviewed for information pertinent to this project. The notes and the maps generated by the surveys provide information on the location of channels, where water was flowing at the time of the surveys, water depth, locations of roads at the time of the surveys, vegetation patterns, locations of fields and buildings, and locations of steep slopes. Other information in the notes can help to identify the presence or absence of trees near survey markers and the size and density of trees present. The detail of the notes vary from surveyor to surveyor somewhat.

T3N, R17E: The headwaters of Swale Creek (T3N, R17E) were surveyed in April of 1868 (surveyed by Edwin Richardson, April 22-28, 1868; Surveyor General's Office, Olympia, Western Territories, 1868). At this time, an unnamed creek was mapped in the roughly the same location of the present day Swale Creek (Figure 29). In April, the notes indicate that the creek was approximately 2 feet wide. Oaks and pines were present in the upper most reaches of two of the tributaries (T3N, R17E, the SE quarter of section 4, the NE and SE quarter of section 8 and the SW quarter of section 9). A narrow band of trees was also noted along a short segment of a tributary in the SW quarter of section 5 and the NW quarter of Section 8. No other trees were noted in the vicinity of the stream within this township.



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T3N, R16E and T3N, R15E: Townships 3N, R16E and 3N R15E were surveyed in 1860 (surveyed by Lewis Van Vleet on October 12th and October 26th, 1860; Surveyor General's Office, Olympia, Washington Territory, 1861). A large swale was mapped in October in townships 3N, R16E and T3N, R15E (Figure 29). The swale extended from a point roughly 1/2 mile upstream of present day Clyde-Story Road to a point just downstream of Uecker Road. The notes do not mention water in the Swale. Interestingly, the 2 foot wide channel that was present upstream of these townships in April of 1868 was not mapped or indicated in any way.

The only timber noted in these two townships was a section of timber (oak and pine) located in section 12 and 13 of T3N, R16E (extending a short distance into sections 11 and 14). This timber was more than a mile from the swale. No channels were documented any where in these two townships. Notes pertaining to the area mapped as a swale include:

- There are two small fields mapped within the boundaries of the swale.
- The survey markers used by the GLO were built within the boundary of the mapped swale. Markers were built of mounded dirt.
- The notes indicated there were no trees in the vicinity, hence the section corner markers were not built with a charred stick and no witness trees were surveyed to help locate the point.
- A road was built adjacent to the swale in T3N, R16E and was built within the boundary of the mapped swale in T3N, R15E.
- At the time the surveys were completed, there were only 4 homesteads in the Swale Creek basin. A schoolhouse was present near the lower end of the swale.
- The notes do not refer to any water depths nor do they refer to the presence of a channel within the area mapped as a swale.

T3N, R14E: Township 3N, R14E contains the present day Swale Creek from just upstream of Warwick to a point approximately 5 miles upstream of the mouth. The survey of this township was completed in September, 1861 (surveyed by N. J. G. Maxon on September 2nd, 1861; Surveyor General's Office, Olympia, Washington Territory, 1861). The survey notes indicate that a 2 foot wide creek flowed in October from roughly present day Warwick to a point approximately 3 miles downstream (roughly 1 miles downstream of present day Harris Road, approximately where the current power line crosses the creek). The location where the end of flowing water was mapped roughly corresponds to the western end of alluvium on present day maps (Figure 2). No flow, standing water, or channel was noted between the power line and the point where the channel turns sharply north in section 29. This portion of the stream overlies Wanapum basalts. From Section 29 downstream through Sections 29 and 20, a dry channel was indicated in the notes and was also mapped. The start of this section begins roughly where the stream leaves the Wanapum basalts and starts to flow over Grande Ronde basalt (Figure 2). A spring was mapped in Section 28 and a dry channel was noted at the boundary between Sections 21 and 22. The notes indicate there was some water in the bottom of the canyon however the channel was dry at the boundary between T3N, R14E and T4N, R14E.

The survey notes indicate a presence of scattering of pine and oak east of section 29. Timber was noted from the corner of sections 20, 21, 28, and 29 north to a ¼ mile north of the boundary between sections 20 and 27. Downstream of there, the notes once again indicated scattered pine and oak along the present day channel and upslope of the channel within the canyon. No witness trees were surveyed in this township, however all section markers included a wooden stake, suggesting that wood was either reasonably available or was transported to the site.

T4N, R14E: Township 4N, range 14E was surveyed in April of 1872 (surveyed by Edwin Richardson on April 25th, 1872; Surveyor General's Office, Olympia, Washington Territory, 1872). At this time, the creek was 16 to 17 feet wide. The notes specifically mention that the water was at high flow. The lower 5 miles of the stream ran through timber; primarily pine and oak with some alder, cherry, and hazel. In most of this area, trees were less than 10 inches in diameter, although a couple of small pockets of larger trees were noted. Witness trees ranged from 2 inches to 14 inches in diameter. Most were less than 6 inches in diameter.

4.5 Current, Recent Historical, and Potential Riparian Vegetation

The vegetation of Swale Creek varies a great deal along its length. There are areas with grasses, willow carrs, alder stands, and areas with bedrock or cobble for long stretches that have no vegetation. This pattern creates alternating stretches that are either fully shaded, or not shaded at all.

Five reaches were defined based primarily on changes in riparian vegetation and aspect (Figure 30). Reach 1 extends from Highway 97 downstream to Warwick, reach 2 extends from Warwick to river mile (RM) 6.3, reach 3 extends from RM 6.3 to RM 3.0, reach 4 extends from RM 3.0 to RM 0.25, and reach 5 extends from RM 0.25 to the confluence with the Klickitat River.

Aerial photographs were available for 1954, 1969, 1979, and 1996. These were used to evaluate changes in vegetation over time. Changes in channel condition and vegetation between sets of photographs may be affected by major storm events.

No stream gage data are available for Swale Creek. Major storm events recorded at the gage on the Little Klickitat River might be a reasonable indicator of when storm events occurred in the Swale Creek basin; however, the gaging of the Little Klickitat River ended in the 1980s. The mainstem Klickitat River near Pitt has a better period of record. The magnitude of peak flows in the Little Klickitat River is not always well correlated to the magnitude of peak flows in the mainstem (Figure 31). This likely reflects the difference in the primary source of flows between the rivers. The mainstem derives the majority of its flow from the Cascade Mountains, while the Little Klickitat flows originate in the Simcoe Mountains. Nevertheless, major events tended to occur in the same year in both drainages (Table 6). Major events likely also occurred in the same years in Swale Creek, although the relative magnitude of those events is unknown.

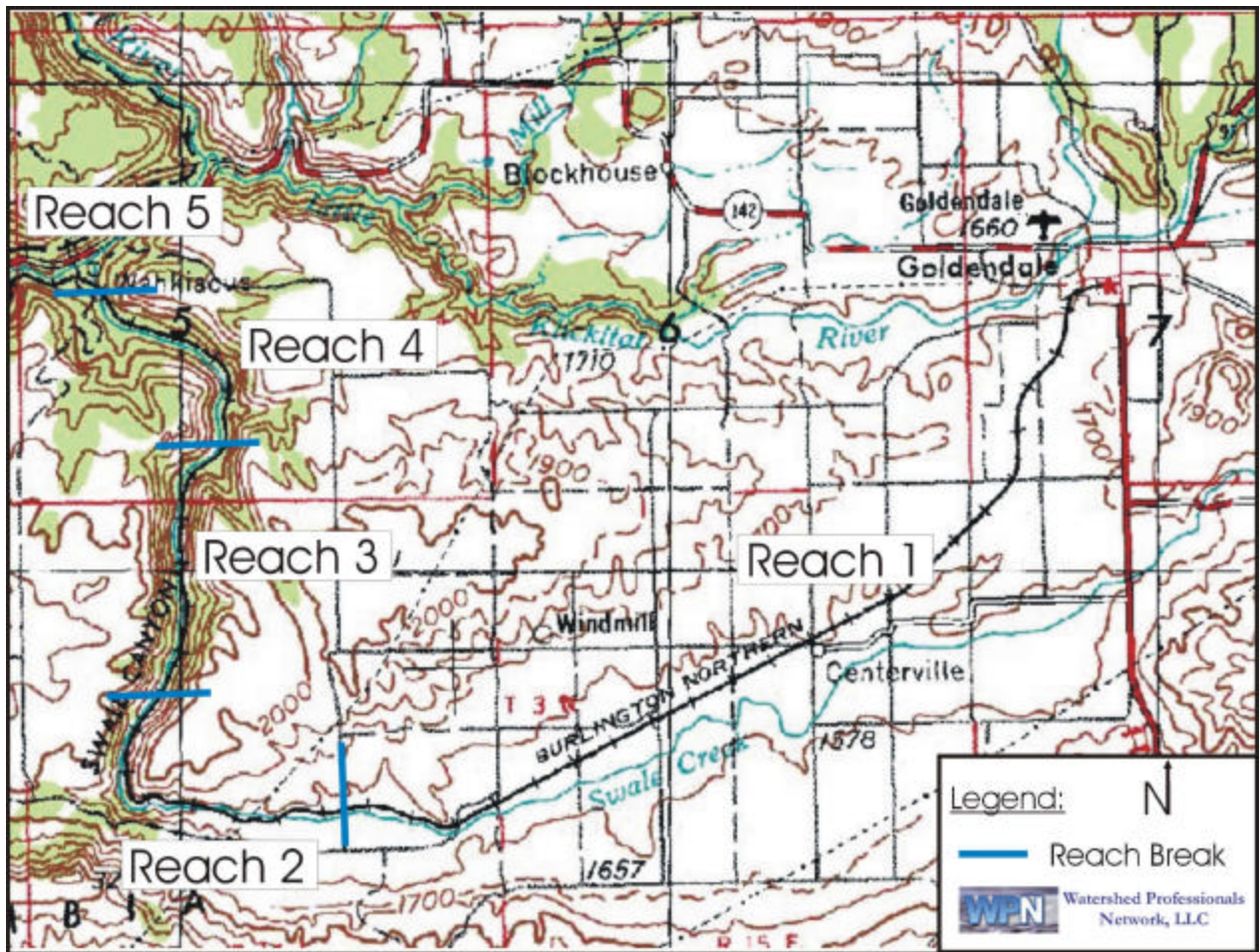


Figure 30. Reach locations in Swale Creek.

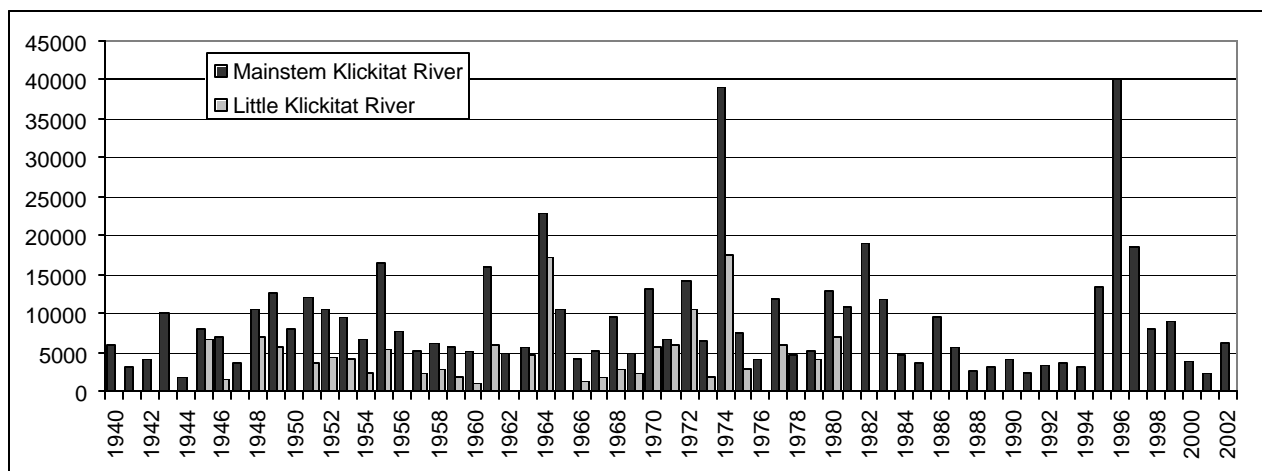


Figure 31. Annual peak flows in the mainstem Klickitat River near Pitt and the Little Klickitat River near Wahkiacus (source: USGS; <http://nwis.waterdata.usgs.gov/nwis>).

Table 6. The top flow events on the mainstem Klickitat River near Pitt in order of magnitude of flow and corresponding Little Klickitat flows, where available (source: USGS; <http://nwis.waterdata.usgs.gov/nwis>).

Date	Mainstem Klickitat Flow (cfs)	Little Klickitat Flow (cfs)
2/8/1996	40,000	
1/16/1974	39,000	17,500
12/22/1933	23,500	
12/23/1964	22,800	17,300
2/21/1982	18,900	
1/2/1997	18,600	
12/22/1955	16,500	5,500
2/10/1961	16,000	5,960
1/21/1972	14,300	10,500
2/1/1995	13,600	
1/23/1934	13,500	
1/23/1970	13,200	5,800
12/26/1980	13,000	6,960
2/17/1949	12,700	5,820
1/3/1934	12,300	
12/30/1937	12,200	
2/11/1951	12,100	3,700
12/14/1977	12,000	5,960
3/30/1983	11,700	
2/18/1983	11,600	

4.5.1 Reach 1

Reach 1 (upstream of Warwick) becomes dry in summer along most of its length. Perennial pools are present in some locations. The reach is not believed to be fish bearing (WPN and Aspect, 2003, Appendix A).

Grasses dominate most of the upper reaches of Swale Creek, although shrubs dominate in a few locations. The lack of water in summer limits riparian vegetation development along the creek. A small canyon-like area with alder (*Alnus sinuata*) and some aspen (*Populus tremuloides*) is located upstream of Highway 97 (Figure 32). Downstream of Highway 97, Swale Creek alternates between



Figure 32. Upstream of Highway 97.

grass and sedge dominated and shrub dominated riparian areas (Figure 33). Willows (*Salix sp.*) are the primary species in the shrub dominated areas. Shade is limited to small stands of willow and alder in a few places. In the shaded places, canopy closure is 60% or less.

Changes in riparian vegetation have occurred locally in this reach over the past few decades. For example, riparian vegetation in the areas just upstream of Warwick is less dense than it was in 1954 and 1969 (Figure 34). Most of the trees in the

photos remain in 1996, but the brushier vegetation has decreased substantially. This could be the result of intentional clearing or grazing. The photos would indicate that the potential exists to grow taller vegetation along the existing channel configuration, such as willows and alder, adjacent to perennial pools. The cadastral surveys of 1860, however, indicate a paucity of woody vegetation at section lines along this reach (Section 4.4).



Figure 33. Reach 1 from under Uecker Bridge.

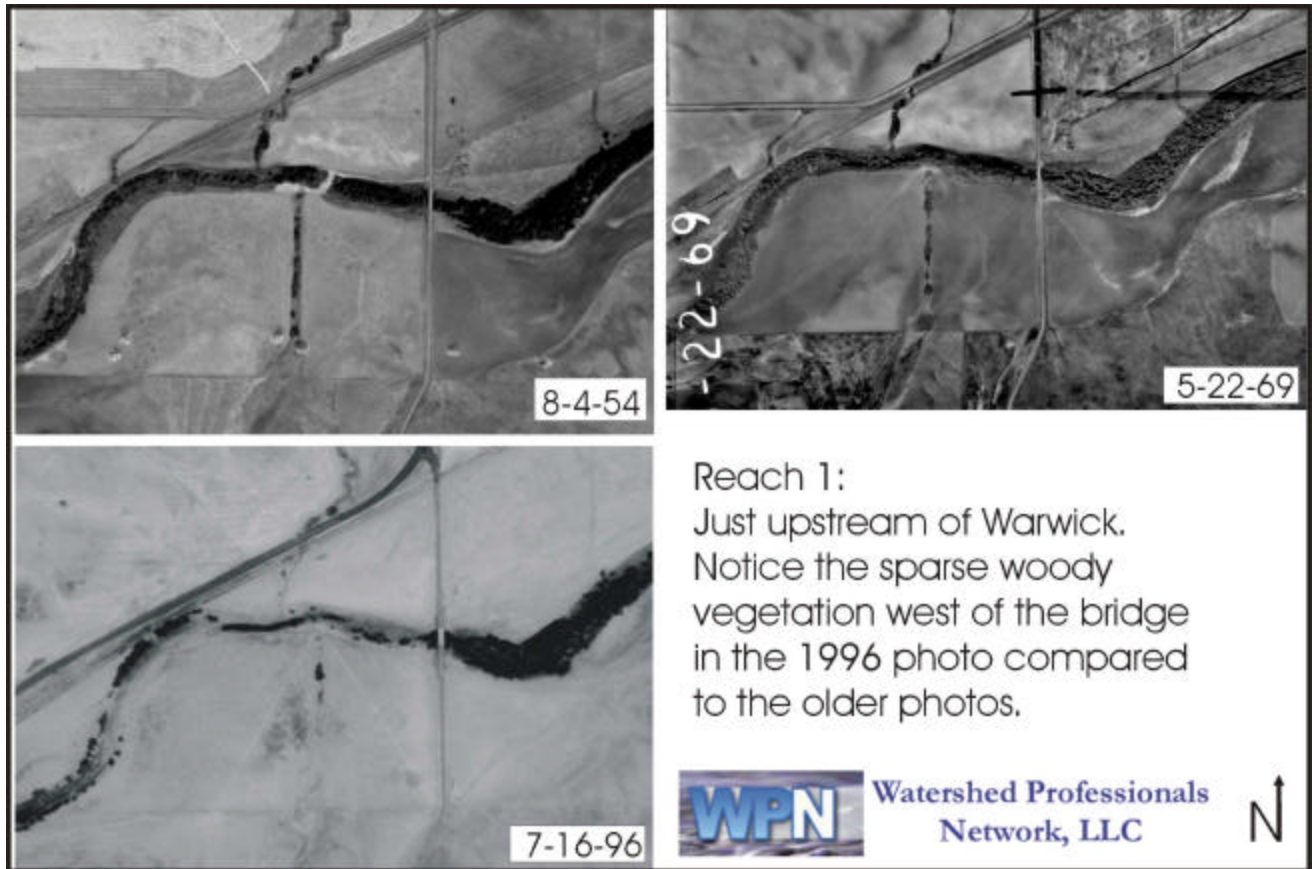


Figure 34. Aerial photographs of reach 1 just upstream of Warwick taken in 1954, 1969, and 1996.

4.5.2 Reach 2

Just downstream of Warwick, Swale Creek descends into a canyon. The creek is confined to basalt pools (Table 7), with occasional areas of narrow flow trickling between the pools. Vegetation is found only where there is available water (Figure 35). Willow stands are found near seeps and pools. Most of the dry bedrock stretches have no vegetation (Figure 37). Canopy closure is typically low (<20%) in the few shaded locations (Figure 36).



Figure 35. Reach 2, upper canyon.



Figure 37. Reach 2, lower end, showing typical shade where vegetation is present.



Figure 36. Swale Creek Reach 2 (upper canyon).

Table 7. Reach 2 characteristics.

Average Pool Width (ft.)	24 Feet
Average Pool Length (ft.)	40 Feet
Average Pool Depth (in.)	17 Inches
Average Vegetation Density (%)	0%
Buffer Width (ft.)	19 Feet
Buffer Height (ft.)	10 Feet

The flood of 1974 had a major impact on the reach 2. This flood was the second largest flood on record at the Pitt gage on the Klickitat River. Apparently the flood washed out the railroad grade and afterwards the railroad owners intervened by pulling many of the large boulders and rocks out of the creek bed. This has had a major impact on both the vegetation and the character of this reach. Before the work was done, this portion of Swale Creek had some large pools, although it did not have surface flow in summer (Crocker personal communication). The aerial photos in Figure 38 show large pools in 1954, that are not as evident in 1969 (the creek is flowing in this May photo), 1979, and 1996 photos. Also notice the vegetated conditions right at the bend in the

creek in the 1954 photo. Riparian vegetation was lost between 1954 and 1969. Although the cause of the loss is not certain, it may have been affected by the flood events occurring in the interim period. Three of the 10 largest magnitude flood events recorded on the mainstem Klickitat River occurred during the period between these photo sets (1964, 1955, and 1961).

In this reach, the potential composition of riparian vegetation under the current channel configuration would not be much different than current vegetation (Figure 36): willow, and riparian grasses. However, there is potential for higher density of vegetation around pools resulting in somewhat shadier conditions.

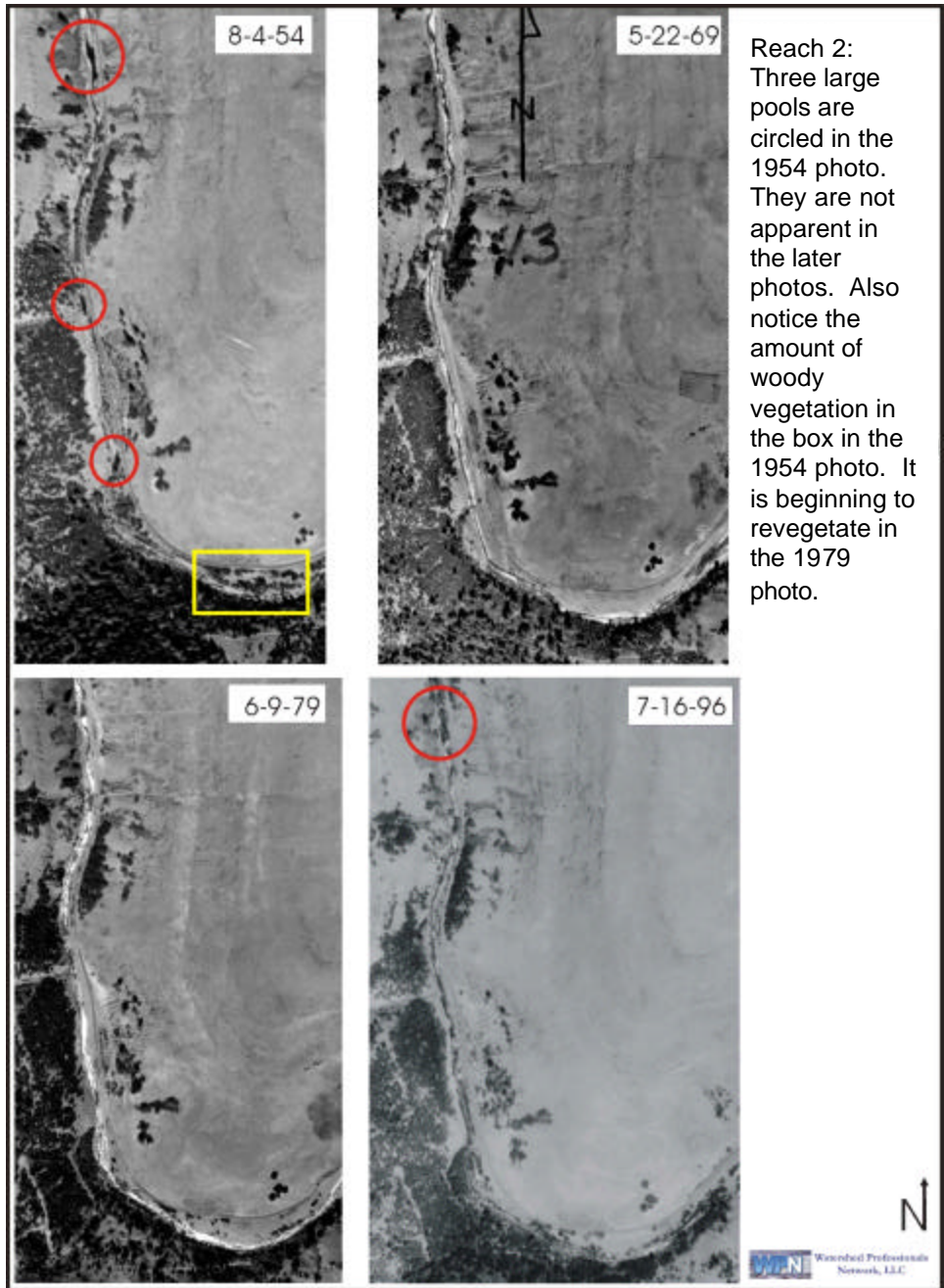
4.5.3 Reach 3

Swale Creek makes a 90-degree turn to north, and downstream of that turn the vegetation begins to shift. Like reach 2, the creek is confined to basalt pools (Table 8, Figure 41), often with a narrow stream trickling between the pools. There are long stretches with little or no vegetation along stretches of dry bed of cobble (Figure 39). Vegetation is again associated with moisture availability. Vegetation is most found most commonly adjacent to perennial pools but is absent where bedrock outcrops exist. Vegetation, where present, is dominated by alder, willows and reed-canary grass (*Phalaris arundinaceae*) (Figure 40). Big leaf maple (*Acer macrophyllum*) is occasionally found in drainage area and near seeps. This pattern of shaded to non-shaded conditions continues for nearly 4 miles. In the few shaded places, density of vegetation may reach up to 55% cover.

This reach has some areas where there have been substantial changes in vegetation in recent decades. There are also stretches that have been consistently barren over time as well. The vegetation over the last 30 years has been influenced by a number of catastrophic flooding events that removed mature vegetation.

Table 8. Reach 3 Characteristics

Average Pool Width (ft.)	23 Feet
Average Pool Length (ft.)	87 Feet
Average Pool Depth (in.)	21 Inches
Average Vegetation Density (%)	18%
Buffer Width (ft.)	14 Feet
Buffer Height (ft.)	18 Feet



Reach 2:
 Three large pools are circled in the 1954 photo. They are not apparent in the later photos. Also notice the amount of woody vegetation in the box in the 1954 photo. It is beginning to revegetate in the 1979 photo.

Figure 38. Aerial photos from 1954, 1969, 1979, and 1996 depicting changes in pool abundance and vegetation over time.



Figure 39. Vegetation around pool in Reach 3.



Figure 40. Example of dry cobble with little vegetation in Reach 3.

An example of the dynamic changes in vegetation is shown in Figure 42. There is good vegetation on the left bank in 1954, but no vegetation in 1969 and 1979 on the left bank of the creek. Substantial vegetation has developed on the left bank by 1991, but is reduced in density in the 1996 photo. There has been no substantial change in land use in this area (light use). The absence of vegetation in the 1969 and 1979 photos may be the result of the numerous floods that occurred in the region between 1954 and 1979. The reduced vegetation in the 1996 photo may be the result of the February 1996 flood event (largest on record). Large flood events also occurred in 1982, 1995, and 1980.

Figure 43 provides an example of an area within reach 3 where the riparian vegetation has changed very little since the mid-1950s. In general, this area has very little riparian vegetation. The potential for high quality riparian vegetation to develop in these types of areas is low. The photos also indicate a great deal of shifting of the channel between photos. Between 1954 and 1969, the upper portion of the channel in the photos changed dramatically, and then, between 1969 and 1979, the channel returned to a path close to its 1954 channel. Between years, there is also a considerable amount of shift in side channels and bars. This is obviously an area of the channel that is highly unstable. Channel movements have contributed to the lack of riparian vegetation through time in this area.



Figure 41. Basalt pool in reach 3.

This reach could potentially have somewhat higher levels of riparian shading in reaches where water is available throughout the summer and the channel is stable. In other areas where the channel is dry and dominated by cobble and boulders or where the channel is highly migratory, little to no riparian vegetation would be expected to develop and persist.

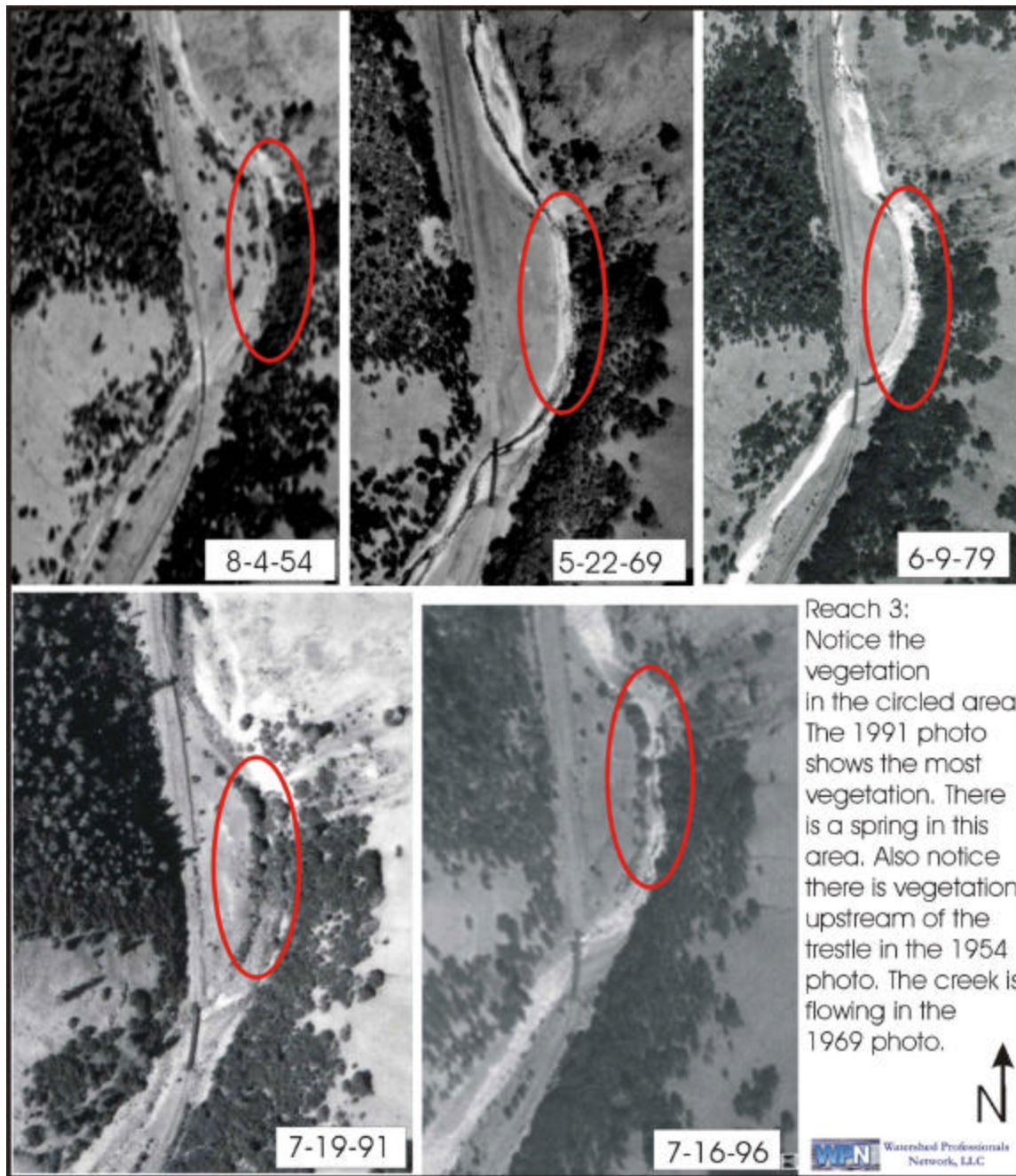


Figure 42. Aerial photos (1954, 1969, 1979, 1991, and 1996) of a stretch of reach 3 demonstrating substantial changes in riparian vegetation over time.

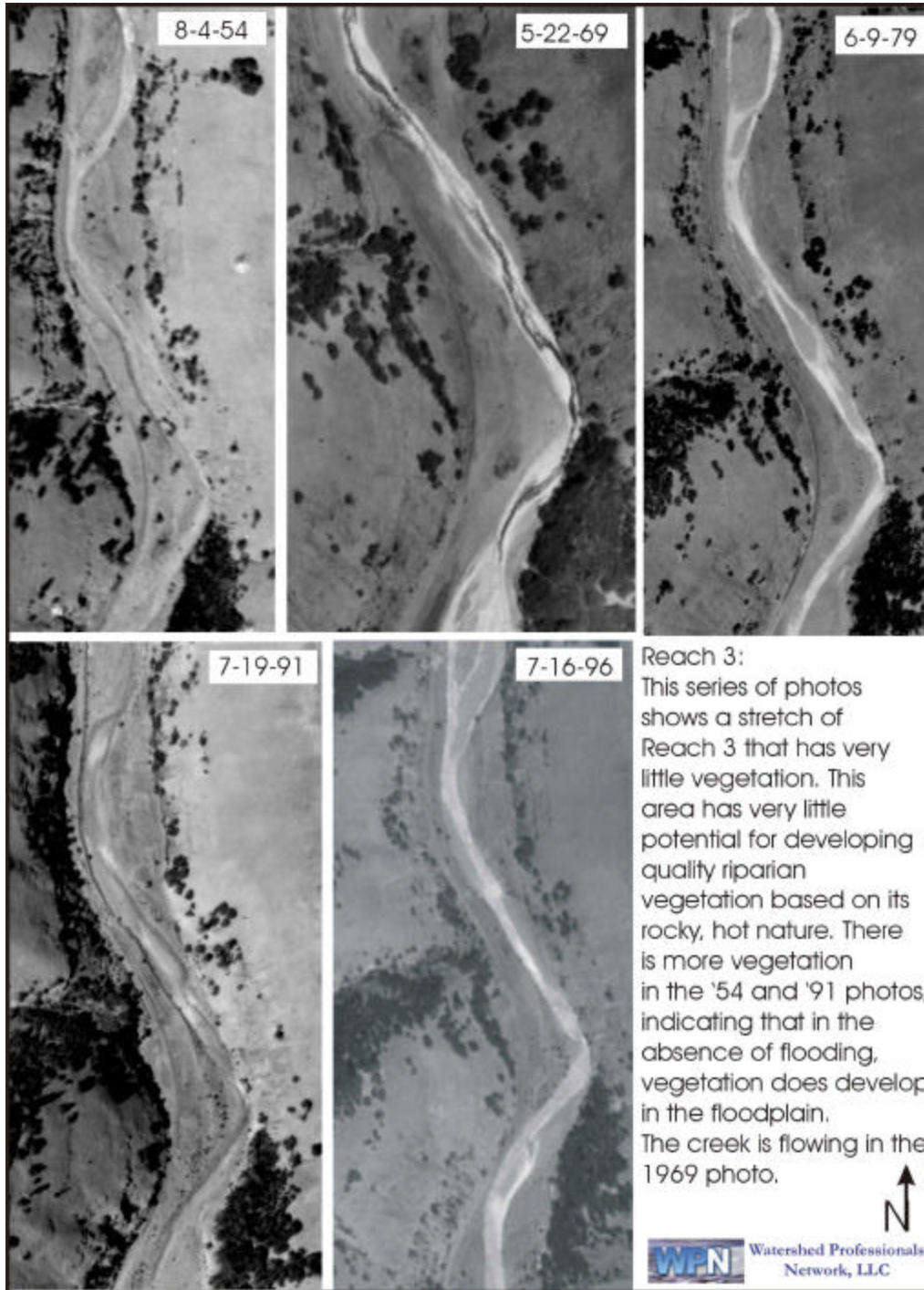


Figure 43. Aerial photos from 1954, 1969, 1979, 1991, and 1996 of an unstable channel within reach 3 where riparian vegetation is consistently low.

4.5.4 Reach 4

In reach 4, Swale Creek makes a wide sweeping turn to the west. It is in this turn that regular stream flow begins to appear, along with alders, willows and reed-canary grass. There are big leaf maple along the creek here, as well as a higher diversity of vegetation including mock orange (*Philadelphus lewisii*), water birch (*Betula occidentalis*), cottonwood (*Populus trichocarpa*) and rose (*Rosa sp.*). Swale Creek continues to flow along its westerly course, maintaining stands of alder along its banks. This area has nearly continuous shading under long stands of alder with a wider floodplain area in places (Figure 44). The creek itself is wide in places, creating non-shaded conditions at the center of the creek. Vegetation can reach densities of 100% cover in many areas (Figure 45). Frequently, only one side of the creek is highly shaded (Figure 46) resulting in the average cover listed in Table 9.



Figure 44. Riparian stands along Reach 4.



Figure 45. Portion of reach 4 with shading on one side of creek.

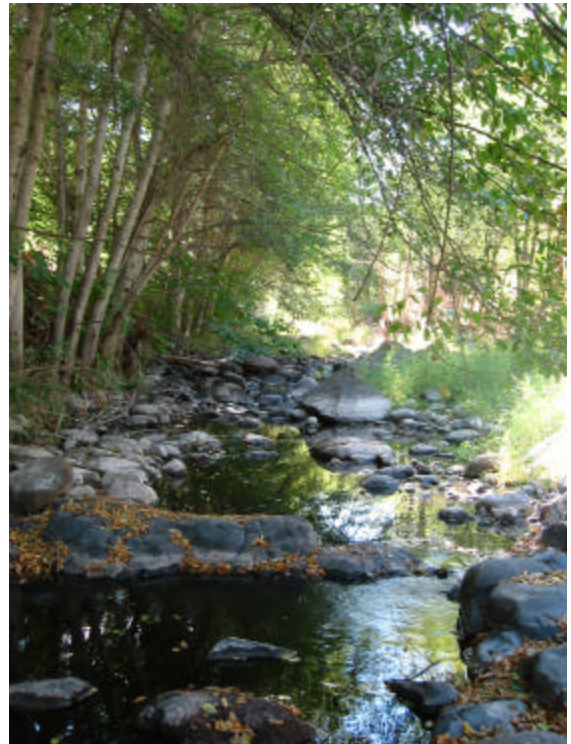


Figure 46. Portion of Reach 4 with nearly 100% shade.

Table 9. Reach 4 Characteristics.

Average Width (ft.)	19 Feet
Average Length (ft.)	122 Feet
Average Depth (in.)	16 Inches
Average Vegetation Density (%)	53%
Buffer Width (ft.)	18 Feet
Buffer Height (ft.)	22 Feet

Riparian vegetation in reach 4 has also changed over time within recent decades. The riparian vegetation appears well established in the 1969 photo (Figure 47), less so in the 1979 photo, highly developed in the 1991 photo, and again less developed in the 1996 photo. Once again, this pattern suggests that flooding plays a major role in vegetation patterns of Swale Creek. The oddity about the pattern is that riparian vegetation was well established in 1969, just 5 years after a major flood event. Alders will grow 20 feet or more in 5 years under the right conditions, so could have developed to the point seen in the photo since the 1964 flood event. The photo from 1979 was taken 7 years after the 2nd largest flood event on record and less than two years following a much smaller flood event. The photo in 1996 was taken just months after the largest event on record.

4.5.5 Reach 5

As the creek nears Horseshoe Bend Bridge at Wahkiacus, flow disappears again into stretches of dry cobble. Alders and willows still line the banks, but shade is lower (Figure 48). Downstream of Horseshoe Bend Bridge, there is a group of young cottonwoods. Further downstream, the vegetation is dominated by grasses, mainly reed-canary grass. Near its mouth, Swale Creek again disappears into a stretch of dry cobble with no vegetation which continues to the creek's confluence with the Klickitat River (Figure 49, Table 10).

Table 10. Reach 5 Characteristics.

Average Pool Width (ft.)	27 Feet
Average Pool Length (ft.)	175 Feet
Average Pool Depth (in.)	13 Inches
Average Vegetation Density (%)	0%
Buffer Width (ft.)	15 Feet
Buffer Height (ft.)	10 Feet

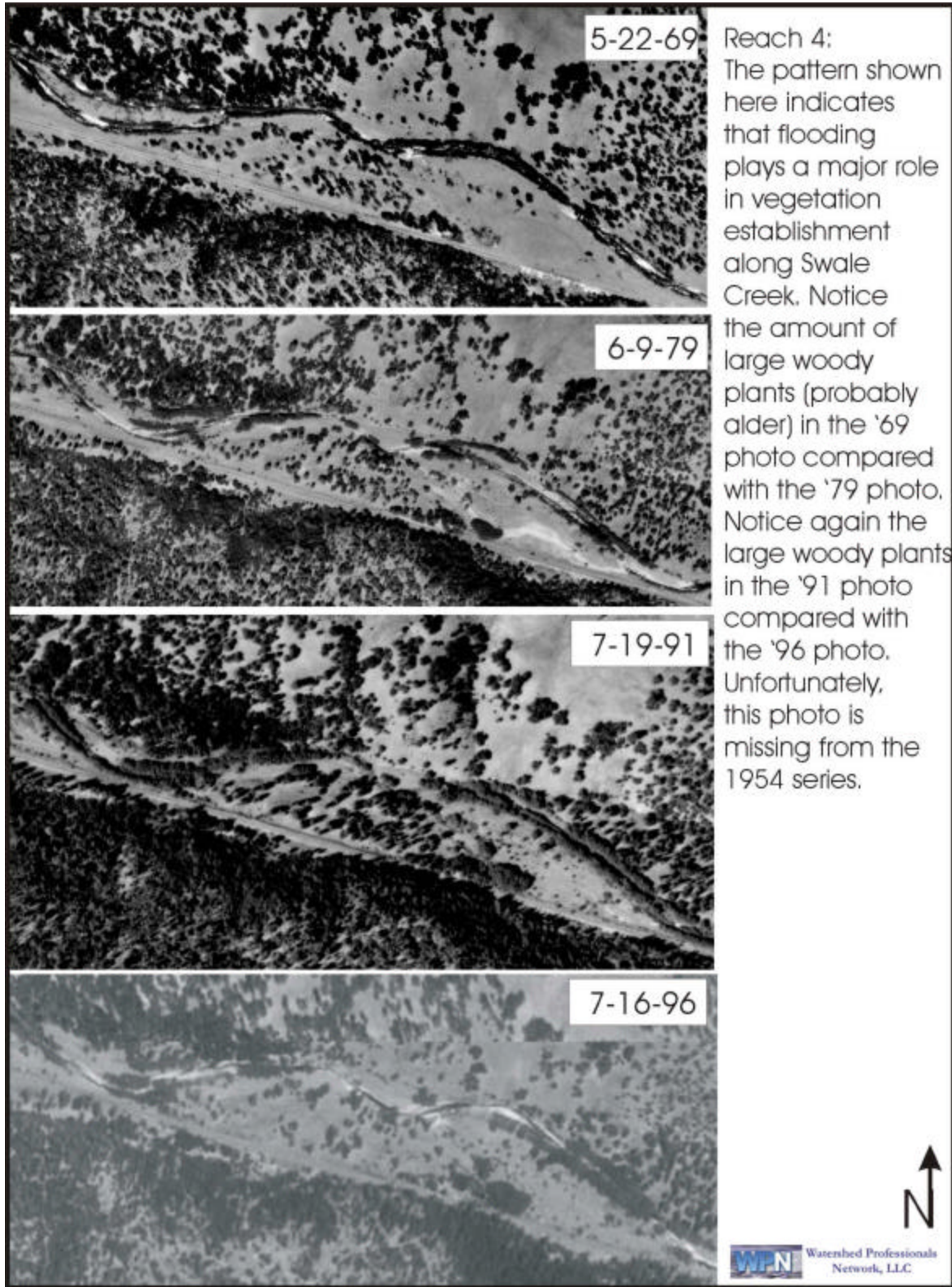


Figure 47. Changes in riparian vegetation over time in reach 4.



Figure 48. Photo of Reach 5.



Figure 49. Reach 5 near confluence with Klickitat River.

Like the reaches upstream of reach 5, this reach also has highly variable riparian vegetation. Mature vegetation is present in the 1969 and 1991 aerial photographs (Figure 50). Lower densities of vegetation are present in the 1979 and the 1996 photo, suggesting that flood events play a major role in the vegetation patterns in this portion of Swale Creek as well. Note, the angle of the camera in 1991 was somewhat more oblique in other years, giving the appearance of taller denser trees, not only in the riparian area, but also in upland areas. Comparison of the 1979 and the 1996 photos, however, indicates that no trees were removed from the upland area. The oblique angle also makes comparison of the riparian stands more difficult; nevertheless, there were more trees in 1991 than in 1979.

In this reach, riparian vegetation is a mixture of alder, cottonwood, big leaf maple, birch, willow, and riparian grasses. There is a long stretch of bare cobble near the mouth where there is potential for vegetation development with some soil deposition. The aerial photographs from reach 5 show vegetation almost all the way to the confluence in the 1969 photograph. The area near the mouth, however, is a depositional area that will be subject to disturbance by flood events over time. Hence, the riparian vegetation in this area will tend to be dynamic; maturing between flood events and then reduced in density during floods.

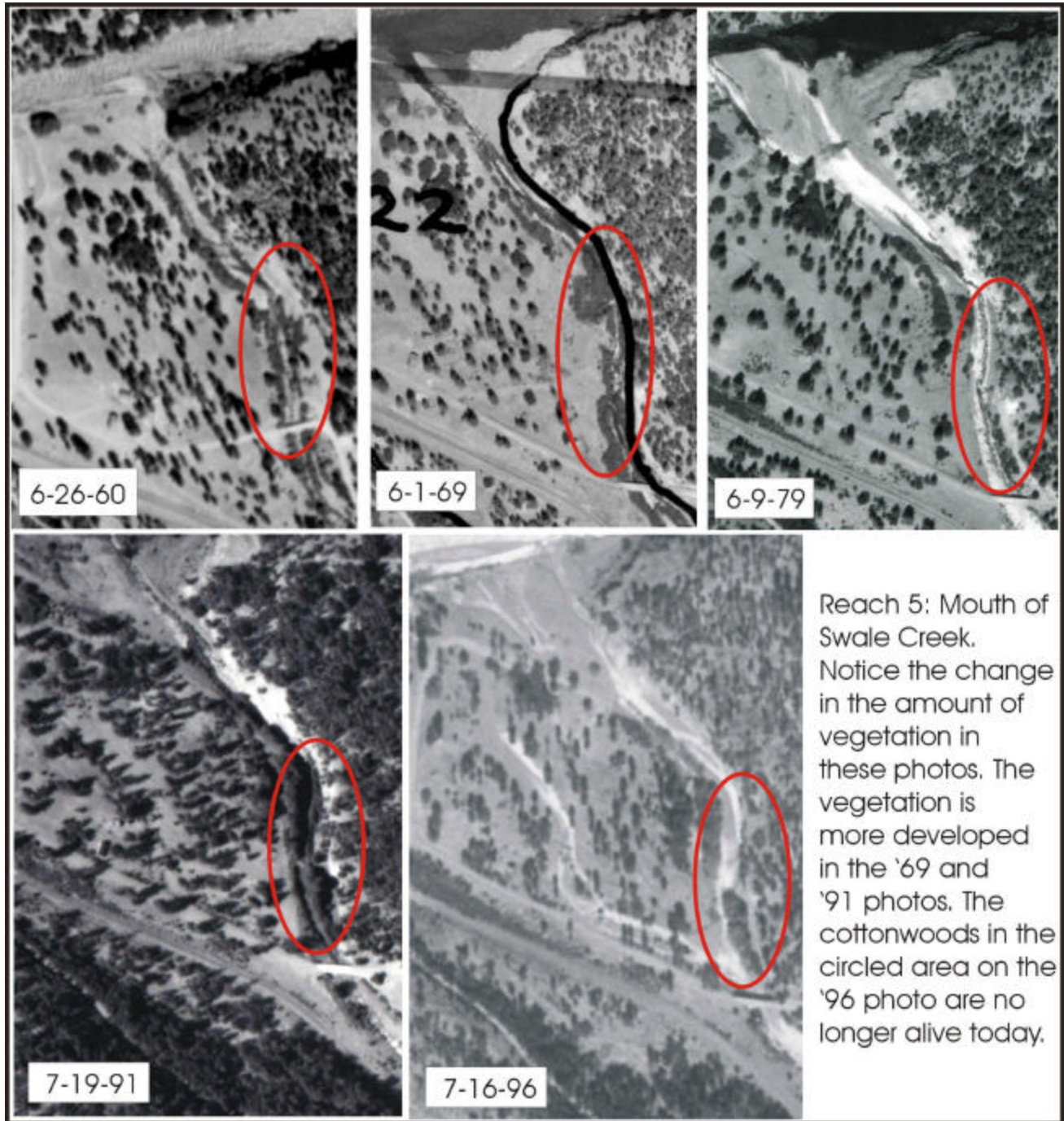


Figure 50. Aerial photos of Reach 5 in 1960, 1969, 1979, 1991, and 1996.

4.6 “Background” Water Temperature

The process for estimating natural background temperature included the development of an estimate of natural background riparian vegetation or shade. Background vegetation could only be estimated. Natural background riparian vegetation was based on the estimated range of potential vegetation under current channel conditions. In some cases, the upper end of the potential range was adjusted upwards where we believed that channel restoration efforts may increase the amount of soil, and hence vegetation, that could be retained along the channel. These estimates in addition to other data previously described were used to model conditions that bound the expected natural temperature conditions.

4.6.1 Calibration

Initial runs of the *Heat Source* model resulted in predicted water temperatures well below those actually measured on July 29, 2003. Input parameters were therefore adjusted to calibrate the model. The difference between actual and predicted temperature was substantial enough that adjustments of the minor parameters was not sufficient to calibrate the model. In order to attain a reasonable calibration of the model, the daily minimum air temperature was increased by 15°C, keeping the daily maximum air temperature the same (i.e., measured minimum and maximum temperatures on July 29, 2003, of 1 °C and 3 °C, respectively, were adjusted to 29°C and 39°C, respectively, in the modeling). This resulted in the range of air temperatures for modeling input being reduced by 60% from that actually measured in the watershed. The value for groundwater temperature was also raised by 7°C, from the initial assumption of 12°C to 19°C.³ Results of the calibration are illustrated in Figure 51 (distance on the horizontal axis in the figures increases in the downstream direction).

To predict temperatures on August 14, 2003, the only input parameters that needed to be changed were stream flow, air temperature, and humidity. Stream flow was estimated in the field at 0.25 to 0.5 cfs. A stream flow of 0.5 was used. Measured air temperatures in the watershed for that date were 12°C minimum and 34°C maximum. Therefore, consistent with the adjustments made for the calibration on July 29, 2003, air temperature range was reduced by 60%, with the change being made only at the minimum air temperature, i.e., inputs to the model for August 14, 2003 were 25°C minimum and 34°C maximum. Humidity recorded in the watershed was also slightly higher on August 14, 2003. Results of the validation are illustrated in Figure 52.

³ It should be noted that we do not necessarily believe that air temperatures above the water column were in fact warmer than those measured in the watershed, nor do we necessarily believe that ground water in the area is 19°C. We used these parameters to make adjustments in order to obtain agreement between the model and measured water temperatures on July 29, 2003, i.e., calibration of the model to this specific stream.

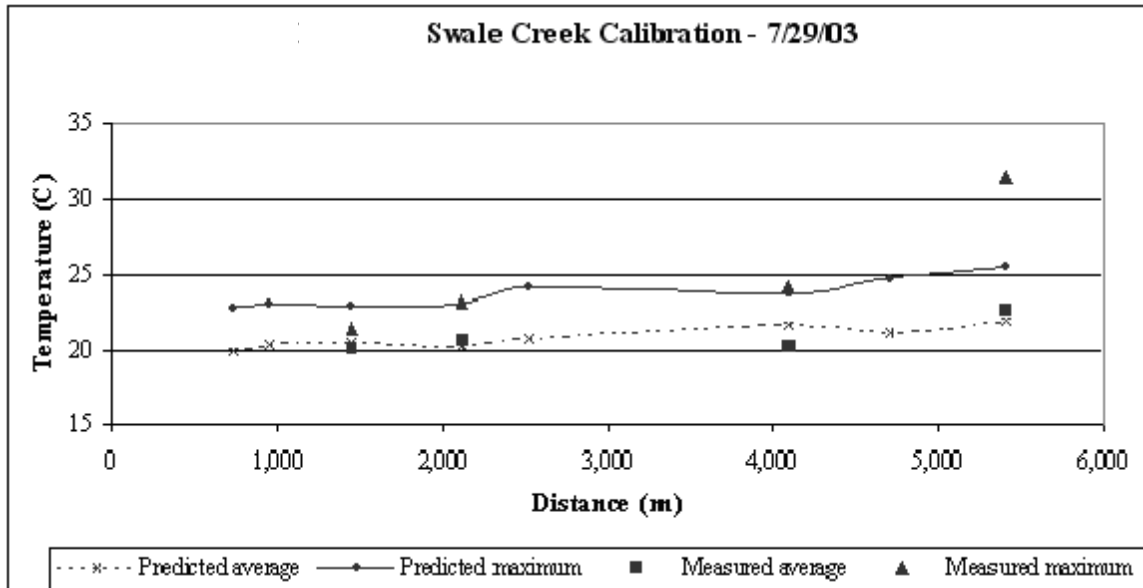


Figure 51. Swale Creek calibration for the data of 7/29/03 showing the actual measured data and the data predicted by the Heat Source model.

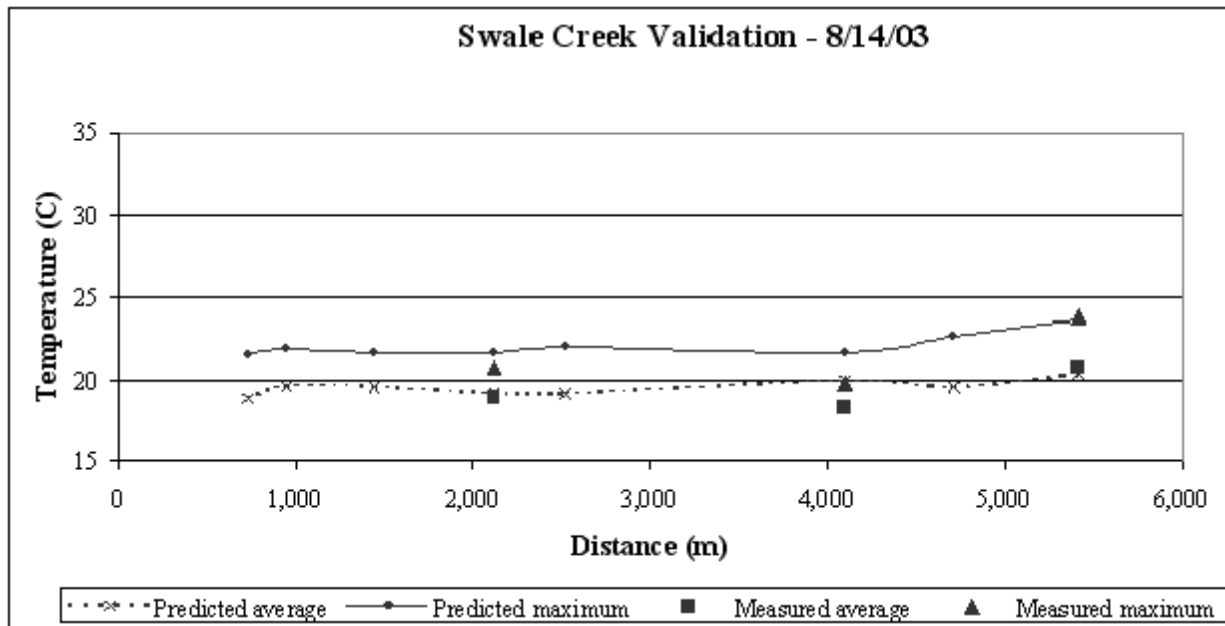


Figure 52. Validation of the calibrated Heat Source model for Swale Creek.

4.6.2 Maximum Natural Thermal Potential

The EPA defines natural thermal potential as the thermal regime that existed in rivers and streams prior to Euro-American settlement. EPA guidance documents also note that the best way of

estimating NTP is through application of mechanistic models. *Heat Source* is a physical process-based “mechanistic” model.

Current thermal conditions as measured by the temperature sensors placed in the watershed in 2003 directly reflect the existing conditions in Swale Creek’s stream channels under current conditions of stream flow, groundwater inflow, hyporheic exchange, meteorology, channel configuration, and vegetation. *Heat Source* considers and accounts for all of these processes, with exception of hyporheic exchange, a poorly understood process with unknown effects. Accordingly, *Heat Source* was used to model current thermal conditions. Estimation of natural thermal potential is based on systematic consideration of how the factors that affect each key process may have been altered from the historic condition to current conditions.

Management activities that potentially affect stream channels include those that increase peak stream flows, physically modify beds and banks, or alter stream bank vegetation through logging, grazing, or clearing. The Swale Creek watershed was likely never heavily forested, and therefore effects of forest clearing on peak flows are most likely negligible. Aerial photographs confirm that the area has not been logged in recent decades. The GLO surveys indicate that tree cover between Harms Road and roughly river mile 5.0 consisted of “scattered” oaks and pines with some pockets of denser vegetation. The lower 5.0 miles had denser tree cover, apparently consisting primarily of smaller sized trees. Although the density of vegetation in 1861 cannot be estimated with much precision, the description of the vegetation present at that time is generally similar to that seen at present.

The Swale Creek watershed is not heavily roaded, and the only road bed in close proximity of the stream is an abandoned railroad bed. This rail bed does encroach on the stream in several places and the potential effect of that encroachment on water temperature deserves some examination.

Although it cannot be confirmed, the rail bed likely has resulted in downcutting of the channel, particularly in reach 2. The 1861 GLO survey notes did not identify a channel in upper two-thirds of reach 2 and the lower one-third of reach 2 had a dry channel in 1861. It is possible that some standing pools were present in some locations along the reach that were not mapped. The surveyor that mapped the portion of Swale Creek where reach 2 lies was generally careful to map dry channels, hence the absence of a channel in the upper 2/3 of reach 2 suggests that seasonal flow in that area may have been diffuse. It is, however, possible that the surveyor in 1861 simply failed to document an existing channel. Currently, the channel is downcut significantly adjacent to the rail bed. At present, most of reach 2 is largely dry in summer, similar to what is indicated in the 1861 survey. Summer water temperatures in the isolated pools of reach 2 may be affected by the railroad to the degree that its presence affects shade along the isolated pools. “Potential” shade was estimated upwards for wetted portions of reaches 2 where modification of the rail bed may increase the development of soils and/or vegetation.

Reach 3 runs through the deepest portion of Swale Canyon. Aerial photographs and field visits indicate that the rail bed has constrained the flood plain in some places, but in general it does not encroach on the channel. Currently, water is intermittent in summer in reach 3 and it appears from the survey notes that it was also intermittent in 1861. “Potential” shade was also estimated upwards for wetted portions of reaches 3 where modification of the rail bed may increase the development of soils and/or vegetation.

At present, reach 4 is continuously wetted in summer and riparian vegetation is relatively dense. Like reach 3, the railroad encroaches on the floodplain in some places, but generally does not encroach on the channel. We know from the 1872 survey notes of this area that forest cover consisted largely of young trees, but was denser than was found in other portions of the basin. We have assumed that substantial riparian vegetation is possible in this reach.

It is unlikely that stream flows or groundwater regimes and interchange in Swale Creek have been affected by management activities in the watershed. Although some groundwater is withdrawn from wells in the upper portions of the watershed for irrigation, the potential loss of groundwater contribution to the stream in the lower (modeled) section of stream is judged to be inconsequential because: a) the geology of the area effectively disconnects that upper basin from the lower basin (see section 1.1), b) the 1860 and 1861 GLO survey notes describe a flow situation similar to that seen today in summer, and c) water withdrawn from deeper aquifers in the upper basin helps to recharge of the upper alluvial aquifer upstream of the Warwick fault. Downstream of Warwick, there are numerous residential wells. In the lower reaches of the creek, the channel flows primarily over Grande Ronde basalts (Figure 2). Information from one well suggests that water pressure in the Grande Ronde basalt in this area has a strong positive pressure (Section 1.1). If this pressure were present throughout the Grande Ronde basalts along the lower Swale Creek, then this would suggest that groundwater pressure, and likely groundwater inputs, have not been substantially affected by those wells. The data supporting this are, however, sparse.

Riparian vegetative shade was determined to be the primary factor capable of resulting in significant changes in Swale Creek water temperatures relative to historic conditions. Based on observations of aerial photography, riparian vegetation in Swale Creek appears to be somewhat cyclical, increasing and decreasing over periods of 10 to 20 years. Whether this is a natural cycling of willows and shrubs or is due to grazing or other human impacts is uncertain, but for the purposes of modeling natural thermal potential, we assumed at least some portion of the variation was management related. Based on review of the aerial photos and a review of current conditions regarding water and soils as they may affect growing conditions, estimates of potential shade were developed. Recognizing that channel changes may have resulted in changes in vegetation potential such that historic conditions are no longer attainable, variables related to shade were assumed to be higher than our estimated potential shade. Modeled potential buffer height was assumed to be 18 meters, modeled potential buffer width was assumed to be in the range of 6 to 10 meters, and canopy density was assumed to be in the range from 30 to 90%. (see Addendum B for details on inputs used for each reach).

Once the model was calibrated and validated for Swale Creek using water temperatures recorded in 2003, water temperatures for a “normal” and an “unusual” year were evaluated for comparison purposes. Normal values for air temperature and humidity were based on averages of meteorological records from Goldendale. Average July air temperature at Goldendale (n=47) is 19.74°C (Western Regional Climate Center, wrc@dr.edu). The 95% confidence interval on this number is 16.86 to 22.63°C. 2003 was chosen as an unusual year, because it was in fact dryer and substantially hotter than normal, although the data regarding inter-annual variability in stream temperature indicate 2003 was a fairly normal year with regards to stream temperature. In 2003, average July air temperature was 22.4°C which corresponds to the upper end of the 95% confidence range.

Potential vegetative conditions were input to the model to estimate natural thermal potential for both a normal year and for an unusual year. In both cases, natural thermal potential was evaluated for the date of July 29; the results of these comparisons are illustrated in Figures 53 and 54.

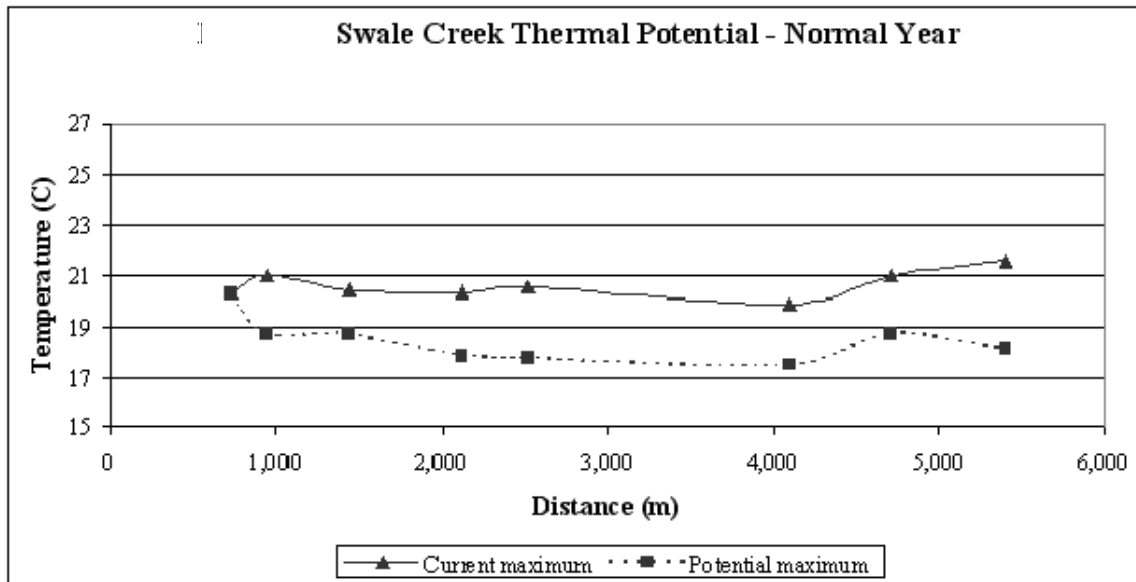


Figure 53. Predicted stream temperature in reach 4 in a normal year under maximum possible shade.

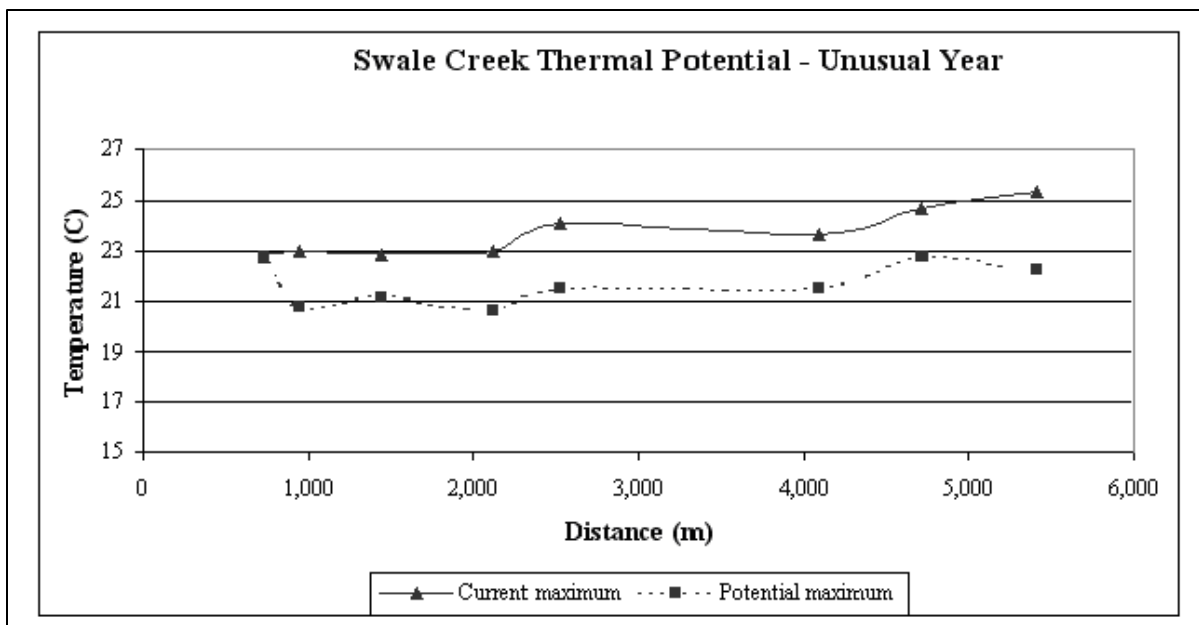


Figure 54. Predicted stream temperature in reach 4 in an unusual year under maximum possible shade.

The greatest estimated change in daily maximum temperatures from historic conditions to current conditions is 3.4 °C, which occurs near the mouth of Swale Creek in a normal year (Figure 53). The estimated average deviation in daily maximum temperatures from historic conditions to current conditions is 2.4 °C in a normal year (Figure 53), and 2.3 °C in 2003 year (Figure 54).

4.6.3. Modeling Uncertainty

There are at least two independent sources of uncertainty in the temperature modeling exercises. The first is related to uncertainties in the model inputs, which occur because all of the input parameters must be estimated for each reach based on a limited amount of measured data. These estimates were developed using averages of field measurements described earlier. The second source of uncertainty is due to the inherent way in which the model works, that is, the way in which it simulates heat transfer processes and the fact that the model is calibrated to measured water temperatures for a specific set of conditions.

The first uncertainty, referred to as parameterization error, is typically on the order of 0.2°C to 0.4°C (WWA, 2002). The other source of uncertainty, calibration error, can be characterized by the “goodness of fit” obtained in the calibration and validation steps (Figures 51 and 52). The standard deviation of the residuals (difference between measured and predicted maximum temperatures) was 2.6°C for calibration on July 29, 2003, and 2.1°C for validation on August 14, 2003. Therefore, an estimate of the uncertainty in predicted maximum temperatures associated with calibration is approximately $\pm 2.4^\circ\text{C}$. Both sources of uncertainty, parameterization and calibration, ought to be combined in order to arrive at an overall estimate of the uncertainty in the predicted maximum temperatures. Combining the two uncertainties derived above in a root-mean-square (RMS) method results in a combined uncertainty of $\pm 2.5^\circ\text{C}$ in the predicted maximum temperatures.

Although the *Heat Source* model is generally considered to be the best mechanistic temperature model available, problems were encountered in applying it in this situation. In this situation, several factors had to be modified to calibrate the model. These included increasing groundwater temperatures and increasing minimum air temperature. The changes required to calibrate the model were much larger than are normally required. This leads us to the conclusion that the model wasn't well adapted to this particular situation. The model was developed primarily to address larger flowing streams, however in this application it was used to model temperature in water with negligible flow. Hence, the model was applied in a situation that was outside the range of data used to develop the underlying relationships between physical parameters and stream temperature. Applications of any model to conditions outside of the range of tested responses inherently increase the error in the outputs and may produce spurious results. Therefore, the results of the modeling should be interpreted carefully.

5 DISCUSSION

5.1 Current Water Temperatures Relative to Standards

The temperature criterion of 17.5 °C was clearly exceeded at all stations monitored in 2003 (Figure 55). From this stand point, 2003 was not unusual. The criterion has been exceeded in all years of monitoring from 1995 to present (Figures 18 and 19). Inter-annual variability was not as high as expected. The differences between years were smaller than the differences within years (Figures 18 and 19).

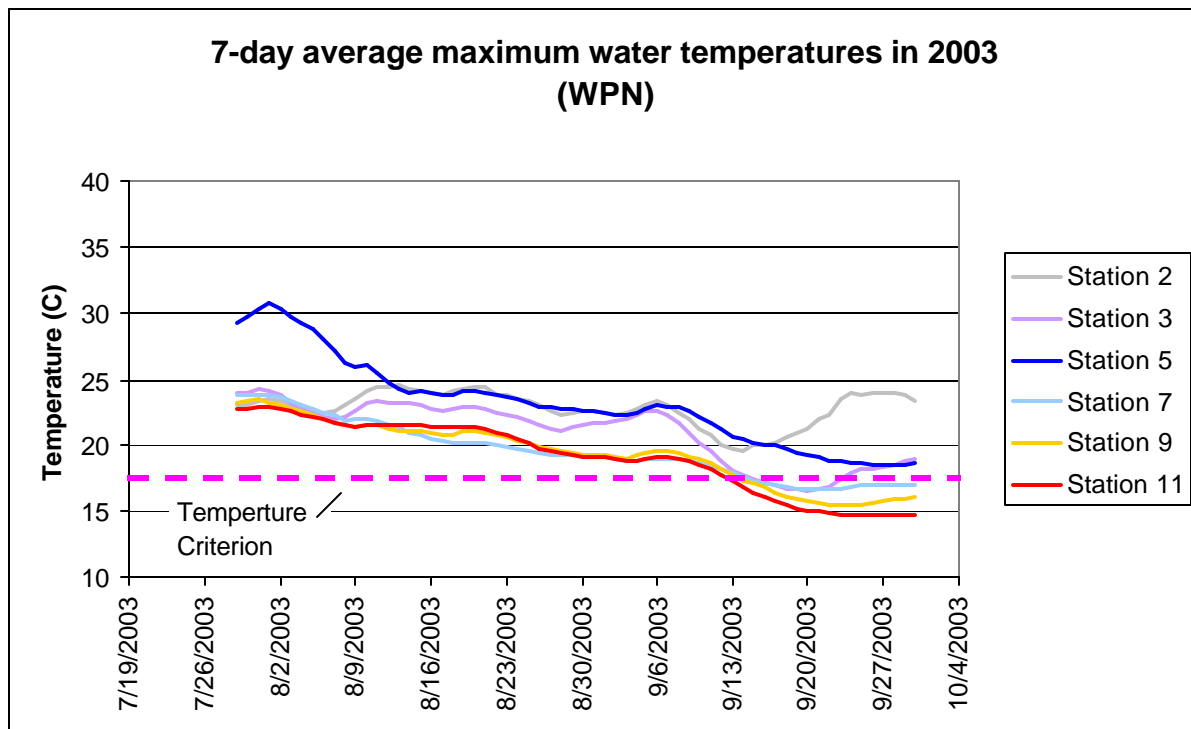


Figure 55 . Maximum daily temperatures at all monitoring sites in 2003. The Stations represented by warmer colors (5, 7, and 9) are within reach 4, the reach that has higher vegetation and continuous water. The rest of the sampling sites were collected in disconnected pools.

The only stream segment currently on the Department of Ecology's 303(d) list is the last mile of Swale Creek, at its confluence with the Klickitat River. It should be noted that the state standards indicate that measurements are to be taken from (A) well mixed portions of rivers and streams, and (B) are not to be taken from shallow stagnant backwater areas, within isolated thermal refuges, at the surface, or at the water's edge. The measurements collected in 2003 meet item A, well mixed, but arguably do not meet item B since all sites had no or negligible flow. There were no areas within Swale Creek that had measurable flow; hence, item B could not be met.

The state temperature standards indicate that “Moderately acclimated (16-20°C, or 60.8-68°F) adult and juvenile salmonids will generally be protected from acute lethality by discrete human actions maintaining the 7-DADMax temperature at or below 22°C (71.6°F) and the 1-day maximum (1-DMax) temperature at or below 23°C (73.4°F).” All sites monitored in 2003 exceeded 23 °C for one or more days. Hence temperatures throughout Swale Creek were within the range is not considered protective against lethality as described by DOE. Likewise, the temperatures described to protect from acute lethality was exceeded at the stations monitored by CKCD and the Yakama Nation from 1995 through 2003.

Actual effects of these temperatures on salmonids will vary with acclimation temperature (Cherry et al, 1977), available food (Brett et al, 1969), life history stage (Raleigh et al, 1984), and species (Cherry et al, 1977; Bjornn and Reiser 1991; Brett, 1976; Brett et al, 1982; Pennell and Barton 1996; Bell 1990). A review of studies summarized by Currie et al (1998) indicates the lethal temperature for juvenile *Oncorhynchus mykiss* is in the range of 22.7 to 29.4°C. Sublethal effects occur at lower temperatures (Brett 1969, Brett et al, 1982, Hicks, 2002). These sublethal effects can include a greater susceptibility to disease, higher caloric needs, reduced feeding efficiency, and increased overall stress.

5.2 Shade Levels

Under current conditions, the upper two reaches of the canyon (covering roughly 9 miles) are largely dry, with isolated bedrock dominated pools. In this area, shade tends to be quite low around the pools (Table 11). Reach 4, which is located in the lower 3 miles of Swale Creek (excluding the mouth), is continuously wet in summer, though flow is negligible (estimated at 0.25 to 0.5 cfs). Shade in the area is denser and reaches almost 100% in some areas.

Table 11. Summary of shade conditions in Swale Creek canyon.

Reach	Characteristics	Average Shade (range)	Maximum Potential Shade
2	Isolated bedrock dominated pools	0-20%	< 5-30%
3	Isolated pools, bedrock and cobble	18% (0-25%)	Variable 0-40%
4	Continuous water through reach, negligible flow	53% (25-100%)	Variable 25-100%
5	Largely dry	0%	Highly Variable 0-25%

The lack of soils and water in Swale Creek downstream of Warwick is the primary limiting factor on the development of riparian vegetation. Much of the upper canyon is bedrock dominated and, hence, has little shade. The lower canyon has better soils and substantially more shade. In most locations where soil is present, the soils are shallow and overly bedrock. In large flood events, the existing vegetation is often uprooted and lost in some areas. As a result, riparian vegetation decreases in some areas during a flood event. In the intervening years between flood events, revegetation starts to re-establish in the disturbed areas where soil is present. This pattern results in a dynamic riparian vegetation situation in many locations under the current condition.

Land management factors that may have affected the current situation are primarily related to factors increasing scour and peak flows. Two actions may have resulted in increased peak flows and subsequent increased scour. The railroad bed, which was constructed in 1902, confined channel, particularly in reach 2, and encroached on the channel and floodplain in places in the other reaches. The encroachment of the railroad bed would tend to concentrate peak flows into a narrower channel. As a result, stream power would be increased and sediments would be more easily transported. The bed confines the channel primarily in the upper 4 miles of the canyon (Inter Fluve, Inc, 2002). Downstream, the channel is wider and the railroad bed is less confining. Following the flood event of 1964, the railroad company apparently removed boulders from the channel. This would have reduced the roughness of the channel and allowed for greater scour of the bed. The presence of the railroad bed also affects riparian growth in areas where the bed encroaches on the channel. Narrowing and deepening of the channel upstream of the Warwick fault may also have increased peak flows, although the magnitude of the effect is unknown. The effect is likely buffered to some degree by the wide alluvial valley present throughout most of the upper basin. This valley tends to flood in peak flow events. Dispersion of flood waters across the valley would tend to reduce the overall effect of the channel modifications. Nonetheless, there may be some unknown effect on peak flows.

“Potential vegetation” was estimated based on available soils and water, adjusted upwards where channel restoration may increase vegetative growth. In reach 2, there are hot, dry, bare areas of bedrock where the potential for any vegetation development would not be expected without a change in soil depositional patterns. The success of revegetation in this reach with a change in soil depositional patterns would be dependent upon the depth and stability of such deposition. The valley is steep and there is not much potential for the development of a wide stable floodplain in most areas. Limited deposition could be created by removing the railroad bed and placing boulders or wood. Growth of vegetation would be unlikely to be substantial enough to have a measurable effect on the shade, and hence the temperature, of the isolated ponds in the reach. Potential vegetation for reach 2 under the current channel configuration was estimated at 0 to 30 percent shade. Reach 3 is similar to reach 2, however more soils are available. Potential shade for reach 3 was estimated at 0-40 percent. Reach 4 currently has a mixture of alder, cottonwood, big leaf maple, birch, willow, and riparian grasses in the riparian area. This reach has higher available moisture which likely contributes to the higher density of vegetation relative to the other reaches. There also appears to be some potential for establishment of some large conifers (ponderosa pine or Douglas fir) in pockets of deep soil (Gunther, Personal Communication).

Shade levels prior to the construction of the road bed are difficult to attain. The GLO surveys indicate that vegetation in the area was either non-existent or “scattered”. Further downstream, the upper end of reach 3 apparently had denser vegetation, however the vegetation in the deepest part

of the canyon was also characterized as “scattered”. The area in the vicinity of reach 4 apparently had relatively dense vegetation dominated by small oaks and pines in the mid-1800s, although most of the trees were small (4–10 inch diameter). This information tends to support a conclusion that historic vegetation was similar in a descriptive manner to what is assumed here as “potential” vegetation. The presence of pines in the lower section of the basin also supports the observation that pines could be supported in this area.

For the purposes of modeling stream temperature, the “potential” shade was assumed to be substantially higher than our estimates would suggest. This assumption will result in an underestimation of historic or potential stream temperature, but represents a conservative assumption.

5.3 Stream Flow

Based on the collective information, flows in Swale Creek downstream of Harms Road are supported principally by runoff from numerous small tributaries draining the surrounding uplands downstream of Warwick (e.g., Columbia Hills and High Prairie). Groundwater discharge provides minimal baseflow to Swale Creek. Because geologic structure (the Warwick Fault) limits groundwater discharge to Swale Canyon, the lack of groundwater baseflow into the canyon has existed for geologic time, unchanged by land use change within the subbasin. The only opportunity for flows in Swale Canyon to have been greater than current conditions is if, pre-development, they were sustained by discharge from the Alluvial Aquifer east of Warwick. The available historical information indicates that was not the case.

Information from GLO surveys conducted in the 1860s (pre-development) suggests that surface water hydrology in Swale Valley and Swale Canyon was similar to current conditions. The 1860s GLO information (depicted on Figure 29) indicates a long narrow swale along the approximate current Swale Creek alignment within Swale Valley east of Warwick. The notes from their October 1860 survey (end of dry season) do not indicate a defined or incised channel within the swale, suggesting low-velocity flows. There were no trees noted in or adjacent to the swale as might be expected if there was perennial flow conditions. Furthermore, the GLO’s survey markers within the swale were constructed using the same methods as those outside the swale indicating that, if water was present, it was not of sufficient depth to cause them to modify their methods. Additionally, two fields and a road were built within the area mapped as a swale suggesting a lack of standing water. One would expect that fields and roads would not be built in water if upland areas were available.

West of Warwick, the notes do not indicate the presence of a channel for much of reach 2 and indicates the upper portion of reach 3 was dry. In the deeper portion of the canyon, the notes indicate that water was present, however the channel was dry at the line between townships 3N and 4N. Surface water flows draining the lower portion of the stream (T4N, R14E) were surveyed in April (wet season); hence survey notes do not provide information regarding the low flow situation in the lower 5 miles of the creek.

Overall, these pre-development wet season and dry season descriptions from the 1860s are fundamentally the same as current hydrologic conditions in the Swale Creek subbasin, although the channel configuration in reach 2 was either very different or failed to be mapped for some

reason. All surveys conducted in Swale basin were conducted during periods that were wetter than normal with the exception of the lower 5 miles of Swale Creek, which was surveyed in a relatively average year (Garfin and Hughes, 1996; Cook et al, 1999); hence pre-development conditions represented by the GLO information were likely to be wetter than normal.

Based on the collective weight of evidence, we conclude that hydrologic conditions, including Swale Creek streamflows, are fundamentally unchanged as a result of land use changes within the Swale Valley or elsewhere in the Swale Creek subbasin. The GLO information collected in the 1860s, prior to development of Swale Valley, indicates that flows in Swale Creek at that time were generally the same as exist now. Runoff from the adjacent uplands sustains Swale Creek flows into late springtime. Once the spring runoff is over, Swale Creek flows quickly diminish, leaving only intermittent flow and discontinuous pools within Swale Canyon. Groundwater discharge from the basalts has never provided a significant contribution to creek flows in Swale Canyon west of Warwick, at any time of the year. In short, the natural hydrologic condition is a limiting factor for instream habitat in Swale Canyon.

5.4 Estimated Stream Temperature under “Background” Conditions

In a previous temperature modeling efforts we found that *Heat Source* produced simulations as good as or slightly better than other stream temperature models (Theurer et al, 1984). *Heat Source* is a mechanistic model that predicts maximum daily temperatures directly. However, process models become somewhat empirical when parameter input values must be estimated from limited data, and during calibration when input values are adjusted to reduce the differential between predicted and measured stream temperatures.

Based on our best estimates of how conditions currently vary from the assumed “maximum potential shade”, the average increase in temperature relative to “historical” temperatures in Swale Creek is approximately 2.4°C, with a maximum increase at any location of 3.4°C. The actual deviation of temperature from current conditions could be somewhat larger or smaller than predicted by our modeling, although we suspect that the predicted deviation is likely an upper limit. The vegetation used to model potential conditions was assumed to be substantially higher than the “potential” vegetation estimated for existing channel configuration. The assumed shade also represents the likely maximum shade level for a system that is naturally variable as a result of changes in vegetation associated with floods. Fire also played a major role in this portion of the country, and historically (Agee 1993) would have contributed to natural variability in shade. The small size of trees (4-10 inches with pockets of larger trees) in the lower portions of Swale Creek in the mid-1880s suggest that the stands were young, possibly due to a stand replacing fire some 10 to 20 years prior to the survey. The presence of pockets of larger trees also suggests a fire regime, which often left seemingly random pockets of vegetation untouched for longer periods of time. As was described above, shade has likely always been variable, affected by flood events (and likely fire). The use of the maximum potential shade in the model runs will tend to reflect conditions several years after a disturbance event, such as flood or fire, but likely overestimates reductions in temperature on average.

As was discussed in Section 5.6.3, problems were encountered in applying the *Heat Source* model in this situation. The model was applied in a situation that was outside of the data used to develop the model. In such cases, the possibility for spurious results exists. Therefore, the results of the

modeling should be interpreted carefully. Actual expected change between scenarios would likely be less than estimated by the model due to conservative assumptions regarding historical vegetation.

5.5 Implications Regarding State Standards

The stream reach that is currently listed on the State of Washington 303(d) list is in the lower portion of reach 4 (extending into reach 5). The Heat Source model predictions suggest that the current temperature criterion may be met in some years in locations within reach 4 where the riparian vegetation is at its maximum development. Predicted temperatures were in the range of 17.2 to 18.9 °C in this reach for average years. For 2003, an unusual year, the model predicts temperatures in the range of 20.9 to 22.9 °C under the assumed historical vegetation, which exceeds the state criterion of 17.5 °C. The predicted stream temperature for 2003 approaches or exceeds the temperature the Department of Ecology defines to avoid lethal conditions.

As was discussed in the previous section, these scenarios represent the maximum attainable level of shade expected within this reach and are likely overestimates of the actual reduction in water temperature that can be attained. Therefore, it is unlikely that the state criterion can be met under any conditions in reach 4.

The State of Washington temperature standard addresses natural temperatures that exceed the criteria. Where the criterion is exceeded, the temperature of the water must be within 0.3°C of the natural temperature to be considered within standard. Our estimates of natural temperature are imprecise. The model has an error of $\pm 2.5\%$ and the calibration of the model required modifications to input variables that likely resulted in an underestimate of natural stream temperature in the reach. Hence, we cannot precisely quantify historical stream temperature. Protection of shade within the reach should prevent excursions beyond the 0.3°C limit. Enhancement of shade, where possible, may result in reductions of stream temperature, although the magnitude of effect may be nominal.

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