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Groundwater-Surface Water Interactions along the Naches and Tieton Rivers, Summer and Fall 2004

Abstract

This study provides information on groundwater inflow and outflow on the Naches and Tieton rivers for a temperature model needed to complete a Total Maximum Daily Load (water cleanup plan) analysis. Methods used included seepage runs, vertical hydraulic gradient measurements, a thermal infrared survey, and hyporheic temperature measurements. Monitoring activities were conducted in the summer and fall of 2004.

The seepage runs consisted of a one-day flow analysis of the lower 43 miles of the Naches River and six miles of the Tieton River. Each river was divided into stretches of 0.6-12 miles, and flow measurements were taken at the top and bottom of each reach. The Naches River flow reaches were then aggregated into six large reaches based on morphologic characteristics. Four aggregated reaches on the Naches showed flow gains. One of the aggregated reaches showed flow losses. Two reaches on the Tieton River indicated flow gains, while two indicated flow losses. The total flow gain estimated on the Naches River during the seepage run was 200 cfs, and flow loss was 59 cfs. The total flow gain estimated on the Tieton River was 42 cfs, and flow loss was 31 cfs.

Gain/loss results from the more localized methods were generally in agreement with the seepage run results.

The temperature of inflowing groundwater measured by instream piezometers and hyporheic temperature loggers was 9.8-17.7°C in the Naches River and 12.7-13.9°C in the Tieton River. August groundwater/hyporheic temperatures were 1-6°C warmer than October groundwater/ hyporheic temperatures.

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Introduction

Purpose

The purpose of this assessment was to (1) gather and interpret evidence of groundwater inflow and outflow along the Naches and Tieton rivers and (2) estimate the temperature and volume of groundwater where evidence indicates inflow to the river. This information is needed for a temperature model of the Naches and Tieton rivers being developed for a Total Maximum Daily Load (TMDL) analysis (LeMoine and Brock, 2004). Several methods were used to identify gaining (groundwater inflow) and losing (groundwater outflow) reaches of the river, including review of existing literature, a seepage study, vertical hydraulic gradient measurements, thermal infrared survey (TIR), and hyporheic temperature measurements.

Background

The Naches Valley is located at the western edge of the Columbia River Plateau and is underlain by Columbia River Basalt Group (CRBG) as well as older pre-Columbia River Basalt (Drost and Whiteman, 1986; Walsh, 1986). The CRBG is thinnest along the edges of the plateau exposing the underlying older pre-Columbia River Basalt in the upper Naches River watershed.

Recent alluvial material underlies the wider areas of the river valley and provides a continuous connection for groundwater/surface water interactions. The alluvial material consists mostly of stream-deposited silt, sand, and gravel. Landslide deposits are also found along the river between river mile (RM) 21 and 24. A cursory scan of a portion of the available drilling logs located near the river indicate that alluvial materials range from non-existent to 50-feet thick along the valley bottoms. Golder Associates (2002) report alluvial deposits up to 150-feet thick along the Naches River channel.

Most of the Naches River Valley downstream of the Tieton River is underlain by the Upper Ellensburg Formation which consists of silts, clays, sands, and gravel deposited on top of or between basalt flows. However, this layer is absent directly below the river as seen in Bentley's (1983) cross-section near the mouth of the river. Saddle Mountain, Wanapum, and Grande Ronde basalt layers underlie the river and the Ellensburg Formation. Grande Ronde Basalt is exposed throughout the valley, especially in the upper watershed. A more recent intercanyon basalt flow, the Tieton Andesite, forms the Naches Heights south of the alluvium along the river between the North Fork of Cowiche Creek and the Tieton River.

Upstream of the confluence with the Tieton River, the narrower Naches channel incised in the basalt may be hydraulically connected with the river. However, connections from fractures are spatially variable and, unless groundwater surfaces as springs, interactions between groundwater and the river are difficult to locate in the basalt.

A more detailed study of geologic logs in the area is needed to determine which aquifer areas connect with the river.

Methods

Seepage Run

A two-day seepage run, or comprehensive flow survey, was conducted on July 20 and 21, 2004 by Ecology and the U.S. Geological Survey (USGS) Tacoma Office staff to identify gaining and losing reaches along the Naches and Tieton rivers as well. Flow measurements were made at 35 sites along the Tieton, Naches, and tributary mouths as listed and shown in Table 1 and Figure 1.

The Naches seepage run extended from the confluence of the Little Naches and American rivers in the upper watershed (RM 43) to the mouth of the Naches River (RM 0.5). The Tieton seepage run extended from below Tieton Canal Headworks (RM 14) to the confluence of the Tieton River with the Naches River (RM 0.4).

Duplicate or replicate flows were measured at 15 sites to evaluate precision. The purpose of the seepage run was to develop a mass balance on all the measurable inflows and outflows as close to the same time as possible. In this way differences in flow between consecutive gaging sites not attributable to surface inflows or outflows could be identified, and groundwater influences investigated in those areas. The mass balance equation for this analysis is:

Net seepage gain/loss = $(Q_{downstream} - Q_{upstream}) - T + D$ where

$Q_{downstream}$ = Streamflow measured at downstream transect
$Q_{upstream}$ = Streamflow measured at upstream transect
T = Inflow from tributaries
D = Diversions

Vertical Hydraulic Gradient

Mini-piezometers were used to evaluate the direction of groundwater flow by providing a comparison of head elevation below the riverbed with that of the river. These long, narrow metal pipes with small openings at the bottom were installed in shallow riverbank areas at eight sites in the Naches River and one site in the Tieton River (Figures 1 and 2). Mini-piezometer measurements were made four times between June 29 and October 19, 2004. An attempt was made to locate mini-piezometers in areas where groundwater discharge was suspected such as wider alluvial areas. Ease of access and aereal coverage of the waterways were also considered in site selection.

Mini-piezometers consisted of 7-foot long, 3/4-inch diameter galvanized steel pipes crimped closed on the bottom. Small holes (1/8-inch diameter) were drilled into the bottom six inches of the pipe to allow water to enter. The piezometers were hand-driven into the streambed using a fencepost driver until the top of the sampler was above the water surface and the bottom was three to five feet below the bottom of the riverbed. Each mini-piezometer was equipped with a

Table 1. Sites where flow was measured for July seepage runs.

River	River Mile	Station ID	Flow Measurements
Naches River			
American River	0.5	38-AME-0.5	
Little Naches River	0.1	38-LIT-0.1	Replicate
Naches River	43.0	38-NAC-43	
Naches River	42.0	38-NAC-42	Two duplicate
Naches River	41.1	38-NAC-41.1	Replicate
Naches River	40.0	38-NAC-40	
Naches River	38.8	38-NAC-38.8	
Naches River	36.0	38-NAC-36	
Naches River	34.0	38-NAC-34	
Naches River	31.1	38-NAC-31.1	Duplicate
Nile River	0.9	38-NIL-0.9	
Rattlesnake Creek	0.2	38-RAT-0.2	
Rattlesnake Creek diversion	0.2	38-RAT-0.2div	Replicate
Naches River	30.5	38-NAC-30.5	
Naches River	28.0	38-NAC-28	
Naches River	26.8	38-NAC-26.8	Duplicate
Naches River	23.9	38-NAC-23.9	
Naches River	20.8	38-NAC-20.8	Replicate
Naches River	17.6	38-NAC-17.6	
Naches River	16.0	38-NAC-16	
Naches River	12.8	38-NAC-12.8	Replicate
Cowiche River	0.5	38_COW-0.5	
Naches River	0.5	38-NAC-0.5	Replicate
Tieton River			
Tieton River	14.0	38-TIE-14	Replicate
Tieton River	13.0	38-TIE-13	
Tieton River	13.0	38-TIE-13side	
Tieton River	11.0	38-TIE-11	Replicate
Tieton River	9.0	38-TIE-9	Replicate
Tieton River	8.5	38-TIE-8.5	
Tieton River	6.1	38-TIE-6.1	Replicate
Tieton River	4.0	38-TIE-4	
Tieton River	3.0	38-TIE-3	
Tieton River	2.3	38-TIE-2.3	Duplicate
Tieton River	1.5	38-TIE-1.5	Two duplicate
Tieton River	0.4	38-TIE-0.4	

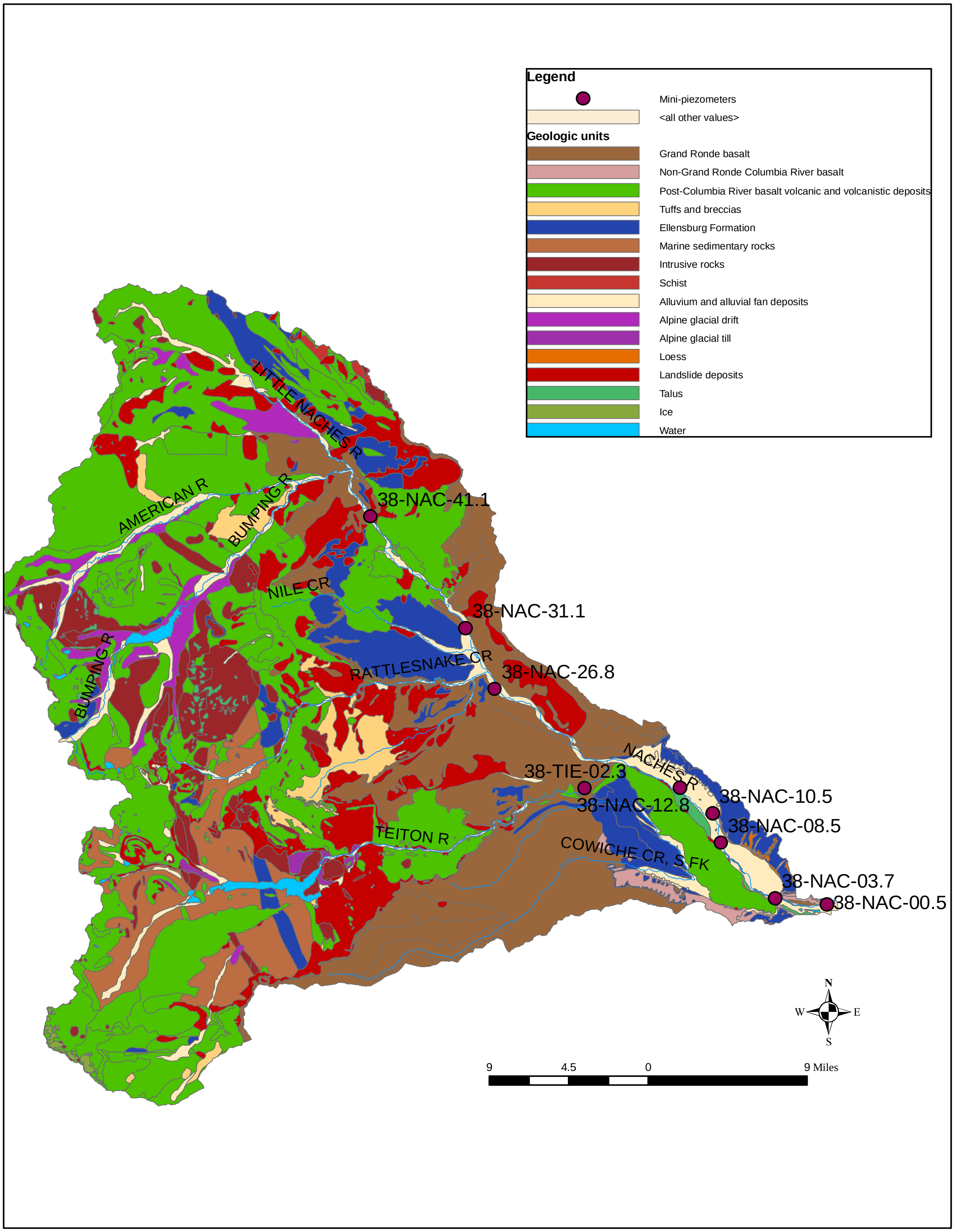

Figure 1. Geologic units and mini-piezometer locations in the Naches Basin (WRIA 38).

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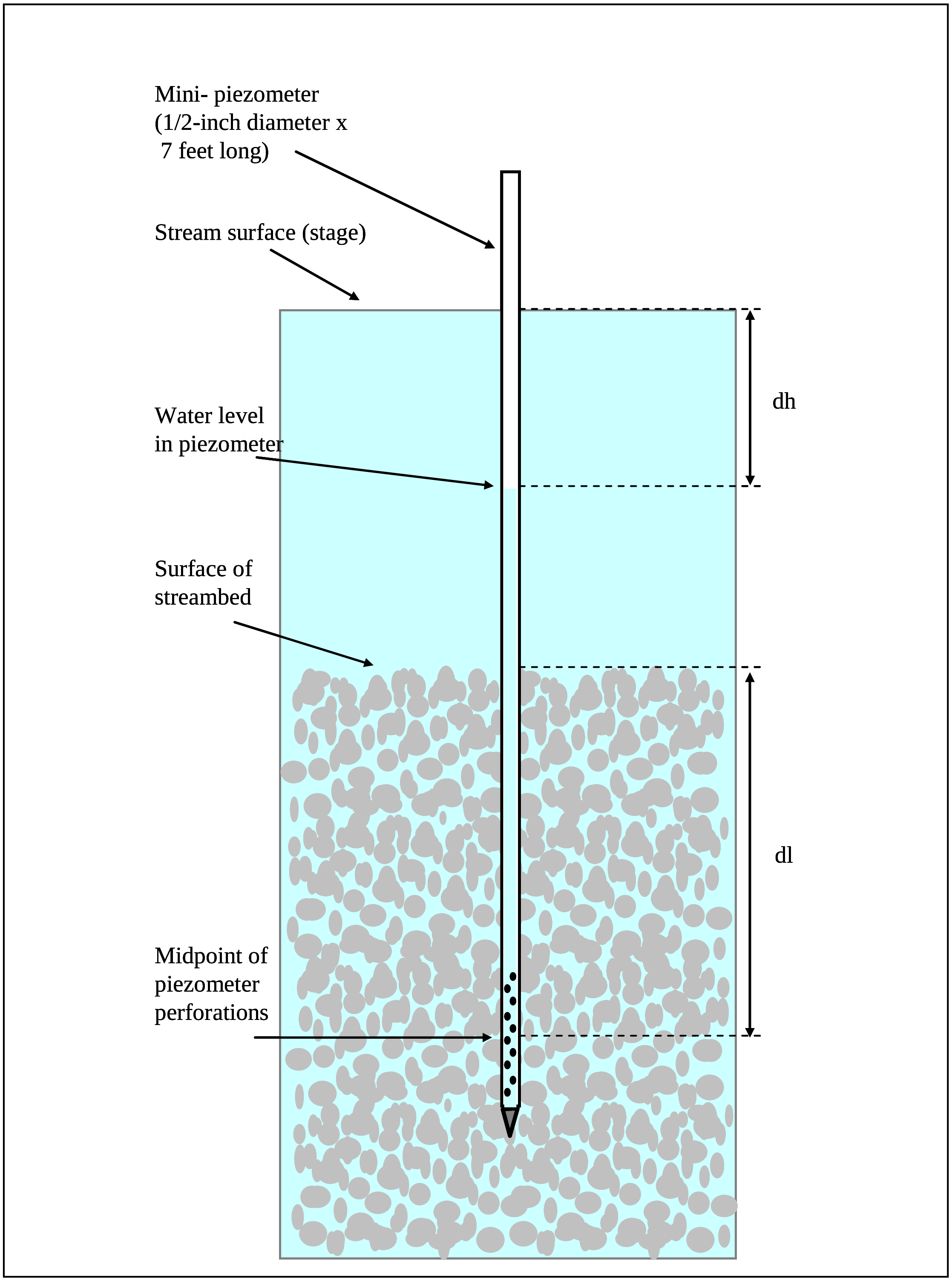

(diagram not to scale)

Figure 2. Schematic of instream mini-piezometer installation (from Sinclair, 2001).

screw-on cap to protect the pipe during installation. The piezometer remained capped except when samples were collected. Each piezometer was developed initially using a peristaltic pump to ensure a good hydraulic connection with the streambed sediments. See Appendix A for mini-piezometers location and construction details.

On the day of installation, mini-piezometers were allowed to equilibrate after installation and development. When the water inside the piezometer had equilibrated (10-15 minutes), the depth-to-water inside the piezometer was measured using an E-tape (electrical water depth sensor). The stream stage was measured by extending an engineer's measuring tape along the outside of the piezometer pipe from the top of the pipe to the river surface. Both measurements were made to the nearest 0.01 foot. During subsequent sampling events, the same procedure was used as on the first day excluding the initial pause for equilibration. If the water level inside the mini-piezometer was higher than the outside river stage, then groundwater was assumed to be discharging to the river. If the water level in the river was higher than that in the mini-piezometer, then water was assumed to be seeping out of the river and into the streambed.

Three of the piezometers were vandalized during the study; therefore, the record is incomplete at those sites (38-NAC-08.5, 38-NAC-10.5, and 38-NAC-12.8). One piezometer was not perpendicular to the streambed. The depth-to-water measurements were corrected at this piezometer using trigonometric calculations.

Streambed water temperatures were measured by lowering a thermometer to the bottom of the piezometer and allowing the thermometer to stablize for about one minute. The thermometer was then lifted to the surface and a measurement recorded. The temperature of the groundwater was monitored until consecutive measurements stablized to within 10%. Surface water temperatures were measured at the same time and location. The mini-piezometers were removed after the last measurements in October 2004.

The vertical hydraulic gradient between the river and the piezometer was calculated as the ratio of the depth of piezometer water below the surface water level (dh) to the distance from the top of the streambed to the mid-point of the piezometer opening (dl) as illustrated in Figure 2 and expressed in the following equation.

$$i_v = dh/dl$$

where: i_v = vertical hydraulic gradient (L/L)
dh = difference between the river water level and the mini-piezometer water level (L)
dl = distance from the top of the streambed to the midpoint of the piezometer perforations (L)

Positive values for i_v indicate groundwater discharge to the river, and negative values indicate surface water flow into the streambed.

Thermal Infrared Survey

A thermal infrared (TIR) survey of the mainstem Naches River was conducted on August 14, 2004. No TIR survey was flown on the Tieton River. The longitudinal stream temperature profile produced by the survey was used to document areas of potential groundwater, tributary, and irrigation water inflows (Watershed Sciences, Inc., 2004). Cameras attached to the underside of a helicopter recorded thermal images as the helicopter was flown longitudinally along the stream channel. These images were linked with GIS locations.

Hyporheic Temperature

Temperature data loggers (Tidbits) were installed at four sites near piezometer and surface water temperature measurement installations in order to distinguish flow direction into or out of the river (38-NAC-08.5, 38-NAC-10.5, 38-NAC-26.8, and 38-TIE-02.3).

A five-foot long steel pipe was pounded into the streambed using a five-foot driver to provide a sleeve for Tidbit installation. When the pipe was pounded to the proper depth, the driver was removed, and the Tidbit and shield were securely fastened onto one end of a metal wire. The Tidbit and shield were threaded through a loop in the wire, the wire twisted closed over the assembly, and duct tape wrapped around the wire, Tidbit, and shield. This assembly was lowered into the bottom of the pipe. The pipe was then carefully removed while the wire remained in place and was fastened to the base of the piezometer pipe.

Two Tidbits were installed at each site below the streambed at two depths: one- to two-foot and three- to four-foot. Differences in temperature with increased depth provide an indication of hyporheic flow direction (Stonestrom and Constanz, 2003). In the case of the Naches River, groundwater is cooler than surface water in summer. If the temperature in the shallower thermistor is warmer than the deeper thermistor, and fluctuates over the course of a day, then flow is assumed to be away from the river. Hyporheic flow would, therefore, not influence surface water temperature. On the other hand, if the temperature in the shallow zone is similar to that in the deeper zone, and relatively stable during the day, then flow is assumed to be toward the river. In this case, hyporheic flow could influence surface water temperature.

Results

Seepage Runs

Changes in river flow between consecutive reaches during the July 20 and 21, 2004 seepage runs are shown in Table 2. Flow measurements at each site are shown in Appendices B and C. In addition to flow measurements for the rivers and tributaries, flows for the major diversions were also taken into account when estimating change in flow from one location to the next. The two largest withdrawals, the Naches-Selah Irrigation Canal (RM 17.1) and the Wapatox Power Canal (RM 18.4), together withdrew 277 cfs on July 20, 2004 (U.S. Bureau of Reclamation (USBoR) Hydromet web site). A comprehensive summary of smaller flows and withdrawals was provided by the USBoR (Dave Henneman, 2005)

The flow on the Tieton River at RM 0.4 was assumed to be the same as that at the confluence with the Naches. The Tieton flow measured at RM 0.4 was 287 cfs on July 20, 2004. The USBoR telemetered daily average flow for the Tieton River near Tieton Canal Headworks at RM 14.2 was 274 cfs on both July 20 and 21, 2004. Therefore, it was assumed that the flow at RM 0.4 and the inflow to the Naches River was also 287 cfs on both days. The Tieton flows into the Naches at RM 17.5.

In order to distinguish real gains and losses from measurement error, a threshold of 5% difference in flow between consecutive sites was used**.** For comparison, the percent differences between duplicate and replicate flow measurements are shown in Appendix D. The measured flow difference exceeded 5% at ten sites on the Naches and four sites on the Tieton (Table 30). On the Naches, reaches showing greater than 5% *gains* were observed in the following stretches: RM 43-42, RM 36-34, RM 30.5-28.0, RM 23.9-20.8, RM 20.8-17.6, and RM 12.8-0.5. Reaches showing greater than 5% *losses* were observed in the following stretches: RM 41.1-40.0, RM 31.1-30.5, RM 26.8- 23.9, and RM 17.6-16.0.

Two stretches on the Tieton River, RM 4.0-3.0 and RM 1.5-0.4, indicated a gain of greater than 5%. The stretch between RM 3.0 and 2.3 had a loss exceeding 5%. There are no official diversions on the Tieton River in the stretch from RM 14.0 to RM 0.4.

Table 2. Differences in flow between consecutive reaches along the Naches and Tieton rivers on July 20 and 21, 2004. Flow data for the river, tributaries, and withdrawals are shown in Appendices B (Naches) and C (Tieton).

Site	Change from upstream (cfs)	Change from upstream (%)
Naches River		
Little Naches and American rivers to 38-NAC-43	-11.4	-3.3
38-NAC-42	60.5	18.0
38-NAC-41.1	-2.9	-0.7
38-NAC-40	-23.2	-5.9
38-NAC-38.8	-7.3	-2.0
38-NAC-36	10.0	2.8
38-NAC-34	21.6	5.8
38-NAC-31.1	-13.3	-3.4
38-NAC-30.5	-54.0	-12.1
38-NAC-28	76.1	19.4
38-NAC-26.8	-4.3	-0.9
38-NAC-23.9	-57.5	-12.4
38-NAC-20.8	64.2	16
38-NAC-17.6	44.7	9.5
38-NAC-16	-33.7	-9.1
38-NAC-12.8	-25.7	-5.5
38-NAC-0.5	95.1	25.9
Tieton River		
38-TIE-14 to 38-TIE-13	9.7	3.7
38-TIE-11	-1.8	-0.7
38-TIE-9	2.6	1.0
38-TIE-8.5	1.2	0.5
38-TIE-6.1	9.0	3.3
38-TIE-4	-16.3	-5.8
38-TIE-3	16.9	6.4
38-TIE-2.3	-3.8	-1.3
38-TIE-1.5	-18.0	-6.5
38-TIE-0.4	25.4	9.7

Table 3. Gaining and losing stretches of the Naches and Tieton rivers based on data from July 20 and 21, 2004 seepage runs (Appendices B and C).

RM stretch	Gain or Loss (cfs)	Length of stretch (mi)	Gain or Loss (cfs/mile)
Naches River			
43.0-42.0	60.5	1.0	61
41.1-40.0	-23.2	0.9	-26
36.0-34.0	21.6	2.0	11
31.1-30.5	-54.0	0.6	-90
30.5-28.0	76.1	2.5	30
26.8-23.9	-57.5	2.9	-20
23.9-20.8	64.2	3.1	21
20.8-17.6	44.7	3.2	14
17.6-16.0	-33.7	1.6	-21
16.0-12.8	-25.7	3.2	-8.0
12.8-0.5	95.1	12.3	7.7
Tieton River			
6.1-4.0	-16.3	2.1	-7.7
4.0-3.0	16.9	1.0	17
2.3-1.5	-18.0	0.8	-23
1.5-0.4	25.4	1.1	23

+: Gain
- : Loss

Aggregated reaches

The larger picture of gains and losses on the Naches is portrayed in this section by aggregating the 17 smaller reaches into six larger reaches based on geology and channel characteristics (including width, gradient, and depth). The estimated gains and losses for the larger reaches are shown in Table 4 with details in Appendix B.

Table 4. Gains and losses in aggregated reaches on the Naches River.

RM stretch	Structural characteristics	Change from upstream (cfs)	Percent change from upstream	Gain or loss where significant (cfs/mile)
43-38.8	Narrow basalt channel, little alluvium.	27.0	8.0	6.4
38.8-31.1	Steep, narrow andesite basalt canyon, upper half contains more alluvium than lower half.	6.8	1.9	NA
31.1-26.8	Wider alluvial valley at the mouths of Nile and Rattlesnake creeks.	26.7	7.0	6.2
26.8-17.6	Narrow basalt channel, little alluvium.	52.7	11.2	5.7
17.6-12.8	Mouth of the Tieton River, widening alluvial fan at the upper end	-59.4	-16.0	-12.3
12.8-0.5	Wide, flat alluvial channel 1-2 miles wide, 150 feet of unconsolidated sediments at RM 7.5.	95.1	25.9	7.7

RM = river mile

Vertical Hydraulic Gradient

Vertical hydraulic gradient estimates are shown in Figures 3 and 4. The data used to calculate gradients are shown in Appendix E. Positive gradients were observed on the Naches River at RM 3.7 and 10.5 and on three out of four dates on the Tieton at RM 2.3, indicating flow of groundwater to the river. Consistent negative gradients were observed on the Naches at RM 0.5, 8.5, 12.8, and 26.8, indicating loss of river water to groundwater. Both positive and negative gradients were observed on the Naches River at RM 31.1 and 41.1, and on the Tieton River at RM 2.3.

Thermal Infrared Survey

TIR results were used to develop the temperature profile for the Naches River shown in Figure 5 (Watershed Sciences, Inc., 2004). Locations and temperatures of tributaries, springs, and other surface inflows shown on Figure 5 are listed in Appendix F.

The temperature of the Tieton River at the confluence with the Naches was 14.7°C according to the TIR output, while that of the Naches River immediately upstream of the confluence was 18.8°C. Figure 5 illustrates the cooling impact of the Tieton River on the Naches River during the TIR survey.

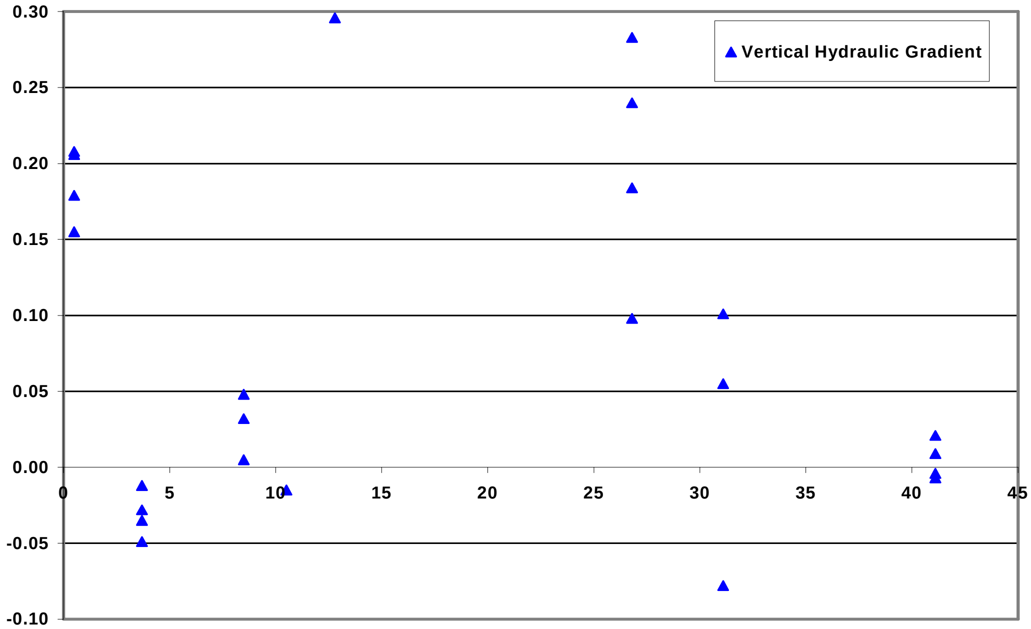

Figure 3. Vertical hydraulic gradient estimates at mini-piezometer sites on the Naches River.

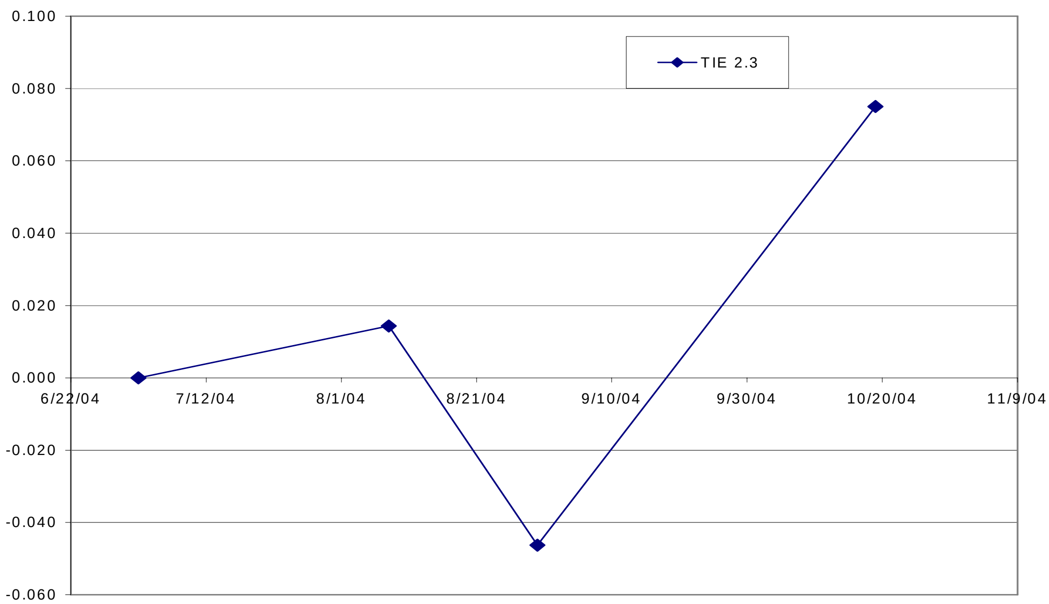

Figure 4. Vertical hydraulic gradient estimates at RM 2.3 on the Tieton River.

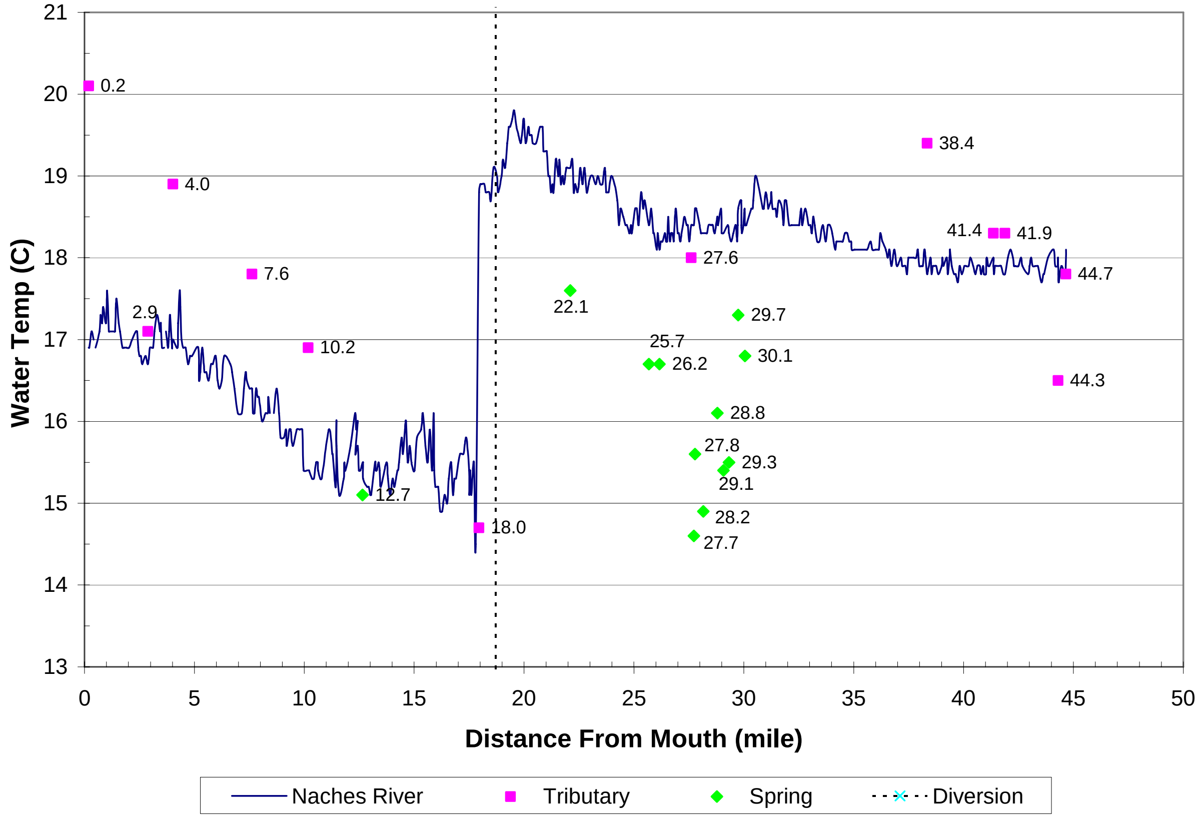

Figure 5. Median sampled temperatures from the TIR survey on the Naches River on August 14, 2004 (Watershed Sciences, Inc, 2004). Distances from the mouth (miles) are 0.5 mile higher than those obtained using USGS 1:24,000 maps.

Hyporheic Temperature

Temperature results for sites with Tidbit thermistors are shown in Figures 6 and 7.

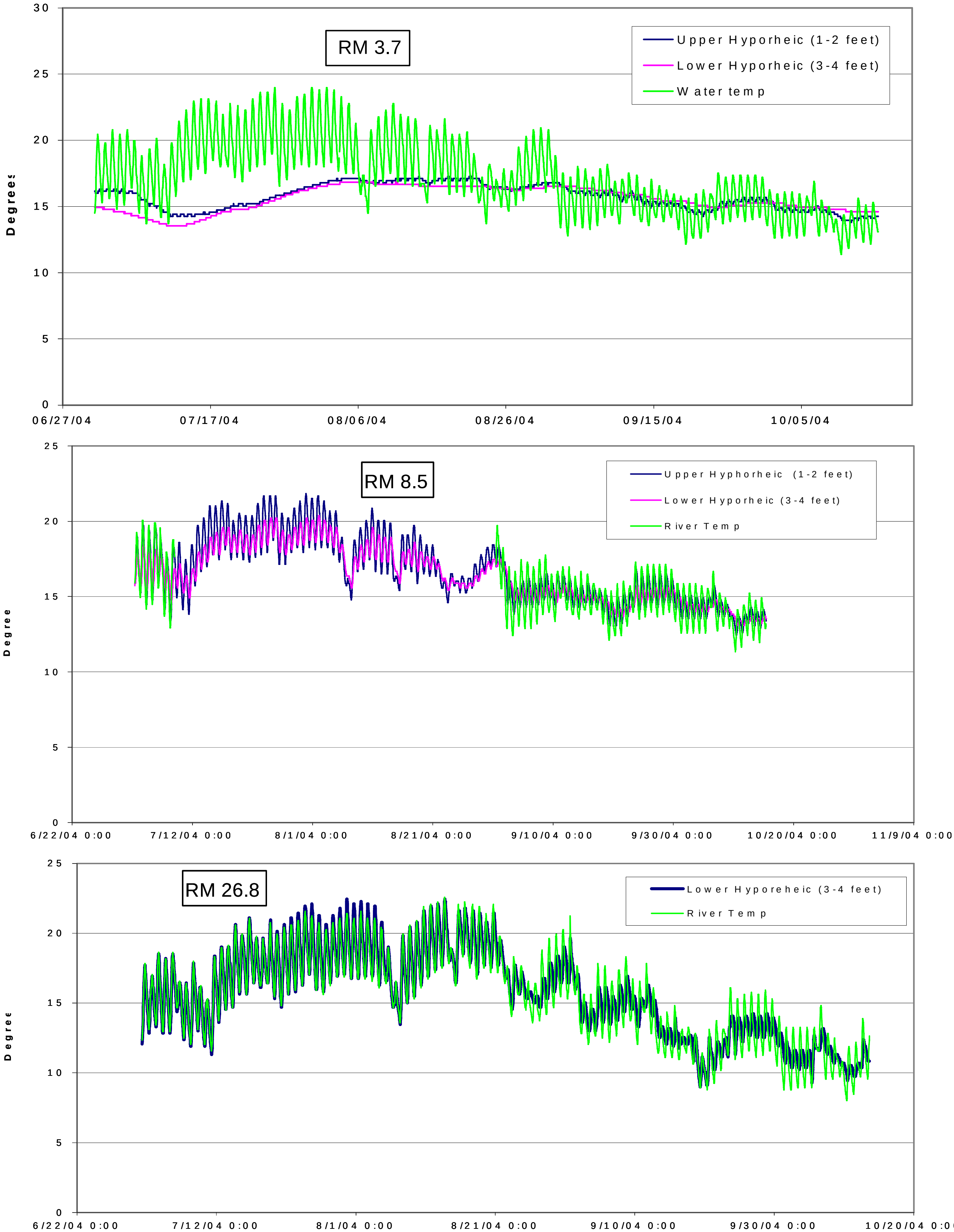

Figure 6. Temperatures in ^{0}C in the upper (1-2 feet) and lower (3-4 feet) depths in the hyporheic zones in the Naches River at RM 3.6, 8.5, and 26.8.

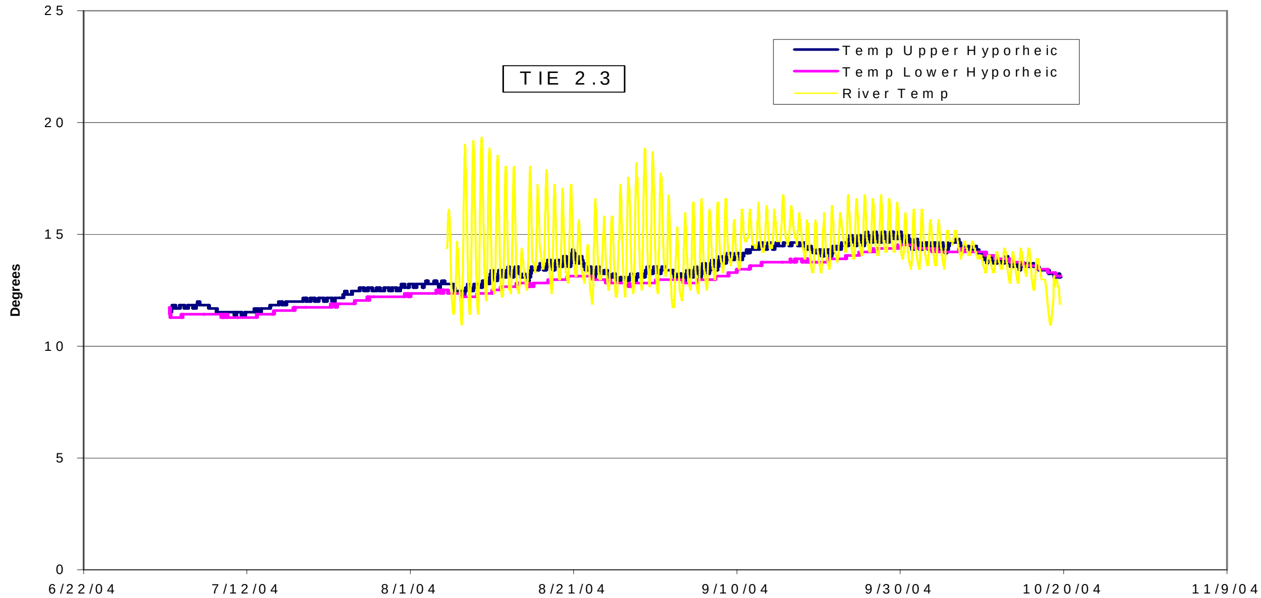

Figure 7. Tidbit temperatures in °C at 1.0-foot (Upper) and 2.3-foot (Lower) depths in the hyporheic zones in the Tieton River at RM 2.3

Temperature of Inflowing Groundwater

The temperature of the inflowing groundwater was assumed to be represented by the values measured in the mini-piezometers and hyporheic thermistors shown in Table 5.

Table 5. Temperatures observed in piezometers (P) and hyporheic thermistors closest to the streambed (H) are reported in °C.

RM	Aug 3-9, 2004	Aug 31-Sept 2, 2004	Oct 11-19, 2004
Naches River			
0.5	NA	16.4 (P)	14.7 (P)
3.7	17.1 (P), 17 (H)	16.8 (P), 17 (H)	13.5 (P), 14 (H)
8.5	15.9 (P)	17.1 (P)	NA
26.8	17.7 (P), 18 (H)	16.8 (P), 16 (H)	11.2 (P), 12 (H)
31.1	14.5 (P)	13.6 (P)	13.5 (P)
41.1	15.6 (P)	14.3 (P)	9.8 (P)
Tieton River			
2.3	12.7 (P), 12.8(H)	13.8 (P), 13.4 (H)	12.3 (P), 13.9 (H)

Discussion

Evaluation of Methods

Seepage run estimates, TIR results, and vertical gradient results were considered the most reliable indicators for groundwater gain or loss. Seepage run estimates indicate the cumulative gain or loss in a reach. In order to understand how similar parts of the Naches River behave, smaller individual reaches were aggregated into six larger reaches based on geologic and fluvial characteristics such as channel gradient, width, and depth. Alluvial areas, in particular, would be expected to respond as a whole due to the high porosity storage capacity compared to consolidated formations.

TIR results included a longitudinal temperature profile and color imagery along the Naches River. Seepage run estimates and TIR analysis both included thorough quality assurance. There is a slight discrepancy between the river mile numbers in the surveys for the same locations. The TIR survey reported river mile numbers that were 0.5 mile higher than those reported for the same location by other survey methods. The other survey methods, including the seepage survey, derived river miles from the USGS 1:24,000 maps for the basin. Therefore, the TIR survey river miles were amended in the following discussion to correspond with the USGS river miles.

Compared with seepage run and TIR analyses, vertical gradient measurements represent a more localized measure of the direction of groundwater movement in the immediate area surrounding the piezometer. The number of locations monitored in this study was too few to adequately characterize the river. However, the measurements are useful for comparison with larger-scale analyses.

The hyporheic temperature results indicate that the Tidbit temperature sensors did not fully equilibrate until the latter part of the study due to the disruption of the substrate caused by installation. A lag time between installation and equilibration has been noted on similar surveys (Sinclair, 2005). Until a relatively high-flow event occurs that rearranges the streambed and fills in around the sensors, results may not be representative of the depth being sampled. However, patterns indicating groundwater inflow or outflow were discernible in this study, even before full equilibration.

Gaining and Losing Reaches

Significant gains in flow were found in the following reaches during the seepage survey.

Naches River

- RM 43-38.8 (8.0%)
- RM 31.1-26.8 (7.0%)
- RM 26.8-17.6 (11.2%)
- RM 12.8-0.5 (25.9%)

Tieton River

- RM 4.0-3.0 (6.4%)
- RM 1.5-0.4 (9.7%)

Losses were measured at the following locations:

Naches River

- RM 17.6-12.8 (-16.1%)

Tieton River

- RM 6.1-4.0 (-5.8%)
- RM 2.3-1.5 (-6.5%)

Results from seepage runs on the Naches and Tieton rivers are compared below with other groundwater/surface water analyses.

Naches River

Naches RM 43.0-38.8

An 8% increase in flow was measured between RM 43.0 and RM 38.8. The narrow basalt channel is lined with alluvial material of unknown thickness, which would facilitate groundwater/surface water exchange. The vertical gradient in the piezometer at RM 41.1 indicated a fluctuating gradient, positive on half of the dates and negative on the other half. The measurement was positive on the date closest to the seepage survey, consistent with the seepage run indication of groundwater inflow.

Naches RM 38.8-31.1

There was no significant change in flow between RM 38.8 and RM 31.1 during the seepage survey. Alluvial material lines the channel, which is wider at the upper end of the stretch than at the lower end. The TIR survey indicated multiple channels and gravel bars in the stretch which also facilitate groundwater/surface water exchange. The vertical gradient measurement at the RM 31.1 piezometer was positive two weeks after the seepage survey, indicating groundwater inflow. However, in early July and September the vertical gradient was negative, indicating that vertical flow direction was variable.

Naches RM 31.1-26.8

The seepage survey indicated a 7% increase in flow in the stretch between RM 31.1 and 26.8. The Rattlesnake and Nile creeks discharge in this stretch and form a wider, alluvial valley channel compared to the confined channel above. More alluvial material would indicate more potential for groundwater/surface water exchange.

TIR results also show the greatest groundwater influence in the river between RM 30.5 and 25.6 (eight springs and seeps). Greater channel complexity, numerous side channels, and alluvial gravel bars found in this stretch are often indicators of groundwater inflow (Watershed Sciences, Inc., 2004). The river temperature decreased below each spring resulting in a gradual cooling over the length of the reach.

The vertical hydraulic gradient at the lower end of the stretch (RM 26.8) was negative on all dates, indicating groundwater outflow from the river. This end of the reach becomes more confined, which may raise the water level of the river higher than that in the formation, causing the gradient to be away from the river.

RM 26.8-17.6

Flow increased by 11% between RM 26.8 and 17.6 during the seepage survey. The channel is more confined in this reach compared to the wider Nile Valley just upstream. This narrowing allows less alluvial material to accumulate for groundwater/surface water exchange. However, landslide alluvial material along the north side of the reach could provide a conduit for groundwater connection with the river. Two small springs were also identified in the TIR survey between RM 25.5 and the confluence with the Tieton River at RM 17.6.

The vertical hydraulic gradient at RM 26.8, the upstream end of the reach, was consistently negative, indicative of losing conditions. However, these measurements represent only a very small area of this 9-mile reach.

The Naches Selah Canal at RM 18.2 diverted an average of 277 cfs from the stretch between RM 20.8 and 17.6 on July 20, 2004 (USBoR Hydromet website). Effects of the withdrawal on heating were not detectable via TIR because of the overwhelming influence of the Tieton River entering the Naches at RM 17.5 just below this stretch. TIR indicated a drop in the Naches River temperature of 3.4°C below the confluence with the Tieton (RM 17.5), from 18.7°C to 15.3°C.

Naches RM 17.6-12.8

Results of the seepage survey indicated a 16% flow loss between RM 17.6 and 12.8. This stretch represents the upper one-third of the wide, deep alluvial valley that extends from about RM 17.0 to RM 3.5. This one- to two-mile wide valley contains 100-200 feet of unconsolidated material (Jones et al., 2006), providing the largest reservoir for groundwater storage of any on the Naches. One vertical hydraulic gradient measurement at RM 12.8 on July 1, 2004, was negative, indicating losing conditions and consistent with seepage survey results.

The Wapatox Canal diversion (RM 16.7) withdrew an average of 155 cfs on July 20, 2004 (USBoR Hydromet website). The contribution from the Tieton River was 287 cfs on the same date. TIR imagery did not detect groundwater gains or losses below the Tieton, although the extreme temperature influence of the Tieton would probably mask any temperature signals that TIR could detect from groundwater.

Naches RM 12.8-0.5

A 26% gain was observed in the lower two-thirds of the Naches Valley channel between RM 12.8 and 0.5 during the seepage analysis. The one- to two-mile wide valley containing 150-200 feet of unconsolidated material (Jones et al., 2006) provides a large potential for groundwater inflow to the river under low-flow conditions.

In contrast with the seepage survey, vertical gradient measurements were consistently negative at RM 8.5 and 12.8, indicative of surface water loss to groundwater. Diel temperature consistency between surface and hyporheic waters at RM 8.5 likewise indicated a loss to groundwater. Parts of the stretch may have been losing groundwater during the seepage survey, while others may have been gaining, resulting in a net gain. On the other hand, the piezometer at RM 3.7 had positive vertical gradients and temperature patterns indicative of groundwater discharge to the river.

The City of Naches Wastewater Treatment Plant (WWTP) discharges to a small side channel of the Naches River. The side channel discharges to the Naches River near RM 12.5. The WWTP discharged approximately 0.12 cfs (0.8 million gallons/day) of effluent on July 20 and 21, 2004. Flow in the side channel is approximately 4.0 cfs during the low-flow periods. Flow in the Naches River at RM 12.8 (measured on July 20, 2004) was approximately 367 cfs. The side channel and WWTP flows equate to approximately 1% of the river flow. Therefore, the WWTP discharge should have had no significant effect on the Naches River flows during the seepage run.

Tieton River

Basalt underlies most of the Tieton River in the study area with little alluvial material to promote groundwater/surface water interactions. The seepage run indicated no measurable gain or loss (greater than 5%) in the upper eight miles of the Tieton River (Table 2). On the other hand, four out of five reaches in the lower six miles of the river had a 5-10% gain or loss. The fast, deep flow in the narrow lower channel of the river made flow measurement difficult at some sites during the seepage run. Differences between triplicate measurements at RM 1.5 ranged from 2.2 to 10.6%, indicating that the measurement variability exceeded the gain/loss value at this site and perhaps at other sites in the lower river.

Stretches where estimated gains or losses exceeded 5% and where vertical hydraulic gradients were measured are described below.

Tieton RM 6.1-4.0

A flow loss of 5.8% was found between RM 6.1 and 4.0 during the seepage run. No other surveys/data are available for this stretch of river.

Tieton RM 4.0-3.0

The seepage run indicated a 6.4% increase in flow in the stretch between RM 4.0 and 3.0. No other surveys/data are available for this stretch of river.

Tieton RM 3.0-2.3

Vertical hydraulic gradient measurements at RM 2.3 were positive on the date closest to the seepage run (August 8, 2004), while the seepage run showed no significant change in flow compared to the next upstream site at RM 3.0 (Appendix E). The gradient was 0 on July 2, 2004 and negative on August 30, 2004. Cooler hyporheic temperature in the early summer compared to river temperatures suggests more flow from groundwater into the river earlier in the summer (Figure 7). A reversal of the temperature difference later in the season suggests flow from the river to groundwater.

No significant gain or loss was observed between RM 3.0 and 2.1 during the seepage run.

Tieton RM 2.3-1.5

Results from the seepage run showed a 6.5% loss in this stretch, despite flow entering from Oak Creek below RM 2.3. Flow at the mouth of Oak Creek, estimated as approximately 1 cfs on July 21, 2004, represents 0.35% of the flow in the Tieton. Therefore Oak Creek is a negligible input to the Tieton River during low-flow conditions.

Tieton RM 1.5-0.4

An increase in flow of 9.7% was estimated between RM 1.5 and 0.4 during the seepage run. No other surveys/data are available for this stretch of river.

Conclusions

Areas of groundwater inflow and outflow along the Naches and Tieton rivers were evaluated using several methods. The seepage analysis and the thermal infrared survey (TIR) survey were the most reliable methods. Both methods provide broad scale measurements. Vertical hydraulic gradient was used as a secondary indicator due to its localized scale and limited number of piezometer locations. Hyporheic temperature data may not have fully stabilized, but the patterns provide a non-quantitative indicator of flow direction into or out of the river.

Stretches where flow increased by more than 5% during the seepage analysis, and where TIR indicated possible groundwater inflow, are listed below along with the respective flow increase per river mile. The Naches River segments were aggregated by geology and flow regime.

Naches River
- RM 43.0-38.8: 6.4 cfs/mile
- RM 31.1-26.8: 6.2 cfs/mile
- RM 26.8-17.6: 5.7 cfs/mile
- RM 12.8-0.5: 7.7 cfs/mile

Tieton River
- RM 4.0-3.0: 17 cfs/mile
- RM 1.5-0.4: 23 cfs/mile

The total of flow gains for the Naches River was 200 cfs on July 20, 2004, and 42 cfs for the Tieton River on July 21, 2004.

TIR analysis indicated numerous groundwater inflows from springs occurred between RM 25.5 and 30.0 on the Naches River.

The losing stretches and the respective flow decrease per river mile are listed below.

Naches River
- RM 17.6-12.8: -12.4 cfs/mile

Tieton River
- RM 6.1-4.0: -7.7 cfs/mile
- RM 2.3-1.5: -23 cfs/mile

The total flow loss for the Naches River was 59 cfs on July 20, 2004. The loss for the Tieton River was 31 cfs on July 21, 2004.

Gain/loss results from the more localized methods were generally in agreement with the seepage run results.

The temperature of inflowing groundwater represented by mini-piezometers and hyporheic tidbits ranged from 9.8 to 17.7°C in the Naches River and from 12.7 to 13.9°C in the Tieton River. Generally, temperatures were cooler upstream than downstream. August groundwater/ hyporheic temperatures were about 1-6° warmer than those measured in October.

References

Bentley, R.D. and N.P. Campbell, 1983. Geologic map of the Yakima quadrangle, Washington. Washington State Department of Natural Resources, Geologic Map GM-29.

Drost, B.W. and K.J. Whiteman, 1986. Surficial geology, structure, and thickness of selected geohydrologic units in the Columbia Plateau, Washington. U.S. Geological Survey Water Resources Investigations Report 84-4326, 11 plates.

Golder Associates, 2002. Naches Basin (WRIA 38) Storage Assessment. Yakima Basin Watershed Planning, December 2002. 48 p.

Henneman, Dave, 2005. Personal communication. U.S. Bureau of Reclamation, Yakima, WA.

Jones, M.A., J.J. Vaccaro, and A.M. Watkins, 2006. Hydrogeologic framework of sedimentary deposits in six structural basins, Yakima River Basin, Washington. U.S. Geological Survey Scientific Investigations Report 2006-5116, 24 p., 6 plates.

LeMoine, M. and S. Brock, 2004. Naches River Temperature Total Maximum Daily Load. Quality Assurance Project Plan. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-110. www.ecy.wa.gov/biblio/0403110.html 35 p.

Sinclair, K., 2001. Assessment of Surface Water and Groundwater Interchange within the Muck Creek Watershed, Pierce County. Washington State Department of Ecology, Olympia, WA. Publication No. 01-03-037. www.ecy.wa.gov/biblio/0103037.html 74 p. + appendices.

Sinclair, K., 2005. Personal communication. Washington State Department of Ecology, Olympia, WA.

Stonestrom, D.A. and J. Constanz (editors), 2003. Heat as a tool for studying the movement of groundwater near streams. U.S. Geological Survey Circular 1260, 96 p.

Walsh, T.J., 1986. Geologic map of the east half of the Yakima quadrangle, Washington. Scale 1:100,000. Washington State Department of Natural Resources, Open File Report 1986-4, 9 p.

Watershed Sciences, Inc., 2004. Aerial survey of Naches River, Washington. Preliminary Report-Draft. November 18, 2004.

Appendix A. Mini-piezometer locations and construction information.

ID	Piezometer location	Latitude (DD)	Longitude (DD)	River Mile[1] (mile)	Piezometer stick-up above streambed (feet)	Piezometer depth below streambed (feet)	Temperature Data Logger depth (feet)	Comment
38-NAC-0.05	Naches River near the mouth (USBoR Station)	46.62678 N	-120.52383 W	0.5	3.25	3.75	0.83	
38-NAC-03.7	Naches River @ Powerhouse Rd	46.63185 N	-120.58547 W	3.7	3.17	3.83	1.5, 3.0	
38-NAC-08.5	Naches River @ Eschbach Park	46.67822 N	-120.64975 W	8.5	2.83	4.17	0.83, 1.5	Vandalized
38-NAC-10.5	Naches River downstream of Naches @ public fishing	46.70275 N	-120.65985	10.5	3.20	3.80	1.0, 2.25	Vandalized
38-NAC-12.8	Naches River @ Naches Tieton Rd	46.72401 N	-120.69912 W	12.8	4.40	2.60		Vandalized
38-NAC-26.8	Naches River @ Lower Nile Rd	46.80605 N	-120.92075 W	26.8	2.58	4.42	1.0, 1.8	
38-NAC-31.1	Naches River @ Upper Nile Rd	46.85656 N	-120.95592 W	31.1	3.42	3.58		
38-NAC-41.1	Naches River @ Boulder Cave Rd	46.94935 N	-121.07055 W	41.1	2.36	4.64		
38-TIE-02.3	Tieton River above Oak Creek	46.72338 N	-120.81297 W	2.3	3.15	3.85	1.0, 2.25	

[1] Miles upstream of the river mouth.

Appendix B. Seepage run results and calculations for the Naches River on July 20, 2004.

Site ID	Structural Characteristics	River Mile	Inputs and Withdrawals (cfs)	River Mile	Discharge (cfs)	Mean Discharge (cfs)	Change from Upstream (cfs)	Percent change from upstream	Reach Length (miles)	Net Seepage Gain or Loss (cfs/mile)	Aggregated Reaches Change from Upstream (cfs)	Per cent change from upstream	Reach Length (miles)	Net Seepage Gain or Loss (cfs/mile)
38-AME-0.5			American River	0.5	284									
38-LIT-0.1			Little Naches River	0.1	62.1									
38-LIT-0.1R			Little Naches River	0.1	65.8	63.9								
38-NAC-43		43.0			336		-11.4	-3.3						
38-NAC-42		42.0			366	397	60.5	18.0	1	61				
38-NAC-42D1		42.0			393									
38-NAC-42D2		42.0			432									
38-NAC-41.1		41.1			390		-2.9	-0.7	0.9	-3.3				
38-NAC-41.1R		41.1			398	394								
38-NAC-40		40.0			371		-23.2	-5.9	1.1	-21				
											RM 43-38.8			
38-NAC-38.8		38.8			364		-7.3	-2.0	1.2	-6.1	27.0	8.0	4.2	6.4
			Anderson Canal (ANSW)	38.6	-2.5									
			Lost Creek/Gold Creek	38.4	14									
	Steep, narrow		Emerick Canal (EMKW)	36.5	-1.0									
38-NAC-36	andesite/basalt	36.0			374		-0.5	-0.1	2.8	-0.2				
	canyon, upper		Rock Creek	33.5	1									
38-NAC-34	half contains	34.0			395		22.6	6.0	2	11.3				
	more alluvium													
38-NAC-31.1	than lower half	31.1			385		-13.3	-3.4	3.9	-3.4	RM 38.8-31.1			
38-NAC-31.1D		31.1			378	382					6.8	1.9	10.0	0.7
			Nile Valley Canal (NIVW)	31.0	-5.8									
38-NAC-30.5		30.5			392		15.8	0.04	0.6	26				
			Nile River Inflow (38-NIL-0.9)	29.4	1.7									
	Wider alluvial		Dry Creek	28.7	0.0									
38-NAC-28	valley at the	28.0			468		74.4	19.0	2.5	30				
	mouth of		Rattlesnake Cr. Inflow (38-RAT-0.2)	27.8	77.7									
	Nile and Rattle-		Rattlesnake Cr. Diversion (38-RAT-0.2 d	27.8	-15.4									
	snake creeks		Fredericks & Hunting Canal (FAHW)	27.4	-3.0									
38-NAC-26.8		26.8		26.8	457									
38-NAC-26.8D		26.8									RM 31.1-26.8			
				26.8	471	464	-63.5	-13.6	1.2	-53	26.7	7.0	4.3	6.2

Appendix B (cont'd)

Site ID	Structural Characteristics	River Mile	Inputs and Withdrawals (cfs)	River Mile	Discharge (cfs)	Mean Discharge (cfs)	Change from Upstream (cfs)	Percent change from upstream	Reach Length (miles)	Net Seepage Gain or Loss (cfs/mile)	Aggregated Reaches Change from Upstream (cfs)	Per cent change from upstream	Reach Length (miles)	Net Seepage Gain or Loss (cfs/mile)
			Stevens Canal (STCW)	26.6	-1.2									
38-NAC-23.9	Narrow basalt	23.9			406		-57.5	-12.4	2.9	-20				
	channel,													
38-NAC-20.8	little alluvium	20.8			463		64.2	15.8	3.1	21				
38-NAC-20.8R		20.8			478	470								
			City of Yakima M&I @ Oak (CYOW)	19.4	-24									
			Naches Selah Canal Diversion (NSCW)	18.4	-122						RM 26.8-17.6			
38-NAC-17.6		17.6			369		44.7	9.5	3.2	14	52.7	11.2	9.2	5.7
	Mouth of the		Tieton River Inflow (38-TIE-0.4)	17.5	287									
	Tieton and		Wapatox Canal Diversion (WOPW)	17.1	-155									
38-NAC-16	widening allu-	16.0			467		-33.7	-9.1	1.6	-21				
	vial fan at		Clark Ditch (CLCW)	14.9	-2.2									
	upper end		S. Naches Channel Canal (SOUW)	14	-59									
			Kelly-Lowry Canal (KLYW)	13.7	-13									
38-NAC-12.8		12.8			369		-25.7	-5.5	3.2	-8.0	RM 17.6-12.8			
38-NAC-12.8R		12.8			365	367					-59.4	-16.1	4.8	-12.4
			Kelly Ditch Drain	10	16									
	Wide, flat		Wapatox Canal Drain (WOPW)	9.7	100									
	alluvial channel		City of Yakima M&I B-Gleed (CYDW)	9.7	-18									
	1-2 miles wide,		Gleed Canal (GLEW)	9.4	-39									
	150 feet of		Congdon Canal (CODW)	8.5	-44									
	unconsolidated		Chapman & Nelson Ditch (CHFW)	6.1	-18									
	sediments at		Naches -Cowiche Ditch (NCOW)	3.6	-19									
	RM 7.5.		Buckskin Slough/Creek	3.3	18									
			Cowiche Creek (CGWW/38-COW-0.5)	2.8	4.0									
			Fruitvale Power Canal (FRUW)	2.7	-19									
			Old Union Canal (OLDW)	2.5	-11									
38-NAC-0.5		0.5			431	432	95.1	25.9	12.3	7.7	RM 12.8-0.5			
38-NAC-0.5R		0.5			433						95.1	25.9	12.3	7.7

R= Replicate
D= Duplicate

Appendix C. Seepage run results and calculations for the Tieton River on July 21, 2004.

Site ID	Mainstem river name	River Mile	Measured Discharge (cfs)	Mean Discharge (cfs)	Change from Upstream (cfs)	Percent Change from Upstream	Reach Length (miles)	Net Seepage Gain or Loss (cfs/mile)
38-TIE-14	Tieton	14.0	266.83					
38-TIE-14R	Tieton	14.0	256.37	261.60				
38-TIE-13	Tieton	13.0	233.37		9.7	3.7	1.0	9.7
38-TIE-13side	Tieton	13.0	37.93					
38-TIE-11	Tieton	11.0	269.70					
38-TIE-11R	Tieton	11.0	269.25	269.47	-1.8	-0.7	2.0	-0.9
38-TIE-9	Tieton	9.0	273.54					
38-TIE-9R	Tieton	9.0	270.63	272.09	2.6	1.0	2.0	1.3
38-TIE-8.5	Tieton	8.5	273.32		1.2	0.5	0.5	2.5
38-TIE-6.1	Tieton	6.1	279.94					
38-TIE-6.1R	Tieton	6.1	284.62	282.28	9.0	3.3	2.4	3.7
38-TIE-4	Tieton	4.0	266.01		-16.3	-5.8	2.1	-7.7
38-TIE-3	Tieton	3.0	282.94		16.9	6.4	1.0	16.9
38-TIE-2.3	Tieton	2.3	(235.18)					
38-TIE-2.3D	Tieton	2.3	279.15	279.15	-3.8	-1.3	0.7	-5.4
38-TIE-1.5	Tieton	1.5	249.42					
38-TIE-1.5D1	Tieton	1.5	255.04					
38-TIE-1.5D2	Tieton	1.5	278.84	261.10	-18.0	-6.5	0.8	-22.6
38-TIE-0.4	Tieton	0.4	286.52		25.4	9.7	1.1	23.1

R= Replicate   D= Duplicate

( ) Value not used because backup Marsh-McBirney flow meter used at this site may not have been calibrated.

Appendix D. Percent difference between replicate and duplicate flow measurements on July 20 and 21, 2004.

Site	Flow (cfs)	% Difference[1]
Naches River		
38-LIT-0.1	62.08	5.83
38-LIT-0.1R	65.80	
38-NAC-42	366.26	7.05
38-NAC-42D1	393.03	
38-NAC-42D1	393.03	9.38
38-NAC-42D2	431.70	
38-NAC-42	366.26	16.40
38-NAC-42D2	431.70	
38-NAC-41.1	390.34	1.89
38-NAC-41.1R	397.78	
38-NAC-31.1	385.32	1.81
38-NAC-31.1D	378.42	
38-RAT-0.2div	15.45	0.17
38-RAT-0.2divR	15.47	
38-NAC-26.8	458.32	2.71
38-NAC-26.8D	470.90	
38-NAC-20.8	463.11	3.12
38-NAC-20.8R	477.81	
38-NAC-12.8	368.87	0.98
38-NAC-12.8R	365.29	
38-NAC-0.5	431.07	0.51
38-NAC-0.5R	433.28	
Tieton River		
38-TIE-14	266.83	3.92
38-TIE-14R	256.37	
38-TIE-11	269.70	0.17
38-TIE-11R	269.25	
38-TIE-9	273.54	1.06
38-TIE-9R	270.63	
38-TIE-6.1	279.94	1.64
38-TIE-6.1R	284.62	
38-TIE-2.3	235.18	15.75
38-TIE-2.3D	279.15	
38-TIE-1.5	249.42	2.20
38-TIE-1.5D1	255.04	
38-TIE-1.5D1	255.04	8.54
38-TIE-1.5D2	278.84	
38-TIE-1.5	249.42	10.55
38-TIE-1.5D2	278.84	

[1] Half the difference between flow measurements divided by the mean times 100.

Appendix E. Vertical hydraulic gradients in Naches and Tieton river piezometers.

Site ID	Date	Stick Up (feet)	Groundwater Depth (ft)[1]	River Level (ft)[1]	dh=difference between groundwater and river levels (ft)	dl=distance from streambed to mid-point of piezometer perforations (ft)	Vertical Hydraulic Gradient, dh/dl (ft/ft)
38-NAC-0.5	6/29/2004		2.07	1.53	-0.54	3.50	-0.155
	8/3/2004	3.06	2.90	2.27	-0.63	3.50	-0.179
	8/31/2004	3.21	2.73	2.00	-0.73	3.50	-0.208
	10/14/2004		2.33	1.61	-0.72	3.50	-0.206
38-NAC-03.7	6/30/2004		1.98	2.02	0.04	3.58	0.012
	8/3/2004	3.20	2.68	2.85	0.18	3.58	0.049
	8/31/2004	3.17	2.38	2.50	0.13	3.58	0.035
	10/15/2004	3.12	1.90	2.00	0.10	3.58	0.028
38-NAC-08.5	7/2/2004		1.67	1.65	-0.02	3.92	-0.005
	8/6/2004	2.96	2.72	2.53	-0.19	3.92	-0.048
	8/31/2004	2.83	2.33	2.21	-0.13	3.92	-0.032
38-NAC-10.5	6/30/2004		0.94	0.99	0.05	3.55	0.015
38-NAC-12.8	7/1/2004	4.40	2.92	2.15	-0.77	2.35	-0.328
38-NAC-26.8	6/30/2004		1.16	0.75	-0.41	4.17	-0.098
	8/5/2004	2.52	2.25	1.48	-0.77	4.17	-0.184
	8/31/2004	2.50	2.46	1.46	-1.00	4.17	-0.240
	10/13/2004	2.55	2.83	1.65	-1.18	4.17	-0.283
38-NAC-31.1	7/1/2004	3.42	1.55	1.22	-0.34	3.33	-0.101
	8/6/2004	3.68	1.82	2.08	0.26	3.33	0.078
	9/2/2004	3.58	2.33	2.15	-0.18	3.33	-0.055
38-NAC-41.1	7/1/2004	2.37	1.13	1.04	-0.09	4.39	-0.021
	8/9/2004	2.32	1.74	1.76	0.02	4.39	0.004
	9/3/2004	2.32	1.71	1.67	-0.04	4.39	-0.009
	10/11/2004		1.80	1.83	0.03	4.39	0.007
38-TIE-02.3	7/2/2004		1.67	1.67	0.00	3.60	0.000
	8/8/2004	3.06	1.64	1.69	0.05	3.60	0.014
	8/30/2004	2.92	1.50	1.33	-0.17	3.60	-0.046
	10/19/2004	2.82	2.11	2.38	0.27	3.60	0.075

[1] Depth-to-water in feet below the top of the piezometer casing.

Appendix F. Temperatures in the Naches River and tributaries reported during the TIR survey (Watershed Sciences, Inc., 2004).

Tributaries, surface springs, and other detected surface inflows

Tributary	Image	km	mile	Tributary °C	Naches R. °C	Difference °C
Tributary Name						
Bumping River (RB)	nac0147	71.9	44.7	17.8	18.1	-0.3
Milk Creek (LB)	nac0167	71.3	44.3	16.5	18.0	-1.5
Devil Creek (RB)	nac0261	67.4	41.9	18.3	17.8	0.5
Swamp Creek (RB)	nac0280	66.6	41.4	18.3	18.0	0.3
Pond Outlet (LB)	nac0387	61.7	38.4	19.4	17.8	1.6
Rattlesnake Creek (RB)	nac0807	44.4	27.6	18.0	18.4	-0.4
Tieton River (RB)	nac1260	28.9	18.0	14.7	18.8	-4.1
Penstock Powerhouse Outlet (LB)	nac1842	16.4	10.2	16.9	15.4	1.5
Unnamed Tributary (RB)	nac1949	12.3	7.6	17.8	16.4	1.4
Unnamed Tributary (LB)	nac2180	6.5	4.0	18.9	17.0	1.9
Cowiche Creek (RB)	nac2223	4.6	2.9	17.1	16.7	0.4
Yakima River (LB)	nac2312	0.3	0.2	20.1	16.9	3.2
Spring						
Spring (RB)	nac0716	48.4	30.1	16.8	18.4	-1.6
Spring (RB)	nac0736	47.9	29.7	17.3	18.6	-1.3
Spring (LB)	nac0750	47.2	29.3	15.5	18.3	-2.8
Spring (RB)	nac0757	46.8	29.1	15.4	18.3	-2.9
Spring (LB)	nac0768	46.4	28.8	16.1	18.5	-2.4
Spring (RB)	nac0791	45.3	28.2	14.9	18.3	-3.4
Spring (LB)	nac0803	44.7	27.8	15.6	18.6	-3.0
Spring (RB)	nac0805	44.6	27.7	14.6	18.4	-3.8
Spring (RB)	nac0856	42.1	26.2	16.7	18.1	-1.4
Spring (MID)	nac0873	41.3	25.7	16.7	18.4	-1.7
Spring (LB)	nac0980	35.6	22.1	17.6	19.1	-1.5
Spring (LB)	nac1729	20.4	12.7	15.1	15.5	-0.4

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