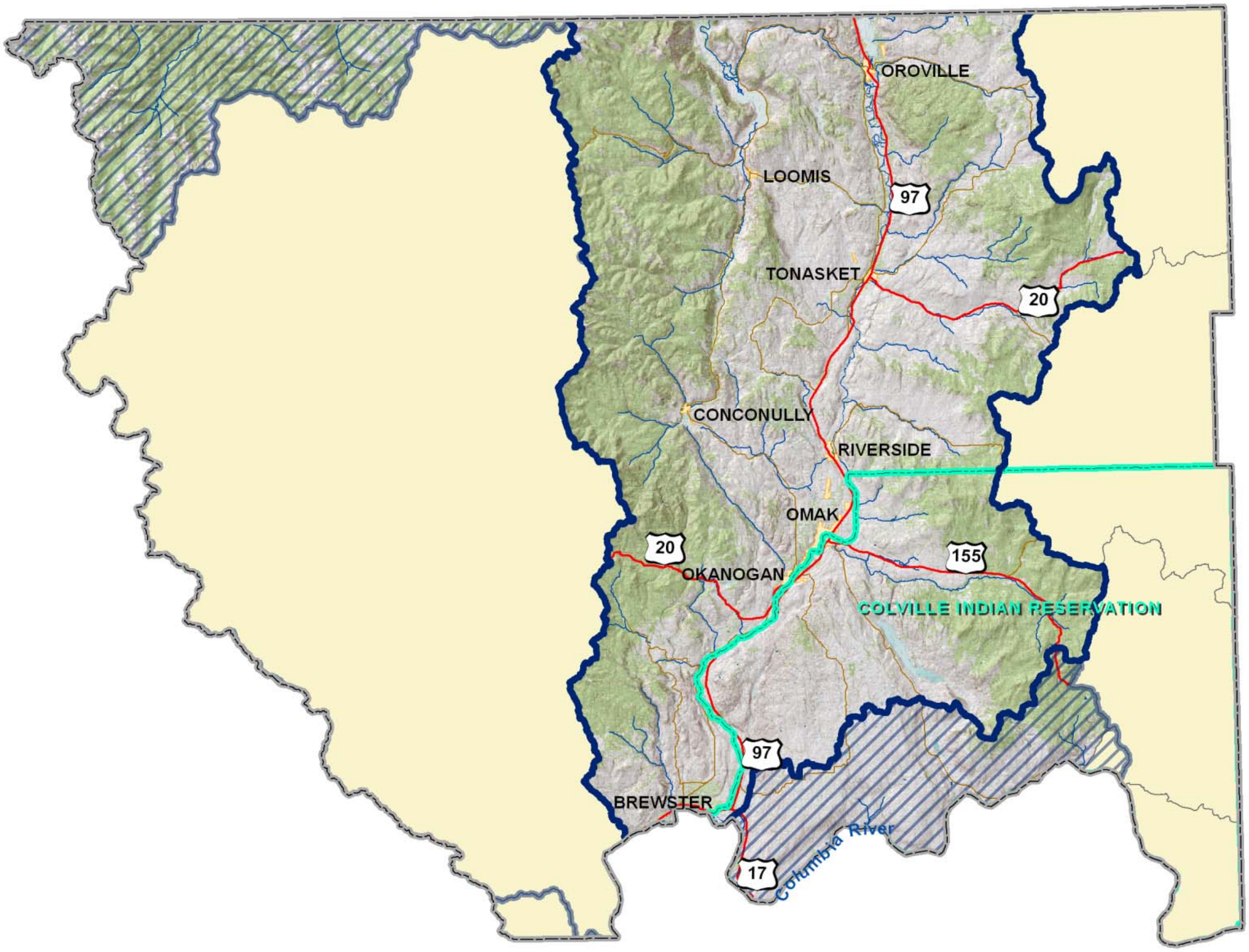
# OKANOGAN WATERSHED PLAN

# USGS Ground and Surface Water Interactions in Selected Streams




## APPENDIX CONTENTS

Prepared in Cooperation with the
Okanogan Conservation District and the
Washington State Department of Ecology

# Preliminary Investigation of Ground-Water/Surface-Water Interactions in Selected Subbasins Tributary to the Okanogan River, Okanogan County, Washington

By S.S. Sumioka and R.S. Dinicola

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# Contents

# Figures

# Tables

# Conversion Factors

Inch/Pound to SI

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| acre | 4,047 | square meter ($m^2$) |
| square foot ($ft^2$) | 0.09290 | square meter ($m^2$) |
| square inch ($in^2$) | 6.452 | square centimeter ($cm^2$) |
| section (640 acres or 1 square mile) | 259.0 | square hectometer ($hm^2$) |
| square mile ($mi^2$) | 259.0 | hectare (ha) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Flow rate | |
| cubic foot per second ($ft^3$/s) | 0.02832 | cubic meter per second ($m^3$/s) |
| | Hydraulic gradient | |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer (m/km) |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C) +32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C= (°F-32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

# Preliminary Investigation of Ground-Water/Surface-Water Interactions in Selected Subbasins Tributary to the Okanogan River, Okanogan County, Washington

By S. Sumioka and R.S. Dinicola

## Abstract

A preliminary investigation into ground-water/surface-water interactions in four tributary subbasins of the Okanogan River found that streamflows and shallow ground-water levels beneath the streams varied seasonally and by location. Streamflows and shallow ground-water levels measured in June 2008 showed that at more than half of the measured sites, the hydraulic gradient was negative indicating movement of surface water to the shallow ground-water system. Measurements of streamflow and ground-water levels made in September 2008 indicated that most of the streams were losing water to the ground-water system, except for the most upstream sites. The greatest losses occurred near the confluences with the Okanogan River, likely due to the presence of thick layers of unconsolidated material in the flood plain of the Okanogan River.

Based on available geologic information compiled from driller's logs and a surficial geologic map by Washington State Department of Natural Resources, the extent and thickness of unconsolidated material in the subbasins play a role in the magnitude of streamflows and the direction of flow between surface water and ground water. Although ground-water withdrawals could affect streamflows, relatively low precipitation in the area, limited ground-water storage capacity, and the presence of

permeable, unconsolidated material underlying the stream channels would all likely lead to loss of surface water to the ground-water system without any withdrawals.

## Introduction

In recent years, increasing demands for water for domestic, agricultural, recreational, and other uses in watersheds of Washington State have created concern that insufficient water resources remain for fish and other uses. The Okanogan River watershed includes portions of British Columbia, Canada and Washington State. The Similkameen River is the biggest tributary of the Okanogan River and also drains British Columbia and Washington. The drainages of the Okanogan and Similkameen Rivers in Washington constitute Water Resources Inventory Area (WRIA) 49, one of many watersheds in Washington where local citizens and governments have elected to coordinate with Tribes and State agencies to develop a watershed management plan, according to the guidelines outlined in the Watershed Management Act of 1998 (Washington State Engrossed Substitute House Bill 2514). With leadership from the Okanogan Conservation District (OCD), the planning group is working to implement a long-range sustainable watershed plan to meet the needs of current and future water demands in the basin, while also working to protect and improve its natural resources. In this report, the Okanogan River basin refers to the mainstem of the Okanogan River south of the Canada/United States boundary.

The WRIA 49 planning group needs information regarding the interaction of ground water and surface water in the tributaries to the Okanogan River as part of the assessment phase. As lead agency for WRIA 49 planning, the OCD selected four subbasins tributary to the Okanogan River (Tunk, Antoine, Bonaparte, and Tonasket Creek basins; fig. 1) in which to investigate ground-water/surface-water interactions. The OCD requested that the U.S. Geological Survey (USGS) collect and evaluate data to better understand those interactions in the selected basins.

## Purpose and Scope

This report presents the results of streamflow discharge measurements and water-level measurements of streams and of shallow ground water beneath streams in the Tunk, Bonaparte, Antoine, and Tonasket Creek subbasins of the Okanogan River in Washington State. The data collection took place during summer and fall low-flow periods when water demand is high and water availability is limited. The data are used to identify net streamflow gains and losses along reaches of the creeks, to determine if ground water is discharging to streams or streamflow is recharging ground water at measurement locations. In addition, those findings are evaluated with regard to available information about the hydrogeologic framework of the subbasins. Suggestions for additional data collection and interpretation that could refine the understanding of ground-water/surface-water interactions in the subbasins are presented.

The streamflow and water-level measurements were made by the USGS during two field trips in June and September 2008. Geologic and hydrogeologic information for the subbasins was obtained from previously-published reports, from surficial geologic maps produced by the Washington State Department of Natural Resources (2005), and from driller's logs either on file at the USGS Washington Water Science Center or downloaded from the Washington State Department of Ecology (WDOE) website (*http://apps.ecy.wa.gov/welllog/textsearch/asp*, last accessed November 7, 2008).

## Previous Water Resources Studies

The water resources for the entire Okanogan River basin were described by Walters (1974), based on water-resources information compiled from a variety of sources. Using existing records of hydrologic conditions (precipitation, streamflow, and ground-water levels) he described, to the extent possible, the amount of water available, the quality or usability of the water, and the frequency of seasonal water shortages or surpluses in the Okanogan River basin and in its tributary subbasins.

Montgomery and others (1995) evaluated existing data and presented an initial assessment of the availability of ground water and surface water that WDOE could use in making decisions regarding water rights.

A more detailed study of the Bonaparte Creek subbasin (Packard and others, 1982) collected ground-water and surface-water data to describe the relationship between ground-water levels, streamflow, and water levels in several lakes in the subbasin. The study also located the ground-water divide between the Bonaparte Creek subbasin and the Sanpoil River basin to the southeast.

## Local Numbers

Wells and other data-collection sites in Washington are assigned so-called local numbers by the USGS that identify their location in a township, range, and section, based on the rectangular subdivision of public land. For example, well number 33N/21E-09C01 (fig. 2) indicates, from left to right, the township (33 North), the range (21 East); the 640-acre section (Section 09); and the 40-acre quarter-quarter section (C) within that section.

## Description of Study Area

The study area consists of four subbasins located on the east side of the Okanogan River in the Okanogan River basin in north-central Washington (fig. 1 and table 1). The Okanogan River flows southward from British Columbia, Canada, to the Columbia River and drains about 8,300 $mi^2$ in the United States and Canada. WRIA 49 encompasses about 2,100 $mi^2$ within that area, and the four subbasins make up about 370 $mi^2$ of the WRIA. The Bonaparte Creek subbasin is the largest of the four (about 160 $mi^2$), and the other three subbasins range between about 60 and 70 $mi^2$. Altitudes of the WRIA range from about 840 feet (ft.) at the mouth of the Okanogan River to about 7,300 ft. in the uplands to the east of the Okanogan River.

The climate of WRIA 49 is characterized by warm summers and cold winters and precipitation typical of semi-arid regions. The median July temperature in the lowlands near the Okanogan River is about 88 degrees Fahrenheit (°F) and the median January temperature is about 20°F. Data from National Oceanic and Atmospheric Administration weather stations in Omak and Desautel (fig. 1) show that precipitation varies from about 11 inches per year (in/yr.) the lowlands (Omak) to about 16 in/yr. in the surrounding highlands (Desautel). Climate data were downloaded from an on-line database maintained by the Western Regional Climate Center (http://www.wrcc.dri.edu/summary/waF.html, accessed November 25, 2008).

The predominant land covers in WRIA 49 and the study area subbasins include open shrub and scrub land, evergreen forests, and pasture/grassland. (Land-cover/land-use data were obtained from 2001 Landsat 7 imagery downloaded from the Multi-Resolution Land Characteristics Consortium at *http://www.mrlc.gov*, accessed April 5, 2007). Most agricultural lands, primarily orchard fruit, are in the lowlands adjacent to the Okanogan River. The major population centers are also adjacent to the Okanogan River, although some residential development has spread into nearby upland areas. Timber and recreational land uses generally take place in the upland areas of the WRIA. Within the study area subbasins, shrub and scrubland cover from about 50 to 60 percent of each subbasin, evergreen forest covers from about 33 to 40 percent of each subbasin, and grasslands cover from about 7 to 18 percent of each subbasin (fig. 3 and table 2). Some of the shrub and scrubland is used for stock grazing. A residential development is planned in the headwater region of a tributary to Tunk Creek.

## Generalized Hydrogeologic Framework

Unconsolidated deposits consisting of clay, silt, sand, and gravel are, in general, the predominant surficial geologic material in the study area. These materials are thickest (in places, several hundreds of feet thick) in the stream valleys. In the upland areas, however, thicknesses may be only a few tens of feet. These materials are the major sources of ground water in the subbasins except in those areas where they are thin or are composed of clay or till. The Tunk Creek subbasin has the highest areal extent (65 percent of the basin) of surficial unconsolidated material of the four subbasins. The areal extent of unconsolidated material in the other three subbasins is about 50 percent of the basin. Underlying the unconsolidated materials are granitic, andesitic, and metamorphosed rocks forming the bedrock of the Okanogan River basin. Wells that are open in these bedrock units generally provide only enough water to satisfy domestic uses. A part of the southeastern part of the WRIA is underlain by basalts of the Columbia River Basalt Group (Walters, 1974) that can potentially yield more ground water, but these basalts are not present in the study area subbasins. More detailed information concerning unconsolidated deposits in the subbasins are presented in the “Ground-Water/Surface-Water Interactions and Subbasin Hydrogeology” section of this report.

## Historical and Current Steamgages and Data

During 2008, the WDOE maintained five streamflow monitoring stations in the study area subbasins (fig. 5). Two are telemetry stations that log stage height every 15-minutes and transmit this data to WDOE, where they are automatically imported into the streamflow database and published on the WDOE web site. The remaining three are manual-stage-height stations, where a stream’s water level is directly read from either a standard staff gage, wire weight gage or measured from a known reference point. Both telemetered and manual-stage-height measurements are converted to instantaneous streamflow using rating tables based on the relationship between a series of stage height measurements and their corresponding in-stream flow measurements. In addition, in the past, the USGS operated two continuous-recording streamgages in two of the study area subbasins.

For this investigation, instantaneous streamflow measurements were made at all the WDOE and USGS stations except for two in the Bonaparte Creek basin (WDOE station 49F150 and USGS station

1244490), where no access was possible. Even though WDOE monitors streamflow in the subbasins, measurements using the same methods and within the same time frame as used for the other sites eliminates two possible sources of variability in comparing measurements.

The telemetry station operated by WDOE on Tunk Creek near Riverside, (station 49E080) is about 1.3 mi. from the mouth of Tunk Creek and has been operating since August 2002. The annual mean daily discharge at the gage for water years 2003-07 ranged from an estimated 2 to 7.5 cubic feet per second ($ft^3/s$), and the lowest mean daily flows (during July, August, or September) ranged from 0.02 to 0.2 $ft^3/s$. Zero flow was never reported for the station. The WDOE telemetry station on Bonaparte Creek near Tonasket, (station 49F070) is near the mouth of Bonaparte Creek and has been operating since September 2002. The annual mean daily discharge at the gage for water years 2003-07 ranged from an estimated 3.4 to 8.2 $ft^3/s$, and the lowest mean daily flows (during July, August, or September) ranged from 0 to 0.3 $ft^3/s$.

WDOE annual-stage-height stations are located near the mouths of Antoine Creek (station 49G060) and Tonasket Creeks (station 49H080) and on Bonaparte Creek near Aeneas Valley (station 49F150) and have been operating since 2002. Zero flow has been reported at least once for each of the three stations and the lowest flows occurred during the summer and early fall.

Historically, the USGS operated continuous-recording streamgages during 1968-73 on Bonaparte Creek in the central part of the subbasin (station 12444490, Bonaparte Creek near Wauconda, WA), and during 1967-79 near the mouth of Tonasket Creek (station 12439300 Tonasket Creek at Oroville, WA, fig. 5). During the stations' periods of record, the lowest mean daily flows in Bonaparte Creek ranged from 0.1 to 1.4 cubic feet per second (cfs), and zero flow was recorded in Tonasket Creek for at least a few days most summers.

## Methods

Candidate streamflow-discharge measurement sites were visited during a reconnaissance trip to the study area in May 2008. About 70 sites were visited in the four study area subbasins and flowing water was observed at about 75 percent of the sites (fig. 6). During this reconnaissance, estimated discharges ranged from less than 1 to about 10 cubic feet per second (cfs). A subset of the visited sites (fig. 7) was selected for subsequent measurements based the likelihood of flow in late summer. We were not able to visit many additional measurement sites that would likely be of high value because of restricted access to private property or terrain constraints.

Streamflow discharge measurements and water-level measurements of streams and of shallow ground-water beneath streams were made during two field trips in June and September 2008. Discharge was measured at selected stream cross sections with an Acoustic Doppler Velocity (ADV) meter in accordance with the surface-water quality-assurance plan for the USGS Washington Water Science Center (Kresch and Tomlinson, 2004). Measured discharges at the beginning and end of a reach were compared, and gaining reaches (where discharge increases downstream) and losing reaches (where discharge decreases downstream) identified.

Shallow ground-water levels were measured using an electronic tape in temporary piezometers installed about 5-ft deep beneath the streambeds, and in stream water levels were measured relative to the top of the same piezometers. The piezometers consisted of small-diameter pipes with holes drilled near one end that were driven into the streambed near the discharge-measuring section on the streams. The difference in water levels in the piezometer and the stream is a measure of the head difference, in feet, between ground water and surface water. Dividing that head difference by the length of pipe below the streambed, in feet, gave a value for the hydraulic gradient at that point, in feet per foot. A positive hydraulic gradient indicates the potential for ground-water discharge to the stream (a gaining reach).

Likewise, a negative hydraulic gradient indicate a potential for streamflow recharge of the shallow ground-water system (a losing reach). A zero gradient indicates no net movement of water between surface and ground water.

## Streamflow Discharge and Water-Level Measurements

Streamflow discharge was measured at 21 sites in June 2008 and at 16 sites in September 2008 (table 4). Both sets of measurements are presented in the same table to easily compare changes in flows between early and late summer. Location information and calculated discharge per unit area for each measurement site are also presented. One site measured in September was not accessible in June, one site measured in June was flooded by backwater (likely from a beaver dam) in September, and four sites were dry. Discharge measurement results are also available on-line at the USGS National Water Information System *http://waterdata.usgs.gov/wa/nwis/measurements*.

The discharge measurements are presented again with coincident stream and ground-water level measurements for June 2008 (table 5) and September 2008 (table 6). Also in those tables are various metrics related to ground-water/surface water interactions, including:

- net differences in discharge between sequential sites,
- net differences in discharge per river mile between sequential sites,
- identification of the reach between sequential sites as gaining or losing, where gaining sites had increased discharge downstream and losing sites had decreased discharge,
- vertical hydraulic gradients beneath the streambed, and
- identification of the specific measurement sites as gaining or losing or neutral, where gaining sites had positive gradients, losing sites had negative gradients, and neutral sites had zero gradients.

The measurements have some limitations that need to be considered when evaluating ground-water/surface water interaction. First, measurements were made several months apart and represent conditions existing at the specific times only. Atypical activities occurring during a measurement, such as exceptionally high, short-term pumpage from a near-stream well would result in atypical measurements for the time of year. Furthermore, gains or losses of streamflow, as described in this report, refer to the cumulative or net gain or loss in streamflow between two measurement sites. It was beyond the scope of this study to locate and measure the potentially numerous small tributaries and surface-water diversions and returns in the subbasins, so the reported losses and gains in streamflow may be due to processes other than ground-water/surface-water interactions. For example, unmeasured surface-water diversions along a reach identified as losing could potentially be large enough to mask or reduce streamflow gains from ground-water discharge, and unmeasured tributaries and return flows could mask or reduce streamflow losses along a reach identified as gaining. Regardless of these limitations, some general patterns appear in the data that provide useful insight into ground-water/surface water interactions in the study area.

## Ground-Water/Surface-Water Interactions

Ground-water/surface-water interactions were generally characterized for the study area subbasins based on changes in measured streamflow discharges between June and September, net gains and losses of streamflow along the lengths of the streams, and gaining or losing hydraulic gradients in shallow ground water at the measurement sites. The interactions were further evaluated with regard to available information on the hydrogeologic framework of the subbasins and the distribution of known existing wells.

## General Streamflow Characteristics

The most obvious difference between the June and September streamflow measurements (table 4) is that there was substantially less water available in all subbasins during September than in June. Beyond that, streamflow in each of the subbasins had unique characteristics.

Measured streamflow changed very little along the length of Tunk Creek during June and during September, although the September streamflows were about an order of magnitude smaller than the June streamflows (table 4 and fig. 8). As is typical for drainage basins with moderate topographic relief, the June discharge per unit of drainage area consistently decreased in a downstream direction, which is likely a result of more precipitation-driven runoff and ground-water recharge in the higher elevation parts of the basin. During September, however, discharge per unit of drainage area at the uppermost measurement site was less than it was at the mid-basin measurement sites. That change was likely a result of either limited ground-water storage capacity and discharge to the stream in the upper basin with presumably thinner unconsolidated sediments, or possibly of relatively greater consumptive use of water in the upper basin. Given that the unconsolidated deposits in Tunk Creek are generally less than 100-ft thick and have relatively low permeability (Walters, 1974), the upper basin likely does have limited ground-water storage capacity and discharge to the stream. The discharges measured by USGS in June and September 2008 at the lowermost site in Tunk Creek were consistent with the 2003-07 June and September discharges from WDOE stream gage 49E080 Tunk Creek near Riverside.

In contrast to Tunk Creek, measured June streamflow in Bonaparte Creek decreased consistently between the uppermost and lowermost measurements sites (table 4 and fig. 9). The September streamflows were substantially smaller than those measured in June, although changes in flow along the length of the creek were quite variable. Similar to Tunk Creek, the June discharge per unit of drainage area consistently decreased in a downstream direction, although the amount of discharge per unit of drainage area was only about half that measured in Tunk Creek. Again similar to Tunk Creek, the September discharge per unit of drainage area at the uppermost Bonaparte Creek measurement site was smaller than it was at the mid-basin measurement sites. Assuming similar amounts of precipitation for Tunk and Bonaparte Creek subbasins, these data suggest that in Bonaparte Creek, more runoff either goes into ground-water storage or is used consumptively (lost to evapotranspiration). Given the potentially large volume of ground-water storage in the mid-basin parts of Bonaparte Creek subbasin (Aeneas Valley) and a correspondingly large amount of ground-water pumpage (Walters, 1974), there appears to be substantial consumptive use of ground water in the Bonaparte Creek subbasin. The discharges measured by USGS in June and September 2008 at the lowermost site in Bonaparte Creek were consistent with the 2003-07 June and September discharges from WDOE stream gage 49F070 Bonaparte Creek at Tonasket.

Measured streamflow discharges and calculated discharges per unit of drainage area during June in Antoine Creek at and above river mile (RM) 5.24 were substantially larger than comparable discharges in the other three subbasins (table 4, fig. 10). In contrast, June streamflows at the two measurement sites below RM 5.24 in Antoine Creek were substantially smaller than comparable discharges in Bonaparte and Tunk Creeks. The substantial decrease in discharge occurred downstream of a long canyon and upstream from an intensively irrigated area in the vicinity of the Siwash Creek confluence with Antoine Creek. The agricultural area is irrigated with ground water (Walters, 1974). There are a number of very productive irrigation wells in the area between Antoine and Siwash Creeks, near the Okanogan River (Walters, 1974). It is possible that ground-water pumpage is at least partly responsible for the rapid decrease in Antoine Creek streamflow. However, the largest decrease in streamflow was measured at site Antoine #5 (RM 4.29; Map ID 71, fig. 7) that is upstream from the irrigated area and at the mouth of the canyon where unconsolidated sediments are likely of limited thickness. Thus, a surface-water diversion for irrigation may be a more likely explanation for the decreased streamflow.

Measured streamflow discharge and calculated discharge per unit of drainage area in Tonasket Creek were substantially less than those in the other three subbasins. Even in June, the uppermost measurement site in Tonasket Creek was dry, and the largest value of discharge per unit of drainage area (0.019 cfs/mi$^2$) was nearly eight times smaller than the largest comparable value for the other three subbasins. The highest elevations in Tonasket Creek subbasin are 1,000 to 2,000-ft lower than those in the other subbasins (table 1), so precipitation in Tonasket Creek subbasin may be slightly less, but that cannot account for the substantial difference in discharge per unit of drainage area during June and September. These data suggest that in Tonasket Creek, there is very limited ground-water recharge from winter/spring runoff and very little ground-water storage in general. Alternatively, the data are consistent with the hypothesis of exceptionally large consumptive use of ground-water and or surface water in the subbasin. Because there are not an exceptional number of wells in the subbasin and there does not appear to be an appreciable volume of ground-water storage (Walters, 1974), naturally limited ground-water resources in the subbasin are indicated. The instantaneous discharges measured by USGS in June and September 2008 at the lowermost site in Tonasket Creek (0.44 and 0 ft$^3$/s) were lower than the average monthly June and September discharges reported for 1967-79 for the old USGS streamgage at the same location (2.5 and 1.0 ft$^3$/s). However, the range of average daily discharges during the months of June and September at the discontinued USGS gage was 0 to greater than 10 ft$^3$/s, and the 2008 measurements fall within that range.

## Gaining and Losing Streamflow

Changes in measured streamflow between sites indicated net gains or losses along the reach of stream between the sites that were at least in part due to ground-water discharge to the stream or streamflow recharge to ground water. The direction of the hydraulic gradient at a measurement site indicated gains or losses to ground water at that specific point, which corresponds to either end of a reach.

During June 2008, more reaches (10 of the 17) and more measurement sites (13 of 20) were identified as losing rather than gaining (table 5 and 6, figs. 12-15). Similar proportions of losing reaches (8 of 16) and sites (14 of 17) were identified during September 2008. All four streams appeared to lose water to the ground-water system as they neared the Okanogan River, and the most dramatic losses were for Antoine Creek, as discussed previously. It is likely that regardless of ground-water pumpage, streamflow losses would occur as the streams flow across the relatively permeable floodplain deposits of the Okanogan River. It is possible that the losses are exacerbated by pumpage from the relatively abundant wells along the Okanogan River, but measured streamflow data alone cannot determine pumpage impacts. Overall, there was good correspondence between losing reaches and losing sites. The only neutral reach (lack of a gain or loss in streamflow) identified was in lower Tunk Creek in September when both measurement sites were dry. This does not necessarily indicate a lack of ground- and surface-water interaction, but rather the cumulative gains and losses between measurement sites equal 0 $ft^3/s$.

For Tunk and Bonaparte Creeks in June, hydraulic gradients at upstream sites were generally positive, indicating ground water was flowing into the stream at these sites. For Antoine and Tonasket Creeks in June, hydraulic gradients were near zero, or slightly less than zero, indicating no or little water movement between the streams and the ground-water system. All streams had losing measurement sites near their mouths. In September, most sites were identified as losing, the exceptions being a few upper basin sites. Zero flows at the two downstream-most sites on Tonasket Creek (Sites 46 and 47, fig. 7) can be assumed to represent losing sites.

In Tunk Creek during June (fig. 12), water entered the creek at the upstream sites and was lost from the creek at the downstream sites. Tunk Creek flows through a thick layer of unconsolidated sediments from about RM 12.4 (Site 8) to slightly west of RM 5.7 (Site 2), and the stream gained water from these sediments in June and lost water to them during September. Downstream of RM 5.7, the unconsolidated material thins and the creek flows through an area where bedrock is near or at land surface. Near RM 1.7 (Site 1), unconsolidated material again forms the near-surface geologic material and the creek lost water from that point to its mouth during June and September.

Hydraulic gradients measured in Bonaparte Creek were similar in June and September (fig. 13). The site downstream of what was termed the ‘bedrock sill segment’ by Packard and others (1983) near RM 5.2 had a relatively large negative hydraulic gradient (losing) in both June and September. Downstream from there, the gradient was less steep but still negative.

Antoine Creek lost water between the two most upstream measurement sites (Sites 38 and 70, fig. 7; RM 13.78 and 14.36, fig. 14) during June and September. Based on drillers’ logs, the thickness of unconsolidated material in this part of the basin appears to be up to about 200 feet. About 10 river miles downstream, after the creek emerges from the narrow, bedrock canyon, the gradients were slightly less negative (Sites 44 and 45, fig. 7). In June, the gradient was zero at RM 5.11 was positive about 0.25 miles downstream, but switched to strongly negative near the mouth of the creek.  The positive to neutral hydraulic gradients combined with the large loss of streamflow at RM. 4.29 indicates a surface-water diversion may be the cause of the decreased streamflow.

The uppermost site on Tonasket Creek (Site 58, fig. 7; RM 10.43, fig. 15) was observed flowing only during the May reconnaissance (it was dry in June and September), and the number of measurement sites on Tonasket Creek with no flow increased from one to three between June and September.  The two upstream sites on Tonasket Creek were losing or neutral in both June and

September (fig. 15). At the downstream sites in June, the hydraulic gradients were more negative, and in September both sites had no flow. Considering the surficial geology of the basin, it is possible there are reaches of the creek that are gaining. Between the two upstream sites at RM 5.26 and 7.95 (Sites 49 and 54) bedrock approaches land surface or may be exposed, which could lead to ground water moving upward and entering the creek. Very few drillers' logs were available for this area to confirm this interpretation. Downstream of RM 5.26 to the mouth, the creek channel is underlain by unconsolidated material, with thicknesses over 150 feet in some places, that would be expected to coincide with negative hydraulic gradients and streamflow losses to ground water.

## Subbasin Hydrogeology

A summary evaluation of subbasin hydrogeology was completed by compiling information from available well logs and recent surficial geologic maps and comparing it to previously published descriptions (Walters, 1974) to determine if any substantial new hydrogeologic features could be discerned. The logs are not an ideal source of information largely because different driller's describe subsurface materials differently, and because there is inherent uncertainty in the driller-provided well locations on the well logs that are, in most cases, accurate to a 40-acre quarter-quarter section (the well-log information was not field checked by USGS). In spite of these limitations, logs were of value because the vast majority of the 1,041 logs reviewed were for wells constructed after the Walters (1974) report was published.

There is a substantially greater extent of unconsolidated surficial materials in the study area subbasins, shown by the 2005 maps (Washington Department of Natural Resources, 2005, fig. 4) compared to Plate 1 in Walters (1974.) However, the distribution of wells in study area subbasins for which driller's logs were reviewed (fig. 16) generally coincides with the extent of quaternary alluvium and terrace deposits mapped by Walters (1974). The WDNR (2005) maps likely include significant areas of mapped unconsolidated materials that are unsaturated or very thin, so the expanded surficial extents of unconsolidated materials do not likely reflect newly-found expanded ground-water storage.

Wells constructed in study area subbasins after 1974 were compiled according to depth to bedrock (fig. 17) for comparison to information presented by Walters (1974). Depth to bedrock is essentially equivalent to thickness of unconsolidated materials. Overall, the Bonaparte Creek subbasin stands out as having the most and deepest wells, which are indicative of it having the most ample ground-water resources. This is consistent with Walter's estimates of ground-water storage in the Siwash-Bonaparte-Chewiliken subarea of 200,000 acre-feet (ac-ft), in the Tunk-Omak subarea of 60,000 ac-ft and in the Tonasket-Antoine subarea of 70,000 ac-ft. Tonasket Creek subbasin has both the fewest and the shallowest wells, which is indicative of having the most limited ground-water resources. This is consistent with the extremely low discharge per unit area values calculated from streamflows measured in June and September 2008, that are in turn indicative of naturally limited ground-water storage and discharge needed to sustain summer low flows.

One conclusion from the Initial Watershed Assessment (Montgomery Water Group, Inc. and others, 1995) was that some locations in the study area may have deep confined aquifers within unconsolidated deposits that may not be in connection with nearby surface water. Most well logs deeper than 100 ft indicate multiple potential confining layers such as blue or gray clays or various cemented units, but evaluating the continuity and hydraulic characteristics of confining layers was beyond the scope of this investigation.

About 65 percent of the Tunk Creek subbasin is mantled with unconsolidated deposits, the highest percentage of the four study area subbasins. The relatively high percentage of unconsolidated materials in the subbasin is consistent with the relatively constant streamflow measured along the length of the creek in June and September 2008. This is because the extensive deposits can store and discharge ground water along most of the length of the Tunk Creek mainstem. Because nearly half of the driller's logs for wells in the basin indicate sediment thicknesses of less than 100 ft, there is a high potential for ground-water withdrawals to affect ground-water discharge to streams.

About half of the Bonaparte Creek subbasin is mantled with unconsolidated deposits, and depths to bedrock may exceed 300 feet especially near the center of the basin following the course of the Bonaparte Creek streambed. Most Bonaparte subbasin well logs with depths to bedrock greater than 300 ft were located in the lowlands immediately adjacent to the Okanogan River and are not typical of unconsolidated deposits further upstream in the subbasin.

About half of the Antoine Creek basin is mantled with unconsolidated deposits. Most of these deposits are found in the upper basin, although about 16 percent lies within about 5 river miles of the mouth of the creek. Driller's logs indicate that the unconsolidated deposits in this lower part of the basin may be relatively thin, about 100 feet thick or less. It was in this area where streamflow measurements indicated an abrupt and substantial decrease in surface-water discharge. Antoine Creek flows through a deep and narrow canyon above this location, the downstream end of which is about 5.5 miles from the mouth of the creek. The canyon is about 4.6 miles long and about 150-200 feet deep. Based on the available logs, the thickest layer of unconsolidated geologic material exists around the town of Havillah, WA near RM 14. Thicknesses exceed 200 feet in this area.

Again, about half the surface is mantled with unconsolidated materials in the Tonasket Creek subbasin, and most of those deposits are in the northern and eastern parts of the basin. Surface and near-surface bedrock is found in the southwestern part of the basin. Based on information contained in the driller's logs, the thickest layer of unconsolidated material, exceeding 300 ft, is found between 2 and 5 miles east of Oroville, WA. Thicknesses in most other areas of the basin range from a few feet to over 100 feet.

## Data Gaps and Suggestions for Further Study

Ground-water resources appear to be relatively limited in most parts of the study area subbasins, which in turn leads to low summer streamflows that have a high potential for being impacted by ground-water withdrawals. However, given the limited precipitation and ground-water storage capacity, together with permeable unconsolidated materials along most of their lengths, the creeks measured during this investigation would also likely lose summer streamflow to ground water over much of their lengths even without ground-water withdrawals. These conditions make it difficult to parse out the specific effects of ground-water pumping on streamflow without intensive measurements and evaluations.

Given those difficulties, it would be expedient to select more limited, high-interest areas where detailed quantitative assessments of ground-water/surface-water interactions would be of most use. The USGS Bonaparte Creek study (Packard and others, 1983) is a reasonable starting point for what a detailed quantitative assessment of ground-water/surface-water interactions would include. In addition, it would be informative to field-locate surface-water diversions and pumping wells with estimates or measurements of the diversion and pumpage amounts, and to use pressure transducers and recorders in selected near-stream wells to measure pumping-induced changes in water levels.

Characterizing possible deep, confined aquifers within unconsolidated deposits that may not be in connection with nearby surface water would also require intensive investigation that again would benefit by focusing on a few limited, high-interest areas. As previously described, most well logs deeper than 100 ft indicate multiple potential confining layers such as blue or gray clays or various cemented units. However, the presence of such layers alone is not indicative of an unconnected deep aquifer. It seems unlikely that a deep, confined, unconnected aquifer exists in the relatively limited unconsolidated materials of the subbasins. That is because the underlying and surrounding bedrock is generally of low permeability, so recharge to a deep aquifer with any appreciable ground-water resource would have to originate from the overlying sediments, and discharge from a deep aquifer would need to be through the overlying sediments in different locations. By definition, the deep aquifer would thus be in connection with nearby surface water. It would be possible to better characterize the nature and timing of ground-water/surface-water interactions, such as when pumping ground water at a given time may affect streamflow. Such a characterization would require more intensive evaluations of both the hydrogeologic framework of the unconsolidated materials and their hydraulic properties. It is unlikely that there are enough existing wells to definitely characterize any deep confined aquifers, so drilling of new monitoring wells would be required. Again, it would likely still be difficult to parse out the specific effects on streamflow of ground-water pumping from a deep, confined aquifer compared to the existing pumping from shallower unconfined aquifers, even with new monitoring wells. A numerical ground-water model would greatly assist in the evaluation, as was done for WRIA 59 in Stevens County (Kahle, and others, 2003).

## Summary and Conclusions

The Okanogan Conservation District (OCD) is the lead agency of a group of local government agencies and citizens undertaking the planning and implementation of a long-range watershed plan for the Okanogan River basin, in north-central Washington State. The plan will be used to meet the needs of current and future water demands within the basin while also working to protect and improve its natural resources. Part of the planning phase includes an assessment of the ground-water/surface-water interactions in tributaries to the Okanogan River. The OCD selected four subbasins tributary to the Okanogan River (Tunk, Bonaparte, Antoine, and Tonasket Creeks) and requested that the U.S. Geological Survey (USGS) collect and evaluate data to better understand ground-water/surface-water interactions in those basins.

The objective of this study was to describe the ground-water/surface-water interactions in valley-fill deposits in the tributary subbasins. Field work included streamflow measurements and shallow ground-water level measurements beneath the streams in the subbasins. In addition, Geologic and hydrogeologic information for the subbasins was obtained from previously-published reports, surficial geologic maps produced by the Washington State Department of Natural Resources (WDNR), and from driller’s logs on file at the USGS Washington Water Science Center or downloaded from the Washington State Department of Ecology database of driller’s logs.

Granitic, andesitic, and metamorphosed rock underlie most of the Okanogan River basin. Wells open in these bedrock units generally provide only enough water to satisfy domestic uses. The Okanogan Lobe of the Cordilleran ice sheet overrode the bedrock units during the last large-scale glaciations and as the ice sheet receded, it deposited layers of clay, silt, sand, and gravel in the river and stream valleys. These unconsolidated rocks represent the major sources of ground water.
The extent of unconsolidated materials near or at land surface ranges from 48 to 65 percent of the subbasins. Driller’s logs suggest that the thickness of these materials ranges from less than 20 feet in the upland areas to several hundreds of feet in the river and stream valleys.

About 70 stream sites in the four subbasins were visited during a reconnaissance trip to the study area in May 2008. Flowing water was observed at about 75 percent of the sites. Estimated streamflows at the sites ranged from less than 1 to about 10 $ft^3/s$. A subset of these sites was selected for streamflow and ground-water level measurements. Streamflow was measured at 21 sites in June 2008 and at 16 sites in September 2008. Shallow ground-water level measurements were made at the same time as the streamflow measurements, using a small-diameter piezometer temporarily installed during the site visit. Measurements of the water level in the piezometer and the distance from the top of the piezometer to the stage of the stream were used to compute the hydraulic gradient between surface water and ground water at that point.

Streamflows in June in all the streams were substantially higher than in September. Streamflow per unit drainage area was calculated for each measurement site. For Tunk Creek, the unit streamflow decreased in a downstream direction in June. In September, unit streamflow at the uppermost measurement site was less than at mid-basin sites. This is likely due to limited ground-water storage capacity and subsequent discharge to the stream resulting in less water entering the stream later in the year. An alternative is greater consumptive use in the upper basin, but given that the thickness of unconsolidated materials is limited, limited storage capacity is the most likely explanation. Streamflow at sites on Bonaparte Creek were higher in June than in September and as for Tunk Creek, streamflow per unit area was lower at the upstream site than at the mid-basin sites. The mid-basin portion of Bonaparte Creek has the potential to store large quantities of ground water, given the thickness of unconsolidated material. In contrast to the Tunk Creek subbasin, however, there may be significant consumptive use of water in the Bonaparte Creek basin that leads to a decrease in streamflow. Streamflow in Antoine Creek downstream of the mouth of a narrow canyon at about river mile (RM) 5.24 was substantially lower than upstream of that point and was also lower than the streamflow per unit area at comparable locations on Tunk and Bonaparte Creeks. A possible explanation is that land use downstream of RM 5.24 appears to be intensively irrigated. Water for irrigation may be from wells or directly from Antoine Creek. In either case, streamflow in Antoine Creek would be affected. Streamflows per unit area in Tonasket Creek were the smallest of the four subbasins. Data suggest that there is little ground-water recharge, even from winter/spring runoff, and little ground-water storage in general.

During June 2008 more reaches (10 of 17) and more measurement sites (13 of 20) were identified as losing reaches for the four stream. Similar numbers of losing reaches were identified during September. All four streams appeared to lose water to the ground-water system as they neared the Okanogan River, with Antoine Creek exhibiting the greatest losses. Streamflow losses probably occur as the streams flow across the relatively thick and permeable floodplain deposits of the Okanogan River.

In June, hydraulic gradients at upstream sites for all four streams indicated that these reaches were either gaining (ground water flowing into the streams) or neutral (no net water movement into or out of the stream). All streams had losing reaches near the mouths. In September, most sites were identified as losing reaches, except for a few upper-basin sites.

An evaluation of WDNR geologic maps indicates the extent of unconsolidated materials in the four subbasins is greater than reported by Walters (1974). However, an evaluation of driller's logs with respect to location and lithology indicate general agreement with the extent map in Walters (1974). The WDNR maps likely include significant areas of unsaturated or very thin unconsolidated materials that may not have been classified as unconsolidated by Walters.

Interpretation of driller's logs to obtain depth-to-bedrock provided an estimate of the thickness of unconsolidated materials. In general, the Bonaparte Creek subbasin had the most and deepest wells, which is indicative of the subbasin having larger ground-water resources than the other subbasins. The Tonasket Creek subbasin had the fewest and shallowest wells, indicating more limited ground-water resources. Due to uncertainties in well locations listed on the driller's logs and the inconsistent naming of geologic materials on the logs, the existence of deep, confined aquifers in the unconsolidated material could not be evaluated. The presence of extensive and (or) thick layers of unconsolidated materials is consistent with relatively constant streamflow in the creek, as in the Tunk Creek basin. Areas of less extensive or thinner layers of unconsolidated materials may lead to abrupt and substantial decreases in streamflow, as in lower Antoine Creek basin.

Ground-water resources appear to be limited in most parts of the subbasins, which results in low summer streamflows, with a high potential to be affected by ground-water withdrawals. However, given the low precipitation, the limited ground-water storage capacity, and the permeable unconsolidated materials underlying the stream channels, the creeks would also likely lose water to the ground-water system without any withdrawals. It is difficult to evaluate the specific effects of ground-water pumping on streamflow without intensive measurements and evaluations. To better evaluate ground-water/surface-water interactions, studies would be helpful that are more limited in areal extent and more focused on quantitative assessments of those interactions are indicated. To determine if deep, confined aquifers exist within unconsolidated deposits, an intensive effort, restricted to a limited geographic area would be required. Currently-available data (driller's logs) are not sufficient to confirm the presence of deep, confined aquifers.

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Bob Clark, of the Okanogan Conservation District and Rusty Post, of the Washington State Department of Ecology provided valuable guidance on developing the scope of work and work plan for this investigation. Appreciation is expressed to landowners who gave permission to measure flow in creeks that crossed their properties and measure water levels in their wells.

# Figures

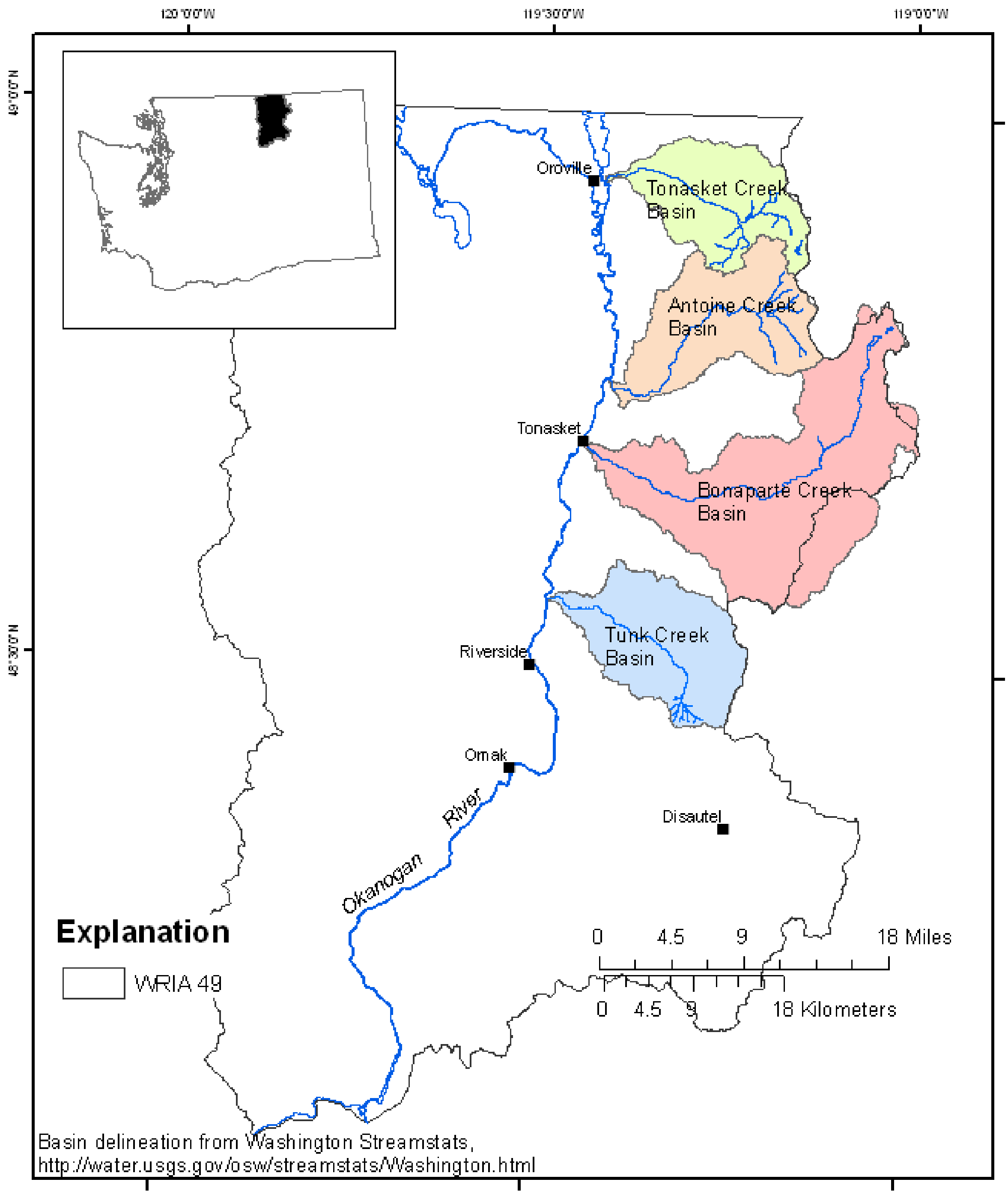


Figure 1. Location of Water Resource Inventory Area 49 and the four subbasins included in the study area

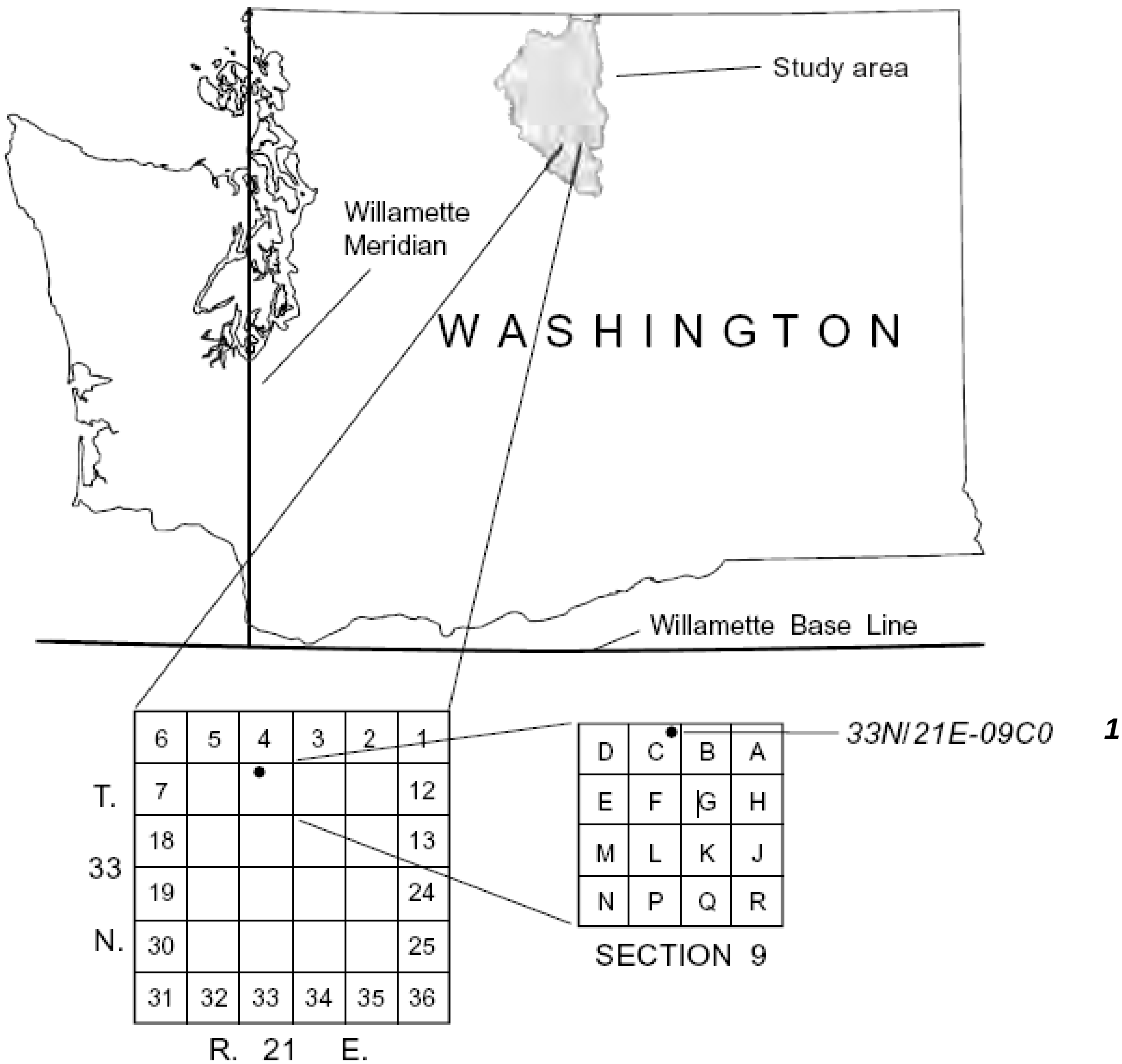


Figure 2. Local number site identification system used in Washington State.

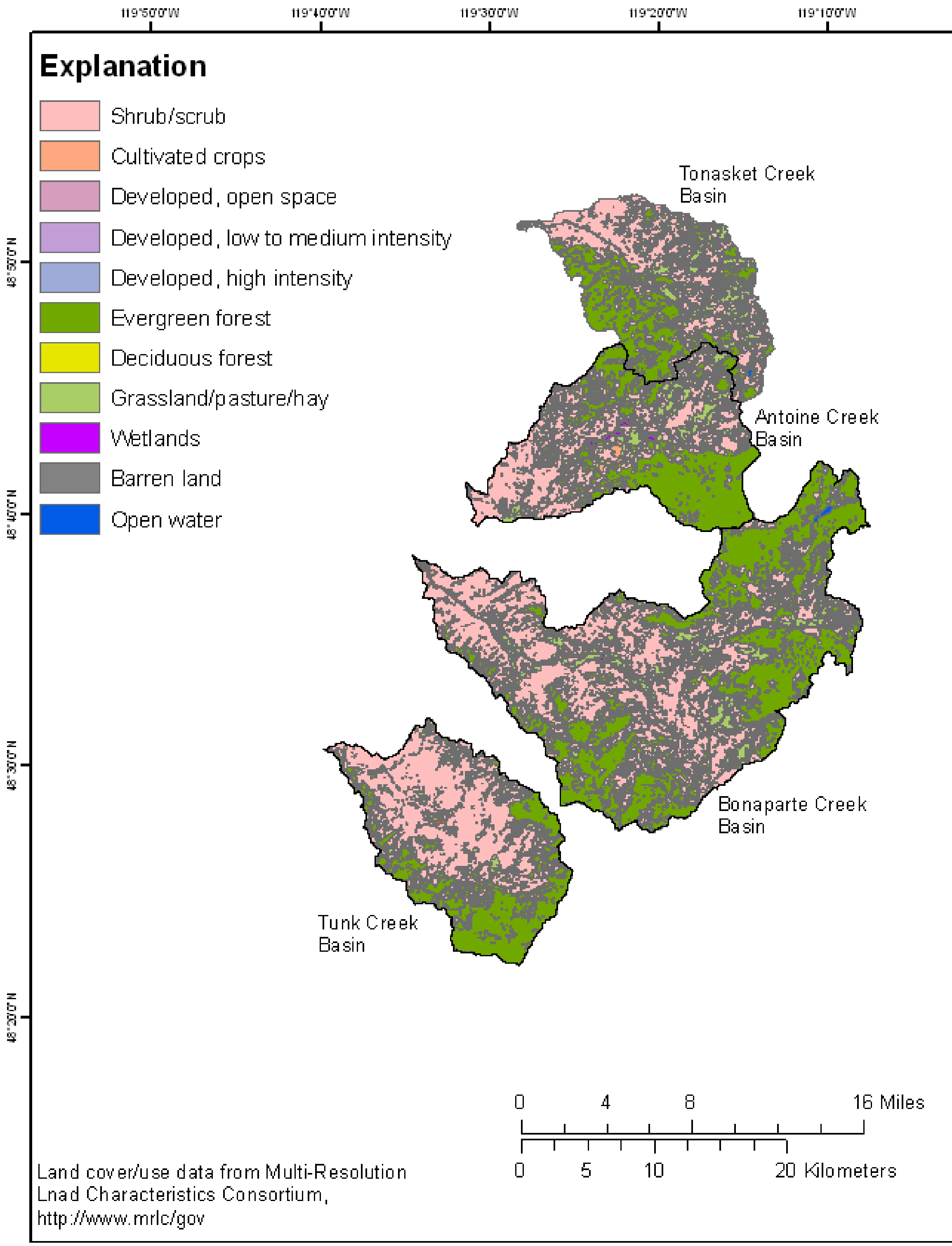


Figure 3. Generalized land cover in the study area subbasins

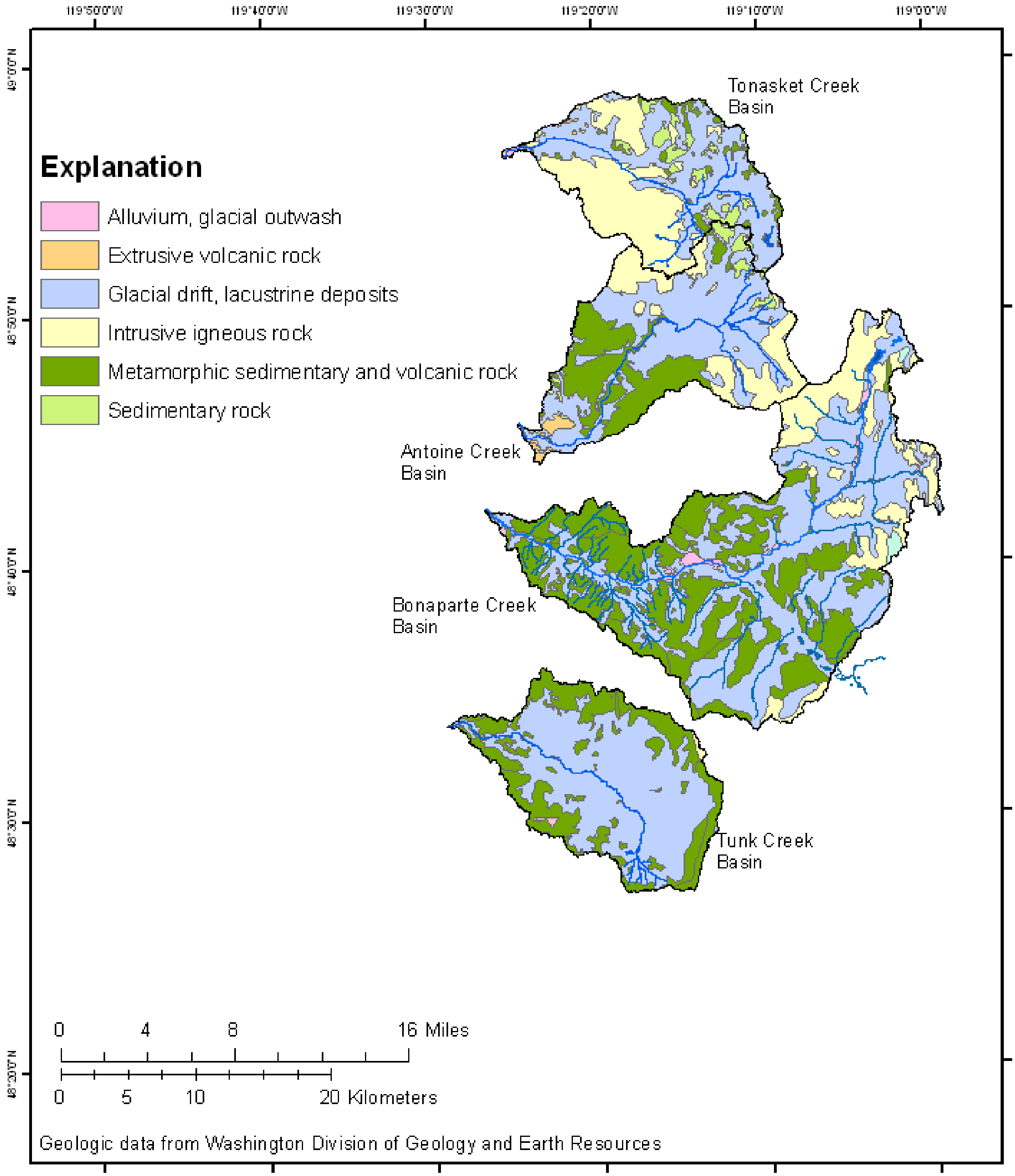


Figure 4. Generalized surficial geology of the study area subbasins

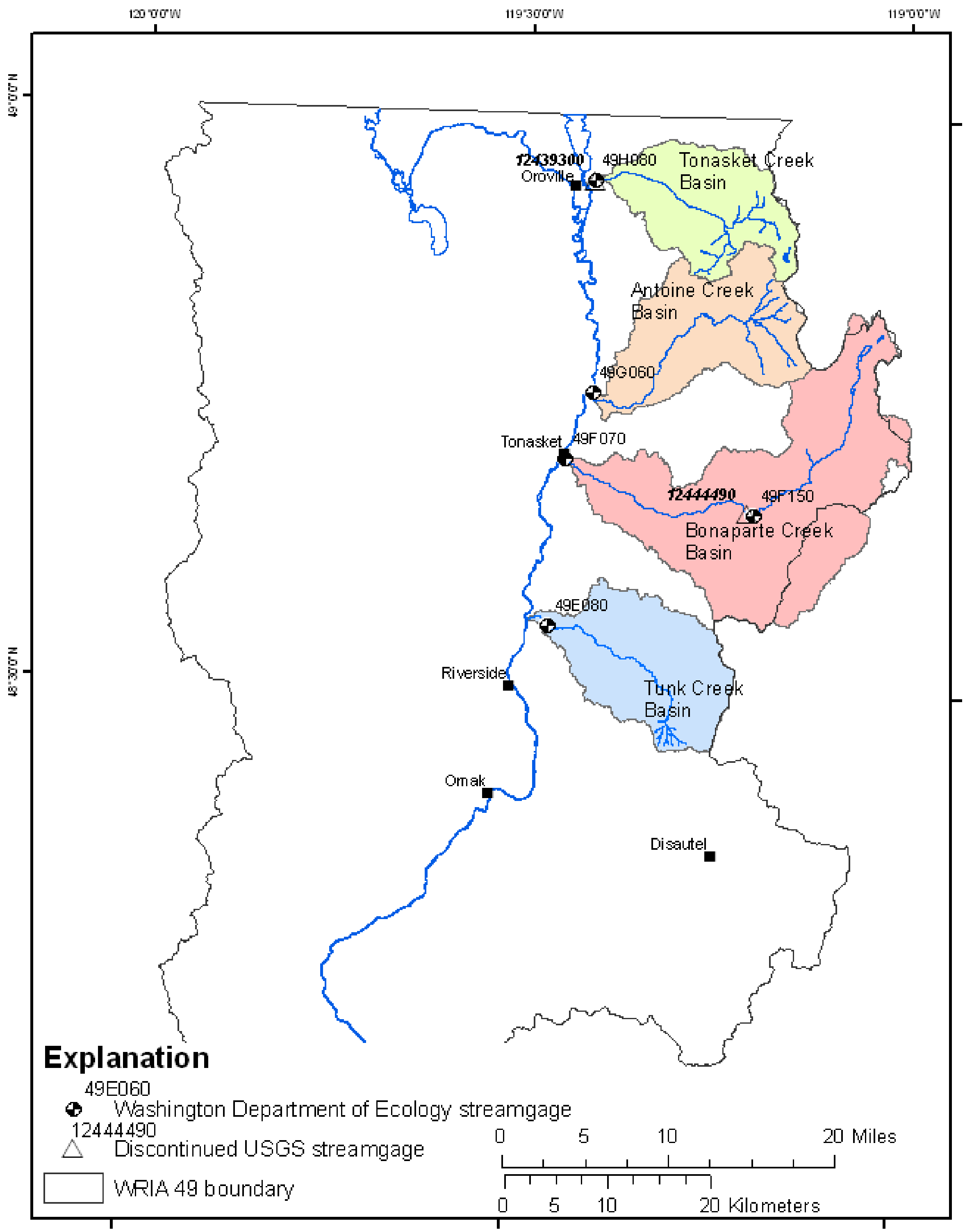


**Figure 5.** Locations of streamflow monitoring stations maintained by the Washington State Department of Ecology, and historical USGS streamgaging stations.

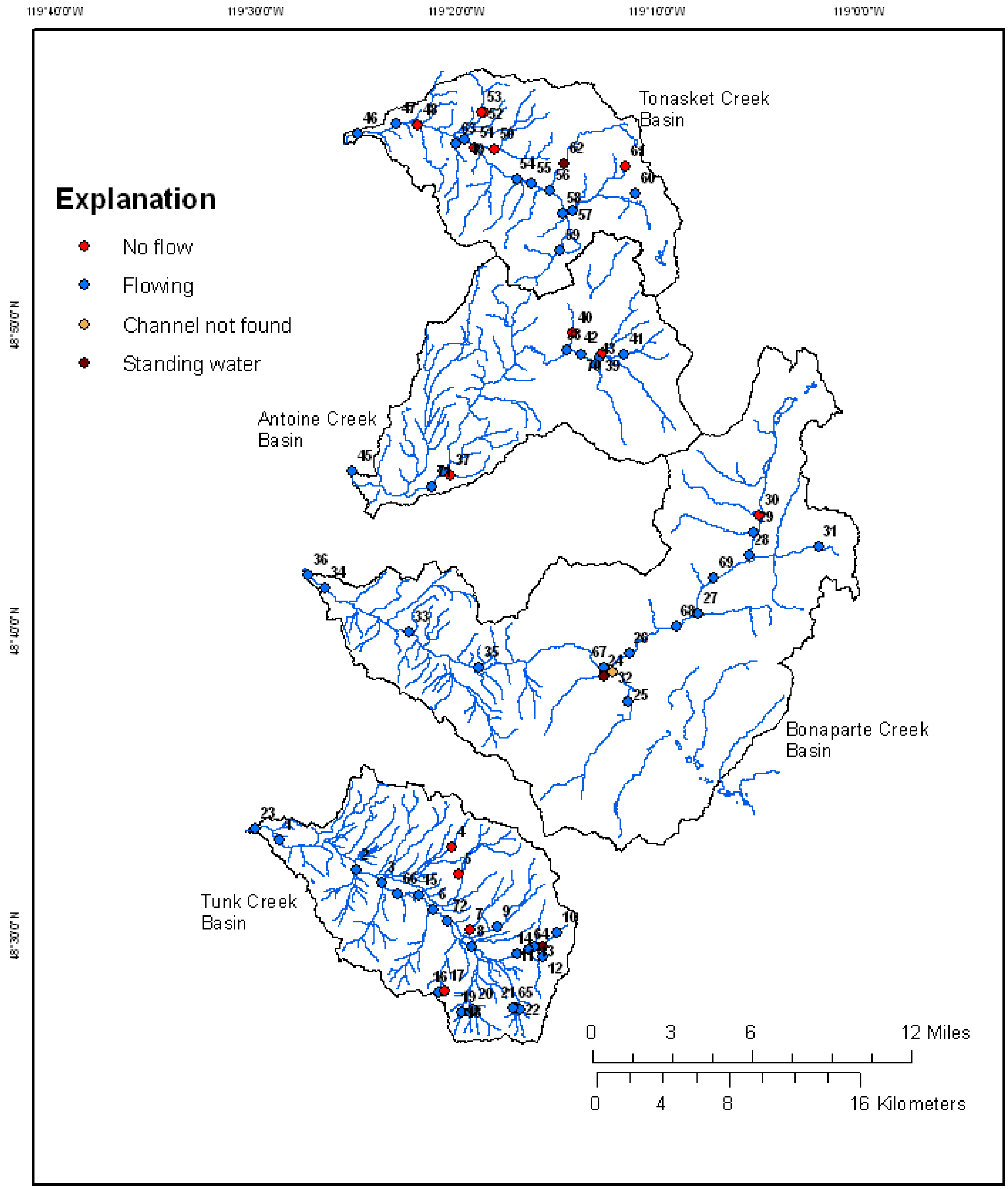


Figure 6. Candidate streamflow measurement sites and streamflow status observed by USGS during May 2008 reconnaissance

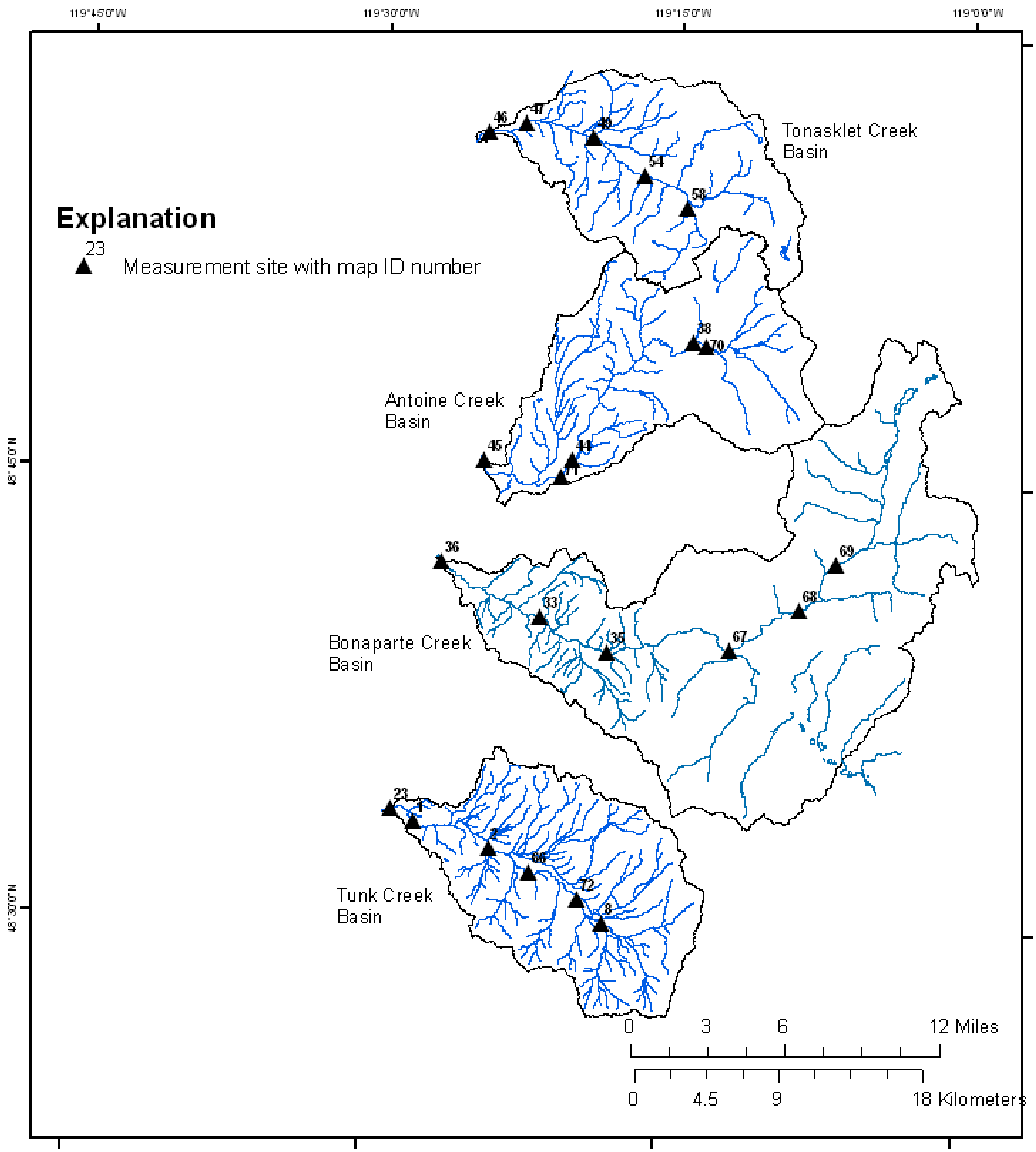


Figure 7. Selected streamflow and water-level measurement sites

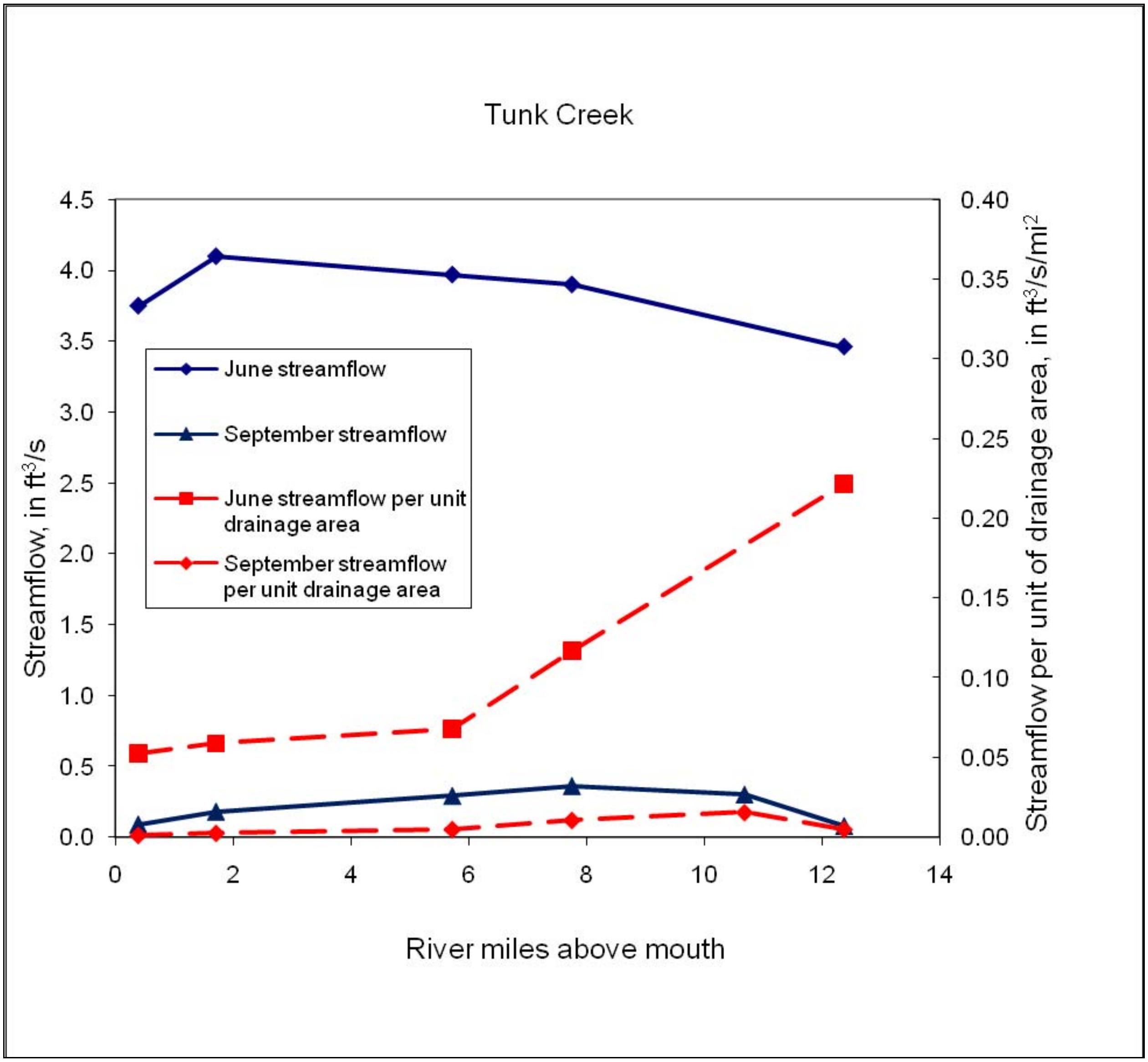


**Figure 8.** Streamflows measured in Tunk Creek in June and September 2008 at the measurement sites.

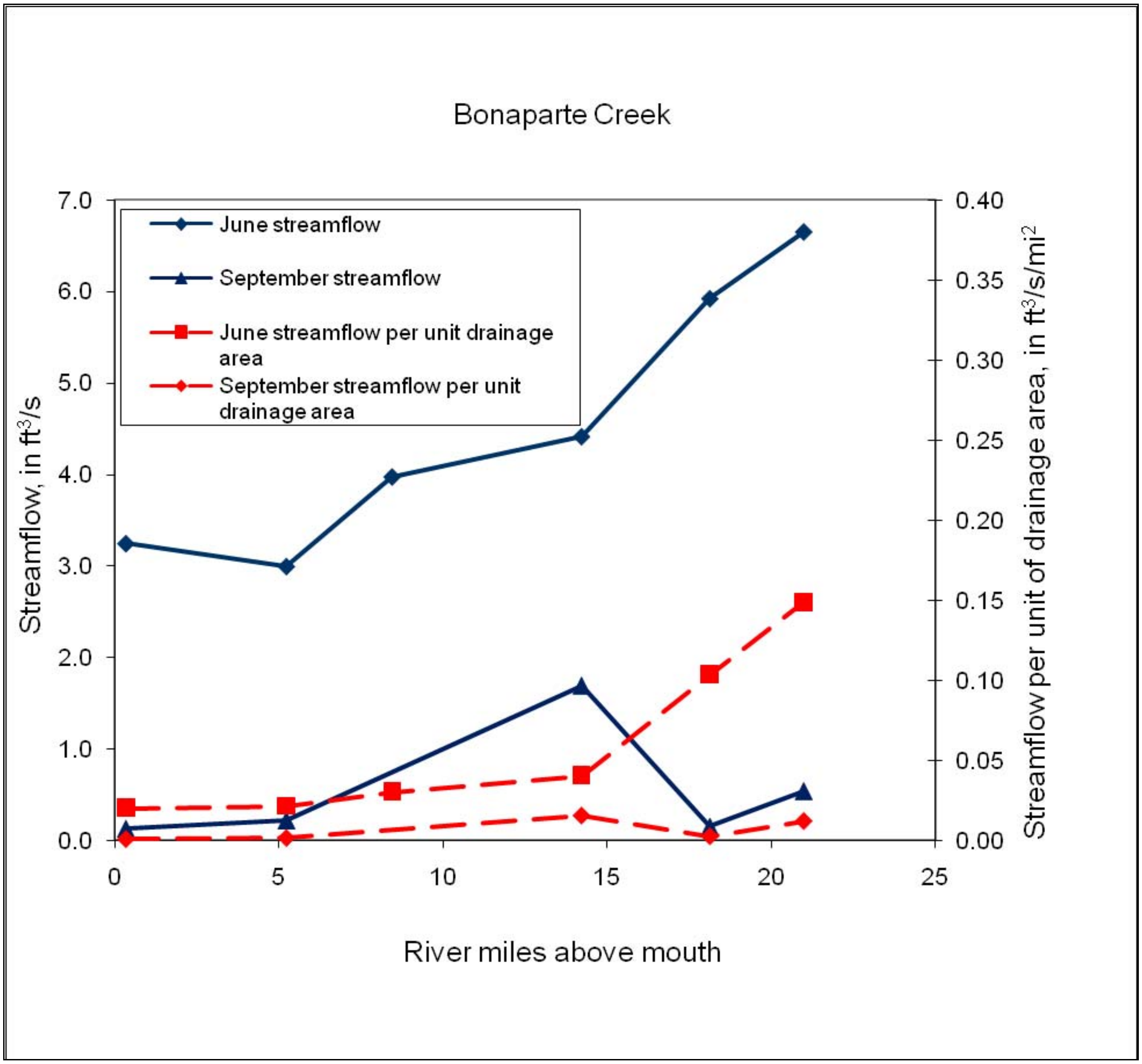


Figure 9. Streamflows measured in Bonaparte Creek in June and September 2008 at the measurement sites.

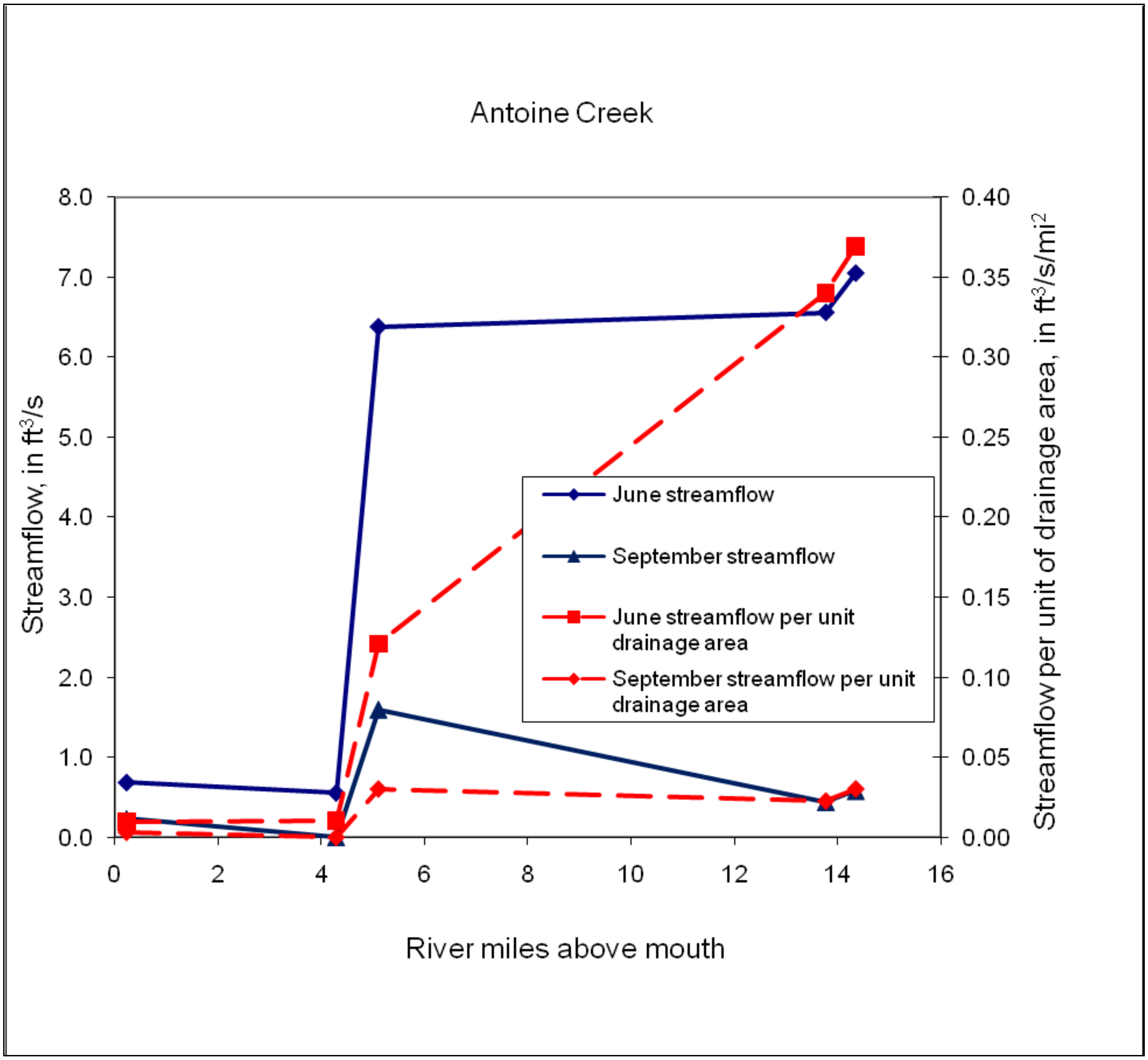


Figure 10. Streamflows measured in Antoine Creek in June and September 2008 at the measurement sites.

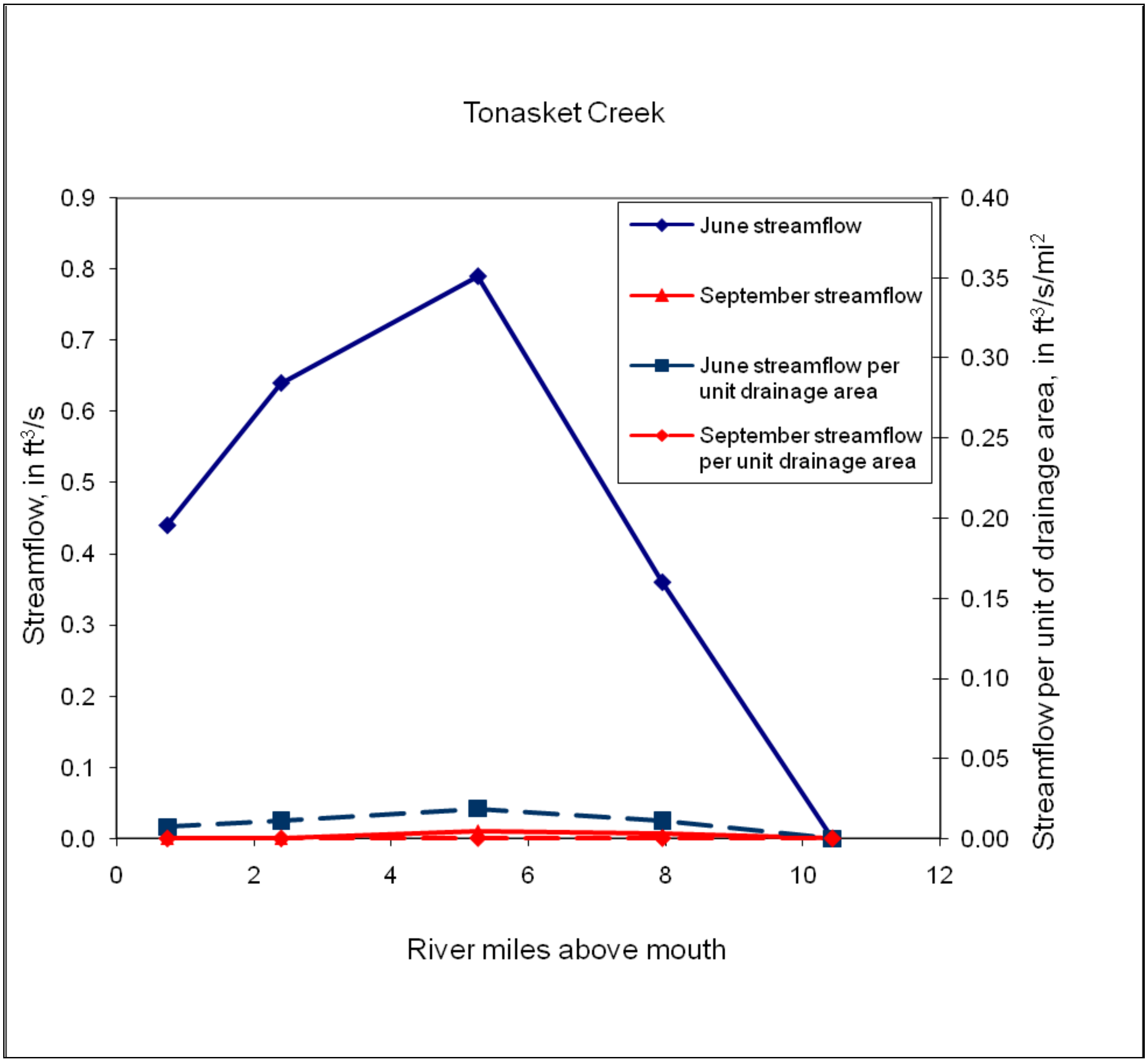


**Figure 11.** Streamflows measured in Tonasket Creek in June and September 2008 at the measurement sites.

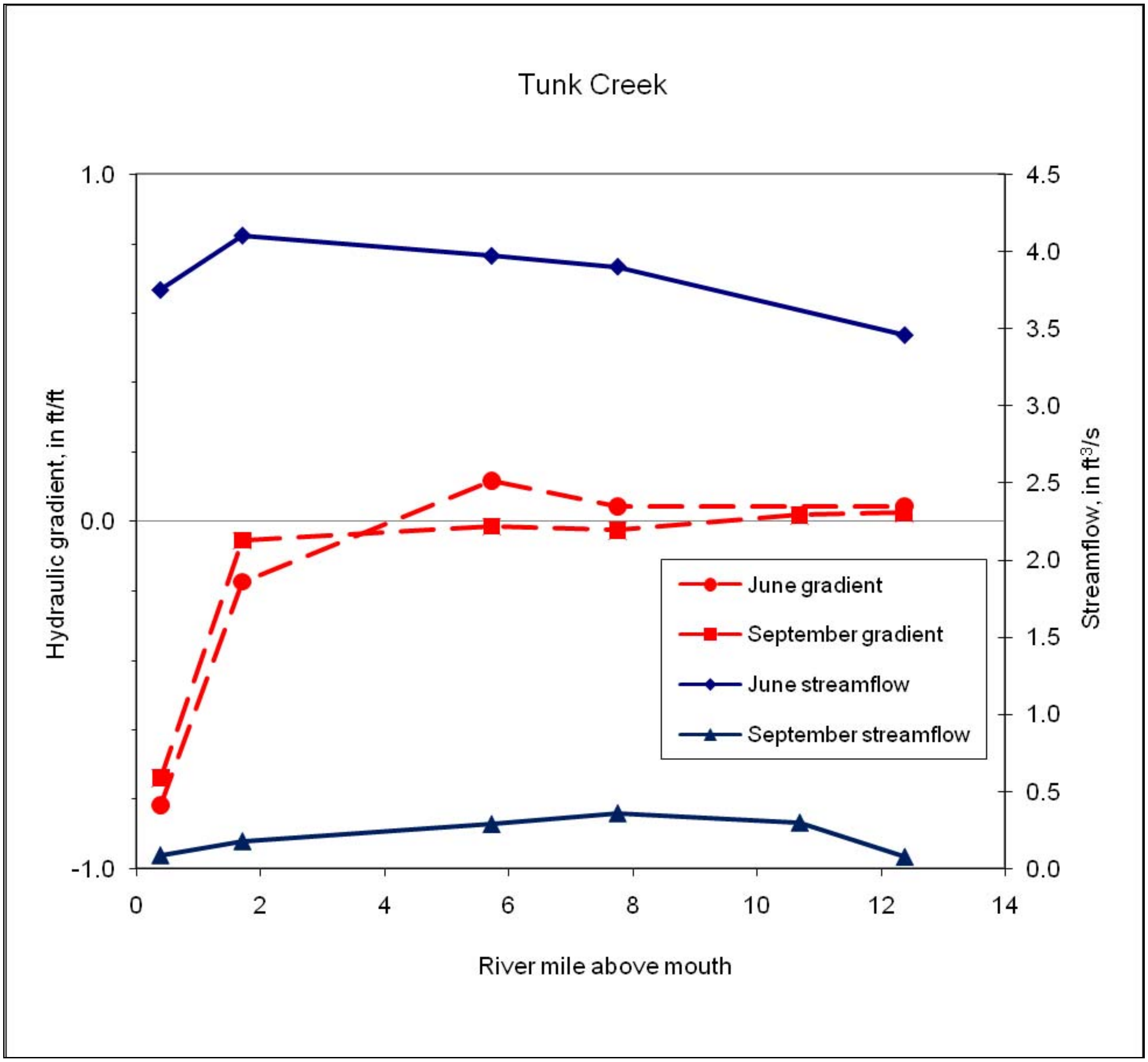


Figure 12. Graph of hydraulic gradients and streamflow in Tunk Creek in June and September 2008

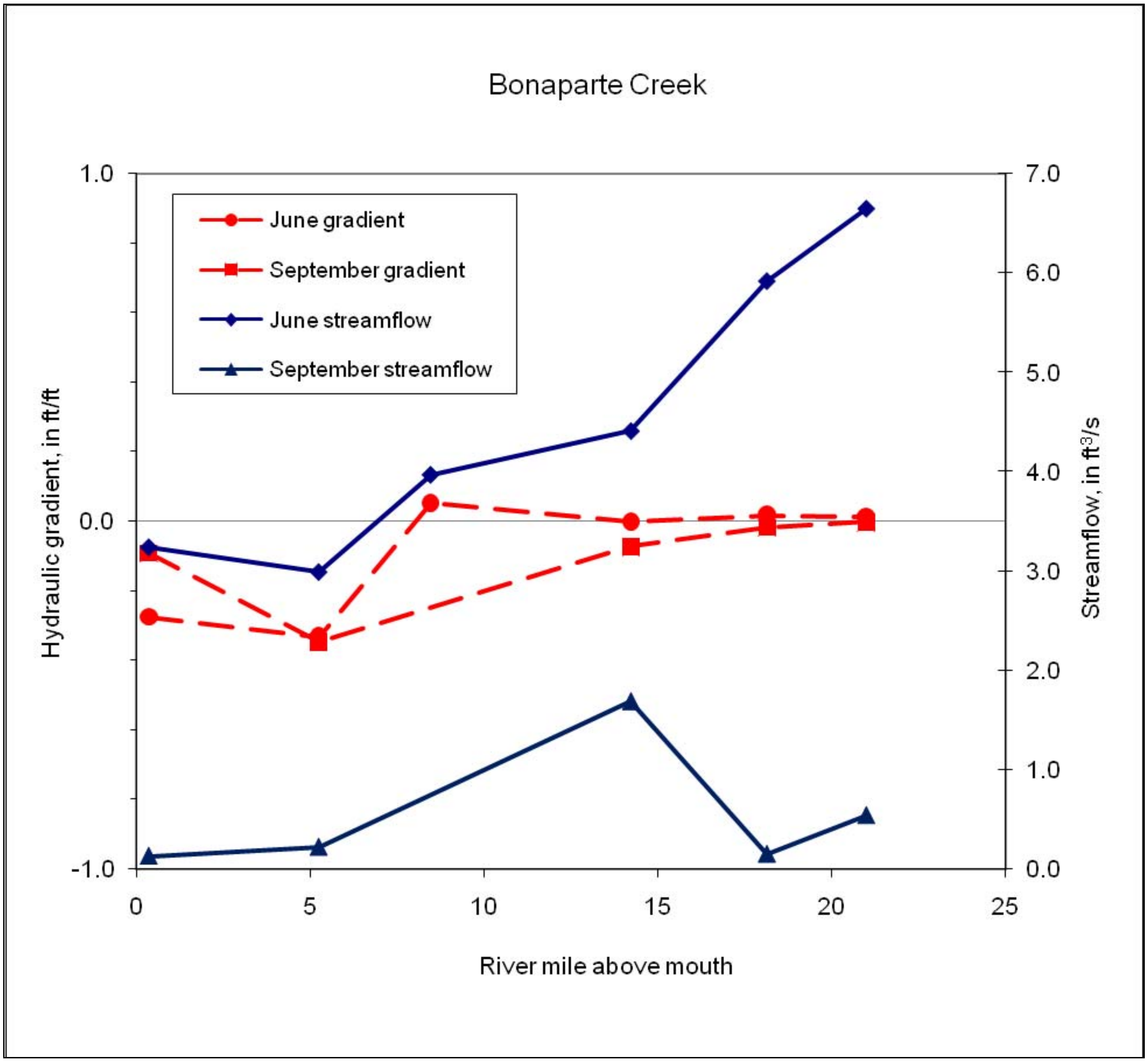


Figure 13. Graph of hydraulic gradients and streamflow in Bonaparte Creek in June and September 2008

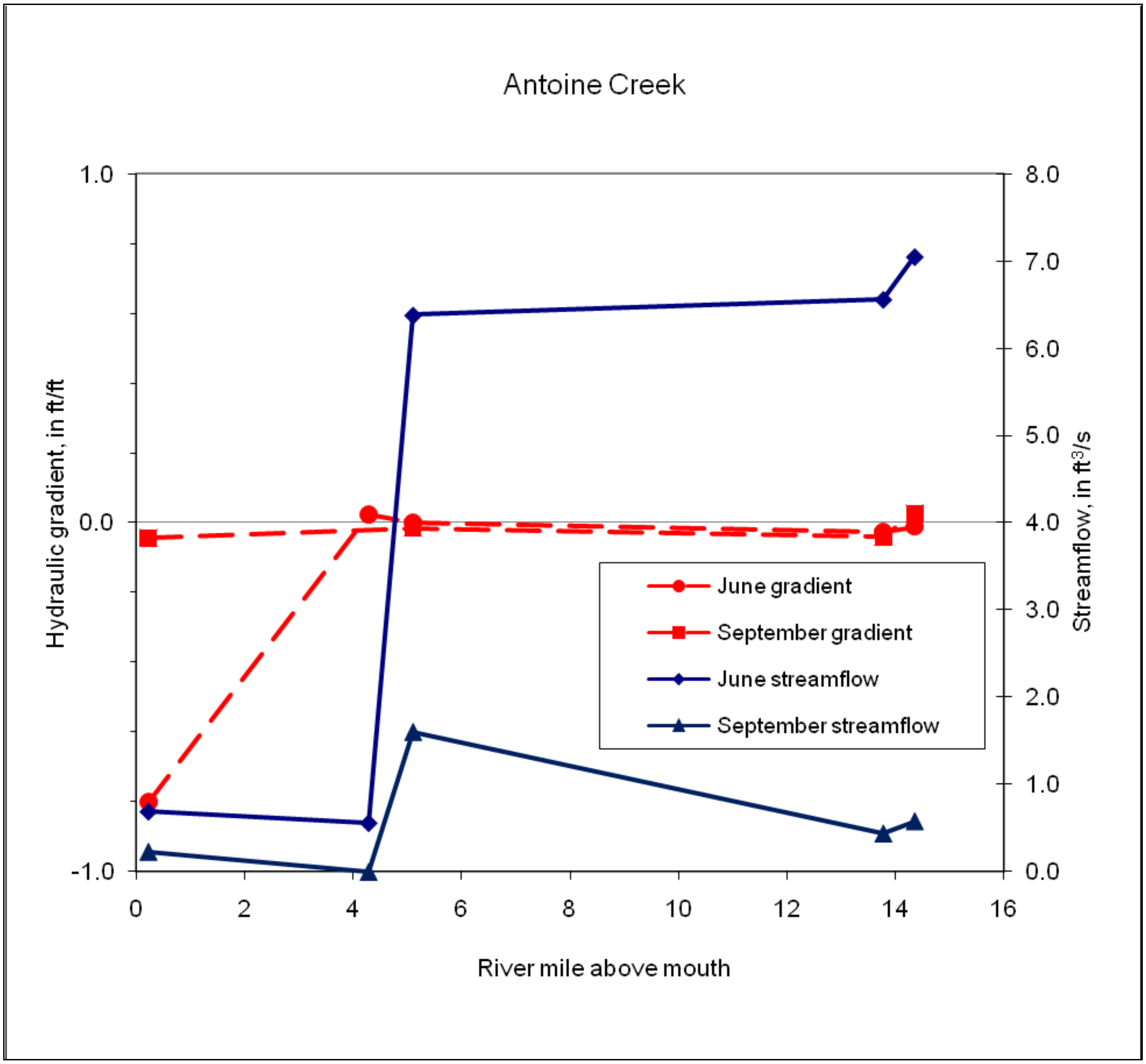


Figure 14. Graph of hydraulic gradients and streamflow in Antoine Creek in June and September 2008

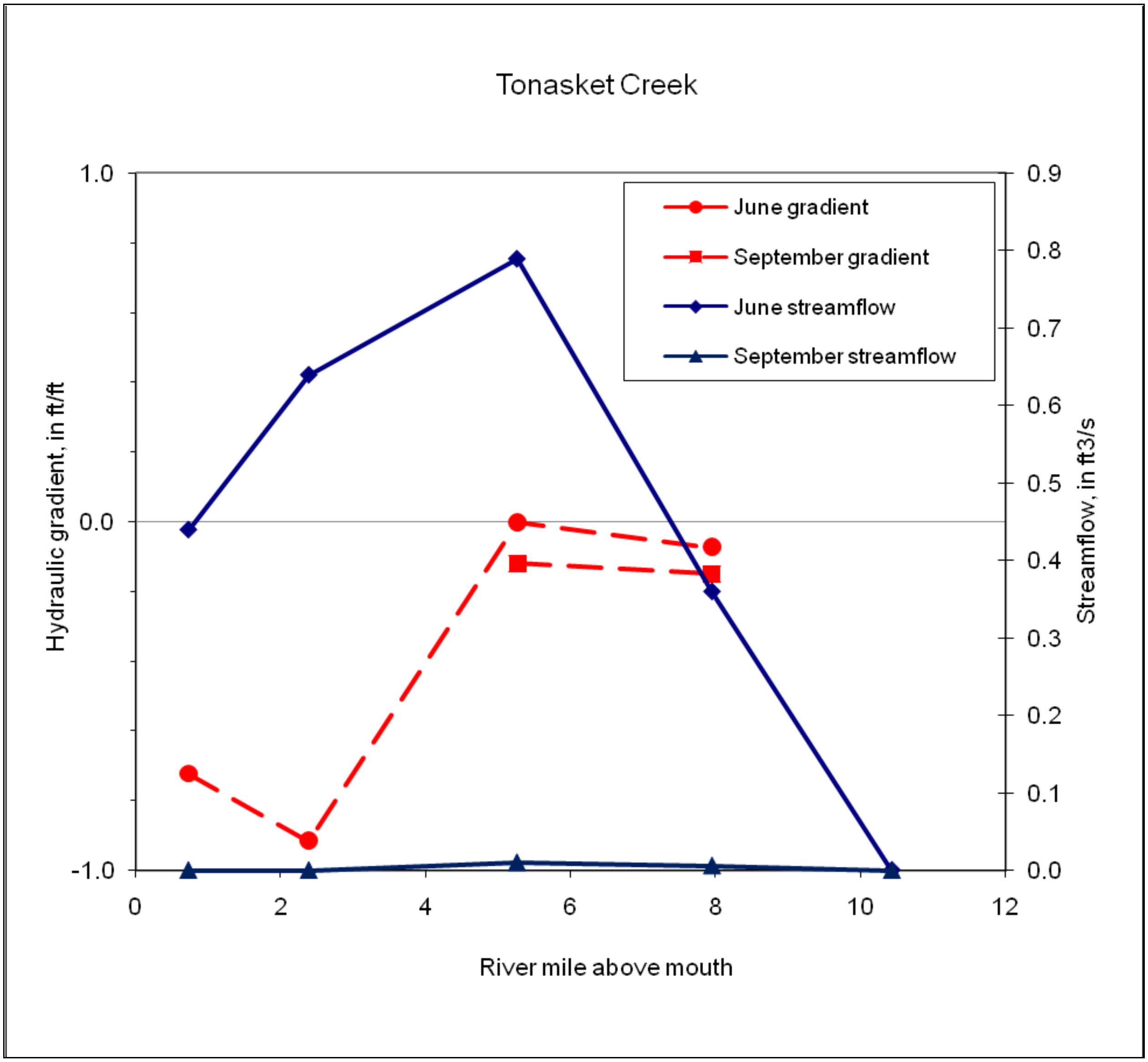


**Figure 15.** Graph of hydraulic gradients and streamflow in Tonasket Creek in June and September 2008

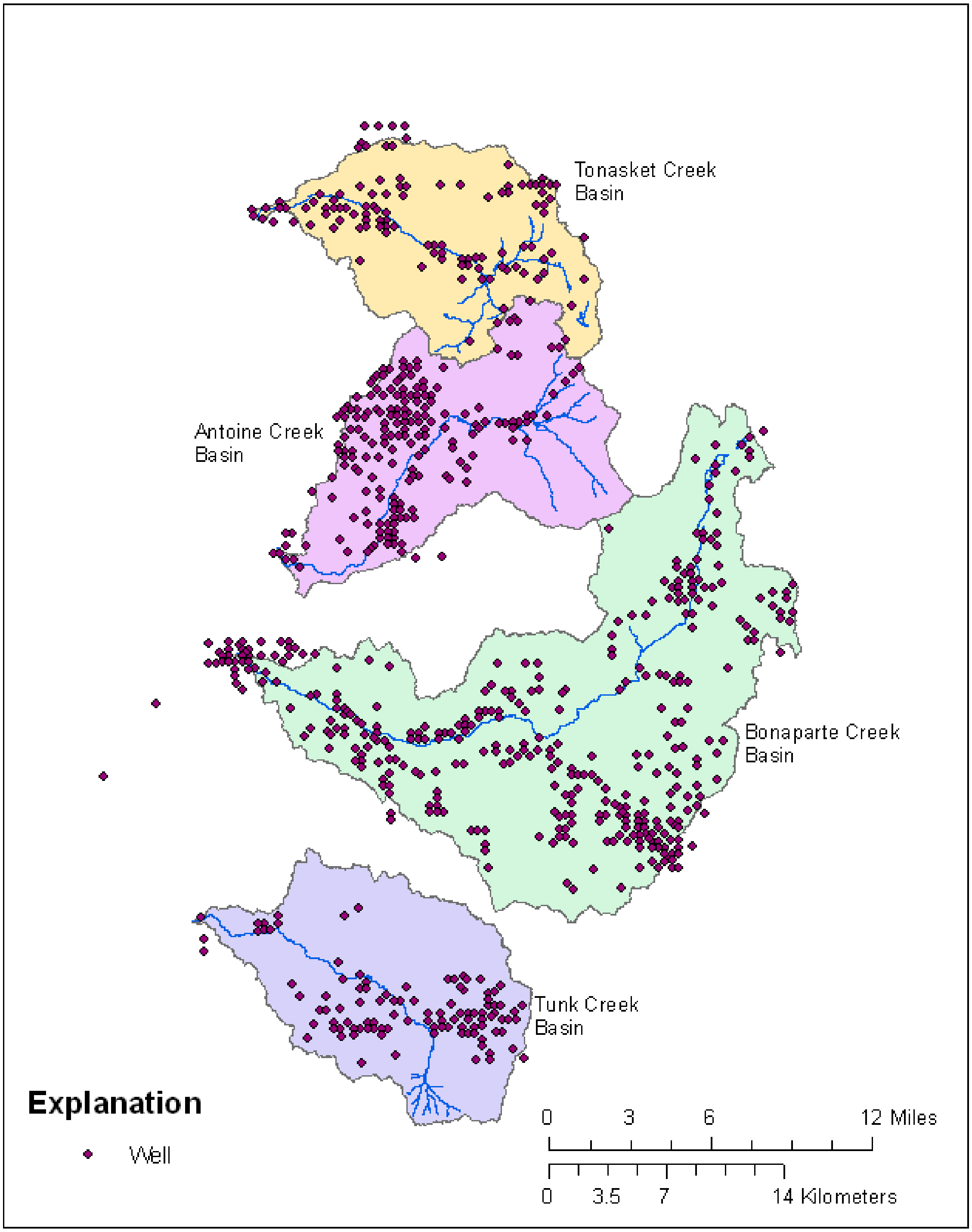


Figure 16. Approximate locations of wells in study area subbasins for which driller's logs were reviewed.

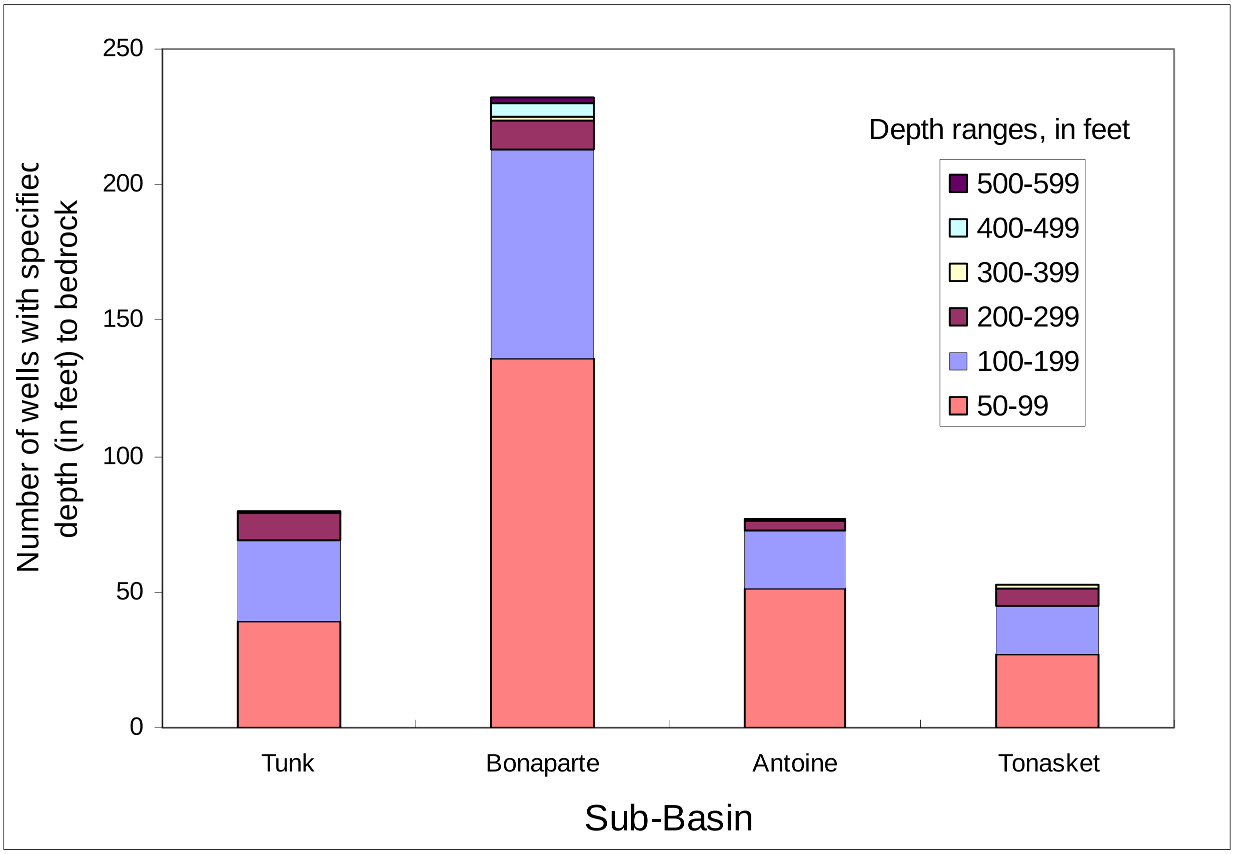


Figure 17. Numbers of post-1974 constructed wells in study area subbasins with specified ranges in depth to bedrock.

# Tables

**Table 1.** Location and selected physical characteristics of study area subbasins. (Basin characteristics from http://streamstats.usgs.gov/wastreamstats/index.asp, accessed November 26, 2008.)

| Subbasin name | Location of subbasin mouth (river miles along Okanogan River) | Area (square miles) | Altitude range (feet) | Average altitude (feet) |
|---|---|---|---|---|
| Tunk Creek | 45.0 | 71.7 | 860 - 6,050 | 3,300 |
| Bonaparte Creek | 56.7 | 161 | 890 – 7,260 | 3,550 |
| Antoine Creek | 61.2 | 73.4 | 900 – 7,250 | 3,440 |
| Tonasket Creek | 77.8 | 60.1 | 920 – 5,090 | 3,300 |

Table 2. Extents of different land covers in the study area subbasins [mi$^2$, square mile]

| Subbasin name | Land cover | Extent (mi$^2$) | Percent of subbasin |
|---|---|---|---|
| Tunk | Open Water | 0.005 | 0.006 |
| | Developed, open space | 0.015 | 0.021 |
| | Developed, low intensity | 0.003 | 0.004 |
| | Deciduous forest | 0.006 | 0.008 |
| | Evergreen forest | 23.852 | 33.406 |
| | Shrub/scrub | 42.030 | 58.865 |
| | Grassland/herbaceous | 5.153 | 7.217 |
| | Cultivated crops | 0.076 | 0.107 |
| | Woody wetland | 0.177 | 0.248 |
| | Emergent herbaceous wetland | 0.084 | 0.118 |
| Bonaparte | Open Water | 0.305 | 0.183 |
| | Developed, open space | 1.098 | 0.659 |
| | Developed, low intensity | 1.125 | 0.675 |
| | Developed, medium intensity | 0.152 | 0.091 |
| | Developed, high intensity | 0.005 | 0.003 |
| | Barren land | 0.012 | 0.007 |
| | Deciduous forest | 0.004 | 0.002 |
| | Evergreen forest | 66.488 | 39.903 |
| | Shrub/scrub | 79.527 | 47.728 |
| | Grassland/herbaceous | 16.266 | 9.762 |
| | Pasture/hay | 0.946 | 0.568 |
| | Cultivated crops | 0.104 | 0.062 |
| | Woody wetland | 0.298 | 0.179 |
| | Emergent herbaceous wetland | 0.296 | 0.178 |
| Antoine | Open Water | 0.026 | 0.035 |
| | Developed, open space | 0.459 | 0.626 |
| | Developed, low intensity | 0.165 | 0.226 |
| | Deciduous forest | 0.011 | 0.016 |
| | Evergreen forest | 26.961 | 36.759 |
| | Shrub/scrub | 33.914 | 46.238 |
| | Grassland/herbaceous | 9.501 | 12.954 |
| | Pasture/hay | 0.638 | 0.870 |
| | Cultivated crops | 0.486 | 0.663 |
| | Woody wetland | 1.049 | 1.430 |
| | Emergent herbaceous wetland | 0.135 | 0.184 |
| Tonasket | Open Water | 0.142 | 0.233 |
| | Developed, open space | 0.436 | 0.716 |
| | Developed, low intensity | 0.223 | 0.366 |
| | Evergreen forest | 19.836 | 32.562 |
| | Shrub/scrub | 28.874 | 47.398 |
| | Grassland/herbaceous | 10.940 | 17.958 |
| | Pasture/hay | 0.024 | 0.039 |
| | Cultivated crops | 0.040 | 0.066 |
| | Woody wetland | 0.252 | 0.413 |
| | Emergent herbaceous wetland | 0.152 | 0.249 |

Table 3. Extents of generalized surficial geologic units in the study area subbasins [$mi^2$, square mile]

| Subbasin name | Unit symbol | Unit name | Extent ($mi^2$) | Percent of subbasin |
|---|---|---|---|---|
| Antoine | Qgd | Pleistocene continental glacial drift, Fraser-age | 37 | 51 |
| | pTbg(t) | pre-Tertiary banded gneiss | 18 | 24 |
| | EPAia(b) | Eocene-Paleocene acidic intrusive rocks | 13 | 18 |
| | PMmm(s) | Permian marine metasedimentary rocks | 2 | 3 |
| | Evc(a) | Eocene volcaniclastic deposits or rocks | 1 | 1 |
| | pTgn | pre-Tertiary gneiss | 1 | 1 |
| Bonaparte | Qgd | Pleistocene continental glacial drift, Fraser-age | 82 | 49 |
| | pTog(a) | pre-Tertiary orthogneiss | 37 | 22 |
| | pTbg(t) | pre-Tertiary banded gneiss | 22 | 13 |
| | EPAia(b) | Eocene-Paleocene acidic intrusive rocks | 18 | 11 |
| | KJigd(w) | Cretaceous-Jurassic granodiorite | 3 | 2 |
| | Qa | Holocene alluvium | 2 | 1 |
| | EPAia(m) | Eocene-Paleocene acidic intrusive rocks | 2 | 1 |
| | pTsc | pre-Tertiary schist, high grade | 1 | 1 |
| Tonasket | Qgd | Pleistocene continental glacial drift, Fraser-age | 29 | 48 |
| | EPAia(b) | Eocene-Paleocene acidic intrusive rocks | 19 | 31 |
| | TRog(o) | Triassic orthogneiss | 4 | 7 |
| | PMmm(s) | Permian marine metasedimentary rocks | 4 | 7 |
| | TRPMmt(k) | Triassic-Permian metasedimentary and metavocanic rocks | 1 | 2 |
| | pTgn | pre-Tertiary gneiss | 1 | 1 |
| | TRPMib | Triassic-Permian basic intrusive rocks | 1 | 1 |
| Tunk | Qgd | Pleistocene continental glacial drift, Fraser-age | 47 | 65 |
| | pTbg(t) | pre-Tertiary banded gneiss | 18 | 25 |
| | pTbg(tm) | pre-Tertiary banded gneiss | 3 | 4 |
| | pTog(c) | pre-Tertiary orthogneiss | 3 | 4 |
| | Eimd(s) | Eocene monzodiorite | 0.3 | 0.4 |

**Table 4.** Site information and measured streamflow discharges in Tunk Creek, Antoine Creek, Bonaparte Creek, and Tonasket Creek during June and September 2008 (page 1 of 2) [sq mi, square mile]

| Site | Map ID on fig. 7 | Site name | USGS Site Number | River mile | Drainage area (sq mi) | Latitude (NAD83) | Longitude (NAD83) |
|---|---|---|---|---|---|---|---|
| Tunk #1 | 23 | TUNK CREEK AT KEYSTONE ROAD NR BARKER, WA | 12445400 | 0.39 | 71.7 | 48 33 44.6 | 119 28 44.4 |
| Tunk #2 | 1 | TUNK CREEK AT TUNK CREEK ROAD NR BARKER, WA | 12445390 | 1.71 | 70 | 48 33 22.4 | 119 27 34.6 |
| Tunk #3 | 2 | TUNK CREEK AT KNOX ROAD NR SYNAREP, WA | 12445200 | 5.72 | 58.6 | 48 32 30.7 | 119 23 43.5 |
| Tunk #4 | 66 | TUNK CREEK AT ED FIGLENSKI ROAD NR SYNAREP, WA | 12445190 | 7.75 | 33.4 | 48 31 44.2 | 119 21 37.3 |
| Tunk #6 | 72 | TUNK CREEK AT SORIANO'S NR SYNAREP, WA | 12445150 | 10.68 | 19.1 | 48 30 54.5 | 119 19 07.4 |
| Tunk #5 | 8 | TUNK CREEK AT CLOUGH HOMESTEAD ROAD NR SYNAREP, WA | 12445100 | 12.37 | 15.6 | 48 30 05.8 | 119 17 53.1 |
| Bonaparte #1 | 36 | BONAPARTE CREEK AT TONASKET, WA | 12444550 | 0.35 | 161 | 48 42 05.7 | 119 26 32.8 |
| Bonaparte #2 | 33 | BONAPARTE CREEK BELOW BANNON CREEK NR TONASKET, WA | 12444530 | 5.24 | 140 | 48 40 19.7 | 119 21 28.4 |
| Bonaparte #3 | 35 | BONAPARTE CREEK ABOVE BANNON CREEK NR TONASKET, WA | 12444510 | 8.46 | 131 | 48 39 13.0 | 119 17 58.5 |
| Bonaparte #4 | 67 | BONAPARTE CREEK BELOW PEONY CREEK NR WAUCONDA, WA | 12444488 | 14.23 | 109 | 48 39 23.9 | 119 11 58.0 |
| Bonaparte #5 | 68 | BONAPARTE CREEK BELOW LITTLE BONAPARTE CREEK NR WAUCONDA, WA | 12444475 | 18.14 | 57.2 | 48 40 46.7 | 119 08 17.2 |
| Bonaparte #6 | 69 | BONAPARTE CREEK ABOVE LITTLE BONAPARTE CREEK NR WAUCONDA, WA | 12444440 | 21 | 44.7 | 48 42 23.3 | 119 06 27.2 |
| Antoine #3 | 45 | ANTOINE CREEK AT US HWY 97 NR ELLISFORD, WA | 12444290 | 0.23 | 73.4 | 48 45 33.2 | 119 24 32.9 |
| Antoine #5 | 71 | ANTOINE CREEK AT WHISKEY CREEK ROAD NR ELLISFORD,WA | 12444225 | 4.29 | 54.5 | 48 45 05.6 | 119 20 36.0 |
| Antoine #4 | 44 | ANTOINE CREEK AT ANTOINE BREAKS ROAD NR ELLISFORD,WA | 12444220 | 5.11 | 52.8 | 48 45 38.7 | 119 20 00.5 |
| Antoine #2 | 38 | ANTOINE CREEK AT MT HULL ROAD NR HAVILLAH, WA | 12444175 | 13.78 | 19.3 | 48 49 43.0 | 119 14 02.5 |
| Antoine #1 | 70 | ANTOINE CREEK NR HAVILLAH, WA | 12444150 | 14.36 | 19.1 | 48 49 35.9 | 119 13 21.6 |
| Tonasket #1 | 46 | TONASKET CREEK AT OROVILLE, WA | 12439300 | 0.73 | 60.1 | 48 56 36.2 | 119 24 47.7 |
| Tonasket #2 | 47 | TONASKET CREEK AT CHESAW RD NR MP3 NR OROVILLE, WA | 12439280 | 2.39 | 58.2 | 48 56 57.6 | 119 22 53.2 |
| Tonasket #3 | 49 | TONASKET CREEK AT W CORRAL ROAD NR OROVILLE, WA | 12439260 | 5.26 | 42.3 | 48 56 32.0 | 119 19 27.8 |
| Tonasket #4 | 54 | TONASKET CREEK AT FOREST SERVICE ROAD 3525 NEAR OROVILLE, WA | 12439240 | 7.95 | 32.2 | 48 55 17.5 | 119 16 47.1 |
| Tonasket #5 | 58 | TONASKET CREEK ABOVE DRY CREEK NR OROVILLE, WA | 12439180 | 10.43 | 6.46 | 48 54 12.7 | 119 14 31.3 |

**Table 4.** Site information and measured streamflow discharges in Tunk Creek, Antoine Creek, Bonaparte Creek, and Tonasket Creek during June and September 2008 (page 2 of 2) [cfs, cubic feet per second; sq mi, square mile]

| Site | Map ID on fig. 7 | Local number | Measurement Date | Discharge (cfs) | Discharge per unit area (cfs/sq mi) | Measurement Date | Discharge (cfs) | Discharge per unit area (cfs/sq mi) |
|---|---|---|---|---|---|---|---|---|
| Tunk #1 | 23 | 35N/27E-04E | 6/16/2008 | 3.75 | 0.052 | 9/16/2008 | 0.09 | 0.0013 |
| Tunk #2 | 1 | 35N/27E-04R | 6/17/2008 | 4.10 | 0.059 | 9/18/2008 | 0.18 | 0.0026 |
| Tunk #3 | 2 | 35N/27E-12R | 6/17/2008 | 3.97 | 0.068 | 9/18/2008 | 0.29 | 0.0049 |
| Tunk #4 | 66 | 35N/28E-17L | 6/17/2008 | 3.90 | 0.12 | 9/18/2008 | 0.36 | 0.011 |
| Tunk #6 | 72 | 35N/28E-22L | -- | -- | -- | 9/18/2008 | 0.3 | 0.016 |
| Tunk #5 | 8 | 35N/28E-26L | 6/17/2008 | 3.46 | 0.22 | 9/18/2008 | 0.079 | 0.0051 |
| Bonaparte #1 | 36 | 37N/27E-16P | 6/17/2008 | 3.24 | 0.020 | 9/19/2008 | 0.13 | 0.0008 |
| Bonaparte #2 | 33 | 37N/28E-30N | 6/18/2008 | 2.99 | 0.021 | 9/16/2008 | 0.22 | 0.0016 |
| Bonaparte #3 | 35 | 36N/28E-02D | 6/18/2008 | 3.97 | 0.030 | 9/19/2008 | -- | -- |
| Bonaparte #4 | 67 | 37N/29E-32P | 6/18/2008 | 4.41 | 0.040 | 9/16/2008 | 1.69 | 0.0155 |
| Bonaparte #5 | 68 | 37N/29E-26D | 6/18/2008 | 5.92 | 0.10 | 9/16/2008 | 0.15 | 0.0026 |
| Bonaparte #6 | 69 | 37N/29E-13G | 6/18/2008 | 6.65 | 0.15 | 9/16/2008 | 0.54 | 0.012 |
| Antoine #3 | 45 | 38N/27E-27R | 6/20/2008 | 0.69 | 0.009 | 9/19/2008 | 0.23 | 0.0031 |
| Antoine #5 | 71 | 38N/38E-31H | 6/20/2008 | 0.56 | 0.010 | 9/17/2008 | 0 | 0 |
| Antoine #4 | 44 | 38N/28E-29L | 6/20/2008 | 6.38 | 0.12 | 9/17/2008 | 1.6 | 0.030 |
| Antoine #2 | 38 | 38N/28E-01A | 6/19/2008 | 6.56 | 0.34 | 9/17/2008 | 0.44 | 0.023 |
| Antoine #1 | 70 | 38N/29E-06C | 6/19/2008 | 7.05 | 0.37 | 9/17/2008 | 0.58 | 0.030 |
| Tonasket #1 | 46 | 40N/27E-27A | 6/19/2008 | 0.44 | 0.007 | 9/17/2008 | 0 | 0 |
| Tonasket #2 | 47 | 40N/27E-24M | 6/19/2008 | 0.64 | 0.011 | 9/17/2008 | 0 | 0 |
| Tonasket #3 | 49 | 40N/28E-29A | 6/19/2008 | 0.79 | 0.019 | 9/17/2008 | 0.01 | 0.00024 |
| Tonasket #4 | 54 | 40N/28E-34J | 6/19/2008 | 0.36 | 0.011 | 9/17/2008 | 0.006 | 0.00019 |
| Tonasket #5 | 58 | 39N/28E-01Q | 6/19/2008 | 0 | 0 | 9/17/2008 | 0 | 0 |

**Table 5.** Measured stream discharges and stream and ground-water levels, and calculated hydraulic gradients at sites in Tunk Creek, Antoine Creek, Bonaparte Creek, and Tonasket Creek, June 2008. [$mi^2$, square mile; $ft^3/s$, cubic feet per second; $ft^3/s/mi$, cubic feet per second per mile; ft btp, feet below top of piezometer; ft/ft, feet per foot]

| Site | Map ID on fig. 7 | Measurement Date | Discharge ($ft^3/s$) | Net difference in discharge ($ft^3/s$) | Net difference in discharge per river mile ($ft^3/s/mi$) | Gaining or losing reach? | Stream water level (ft btp) | Ground-water level (ft btp) | Hydraulic gradient (ft/ft) | Gaining or losing site? | Gaining or losing reach? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tunk #1 | 23 | 6/16/2008 | 3.75 | -0.35 | -0.27 | losing | 2.99 | 5.05 | -0.82 | losing | losing |
| Tunk #2 | 1 | 6/17/2008 | 4.10 | 0.13 | 0.03 | gaining | 3.64 | 3.95 | -0.17 | losing | gaining |
| Tunk #3 | 2 | 6/17/2008 | 3.97 | 0.07 | 0.03 | gaining | 3.69 | 3.48 | 0.12 | gaining | gaining |
| Tunk #4 | 66 | 6/17/2008 | 3.90 | 0.44 | 0.10 | gaining | 2.46 | 2.33 | 0.04 | gaining | gaining |
| Tunk $6 | 72 | 6/17/2008 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tunk #5 | 8 | 6/17/2008 | 3.46 | | | | 2.97 | 2.85 | 0.04 | gaining | |
| Bonaparte #1 | 36 | 6/17/2008 | 3.24 | 0.25 | 0.05 | gaining | 3.97 | 4.53 | -0.28 | losing | gaining |
| Bonaparte #2 | 33 | 6/18/2008 | 2.99 | -0.98 | -0.30 | losing | 3.11 | 3.83 | -0.33 | losing | losing |
| Bonaparte #3 | 35 | 6/18/2008 | 3.97 | -0.44 | -0.08 | losing | 1.86 | 1.67 | 0.05 | gaining | losing |
| Bonaparte #4 | 67 | 6/18/2008 | 4.41 | -1.51 | -0.39 | losing | 2.00 | 2.00 | 0.00 | neutral | losing |
| Bonaparte #5 | 68 | 6/18/2008 | 5.92 | -0.73 | -0.26 | losing | 2.36 | 2.30 | 0.02 | gaining | losing |
| Bonaparte #6 | 69 | 6/18/2008 | 6.65 | | | | 3.08 | 2.97 | 0.01 | gaining | |
| Antoine #3 | 45 | 6/20/2008 | 0.69 | 0.13 | 0.03 | gaining | 3.16 | 5.05 | -0.80 | losing | gaining |
| Antoine #5 | 71 | 6/20/2008 | 0.56 | -5.82 | -7.10 | losing | 2.04 | 1.95 | 0.02 | gaining | losing |
| Antoine #4 | 44 | 6/20/2008 | 6.38 | -0.18 | -0.02 | losing | 3.00 | 3.00 | 0.00 | neutral | losing |
| Antoine #2 | 38 | 6/19/2008 | 6.56 | -0.49 | -0.84 | losing | 1.98 | 2.08 | -0.03 | losing | losing |
| Antoine #1 | 70 | 6/19/2008 | 7.05 | | | | 2.29 | 2.33 | -0.01 | losing | |
| Tonasket #1 | 46 | 6/19/2008 | 0.44 | -0.2 | -0.12 | losing | 3.49 | 5.05 | -0.72 | losing | losing |
| Tonasket #2 | 47 | 6/19/2008 | 0.64 | -0.15 | -0.05 | losing | 2.48 | 5.65 | -0.92 | losing | losing |
| Tonasket #3 | 49 | 6/19/2008 | 0.79 | 0.43 | 0.16 | gaining | 2.75 | 2.75 | 0.00 | neutral | gaining |
| Tonasket #4 | 54 | 6/19/2008 | 0.36 | 0.36 | 0.15 | gaining | 2.41 | 2.93 | -0.07 | losing | gaining |
| Tonasket #5 | 58 | 6/19/2008 | 0 | | | | -- | -- | -- | -- | |

**Table 6.** Measured stream discharges and stream and ground-water levels, and calculated hydraulic gradients at sites in Tunk Creek, Antoine Creek, Bonaparte Creek, and Tonasket Creek, September 2008. [mi2, square mile; ft3/s, cubic feet per second; ft3/s/mi, cubic feet per second per mile; ft btp, feet below top of piezometer; feet per foot]

| Site | Map ID on Fig. 7 | Measurement Date | Discharge ($ft^3/s$) | Net difference in discharge ($ft^3/s$) | Net difference in discharge per river mile ($ft^3/s/mi$) | Gaining or losing reach? | Stream water level (ft btp) | Ground-water level (ft btp) | Hydraulic gradient (ft/ft) | Gaining or losing site? |
|---|---|---|---|---|---|---|---|---|---|---|
| Tunk #1 | 23 | 9/16/2008 | 0.09 | -0.09 | -0.068 | losing | 2.5 | 3.98 | -0.74 | losing |
| Tunk #2 | 1 | 9/18/2008 | 0.18 | -0.11 | -0.027 | losing | 3.78 | 3.89 | -0.06 | losing |
| Tunk #3 | 2 | 9/18/2008 | 0.29 | -0.07 | -0.034 | losing | 3.26 | 3.3 | -0.01 | losing |
| Tunk #4 | 66 | 9/18/2008 | 0.36 | 0.06 | 0.020 | gaining | 3.37 | 3.43 | -0.03 | losing |
| Tunk $6 | 72 | 9/18/2008 | 0.30 | 0.221 | 0.13 | gaining | 1.9 | 1.84 | 0.02 | gaining |
| Tunk #5 | 8 | 9/18/2008 | 0.079 | | | | 2.96 | 2.89 | 0.02 | gaining |
| Bonaparte #1 | 36 | 9/19/2008 | 0.13 | -0.09 | -0.018 | losing | 3.66 | 3.86 | -0.09 | losing |
| Bonaparte #2 | 33 | 9/16/2008 | 0.22 | -- | -- | -- | 2.84 | 3.83 | -0.35 | losing |
| Bonaparte #3 | 35 | 9/19/2008 | -- | -- | -- | -- | -- | -- | -- | -- |
| Bonaparte #4 | 67 | 9/16/2008 | 1.69 | 1.54 | 0.39 | gaining | 3.14 | 3.22 | -0.07 | losing |
| Bonaparte #5 | 68 | 9/16/2008 | 0.15 | -0.39 | -0.14 | losing | 2.01 | 2.08 | -0.02 | losing |
| Bonaparte #6 | 69 | 9/16/2008 | 0.54 | | | | 3.78 | 3.79 | -0.002 | losing |
| Antoine #3 | 45 | 9/19/2008 | 0.23 | 0.23 | 0.06 | gaining | 3.75 | 3.84 | -0.04 | losing |
| Antoine #5 | 71 | 9/17/2008 | 0 | -1.6 | -2.0 | losing | -- | -- | -- | -- |
| Antoine #4 | 44 | 9/17/2008 | 1.6 | 1.16 | 0.13 | gaining | 2.56 | 2.6 | -0.02 | losing |
| Antoine #2 | 38 | 9/17/2008 | 0.44 | -0.14 | -0.24 | losing | 2.4 | 2.54 | -0.04 | losing |
| Antoine #1 | 70 | 9/17/2008 | 0.58 | | | | 2.68 | 2.59 | 0.03 | gaining |
| Tonasket #1 | 46 | 9/17/2008 | 0 | 0 | 0 | neutral | -- | -- | -- | -- |
| Tonasket #2 | 47 | 9/17/2008 | 0 | -0.01 | -0.0035 | losing | -- | -- | -- | -- |
| Tonasket #3 | 49 | 9/17/2008 | 0.01 | 0.004 | 0.0015 | gaining | 3.13 | 3.25 | -0.12 | losing |
| Tonasket #4 | 54 | 9/17/2008 | 0.006 | 0.006 | 0.0024 | gaining | 2.01 | 2.16 | -0.15 | losing |
| Tonasket #5 | 58 | 9/17/2008 | 0 | | | | -- | -- | | -- |