QUALITY ASSURANCE PROJECT PLAN
GROUNDWATER–SURFACE WATER INTERACTIONS
ALONG CHUMSTICK CREEK & MISSION CREEK IN WRIA 45
CHELAN COUNTY, WASHINGTON

Submitted to:

Chelan County Natural Resource Department, Wenatchee, WA

Submitted by:

AMEC Geomatrix, Inc., Lynnwood, WA

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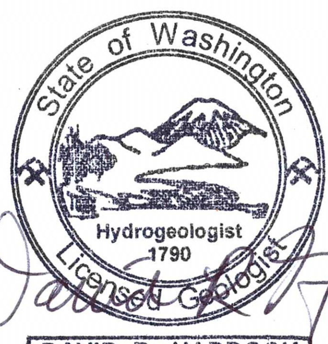

8/8/08

David R. Haddock, L.Hg
Principal Hydrogeologist

QUALITY ASSURANCE PROJECT PLAN:
Groundwater–Surface Water Interactions
along Chumstick Creek and Mission Creek in WRIA 45
Chelan County, Washington

TITLE AND APPROVAL SHEET

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Chelan County Natural Resource Department — Date

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ABSTRACT

The Wenatchee Watershed (Water Resources Inventory Area [WRIA] 45) has been identified by the Washington State Department of Ecology as one of 16 watersheds in the state where water quantity is a probable limiting factor for anadromous fisheries resources. Increasing competition for hydrologic resources in the watershed in conjunction with seasonal low flow conditions contribute to inadequate streamflows for fish, particularly during periods of late summer and early fall (Wenatchee Watershed Planning Unit [WWPU], 2006).

In an effort to address the condition of water resources within the Wenatchee Watershed, a final Wenatchee Watershed Management Plan (WWMP) was completed in April 2006. The WWMP identified insufficient streamflow, diminished water quality, and a lack of geologic and hydrologic data on which to evaluate water availability and management strategies within two Wenatchee subwatersheds (Chumstick Creek and Mission Creek). In 2007, existing data were utilized to prepare a water balance for the Chumstick Creek and Mission Creek subwatersheds and recommendations were provided to collect additional data that would reduce uncertainties associated with the water balance (Geomatrix, 2007a, 2007b). This Quality Assurance Project Plan describes measurements that will be completed to gain a better understanding of groundwater–surface water interactions in Chumstick Creek and Mission Creek and surface water discharge during critical low flow periods.

QUALITY ASSURANCE PROJECT PLAN

Groundwater–Surface Water Interactions
along Chumstick Creek and Mission Creek in WRIA 45
Chelan County, Washington

1.0 BACKGROUND

This Quality Assurance Project Plan (QAPP) documents the standards, methods, and procedures to be used by AMEC Geomatrix, Inc. (AMEC) and Chelan County Natural Resource Department staff for activities related to the collection, processing, storage, and analysis of hydrologic data. Project staff will use the QAPP to ensure that the technical quality and reliability of hydrologic data and derived products meets data quality objectives. The procedures and methods presented in this QAPP generally conform to guidelines presented in several U.S. Geological Survey (USGS) and Washington State Department of Ecology (Ecology) reports (McCobb and Weiskel, 2003; Butkus, 2005; Gotvald and Stamey, 2005).

Previous work performed in the Wenatchee Watershed includes a groundwater level investigation in the Chumstick basin (Wildrick, 1979), as well as stream network gaging and total maximum daily load (TMDL) analysis for the Wenatchee River and selected tributaries including Mission Creek and Chumstick Creek (Redding, 2005; Springer, 2005). As part of the TMDL study, six monitoring sites were selected in Mission Creek for piezometer installation. At each location, temperature, manometer board, and electric tape measurements were recorded to identify gaining and losing reaches from June through October 2003. Similarly, two piezometers were installed in Chumstick Creek in order to characterize groundwater–surface water interactions using hydraulic gradient measurements and water temperature profiles during the June through October 2008. These studies successfully identified gaining and losing reaches; however, they did not include regional groundwater monitoring.

In this study, there will be several types of data collected for this project including groundwater levels, stream discharge, and vertical head gradients across the hyporheic zone. This information will fill data gaps from previous investigations and will provide information that has not already been generated by previous work. Collection of groundwater data from area monitoring wells in addition to instream monitoring will facilitate an understanding of the interactions between the regional groundwater system and the Wenatchee River and its tributaries. More specifically, this study will help facilitate decisions pertaining to water resources allocation within the Wenatchee Watershed with the goal of maintaining adequate baseflow contributions during seasonally low streamflow conditions. Each data set collected will possess a unique set of associated information that will fully document the data values. All data collection will occur according to specified methods. Methodologies follow established standards and ensure data consistency, accuracy, and reproducibility. Quality control standards will use established criteria to meet project requirements. Collection methodology, quality control procedures, and quality standards will be established for all collected data. AMEC personnel will install monitoring wells, staff gages, piezometers, and pressure transducers and, along with Chelan County staff, conduct the first round of field measurements. Subsequent data collection will be the primary responsibility of Chelan County staff. Any work performed by non-licensed AMEC personnel and Chelan County staff, such as groundwater level measurements, will occur under the direct supervision of Dave Haddock, the project hydrogeologist and a Washington State licensed hydrogeologist.

Project data will be provided to AMEC. The data will be reviewed to ensure they meet data quality objectives and entered and archived within an appropriate database using established methods and quality control procedures. All project participants will be expected to use Excel data management software.

2.0 PROJECT DESCRIPTION

The project will characterize surface water flows within Chumstick Creek and Mission Creek by installing manual stage height gages (staff gages) and collecting discharge data at these locations over a range of flow conditions to develop rating curves that relate stage height with creek discharge. Mini-piezometers will also be installed at all gage locations to define the vertical hydraulic gradient and direction of water flow between the creek and underlying aquifer. Pressure transducers will be installed at all stream monitoring stations to measure water depth. Once the rating curves have been established for the staff gages, the pressure transducer data will allow a synoptic characterization of discharge within the Chumstick Creek and Mission Creek subwatersheds. The pressure transducers will be a combination of County equipment as well as transducers provided for the project by Ecology.

The project will also include installation of 12 groundwater monitoring wells to record water levels on a quarterly basis. Quarterly monitoring is considered sufficient to adequately capture seasonal groundwater flow patterns while avoiding the higher costs associated with more frequent groundwater level measurements. While monitoring privately owned wells was previously considered as a cost-effective alternative to new well installation, landowners have generally been hesitant in granting access to their property.

It should be noted that streams, and the associated interactions between streams and groundwater systems, are highly dynamic, both spatially and temporally. Synoptic surveys will allow for all data to be collected at the same time, which is adequate for the project goals.

2.1 INSTALLATION OF MANUAL STAGE HEIGHT GAGES AND DEVELOPMENT OF RATING CURVES

Correct installation and continued maintenance of stage height gaging stations are important for ensuring quality streamflow data collection and analysis. Figure 1 shows the schematic for a completed stream gage planned for use in this study. At each of the 18 recording stations, a staff gage will be secured to a 2-inch by 6-inch board that is attached to an angle-iron post. All staff gages will have a resolution of 0.01 foot, and gage range should cover all anticipated flow values. Based upon a review of stage records from October 2002 through July 2008, a maximum stage fluctuation of approximately 2 feet is typical near the outlets of Chumstick Creek and Mission Creek. Any stage variation upstream of these locations is expected to be less than the range observed at the subwatershed outlet. Additionally, a single staff gage at each proposed location (see below) should be sufficient to accommodate typical variability in stage.

Variability in discharge may be high depending on stream geomorphology at each of the monitoring locations. For water years 2003 through 2007, Mission Creek discharge near the subwatershed outlet has generally ranged from 0 cubic foot per second (cfs) to over 300 cfs during larger flood events (Geomatrix, 2007b). For water years 2004 through 2007, Chumstick Creek discharge near the subbasin outlet has typically been between 0 cfs and 50 cfs, with occasional large flow events above 100 cfs (Geomatrix, 2007a).

After staff gage installation is completed, each gage will be surveyed using Ecology's standard NAD83HARN horizontal datum and a NAVD88 vertical datum. Survey checks for staff gages are described in Section 6.1.3.

Manual stage height gage locations will be installed at the following eight locations in the Mission Creek subwatershed (Figure 2):

1. Mission Creek below Yaksum Creek,
2. Mission Creek upstream of Yaksum Creek,
3. Mission Creek below Tripp Creek,
4. Mission Creek above Tripp Creek,
5. Sand Creek above Mission Creek,
6. Mission Creek above Sand Creek,
7. East Fork of Mission Creek below Crow Canyon, and
8. East Fork of Mission Creek above Crow Canyon.

Manual stage height gage locations will be installed at the following 10 locations in the Chumstick Creek subwatershed (Figure 3):

1. Chumstick Creek below Eagle Creek,
2. Eagle Creek above Bjork Canyon,
3. Eagle Creek below Van Creek,
4. Chumstick Creek above Eagle Creek,
5. Chumstick Creek below Spromberg Canyon,
6. Chumstick Creek above Spromberg Canyon,
7. Chumstick Creek below Sunitsch Canyon,
8. Chumstick Creek above Clark Canyon,
9. Chumstick Creek below Little Chumstick Creek, and
10. Chumstick Creek above Little Chumstick Creek.

The site selection for staff gage installation at each of the previously listed general locations will be made according to the following guidelines adapted from McCobb and Weiskel (2003) and Butkus (2005):

- The general course of the stream should be relatively straight for approximately 100-m upstream and downstream of the site. Installation sites should not be characterized by excess turbulence.
- The stream channel is free of vegetative growth and the streambed is not subject to scouring and deposition of bed material.
- Streambanks are stable, free of brush, and capable of sustaining the maximum flow event within bank walls.
- The streambed is relatively uniform with only minor irregularities (no large cobbles or boulders).
- The staff gage installation site is far enough upstream from reservoirs, lakes, the confluence with other streams, or reaches with rapid changes in streambed elevation to prevent variable backwater effects.
- The selected reach is readily accessible for installation, monitoring, and maintenance of instrumentation.

Often the desired cross section does not meet all of the selection criteria. If flow is impeded, then efforts will be made to reduce the impact on streamflow measurements prior to staff gage installation and subsequent stage measurements. Flow impedance may be caused by aquatic plants, woody debris, or large rocks and boulders. Garden rakes or shovels will be used to remove any objects that obstruct flow in the area of the desired site location (Butkus, 2005).

Once the cross section has been cleared, streambanks will be examined to ensure that large streamflow events will be contained within channel walls. If the streambed possesses sloped banks, rocks or other available materials may be used to create a well-defined stream edge. It is important that minimal streamflow bypasses these bank alterations (Butkus, 2005).

2.2 INSTALLATION OF INSTREAM MINI-PIEZOMETERS

Following methodology found in Simonds and Sinclair (2002), instream mini-piezometers will be installed at each manual stage height gage location to define the vertical hydraulic gradient and flow directions between the river and the water table aquifer. Each instream mini-piezometer will be purchased from a commercial vender or constructed from 7 foot lengths of ½-inch-diameter galvanized pipe. One end of the pipe will be crimped shut to form a drive point and then perforated across the bottom 6 inches with several 1/8-inch-diameter holes. The upper end of each piezometer will be threaded and fitted with a standard pipe couple to provide a strike surface used during mini-piezometer installation.

Each mini-piezometer will be driven with a fence post driver to a depth of approximately 5 feet or until downward progress is no longer possible. If the possibility exists that river stage could rise above the 2 feet of remaining stickup, additional piping will be attached to prevent inundation of the mini-piezometer during periods of high flow. The connection between the two lengths of pipe will be properly sealed. Following installation, each piezometer will be developed using a peristaltic pump to ensure good hydraulic connection with streambed sediments. Each piezometer will be purged until a minimum of 10 saturated casing volumes of water have been removed and until discharge water is sediment free.

In addition, construction details will be recorded including latitude, longitude, installation date, piezometer length, installation depth, and depth below streambed of the center of perforations. If mini-piezometers are damaged or lost during the study period, they will be replaced to the extent possible given the project budget.

Because it is not possible to install a standard surface seal for the piezometer beneath the water surface, there is a potential for direct hydraulic communication between surface water and the piezometer intake due to annular leakage along the outside wall of the piezometer. To minimize potential annular leakage the following steps will be taken:

1. Piezometers will be allowed to equilibrate at least one week after installation before obtaining water levels. This will allow formation material to reestablish contact with the outside wall of the piezometer due to natural consolidation.

2. To verify that annular leakage is not occurring, a sample of the surface water at each location will be initially tested for field parameters and compared to piezometer results. Substantial differences of piezometer and surface water results will be used as evidence that direct hydraulic communication is not occurring.

Pitz (2003) successfully used this approach in a lake study to verify that pore-water samplers were not in direct hydraulic connection with the lake. In addition, the local vertical hydraulic gradient will be determined using relative water level elevations of the piezometer and the surface water as described previously. The existence of a vertical hydraulic gradient (i.e., a difference in hydraulic head) will serve as another indicator of the absence of annular leakage. If field evidence indicates leakage through the annular space is occurring, additional steps will be used to eliminate the problem (e.g., tamping of the sediments surrounding the piezometer, additional development, or reinstallation of the piezometer).

Because instream piezometers are considered resource protection wells, installation and decommissioning of instream piezometers will occur under the direction of a licensed well driller or professional engineer. All other required applications and variance requests will be submitted to the proper governmental agency.

2.3 Synoptic Surveys of Stream Discharge and Development of Rating Curves

To understand the effects of groundwater withdrawals and return flows along the length of Mission Creek and Chumstick Creek, synoptic surveys will be conducted during the low flow season. A synoptic survey collects discharge data from multiple stations along the same stream at essentially the same time. By collecting the discharge information in this way, changes in discharge along the stream length due to groundwater inflow and outflow, surface water diversions, and the contribution of major tributaries can be characterized. For example, a downstream decrease in discharge between two stations would indicate a “losing” reach, which may indicate consumptive use between stations. The synoptic survey uses pressure transducers to record stage data at individual locations within each basin from headwater locations to the watershed outlet.

Each location chosen for a manual staff gage (Section 2.1) will be instrumented with a submersible pressure transducer according to the following design. All flow monitoring stations will use a section of slotted 2-inch PVC pipe to house a Hobo Data Logger water level recorder or similar submersible pressure transducer. The PVC pipe will be secured to the angle-iron post with hose clamps that are screwed to the 2-inch by 6-inch board. To minimize the likelihood of vandalism or theft, the PVC pipe housing will be capped with a locking device. Currently, Chelan County is able to provide funding for nine pressure transducers. Ecology has offered to supply the additional pressure transducers required for the remaining monitoring locations. Ecology has also indicated a willingness to assist AMEC and Chelan County staff with equipment installation.

Site visits for the synoptic survey will be made at least once during each month of August, September, and October. More frequent surveys may be performed by Chelan County staff if they have available time. Following completion of the synoptic survey, these sites will remain instrumented during the spring, summer, and fall seasons. A rating curve will be developed for each location. All pressure transducers and PVC housing will be removed from Chumstick Creek and Mission Creek prior to the winter season to prevent damage or loss of equipment due to harsh weather conditions (submersible pressure transducers can be damaged by freezing). This equipment will be redeployed during the following spring, once streams have thawed and overnight temperatures within the region consistently above 35°F.

Using a rating curve, the stage data recorded at each instrumented location will be used to generate a discharge time series allowing temporal and spatial identification of losing and gaining reaches throughout the subwatershed. Once a reliable rating curve is generated at each site, it is recommended that the curve be updated and verified through additional measurements. Changes in stream network geometry and structure will alter the stage-discharge relationship of the rating curve. Consequently, measurements should be taken throughout the water year, particularly following large flow events. If the rating curve is no longer valid due to geomorphic changes, then a new rating curve should be constructed.

Data collected from pressure transducers at each site will require corrections to remove stage fluctuations caused by variability in atmospheric pressure. A single pressure transducer will be placed in Chumstick Creek and Mission Creek subwatersheds, respectively, to record atmospheric pressure. Each pressure transducer will be placed in a secure location, likely on private property. The location will be determined during the installation of the staff gages. Data from all transducers, both stage recording and atmospheric pressure recording, will be downloaded during each sampling visit.

2.4 MONITORING WELL INSTALLATION

As part of the hydrogeologic investigation of the Chumstick Creek and Mission Creek subwatersheds, 12 monitoring wells will be installed in easily accessible areas within County road right-of-ways (Figures 5 and 6).

The purpose of the wells is to allow collection of (1) groundwater head data, which will be used to estimate flow gradients, and (2) aquifer grain-size distribution, which will be used to estimate aquifer hydraulic conductivity. The groundwater measurements will allow refinement of basin-wide water balance calculations for each subwatershed. The selection of well locations was made to allow for a general understanding of hydrogeologic conditions throughout each subwatershed. However, the locations were purposely biased to selecting locations within the lower subwatersheds where groundwater may either flow toward the subwatershed creeks or toward the Wenatchee River. The understanding of the groundwater flow regime in the lower areas is critical for the water balance work.

Following installation, the wells will be surveyed during a separate event. The wells will then be monitored for water levels on a quarterly basis. The scope of work for well installation, surveying, and monitoring is described in more detail below:

2.4.1 Well Installation and Development

Prior to any fieldwork, a Health and Safety Plan will be prepared by AMEC. A One-Call public utility locate will also be called in by AMEC to identify right-of-way subsurface utilities. Well locations will be chosen so that the drill rig is at least 10 feet away from overhead power lines (in addition, the drill rig will not drill underneath power lines). A traffic control plan will not be prepared by AMEC; it is assumed that Chelan County will obtain the appropriate street permits and arrange for any necessary traffic control for well installation and development.

The wells will be installed by Tumwater Drilling using an air rotary rig, which will be somewhat noisy. The rig, support truck, and crew require a working area footprint of 24 feet by 40 feet. The drill rig itself is 35 feet long and 8 feet wide. The rig tower is 35 feet high. Each well installation is expected to last approximately 4 to 5 hours.

The wells will be approximately 50 feet deep, installed in 6-inch or 10-inch-diameter boreholes. Eleven of the wells will be constructed of 2-inch-diameter PVC pipe and one will consist of 6-inch-diameter PVC pipe (the 6-inch diameter well will potentially be used for future aquifer testing including pumping tests). The annular space between the 2-inch or 6-inch-diameter PVC pipe and the 6-inch or 10-inch-diameter boreholes will be filled with sand, bentonite chips or bentonite grout, and concrete. The uppermost sections of each well will be precut so that when the well is in place, the top of the well riser will be approximately 6 inches below ground surface for a flush mount well casing. The well monument will be an 8-inch-diameter steel flush mount monument (flush with the ground surface) set in a square pad of concrete no larger than 3 feet by 3 feet.

Following monitoring well installation, each well will be developed using a submersible pump until a minimum of 10 borehole volumes of water have been removed and until discharge water is sediment free.

The drilling and well development activities will generate approximately 1.5 yards of soil cuttings per well and 100 to 600 gallons of water per well. Soil cuttings and water waste will be spread on site. Every attempt will be made to place cuttings and water in a discrete area, off the road.

2.4.2 Well Survey

Ground surface and top of casing elevations of the new monitoring wells will be surveyed by a licensed surveyor in the state of Washington. Horizontal (X and Y) coordinates will be estimated by AMEC using a global positioning system (GPS) unit. The surveying is expected to last no longer than 2 hours per well.

2.4.3 Quarterly Monitoring

Quarterly water level data will be collected from the new wells (every 3 months). Quarterly monitoring is considered sufficient for this study and is consistent with project goals, given the local seasonal fluctuations in groundwater and the cost of more frequent measurements. The first quarterly event will be completed by AMEC and will be used to train Chelan County staff. County staff will be responsible for collecting water levels in subsequent quarters. Water level measurements will be performed by one or two people using a small electronic water level probe, and will not require any traffic control. Water level collection at each well is expected to last no longer than 20 minutes.

Ecology has pressure tranducers that may be used to instrument groundwater monitoring wells on this project in lieu of or in combination with manual water level indicator measurements. County staff have indicated an interest in using Ecology's equipment to supplement their own and Ecology staff could be available to help with installation of this equipment. If pressure transducers can be used, substantial additional data, including synoptic data, will be available with only a marginal additional cost.

3.0 ORGANIZATION

The partnership between Chelan County and AMEC to study groundwater-surface water interactions in the Wenatchee Watershed includes specialists from both organizations who will fulfill various roles that are essential to the success of the project. Key personnel, contact information, and general responsibilities for individuals involved in this study are listed below. Any work performed by non-licensed AMEC and Chelan County staff, such as groundwater level measurements, will occur under the direct supervision of Dave Haddock, the project hydrogeologist and a Washington State licensed hydrogeologist. The installation of the piezometers will be overseen by a licensed well driller (Tumwater Drilling) or AMEC professional engineer.

Personnel	Phone	Email	General Duties
Lee Duncan (Chelan County)	(509) 667-6640	lee.duncan@co.chelan.wa.us	Chelan County Project Manager
Steve Ellis (AMEC Geomatrix)	(425) 921-4022	steve.g.ellis@amec.com	Consultant Project Manager
Dave Haddock (AMEC Geomatrix)	(206) 342-1787	dave.haddock@amec.com	Consultant Principal Hydrogeologist (L.Hg. 1790)
Zanna Satterwhite (AMEC Geomatrix)	(206) 342-1772	zanna.satterwhite@amec.com	Consultant Field Support (L.G. 2568)
Robert Wyckoff (AMEC Geomatrix)	(443) 926-4886	robert.wyckoff@amec.com	Consultant Field Support; Consultant Team Quality Assurance Manager
Gary Maxwell (AMEC Geomatrix)	(425) 921-4027	gary.maxwell@amec.com	Consultant Team Field Manager
Dave Holland (Ecology)	(509) 457-7112	dhol461@ecy.wa.gov	Ecology Project Manager
Dave Nazy (Ecology)	(360) 407-6038	dnaz461@ecy.wa.gov	Ecology Lead Hydrogeologist

4.0 QUALITY OBJECTIVES

According to Butkus (2005), there are two types of quality control objectives: Measurement Quality Objectives (MQOs) and Data Quality Objectives (DQOs). MQOs are acceptance thresholds for data quality indices such as precision, bias, and sensitivity. Field-based measurements, such as groundwater levels and stream stage, present challenges for institution of MQOs because no reference value is available. Nonetheless, some MQO indices, such as bias and precision, can be evaluated once a reference data set and standard data set have been created.

In this study, stage will be measured manually at all locations and with pressure transducers at 18 locations across the Chumstick Creek and Mission Creek subwatersheds. Data from each pressure transducer will be compared to manual stage measurements to check for instrument drift or malfunction. Staff gage location and elevation will be measured relative to an established reference point at the time of each site visit to ensure gage movement has not occurred. If the difference between the manual stage measurement and pressure transducer reading is less than the accuracy of the pressure transducer (i.e., ± 0.02 foot), the pressure transducer data will not be qualified. If the difference between the manual stage measurement is greater than 0.02 foot, the difference between all of the measurements at a given location will be evaluated to determine an appropriate adjustment and data qualifier. The following approach will be followed:

Water height determined from the staff gage (Y variable) will be plotted against the water height measured by the pressure transducer (X variable). A linear regression through the origin will be performed using all measurements for a given location. If there is a significant relationship between the two variables (i.e., slope is significantly different than 0; $p <= 0.05$), then the regression equation will be used to adjust all pressure transducer data for the given location and the data will be qualified with a J1 data qualifier. If there is not a significant relationship between the two variables, the pressure transducer data will not be adjusted and all data will be qualified with a J2 data qualifier.

Stream discharge, vertical head gradients, and groundwater levels will each be determined using a single methodology for each measurement. Because a second measurement with an alternate methodology will not be taken, calculation of MQOs for each of these three variables will not be feasible. Consequently, it is essential that instrumentation used to collect measurements is maintained in good working order and calibrated daily prior to use.

DQOs are needed for studies where results are compared to a standard or used to make a selection from two possible conditions. An example of data which may be subject to DQOs is the evaluation of long-term trends in streamflow data (Butkus, 2005). As with MQOs, the type of variables measured and the study duration will influence whether meaningful DQOs can be established.

5.0 MONITORING DESIGN

Butkus (2005) presents two types of monitoring designs: judgment and probability. In the case of judgment design, monitoring locations are based upon best professional judgment and selected sties are considered representative of an entire subpopulation (i.e., mountainous tributary surface waters). Alternatively, probability based design selects a random sample of an entire population to ensure subpopulations are selected without introducing bias.

In this study the type of monitoring design utilized is based upon professional judgment. Existing wells and stream gages will be selected based upon availability and initial screening criteria. Additional staff gages and monitoring wells will be installed using professional judgment to dictate location.

6.0 MEASUREMENT PROCEDURES

The following sections discuss groundwater and surface water field procedures.

6.1 SURFACE WATER FIELD PROCEDURES

Surface water field procedures are presented below.

6.1.1 Time

Pacific Standard Time (PST) will be used year round. During Pacific Daylight Time, one hour will be subtracted to convert to standard time. All entries into spreadsheets and databases will be in PST (Butkus, 2005).

6.1.2 Site Visits

Synoptic surveys will require a single visit to both recording and non-recording staff gages during August, September, and October, respectively. Following this 3-month period, additional site visits to recording staff gages will be required for manometer board readings, staff gage measurements, develop a vertical velocity profile, and to download data from water level loggers. Site visits to non-recording staff gages will be required to read staff gages and take manometer board measurements. Site visits occurring after the synoptic survey will take place approximately every 60 days. Real-time flow conditions should play a factor when deciding the timing of field visits such that a wide range of stage values are incorporated within the rating curve. Available real-time radar data from the National Oceanic and Atmospheric Administration (NOAA) and real-time discharge from U.S. Geological Survey (USGS) National Water Information Service (NWIS) are useful data sources for determining when field visits are appropriate based upon recent precipitation and subsequent streamflow conditions.

Additionally, data from Ecology's existing real time stream gages that are depicted on Figures 2 and 3, respectively (Mission Creek Station 45E070 and Chumstick Creek Station 45C060), will be used to supplement the study as needed.

AMEC personnel will help notify Chelan County staff of streamflow events suitable for development of a stage-discharge relationship. It is likely that field visits may need to occur on short notice.

6.1.3 Measuring Stage Height

Stream stage measurements will follow standard USGS procedures. During each site visit, stage will be measured at all staff gage locations. Staff gage measurements will be made under varying streamflow conditions to ensure that the rating curve covers a sufficient range of discharge values. At the time of measurement, water surface elevation data from staff gages associated with pressure transducers will be downloaded. Following the site visit, the water elevation from the pressure transducer and staff gage reading will be compared. If substantial discrepancies exist, the data logger will be recalibrated in the field if possible. If it is not feasible to perform recalibration in the field, the manufacturer will be notified and appropriate steps will be taken to have the instrument repaired. Field notes will be recorded to document time and date of measurement, measurement value to the nearest 1/100 foot, and any variation in stream and channel conditions that may affect the stage-discharge rating.

When stage is measured at instrumented locations, field staff will check the slots in the PVC pipe to verify water is able to flow freely between the stream and the data logger. Sediment and other debris, which can clog the slots and reduce accuracy of pressure transducer measurements, will be removed during site visits.

Prior to measurement, PVC gage housing survey elevations will be checked during every visit using a laser level and a leveling rod. A suitable benchmark away from the shoreline will be used, such as a large boulder, bridge, or road. If the secondary survey indicates that the housing has moved, then the housing will be resurveyed.

6.1.4 Stream Discharge Measurement

Stream discharge will be determined by velocity-area methodology using an Acoustic Doppler Velocimeter (ADV).

6.1.5 Selecting a Cross Section

The factors considered for selecting a site for manual staff gage installation are comparable to the conditions necessary for choosing a good cross section. This will ensure that the velocity profile developed for each cross section is indicative of streamflow conditions at the staff gage location. The reader should refer to Section 2.1 for a discussion of these criteria. Once a cross section is chosen, rebar will be driven into the streambank on each bank to ensure that the same location is used for all subsequent measurements.

Additionally, it is important that cross sections are perpendicular to the dominant streamflow velocity vector.

6.1.6 Dividing the Stream Channel into Segments

The velocity-area methodology requires division of the stream cross section into N segments. Generally, the accuracy of discharge measurements will improve with increasing N. It is recommended that each segment is spaced such that less than 5 percent of the total discharge occurs within each segment with no segment accounting for more than 10 percent of total flow (Bras, 1990; Dingman, 2002). This will result in wider stream segments in shallow, slow moving portions of the stream and narrower segments in areas of deeper flow with high velocity (Dingman, 2002). As a general rule, following the above criteria will result in $N \geq 25$. For each site visit, the location of each segment will be noted on field data sheets or in the field notebook.

Each segment interval will be defined using a measurement tape. The measurement tape will stretch between opposing banks and be secured to minimize slack in the tape. Locations on each bank where the tape is secured will be recorded in the field notebook and marked with rebar as discussed above, so that the cross section selected is the same for all site visits.

6.1.7 Measuring Velocity of the Stream Segments

Velocity for each stream segment will be measured using a SonTek® brand ADV or a meter with similar capabilities. Use of an acoustic current profiler is encouraged because it allows for more rapid collection of data, making the discharge data collected more closely spaced in time. The following procedure is from Gotvald and Stamey (2005).

Typically, ADVs are designed for mounting on a standard top-setting wading rod. The USGS recommends using an offset bracket so that the sample volume is located as close to the wading rod as possible while remaining outside the area of flow disturbance generated by the wading rod. When mounting the ADV, care will be taken to avoid abrasion of the cable. The cable is susceptible to environmental noise, which can reduce measurement quality.

The ADV will be oriented so that the tagline is parallel to the longitudinal axis passing through the centerline of the instrument. The receiving arm will be pointed downstream. It is important that the ADV is held so that the instrument does not strike a boundary. To help prevent instrument strikes against objects, the sample will be taken at least 2 inches from any boundary. Measurements taken within 2 inches of a boundary will be noted on the measurement sheets or in the field notebook.

Typically, minimum recommended velocity for SonTek® ADVs is 0.1 foot/second (ft/s). If the velocity measurement is less then 0.1 ft/s, the reading will be flagged on the field data sheets or field notebook.

Stream velocity measurements will follow the 0.6 depth vertical velocity method (1 point) for streamflow depths equal to or less than 1.5 feet. For streamflow depths greater than 2.5 feet, the 0.2 and 0.8 depth vertical velocity method (2 point) will be used. If streamflow depths fall between 1.5 and 2.5 feet, then either the 1- or 2-point method can be used. If measurements are taken using the 2-point method and the 0.2 measured velocity is less than the 0.8 velocity or if the 0.8 velocity is less than half of the 0.2 velocity, then the user will measure velocity at the 0.6 depth location.

At all times, special care will be taken to protect the ADV probe head. If the probe receiver arms become bent or the transducers sustain scratching, then the unit will no longer be used for measurements. The unit will be returned to the manufacturer for reconditioning or repairs.

Finally, data will be downloaded from the instrument at least once daily to provide adequate data backup.

6.1.8 Quality Assurance of Velocity Measurements

Before using the ADV, staff will familiarize themselves with the instrument by thoroughly reading available documentation. Additionally, users should understand all instrument controls including keypad operations before collecting measurements. Prior to and following trips to the field, a full diagnostic test will be performed for the instrument. Diagnostic tests for SonTek® ADVs typically include signal strength plots for each ADV receiving transducer. Instrument manuals provide examples of good and problem signal-strength plots. If the signal-strength plots suggest instrument malfunction, the instrument will not be used to collect field data. In this case, it may be necessary to revert to Price-type or pygmy current meters until the ADV can be repaired (Gotvald and Stamey, 2005).

Each ADV diagnostic test will be logged and noted on the data measurement sheet or in a field notebook. Diagnostic tests need to be stored electronically so that when instrument malfunction occurs, the diagnostic tests can be provided to the manufacturer for trouble shooting. If instrument malfunction is suspected in the field or a shock occurs to the probe (such as hitting a boulder), an ADV diagnostic test will be conducted prior to collecting any additional data (Gotvald and Stamey, 2005).

Before each discharge measurement or velocity profile collection, the following ADV items will be checked. The date and time displayed by the instrument should be correct. Check that adequate data storage capacity is available for recording all velocity or discharge measurements for the entire profile. The ADV probe will be immersed in the stream and the temperature will be recorded. At least once per day, stream temperature from the ADV will be compared to stream temperature measured from an independent source, such as a digital thermometer. Small errors in temperature readings can cause substantial error in the velocity and discharge measurement. Stream temperature should be stable prior to data collection and both the ADV and independent measurement should be noted on data collection sheets or in the field notebook. Verify that the instrument has enough battery strength to complete the discharge measurement or velocity data run. Finally, check and record the signal to noise ratio (SNR). Streamflow conditions where the SNR is low (i.e., below 10) may introduce data quality problems and an alternative methodology for determining stream discharge may be required (Gotvald and Stamey, 2005).

6.1.9 Duplicate-Discharge Measurements

For each field visit, a duplicate-discharge measurement at a randomly selected stream cross section will be made. Both measurements will be considered official and entered into the field notebook. If stage changes significantly between the conclusion of the first measurement and the beginning of the duplicate measurement, the duplicate-discharge measurement will be taken at another cross section. If conditions become unsafe, the duplicate-discharge measurement will be made at the next station where safe conditions are sustained for the duration needed for two measurements (Butkus, 2005).

The cross section used in the first measurement will also be used for the duplicate measurement. However, duplicate-discharge measurements should not be performed using the same stream segmentation as the original measurement. Butkus (2005) gives the example that if the first segment in the first measurement is taken at 2 feet and the remaining verticals were at 2-foot intervals, then the first measurement for the duplicate measurement might be set at 3 feet with subsequent measurements occurring at 2-foot intervals.

The goal of taking duplicate measurements is to capture random variability inherent in the measurement procedure. The relative percent difference (RPD) is calculated and compared to the Measurement Quality Objective (MQO) of 5 percent. Because the cross section location does not change for either measurement, the stream cross-sectional area and the average velocities for both measurements should also be within 5 percent. Relative percent difference is calculated as

$$RPD = \frac{|R1 - R2|}{R_{avg}} * 100$$

where *R1* is the result for the first measurement, *R2* is the result for the second measurement, and R_{avg} is the average of *R1* and *R2* (*Butkus*, 2005).

At least one time per year, Chelan County staff will take a side-by-side flow measurement with a representative from Ecology at either the Mission Creek near Cashmere or Chumstick Creek near Mouth stream gage. This will provide an opportunity for Chelan County staff to maintain proper field measurement techniques.

6.1.10 Calculating Streamflow

The ADV will provide discharge measurements for each stream segment across the profile. In this case, total discharge is given by:

$$Q_T = \sum_{i=1}^{N} q_i,$$

where Q_T is total discharge (L^3/T^{-1}), q_i is discharge per respective stream segment (L^3/T^{-1}), and N is total number of segments. Note that q_i will be an averaged value for the 2-point method or a single reading for the 1-point method discussed in Section 6.1.7.

If the ADV provides only velocity readings for each segment and the depth of each segment is known, total streamflow can be calculated using the mid-section method. Discharge through the cross section is calculated as:

$$Q_T = \sum_{i=1}^{N} U_i * A_i \,,$$

where cross-sectional area of each stream segment, A_i, is given by

$$A_i = Y_i * \frac{|X_{i+1} - X_{i-1}|}{2},$$

where Q_T is total discharge ($L^3\ T^{-1}$), U_i is vertically averaged velocity within each segment, and Y_i are depths at each segment.

USGS practice is to use the 0.6 depth method to calculate U_i when Yi < 2.5 feet. Under these conditions, the 0.6 depth method assumes that velocity measured at $0.6*Y_i$ below the surface is the average velocity at the i^{th} segment of the cross section (Dingman, 2002).

When Yi > 2.5 feet, USGS practice is to use the 0.2 and 0.8 depth method. In this case the average vertical velocity is determined as

$$U_i = \frac{U(0.2*Y_i) + U(0.8*Y_i)}{2}.$$

Thus average vertical velocity is estimated as the average of the velocity occurring at $0.2*Y_i$ and 0.8 Y_i.

6.1.11 Mini-Piezometer Measurements

Mini-piezometer measurements will be made whenever stage is measured. Consequently, measurements will occur at both the recording stage sites and non-recording stage sites. A manometer board (Figure 4) will be constructed to measure head gradients in the stream and water levels in the mini piezometers (Simonds and Sinclair, 2002). The difference in water levels between the mini piezometers and the surface water body provides an indication of flow direction. If river stage is higher than water elevation in the piezometer, flow is downward through the streambed in the immediate vicinity of the piezometer. Alternatively, if river stage is lower than water elevation in the piezometer, groundwater flow is upward through the streambed and the stream is gaining in the area immediately surrounding the piezometer.

Vertical hydraulic gradients are calculated using

$$i = \frac{dh}{dl},$$

where i is the vertical hydraulic gradient (L/L), dh is the difference between water height in the mini-piezometer and river stage (L), and dl is the vertical distance between the streambed and the center of the mini-piezometer perforations (Simonds and Sinclair, 2002). Negative values indicate losing reaches while positive values indicate gaining reaches (Simonds and Sinclair, 2002).

6.2 GROUNDWATER FIELD PROCEDURES

Quarterly manual monitoring of water levels is planned for the proposed locations shown on Figures 2 and 3. Water levels will be taken with a water level tape to the nearest 0.01 foot. Each measurement will be taken relative to a surveyed reference point marked on the well casing. The instrument will be cleansed after every water measurement using an Alconox rinse followed by a distilled water rinse. Date, time, and depth to water will be recorded for each measurement. The following sections describe methods for water level collection using (a) an electric water level sounder, and (b) pressure transducers (optional).

6.2.1 Measuring Water Levels in Wells Using an Electric Water Level Sounder

Water level measurements at a site will be taken as quickly as practical, to best represent the potentiometric surface across the site at a single time. In order to ensure that water level measurements accurately represent static water level conditions, if pressure is suspected or has developed inside the well casing, the well will be allowed to stand without a cap for a few minutes or until the water level stabilizes before taking the water level measurement. Water level measurements will be recorded to the nearest hundredth (0.01) foot. Care will be taken not to drop foreign objects into the wells and not to allow the tape or sounding device to touch the ground around the well during monitoring.

An electric water level sounder consists of a contact electrode suspended by an insulated electric cable from a reel that has an ammeter, a buzzer, a light, or other closed circuit indicator attached. The indicator shows a closed circuit and flow of current when the electrode touches the water surface. Electric sounders will be calibrated periodically by measuring each interval and remarking them where necessary.

The procedure for measuring water levels with an electric sounder is as follows:

1. Turn sounder on and check that it is working.
2. Lower the electric sounder cable into the well until the ammeter or buzzer indicates a closed circuit. Raise and lower the electric cable slightly until the shortest length of cable that gives the maximum response on the indicator is found.
3. With the cable in this fixed position, note the length of cable at the measuring point.
4. If the electric cable is not graduated between foot markings, use a pocket steel tape measure (graduated in hundredths of a foot) to interpolate between consecutive marks. Care must be taken to ensure that the tape measurements are subtracted from the graduated mark footage value when the water level hold point (determined in Step 3) is below the graduated mark and added when it is above the mark. Record the resulting value as water level below the measuring point on the field form.

6.2.2 Measuring Water Levels in Wells Using Submersible Pressure Transducers (Optional)

Ecology has pressure tranducers that may be used to instrument groundwater monitoring wells on this project in lieu of or in combination with manual water level indicator measurements. County staff have indicated an interest in using Ecology's equipment to supplement their own and Ecology staff could be available to help with installation of this equipment.

6.2.2.1 Materials and Instruments

1. Transducer (only gauge or differential should be used, with vent tube), data logger, cables, suspension system, and power supply.
2. Data readout device (i.e., laptop computer loaded with correct software) and data storage modules or diskettes.
3. Well cover or recorder shelter with key.
4. Water level indicator graduated in hundredths of feet (electric sounding tape).

5. Forms including:
   a) Well completion form,
   b) Log book with records of previous measurements for comparison,
   c) Transducer calibration worksheet.
   d) Water level measurements field form or groundwater inspection sheet.

6. Pen or pencil.

7. Calculator and watch.

8. Spare desiccant, replacement batteries.

9. Tools, including high-impedance (digital) multimeter, connectors, crimping tool, and contact-burnishing tool or artist's eraser.

10. Camera and film.

11. GPS instrument.

6.2.2.2 Data Accuracy and Limitations

1. Water levels should be measured to 0.01 foot, where possible.

2. Tape measurements for the in-place calibration of pressure transducers should be made to the nearest 0.01 foot.

3. Pressure transducers are subject to drift, offset, and slippage of the suspension system. For this reason, the transducer readings should be checked against the water level measured with electric sounding tape in the well on every visit, and the transducer should be recalibrated periodically and at the completion of monitoring.

6.2.2.3 Instructions

If preparing a new installation:

1. Check that the well is unobstructed and open to the aquifer (i.e., perform a slug test).

2. Keep the transducer packaged in its original shipping container until it is installed. Avoid dropping the transducer or permitting sharp contact with the sides of the well casing. Do not allow the transducer to free fall into the well.

3. Conduct a field calibration of the transducer by raising and lowering it over the anticipated range of water level fluctuations. Take three readings at each of a minimum of five intervals, during both the raising and lowering of the transducer. Record the data on a calibration worksheet.

4. Lower the transducer to the desired depth below the water level (caution: do not exceed the depth range of the transducer).

5. Fasten the cable or suspension system to the well head using tie wraps or a weatherproof strain-relief system. If the vent tube is incorporated in the cable, make sure not to pinch the cable too tightly or the vent tube may be obstructed.

6. Make a permanent mark on the cable at the hanging point, so that future slippage, if any, can be determined.

7. Measure the total depth and the static water level in the monitor well with a steel tape or electric sounding tape. Repeat if measurements are not consistent within 0.02 foot.

8. Record the well and the measuring point configuration with a sketch. Include the measuring point height above the land surface, the hanging point, and the hanging depth.

9. Connect the data logger, power supply, and ancillary equipment. Configure the data logger to ensure that the channel, scan intervals, etc., selected are correct. Activate the data logger. Most loggers will require a negative slope in order to invert water levels for groundwater applications.

10. Take photographs of the site/installation and take a GPS reading.

If visiting an existing installation:

1. Record the well number and location; measuring point; if the well was being pumped when measured, was pumped recently, or a nearby well was pumping during the measurement; and any other changes at or near the site that may affect the measurements.

2. Retrieve groundwater data using instrument or data logger software.

3. Measure the water level with a steel tape or electric sounder and compare the reading with the value recorded by the transducer and data logger.

4. If the tape and transducer readings differ, raise the transducer out of the water and take a reading to determine if the cable has slipped or if the difference is due to drift.

5. If drift is significant, recalibrate the transducer with an independent water level value.

6. Check the charge on the battery and the charging current supply to the battery. Check connections to the data logger and tighten as necessary. Burnish contacts if corrosion is occurring.

7. Replace the desiccant, battery (if necessary), and data module. Verify that the logger channels and scans intervals, documents any changes to the data logger program, and activates the data logger.

8. If possible, wait until the logger has logged a value, and then check for reasonableness of data.

6.2.2.4 Data Recording

All data times of measurement are recorded in the field notebook or trip log and on the groundwater inspection sheet or water level field measurements form. Depending on the type of data logger used, data from the data logger are transferred to the office computer in a data module, downloader, or diskette.

7.0 QUALITY CONTROL PROCEDURES

This QAPP provides the methodology for measuring streamflow discharge and groundwater elevation in the Chumstick Creek and Mission Creek subwatersheds. All personnel will be issued a copy of the QAPP prior to conducting field activities.

All instruments will be subjected to regular testing and calibration to maintain high levels of quality and dependability. The methodology provided below describes the approach that will be used to determine the quality of stream discharge measurements with the use of calibrated reference instruments.

Some Acoustic Doppler Velocimeter (ADV) instruments provide parameters to help determine the quality of discharge measurements. If such parameters are available from the ADV selected for use in this study, they will be reported as part of the quality control data. As an example, if the average standard error for a measurement is greater than 8 percent of the mean measurement velocity, the measurement should not be rated better than fair. If the standard error is greater than 10 percent of the mean measurement velocity, the measurement should not be rated better than poor (Gotvald and Stamey, 2005). Other criteria that can be reported as part of quality control procedures includes the number of velocity spikes that occur during the velocity measurement. If the number of spikes exceeds 10 per measurement, data may be down rated (Gotvald and Stamey, 2005).

8.0 DATA MANAGEMENT PROCEDURES

Data collection will be managed in an Excel spreadsheet. Measurements including groundwater levels, stream stage, manometer board readings, stream segment discharge, and total discharge will be entered into the spreadsheet and checked for accuracy by the person that entered the recordings in the field notebook and reviewed by the AMEC project manager.

Discharge measurements will be reviewed by the AMEC project manager and returned to field staff to make necessary adjustments or corrections. Discharge and stage measurements will then be used to create a flow rating curve. The curve is generated by plotting instantaneous discharge measurements against the corresponding stage height. Discharge is predicted at stages where data are not available by interpolating between data points. The rating curve should not be extended to either twice the highest measured discharge or half of the lowest measured discharge. Any interpolation beyond these thresholds should be considered discharge estimates and qualified as such in any reporting.

Hydrologic data will be reviewed quarterly throughout the year and an annual review of each station's data will be made at the completion of the water year. Anomalies within the dataset will be flagged and explained. All data analysis, including rating curves, should incorporate the most recent period of data collection.

Data will be qualified with a J value. If water levels are not collected within an 8-hour period of each other, they will be rejected.

After any necessary data qualification, data will be uploaded to Ecology's Environmental Information Management (EIM) system[1]. The EIM is the main database for environmental monitoring data. The EIM contains records on physical, chemical, and biological analyses and measurements. Supplementary information about the data (metadata) is also stored, including information about environmental studies, monitoring locations, and data quality. AMEC will provide EIM submittals within 90 days of final approval of reports by Chelan County and Ecology.

Project data will be submitted to the Ecology EIM in three parts: study information, sample location data, and water level data.

1 http://www.ecy.wa.gov/eim/index.htm

9.0 AUDITS AND REPORTS

Despite instituting standardized protocols for data collection, differences in application by field staff and in the instrumentation used for data collection can result in variability within a dataset that is not a function of physical processes within the environment. Because of the limited budget for this project, one individual will be responsible for all stream monitoring locations in the Chumstick Creek and Mission Creek subwatersheds. It is expected that this individual will employ consistent sampling protocols across all measurement events. Side-by-side measurement comparisons performed with Ecology staff (Section 6.1.9) will help ensure that correct sampling protocols are routinely followed.

Data from streamflow measurements cannot be analyzed for accuracy because there is not a field reference standard available for comparison. Consequently, instrument calibration must be performed routinely and correctly to ensure the quality of collected data. Furthermore, the Acoustic Doppler Velocimeter (ADV) will be returned to the manufacturer yearly for routine maintenance. If maintenance is required that introduces issues regarding data quality, then data collected while the instrument was compromised will be flagged.

At the close of each water year, all groundwater and surface water data will be provided to the Chelan County project manager. The dataset will contain flags for stage data corrections due to pressure transducer drift and ADV maintenance. However, specific thresholds or targets for stream discharge will not be set because only one instrument is available for measurement. As discussed previously, this precludes the establishment of specific data quality objectives for stream discharge measurements.

10.0 DATA VERIFICATION AND VALIDATION

Each discharge measurement will be assigned an overall quality index of poor, fair, good, or excellent. A numerical approach will be developed to assign a quality index through the quantification of key physical attributes of the cross section (i.e., cross section is perpendicular to the main velocity vector) as well as other parameters involved in the discharge measurement including the number of stream segments and the percentage of flow contained within each segment. The quality index determines the tolerance for performing adjustment of the stage-discharge rating curve at a particular stream cross section and it also provides a numerical value that indicates reliability of the rating curve. Curves should coincide with measured values if the rating curve is generated from data points possessing high quality indices. In contrast, curves with lower ratings will possess larger residual values between data points and the rating curve (Butkus, 2005).

Butkus (2005) provides the following illustrative example. Two discharge measurements are made near the same stage value and both data points are rated as excellent. Flow predicted by the rating curve at that specific stage differs by less than 1 percent from the measured values. At a later date, two additional measurements at similar stages are rated as only fair and discharge predicted by the rating curve differs from the measurement value by greater than 7 percent. In this case, the rating curve should not be adjusted to achieve a better fit to the “fair” data if it results in larger residuals for data points rated “excellent.” As a general rule, curves should have the lowest residuals for data points ranked as “excellent” or “good” and larger residuals for data points considered “poor” or “fair.”

At the conclusion of each Water Year, streamflow data will be reviewed and any final adjustments will be made to the rating curve for each instrumented cross section. Upon completion of data entry, a technical report will be drafted. The report will include discussion of the discharge measurement quality over the previous year as well as the implications of measurement quality for each site’s rating curve.

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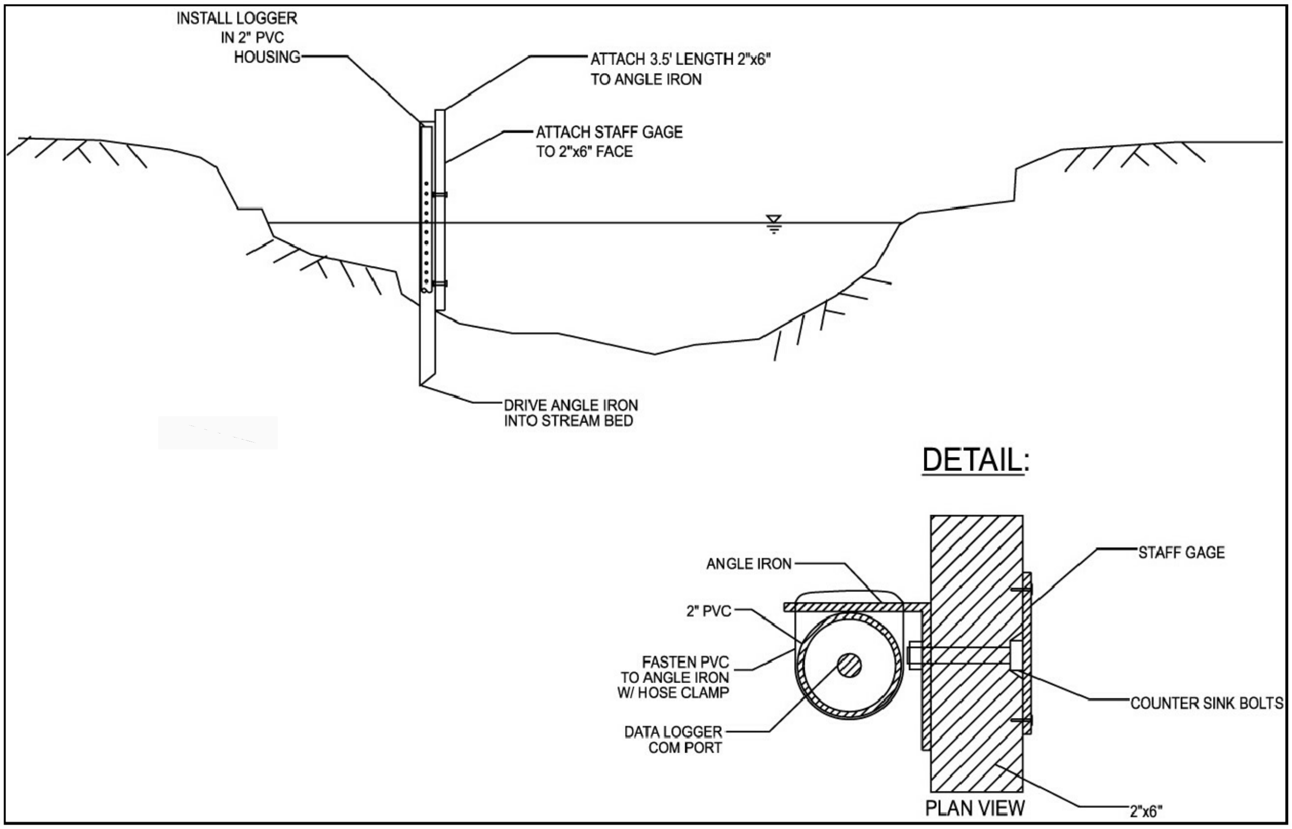
FIGURES



Notes:

1. Diagram from Grays Harbor County (2002)
2. Diagram Not to Scale

PLANNED STAFF GAGE CONSTRUCTION
Wenatchee Watershed Water Resource
Technical Assistance
Chelan County, Washington

By: APS	Date: 07/10/08	Project No. 12817.000
AMEC Geomatrix		Figure 1

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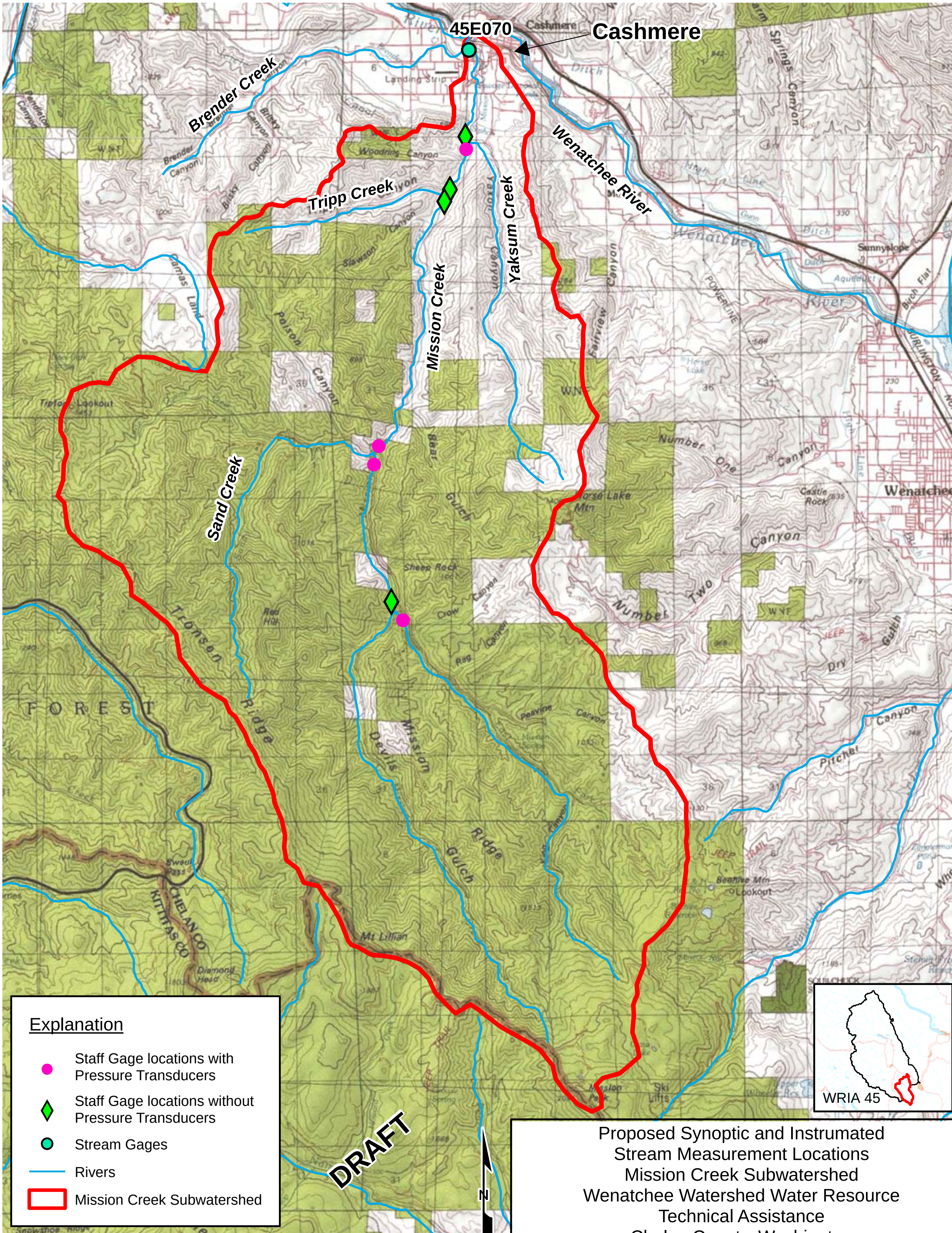

Proposed Synoptic and Instrumented
Stream Measurement Locations
Mission Creek Subwatershed
Wenatchee Watershed Water Resource
Technical Assistance
Chelan County, Washington

By: APS	Date: 07/09/08	Project No. 12817.000
AMEC Geomatrix		Figure 2

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Miles

Note: Topographic Base map from U.S.G.S. 100k DRGs

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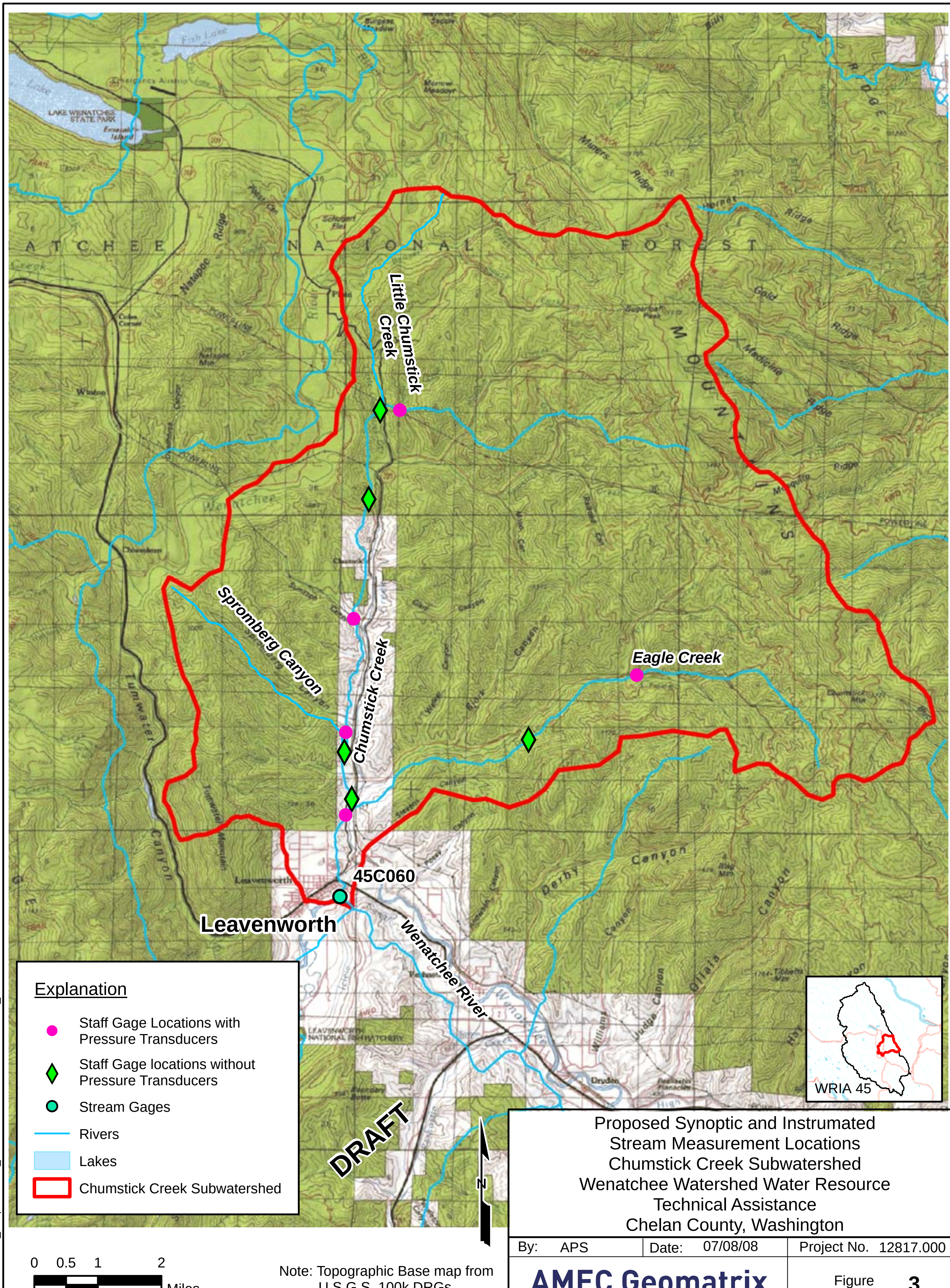

Note: Topographic Base map from U.S.G.S. 100k DRGs

Proposed Synoptic and Instrumated
Stream Measurement Locations
Chumstick Creek Subwatershed
Wenatchee Watershed Water Resource
Technical Assistance
Chelan County, Washington

By: APS	Date: 07/08/08	Project No. 12817.000
AMEC Geomatrix		Figure 3

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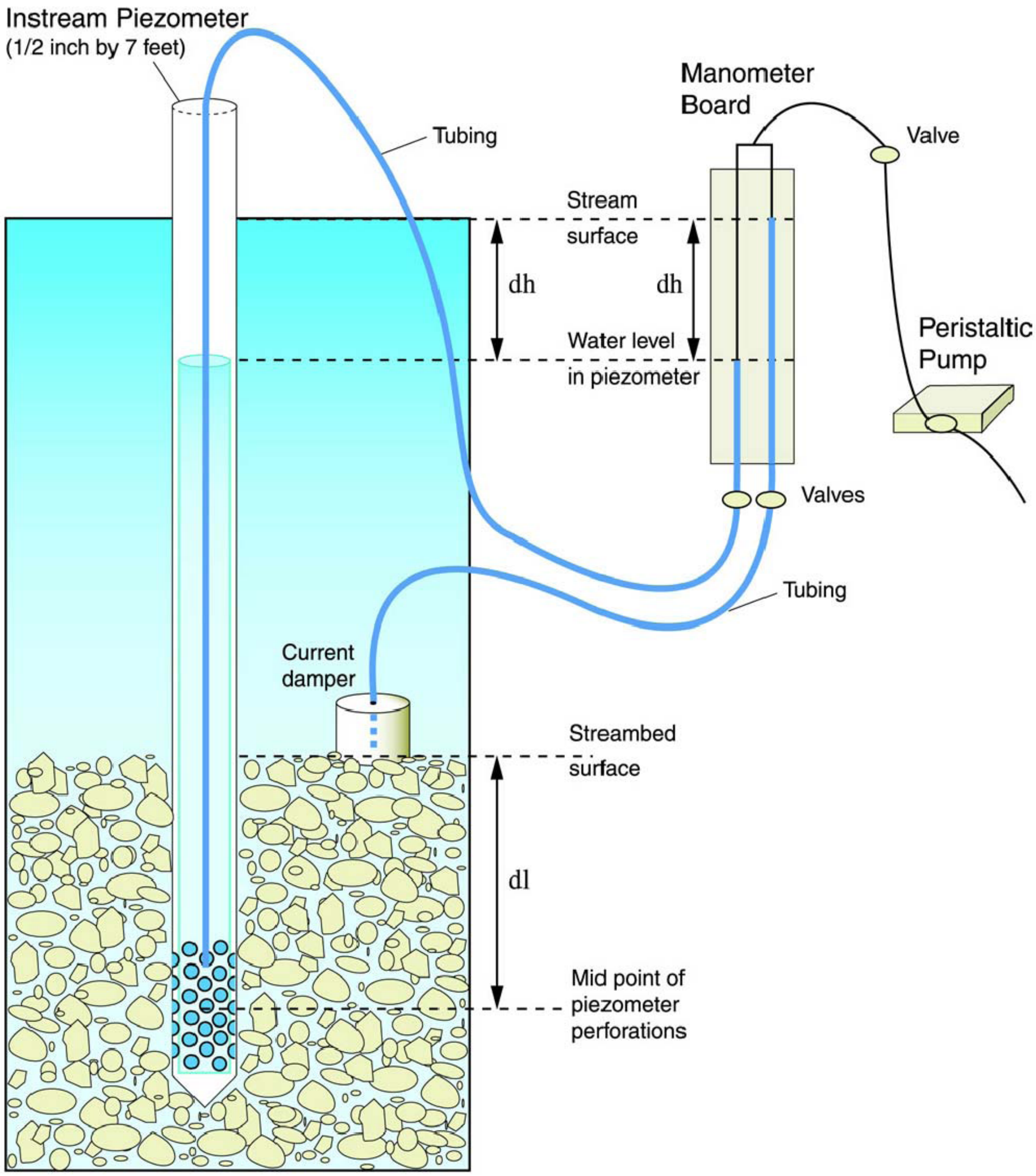

Notes:

1. Diagram from Simonds and Sinclair (2002)
2. Diagram Not to Scale

MANOMETER BOARD MEASUREMENT DESIGN
Wenatchee Watershed Water Resource
Technical Assistance
Chelan County, Washington

By: APS	Date: 07/10/08	Project No. 12817.000
AMEC Geomatrix		Figure 4

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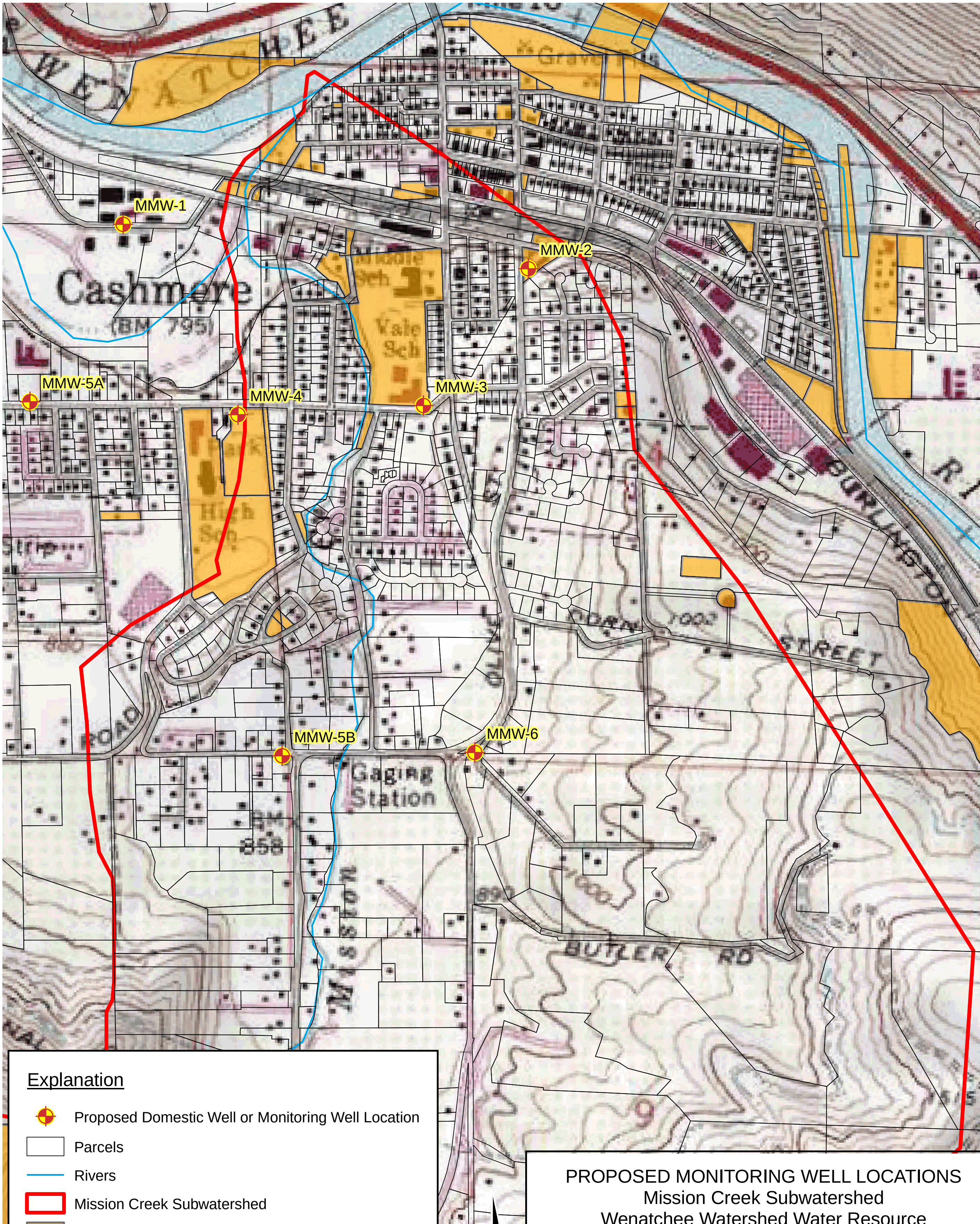

PROPOSED MONITORING WELL LOCATIONS
Mission Creek Subwatershed
Wenatchee Watershed Water Resource
Technical Assistance
Chelan County, Washington

By: APS	Date: 08/05/08	Project No. 12817.000
AMEC Geomatrix		Figure 5

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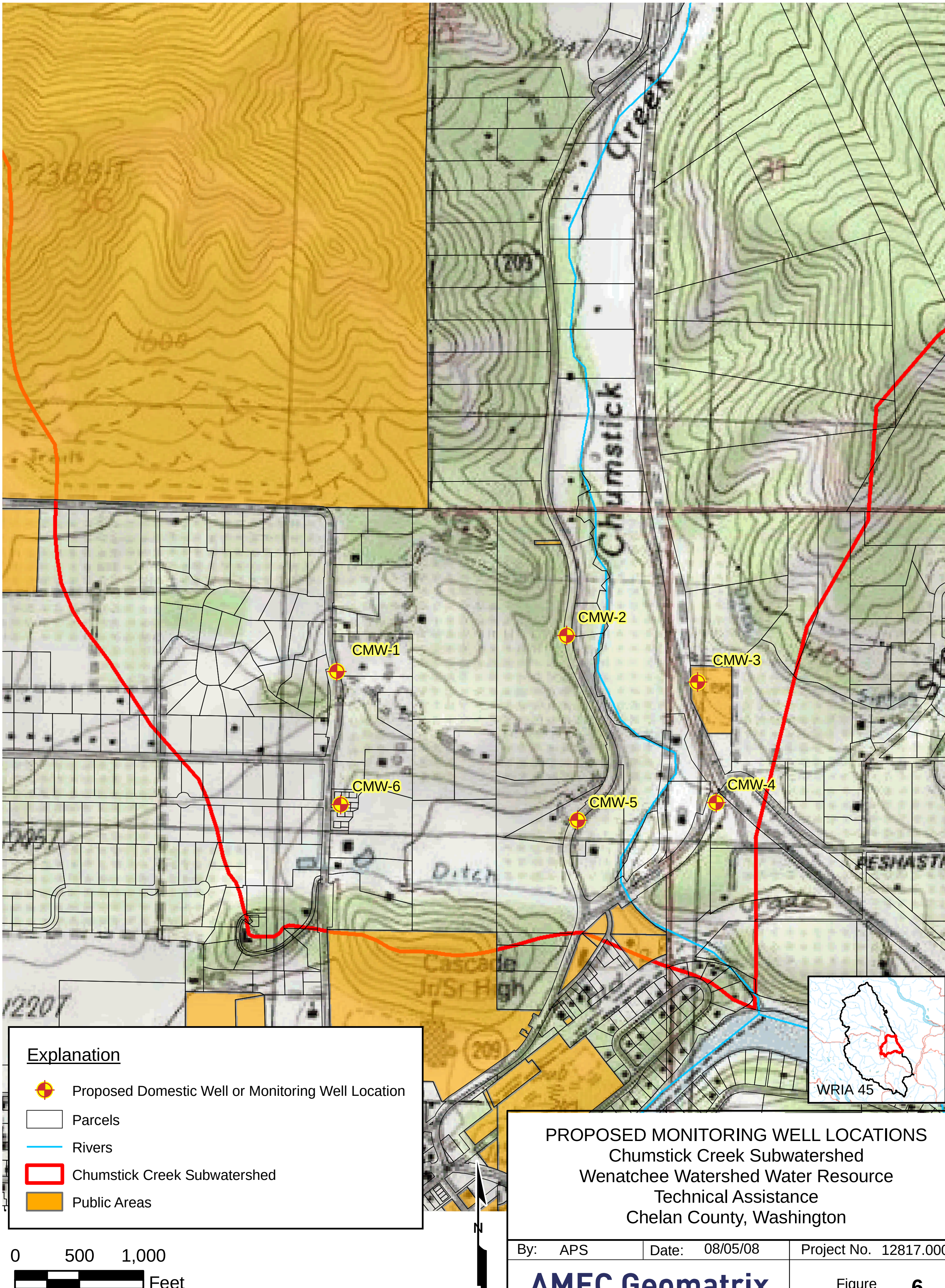

PROPOSED MONITORING WELL LOCATIONS
Chumstick Creek Subwatershed
Wenatchee Watershed Water Resource
Technical Assistance
Chelan County, Washington

By: APS | Date: 08/05/08 | Project No. 12817.000

AMEC Geomatrix

Figure 6

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