Wide Hollow Creek
Water Quality Study for Aquatic Life Use

Water Quality Study Design
(Quality Assurance Project Plan)

September 2013

Publication No. 13-03-116

DEPARTMENT OF
ECOLOGY
State of Washington

Publication and Contact Information

Each study conducted by the Washington State Department of Ecology (Ecology) must have an approved Quality Assurance Project Plan. The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completing the study, Ecology will post the final report of the study to the Internet.

The plan for this study is available on the Department of Ecology's website at https://fortress.wa.gov/ecy/publications/SummaryPages/1303116

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Cover photo: Wide Hollow Creek

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QAPP: Quality Assurance Project Plan
EAP: Environmental Assessment Program, Washington State Department of Ecology
EIM: Environmental Information Management database.

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Abstract

Located in Yakima County of central Washington State, the Wide Hollow Creek watershed originates in the upland areas to the west of the City of Yakima about 17 miles above its confluence with the Yakima River near the city of Union Gap. The flow in the creek is dominated by irrigation water conveyance.

By default, the aquatic life use category for Wide Hollow Creek is designated as salmonid spawning, rearing, and migration. Wide Hollow Creek does not meet the temperature, dissolved oxygen, or pH criteria needed to support its aquatic life use category and is on Washington State′s list of impaired waters (303(d) list) for not meeting those criteria.

To understand the causes of the impairments, the Washington State Department of Ecology (Ecology) will conduct a year-long water quality study between July 2013 and June of 2014. Ecology will collect data to develop and calibrate a numerical water quality model of the creek to simulate continuous temperature, dissolved oxygen, pH, and other water quality parameters. Additionally, Ecology will conduct a biological and habitat assessment of Wide Hollow Creek.

Ecology will examine the water quality limitations in Wide Hollow Creek and attempt to determine what temperature, dissolved oxygen, and pH levels are potentially attainable in Wide Hollow Creek. Biological and habitat conditions will also be examined for the purpose of assessing the potential fish and wildlife use of the creek.

This Quality Assurance Project Plan describes the methods, data quality procedures, study design, and the water quality modeling approach to be implemented during this study.

What is the Clean Water Act?

Federal Clean Water Act requirements

The Clean Water Act established a process to identify and clean up polluted waters. The Clean Water Act requires each state to have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of (1) designated uses for protection, such as cold water biota and drinking water supply, and (2) criteria, usually numeric criteria, to achieve those uses.

The Water Quality Assessment and the 303(d) List

Every two years, states are required to prepare a list of water bodies that do not meet water quality standards. This list is called the Clean Water Act Section 303(d) list. In Washington State, this list is part of the Water Quality Assessment (WQA) process.

To develop the WQA, the Washington State Department of Ecology (Ecology) compiles its own water quality data along with data from local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data in this WQA are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the assessment. The list of waters that do not meet standards [the 303(d) list] is the Category 5 part of the larger assessment.

The WQA divides water bodies into five categories. Those not meeting standards are given a Category 5 designation, which collectively becomes the 303(d) list.

Category 1 – Waters that meet standards for parameter(s) for which they have been tested.

Category 2 – Waters of concern.

Category 3 – Waters with no data or insufficient data available.

Category 4 – Polluted waters that do not require a clean-up plan because they:
    4a. – Have an approved water clean-up plan being implemented.
    4b. – Have a pollution-control program in place that should solve the problem.
    4c. – Are impaired by a non-pollutant such as low water flow, dams, and culverts.

Category 5 – Polluted waters that require a water clean-up plan – the 303(d) list.

Further information is available at Ecology's Water Quality Assessment website.

The Clean Water Act requires that a clean-up plan called a Total Maximum Daily Load (TMDL) be developed for each of the water bodies on the 303(d) list. A TMDL is numerical value representing the highest pollutant load a surface water body can receive and still meet water quality standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

Why is Ecology Conducting a Water Quality Study in This Watershed?

Background

Located in Yakima County of central Washington State, the Wide Hollow Creek watershed originates in the upland areas to the west of the City of Yakima about 17 miles above its confluence with the Yakima River near the city of Union Gap. The flow in the creek is dominated by irrigation water conveyance.

By default, the aquatic life use category for Wide Hollow Creek is designated as salmonid spawning, rearing, and migration. Wide Hollow Creek does not meet the temperature, dissolved oxygen, or pH criteria needed to support its aquatic life use category and is on Washington State′s list of impaired waters (303(d) list) for not meeting those criteria.

To understand the causes of the impairments, Ecology will conduct a year-long water quality study beginning in July 2013 and ending in June 2014. As part of this study, Ecology will collect data to develop and calibrate a numerical water quality model of the creek to simulate continuous temperature, dissolved oxygen, pH, and other water quality parameters. Additionally, Ecology will conduct a biological and habitat assessment of Wide Hollow Creek.

Ecology will examine the water quality limitations in Wide Hollow Creek and attempt to determine what temperature, dissolved oxygen, and pH levels are potentially attainable in Wide Hollow Creek. Biological and habitat limitations and attainment will also be examined.

Study area

Wide Hollow Creek is located in Yakima County and encompasses parts of the cities of Yakima and Union Gap. It is in Water Resource Inventory Area (WRIA) 37. The watershed drains the south slope of Cowiche Mountain and a portion of the east slope of Pine Mountain. The drainage area is about 70 square miles (CFHMP, 2012). Several of the smaller sub-drainages have names (Cottonwood, Shaw, and East Spring creeks).

The watershed is intensely farmed, although urban spread from the cities is increasing. The watershed is extremely arid and requires irrigation for agriculture. Still, the watershed is subject to infrequent flooding, most recently in 1974 and mid 1990s. The flooding is blamed on rare rain on snow events in the upper watershed (CFHMP, 2012).

Most of the middle and lower watershed is irrigated by waters imported from the Naches and Tieton rivers. Many irrigation ditches and drainage channels have been constructed since the 1890s to promote agriculture. The hydrology, geometry, and locations of channels have been greatly altered and sometimes created by the introduction of irrigation to the watershed.

The public land surveys from the mid-1860s do not map or describe Wide Hollow Creek. The public land survey mapped all water resources and likely would not have missed it. The first reference to the creek is from a 1901 soil survey of the Yakima area where it is described as the “Wide Hollow waste slough”. It is likely that the waste slough was dug to waste the tail end of the Congdon Canal, which was dug in 1893. An 1899 U.S. Geological Survey (USGS) map shows the continuity of Congdon Canal with the waste slough.

Currently, the creek is perennial in the lower reach even during no irrigation flow, apparently from groundwater inflow; an inspection of channels above irrigated lands in the spring of 2013 showed that all channels were dry.

Studies have shown that aquatic life in Wide Hollow Creek is limited by habitat and water quality issues. A salmonid fishery in the creek is desired by the Washington Department of Fish and Wildlife and the Yakama Tribe.

Figure 1. Study area for the Wide Hollow Water Quality Study.

Impairments addressed by this water quality study

This study will measure the degree of impairment for temperature, dissolved oxygen, and pH in Wide Hollow Creek. Temperature, dissolved oxygen, and pH impairments have been listed in the 303(d) list (Table 1) since 1998. Each listing documents a specific location in Wide Hollow Creek where the impairment was measured. We will be looking at this watershed more thoroughly and may find other impaired locations for temperature, dissolved oxygen, and pH.

Table 1. Wide Hollow Creek listings on the 2012 303(d) list for temperature, dissolved oxygen, and pH.

Water Body	Parameter	Listing ID	NHD Reach Code
Wide Hollow Creek	Temperature	8307	17030003000812
Wide Hollow Creek	Temperature	16095	17030003000812
Wide Hollow Creek	Dissolved oxygen	16097	17030003000812
Wide Hollow Creek	Dissolved oxygen	47370	17030003007003
Wide Hollow Creek	Temperature	48211	17030003000812
Wide Hollow Creek	Temperature	48213	17030003000812
Wide Hollow Creek	pH	50677	17030003000812
Wide Hollow Creek	pH	50681	17030003000812

NHD: National Hydrography Dataset

There are other 303(d) listed parameters in Wide Hollow Creek, but this study does not address them (Table 2). Water quality TMDL technical studies have already been completed to address the bacteria listings (Tarbutton, 2012) and toxic listings (Johnson et al., 2010).

Table 2. Wide Hollow Creek listings on the 2012 303(d) list not addressed by this study.

Water Body	Parameter	Listing ID	NHD Reach Code
Wide Hollow Creek	Bacteria	multiple	17030003000812
Wide Hollow Creek	4,4'-DDE	8848	17030003000812
Wide Hollow Creek	4,4'-DDD	8849	17030003000812
Wide Hollow Creek	DDT	8855	17030003000812
Wide Hollow Creek	Dieldrin	8856	17030003000812
Wide Hollow Creek	Endosulfan	8857	17030003000812

NHD: National Hydrography Dataset

How will the results of this water quality study be used?

This study will assess the current water quality conditions in Wide Hollow Creek related to temperature, dissolved oxygen, and pH. This study also hopes to identify the limits to attaining better water quality and to determine if the current designated aquatic life uses and supporting criteria are appropriate. If there are limitations, the calibrated water quality model can be used as a tool to identify what kind of water quality might be attained in Wide Hollow Creek if a clean-up plan is completed. Ecology and local partners can use these results to figure out where to focus water quality improvement activities. The study may also suggest areas for follow-up sampling.

Water Quality Standards and Numeric Targets

Washington's administrative code outlines water quality standards for the state of Washington (WAC 173-201A). In the state water quality standards, fresh water aquatic life use categories are described using key species (salmonid versus warm-water species) and life-stage conditions (spawning versus rearing). Wide Hollow Creek was never given a specific aquatic life use designation; therefore, a default aquatic life use category is applied by the standards: salmonid spawning, rearing, and migration. The criteria used to protect this aquatic life use are outlined in Table 3 and described in further detail below.

Table 3. Washington State water quality criteria for temperature, dissolved oxygen, and pH in Wide Hollow Creek.

Parameter	Criteria
Temperature	To protect the designated aquatic life uses of "Salmonid Spawning, Rearing, and Migration," the highest 7-DADMax temperature must not exceed 17.5°C (63.5°F) more than once every ten years on average.
Dissolved Oxygen	To protect the designated aquatic life use of "Salmonid Spawning, Rearing, and Migration," the lowest 1-day minimum oxygen level must not fall below 8.0 mg/l more than once every ten years on average.
pH	To protect the designated aquatic life uses of "Salmonid Spawning, Rearing, and Migration," pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.5 units.

Temperature

Temperature affects the physiology and behavior of fish and other aquatic life. Temperature may be the most influential factor limiting the distribution and health of aquatic life and can be greatly influenced by human activities.

Temperature levels fluctuate over the day and night in response to changes in climatic conditions and river flows. Since the health of aquatic species is tied predominantly to the pattern of maximum temperatures, the criteria are expressed as the highest 7-day average of the daily maximum temperatures (7-DADMax) occurring in a water body.

Washington State uses the criteria described above to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying below the fully protective temperature criteria. When a water body is naturally warmer than the above-described criteria, the state provides a small allowance for additional warming due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.3°C (0.54°F) increase above the naturally higher (inferior) temperature condition. Whether or not the water body is naturally high in temperature is determined using a model. The model roughly approximates natural conditions and is appropriate for determining the implementation of the temperature criteria. Model simulated natural conditions are also called the “system thermal potential” or “system potential” of the water body.

Stream heating processes

The temperature of a stream reflects the amount of heat energy in the water. Changes in water temperature of a stream are induced by the balance of the heat exchange between the water and surrounding environment as the water moves downstream. If there is more heat energy entering the water than leaving, the stream temperature will increase. If there is less energy entering the water than leaving, then the temperature will decrease.

The following environmental variables are important drivers of water temperature:

- Stream Depth. Stream depth affects the magnitude of the stream temperature fluctuations.
- Air temperature. Daily average stream temperatures and daily average air temperature are both highly influenced by incoming solar radiation. When the sun is not shining, the water temperature tends towards the dew-point air temperature.
- Solar radiation and riparian vegetation. The daily maximum water temperatures are influenced by direct solar heating. The loss of shade by riparian vegetation removal strongly influences the water temperature.
- Groundwater. Inflowing groundwater can have an important cooling effect on stream temperature.

Point sources that introduce flow will cause a temperature change if the temperature is different from the receiving water of the stream.

Dissolved oxygen

Aquatic organisms are very sensitive to reductions in the level of dissolved oxygen in the water. The health of fish and other aquatic species depends on maintaining an adequate supply of oxygen dissolved in the water. Oxygen levels affect growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants. While direct mortality due to inadequate oxygen can occur, the state designed the criteria to maintain conditions that support healthy populations of fish and other aquatic life.

Oxygen levels can fluctuate over the day and night in response to changes in climatic conditions as well as the respiratory requirements of aquatic plants and algae. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criteria are the lowest 1-day minimum oxygen concentrations that occur in a water body.

The criteria described above are used to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective dissolved oxygen criteria. When a water body is naturally lower in oxygen than the criteria, the state provides an additional allowance for further depression of oxygen conditions due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.2 mg/l decrease below that naturally lower (inferior) oxygen condition. Whether or not the water body is naturally low in oxygen is determined using a model. The model roughly approximates natural conditions, and is appropriate for determining the implementation of the dissolved oxygen criteria.

pH

The pH of natural waters is a measure of acid-base equilibrium achieved by the various dissolved compounds, salts, and gases. pH is an important factor in the chemical and biological systems of natural waters. pH both directly and indirectly affects the ability of waters to have healthy populations of fish and other aquatic species. Changes in pH affect the degree of dissociation of weak acids or bases. This effect is important because the toxicity of many compounds is affected by the degree of dissociation. While some compounds (e.g., cyanide) increase in toxicity at lower pH, others (e.g., ammonia) increase in toxicity at higher pH.

While there is no definite pH range within which aquatic life is unharmed and outside which it is damaged, there is a gradual deterioration as the pH values are further removed from the normal range. However, at the extremes of pH, lethal conditions can develop. For example, extremely low pH values (<5.0) may liberate sufficient CO2 from bicarbonate in the water to be directly lethal to fish.

The state established pH criteria in the state water quality standards primarily to protect aquatic life and to protect domestic water supply sources. Water supplies with either extreme pH or that experience significant changes of pH even within otherwise acceptable ranges are more difficult and costly to treat for domestic water purposes. pH also directly affects the longevity of water collection and treatment systems, and low pH waters may cause compounds of human health concern to be released from the metal pipes in distribution systems.

Stream processes affecting dissolved oxygen and pH

Biological processes influence the amount of DO and pH in streams. Primary producers photosynthesize and respire dissolved oxygen and carbon dioxide. Bacteria decompose organic materials in the water and consume oxygen and create dissolved carbon and carbon dioxide. Nutrients play an essential role in primary productivity and therefore influence DO and pH in streams.

Watershed Description

Climate

The Wide Hollow Creek watershed is located in a very arid region, with most of its watershed receiving very little average annual precipitation; ranging from around 5 inches at its mouth to an average of about 20 inches in the upper watershed. The valley lies in the rain shadow of the Cascades, largely protected from rain and snow accumulation. The minimal precipitation that does fall is from snow during winter. Agriculture in the valley is dependent on irrigation. The climate is dominated by warm and dry summers with relatively mild winters. The air temperatures in Yakima reach an average daily high of 87°F (30.5°C) in July dropping to an average daily high of 37°F (2.7°C) in January.

Geology

Yakima's West Valley is located on the western boundary of the Yakima Fold Belt. Elevations range from almost 4000 feet at the top of Pine Mountain to about 1000 feet at the mouth near Union Gap. The Yakima Fold Belt is characterized by east-west trending ridges and valleys formed by the folding of basalt flows of the Miocene-aged Columbia River Basalt Group (CRB). Overlying and interbedded with the CRBs are the sandstones and volcaniclastic sediments of the Miocene Ellensburg Formation. In the vicinity of West Valley, the CRB and Ellensburg Formations are overlaid by Pliocene-aged consolidated gravels of the Thorp Formation.

Soils and vegetation

The bottom of the watershed is formed on low terraces and a flood plain of the Yakima River. The soils are silt loams (Umapine, Esquatzel, and Warden) and are generally artificially drained to reduce alkali effects. The native vegetation is alkali-tolerant grasses, forbs, and shrubs.

The middle of the watershed is formed on terraces with a variety of loams and silt loams (e.g., Harwood, Selah, Cowiche, and Gorst), some of which are unique and important to agriculture. Many of the soils of these dissected terraces were formed from Pleistocene-aged loess deposits. The potential native vegetation on this unit is mainly bluebunch wheatgrass, big sagebrush, and Sandberg bluegrass. The terraces are generally used for irrigated field and orchard crops, rangeland, and homesites. Grasses and legumes are grown for hay, pasture, or seed.

The upper watershed which drains Cowiche and Pine Mountains has predominately very stony silt loam soils (Rock Creek and Kiona) with much sparser vegetation than on the terrace benches and is generally used for rangeland.

There are no forest lands in the watershed now and none were indicated in the public land surveys of the mid-1860s.

Hydrology

Wide Hollow Creek has seasonal hydrologic characteristics that are dominated by agricultural irrigation or drainage operations, e.g., high summer irrigation flows and low winter natural base flows (Figure 2). Wide Hollow Creek delivers more water than the watershed can generate naturally. During the irrigation season, Wide Hollow Creek carries imported irrigation water transferred through the irrigation network, mainly from the Naches and Tieton Rivers. These flows can be highly variable because they depend on water availability, the water needs of specific crops, and operational management of the irrigation network. Generally, irrigation flows begin in March and end in October every year.

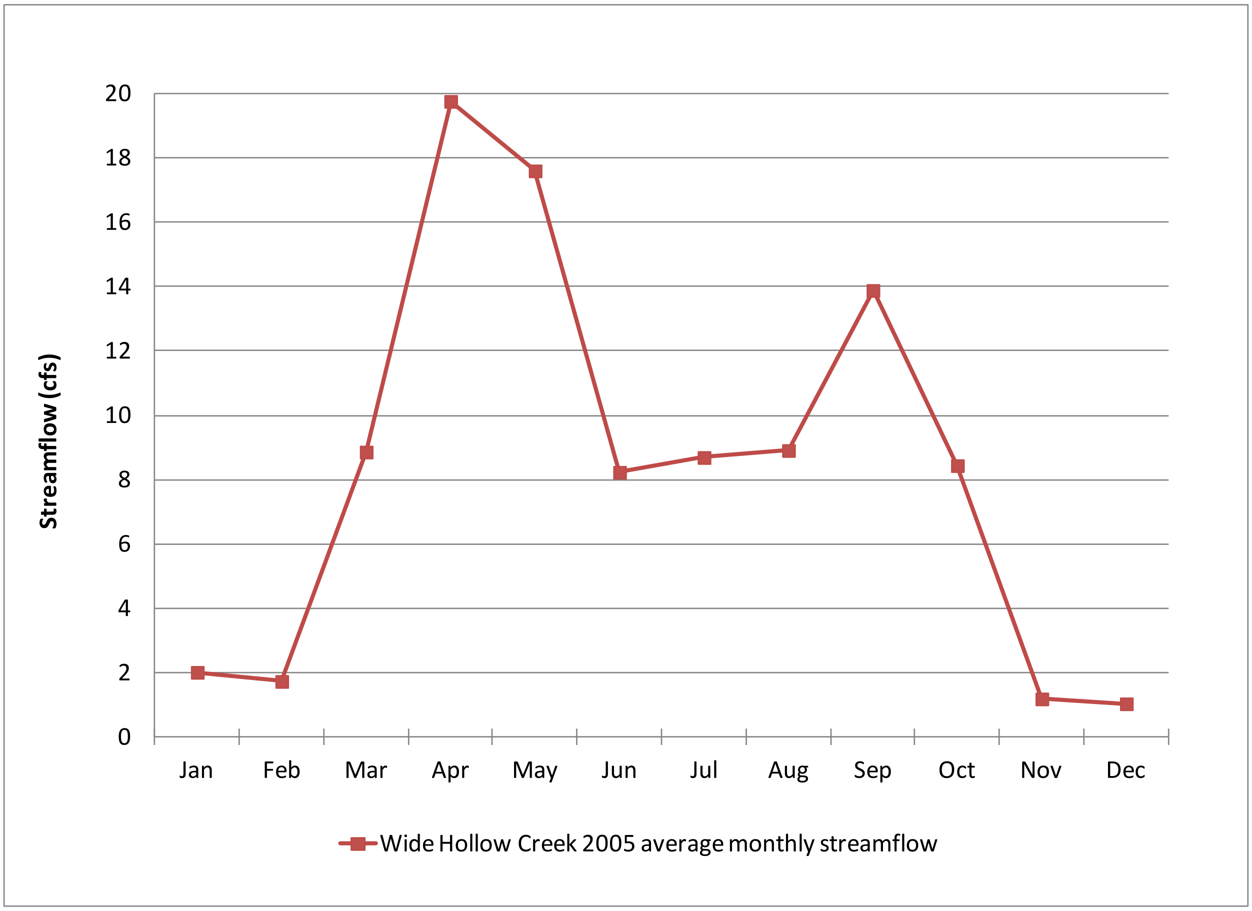

Figure 2. Historical streamflow illustrating the seasonal hydrologic characteristics associated with agriculture irrigation and drainage operation in Wide Hollow Creek.

2005 data from Ecology gage – 37E120 located near Randall Park

Wide Hollow Creek enters the Yakima River at river mile 107.4 after crossing under Interstate 82 and being joined by a diversion of Spring Creek East from the north.

A diversion of Spring (Chambers) Creek East flows through the eastern edge of the City of Union Gap and is a tributary to Wide Hollow Creek near its confluence with the Yakima River. The diversion is a part of Spring Creek East that has been diverted before it flows through a floodgate under Interstate 82 to the Yakima River. Currently, Spring Creek East flows are derived from springs and from stormwater drainage.

Land use

The upper watershed is mainly rangeland, some of which is managed by the Washington Department of Natural Resources. The transition to pasture, orchards, and cropland occurs down valley where irrigation systems convey water from the Naches and Tieton Rivers. Several irrigation districts manage irrigation in the lower portions of the valley.

Wide Hollow Creek continues to be bordered by agricultural orchards and livestock pasture; however, the West Valley area is experiencing rapid urbanization from Yakima, with residential, commercial, and light industrial land usage all the way to Union Gap. Urban land use comprises about 28% of the Wide Hollow Creek watershed.

Potential pollutant sources

Permitted sources

Municipal wastewater

At one time, treated wastewater from Union Gap was discharged into Wide Hollow Creek, but for the past 30 years it has been sent to the Yakima Wastewater Treatment Plant (WWTP). There are no longer any municipal wastewater treatment plant discharges to Wide Hollow Creek.

Municipal stormwater

Within the study area, three municipal entities maintain stormwater infrastructure covered under the general National Pollutant Discharge Elimination System (NPDES) Phase 2 municipal stormwater permits for eastern Washington, including Yakima County, as well as the cities of Yakima and Union Gap.

Other permitted facilities

Numerous other permitted facilities exist within the study area. They operate under a variety of different permit types including state individual industrial wastewater permits and general permits for industrial stormwater, confined animal feeding operations (CAFO), sand and gravel, and construction stormwater. One facility on Wide Hollow Creek has an individual industrial NPDES stormwater permit:

- The Del Monte plant discharges stormwater to the city of Yakima stormwater system. The stormwater drain discharges to Wide Hollow Creek 2.5 miles to the south.

Table 4. Individual industrial wastewater NPDES permit holders in the study area.

Permit Holder	Receiving Water	Permit Number	Permit Type
Clasen Fruit and Cold Storage	Wide Hollow Creek	WAG435176B	Fruit
Borton and Sons	Wide Hollow Creek via Lateral T	WAG435131B	Fruit
Eakin Fruit Company	Wide Hollow Creek via Stormwater Pipe	WAG435031B	Fruit
Del Monte Foods 125	Wide Hollow Creek	SO3000215D	Industrial SW
Western Recreational Vehicles	Wide Hollow Creek	SO3004527B	Industrial SW
Yakima County	All creeks and drains in urbanized areas	WAR046014	Phase II SW
City of Yakima	Wide Hollow Creek	WAR046013	Phase II SW
City of Union Gap	Wide Hollow Creek	WAR046010	Phase II SW
Yakima Valley Community College	Wide Hollow Creek	WAR046201	Phase II SW
Washington Dept. of Transportation	Wide Hollow Creek	WAR043000	Phase II SW

Fruit: NPDES Wastewater Discharge General Permit for Fresh Fruit Packing
Industrial SW: Industrial Stormwater Permit
Phase II SW: Future Municipal NPDES Stormwater Permit

There may be other active permits within the study area covered under the Construction Stormwater General Permit. Permitted actions that discharge stormwater to 303(d) listed water bodies for turbidity, pH, and phosphorus are required to monitor water quality and meet permit limitations.

Nonpoint sources

Nonpoint sources are diffuse sources not covered by an NPDES permit. Nonpoint sources can include groundwater inflows, rainfall washoff processes, erosion, and direct discharges (such irrigation water from managed return flows or field runoff returns).

Numerous potential nonpoint sources of nutrients are present within the watershed including:

- Irrigation water return flows.
- On-site septic systems, particularly those that are failing, poorly constructed, or poorly maintained.
- Range and pastured livestock with direct access to water bodies.
- Poor livestock or pet manure management on non-commercial, or "hobby" farms.

- Improperly stored or applied manure from commercial farms.
- Fertilization of landscaping.
- Sediment from erosion.
- Pet manure from residential areas.
- Wildlife.

Other background sources of nutrients, both within and upstream of the study area, include:

- Atmospheric deposition (rainfall, snow, particulates).
- Geologic weathering.
- Decomposing plant, invertebrate, and animal material.

Some potential nonpoint sources that affect water temperature include:

- Irrigation water runoff.
- Increases in temperature from vegetation removal on stream banks, which exposes water to solar gain.
- Decreases in depth of a channel by widening of the streambed or increased sedimentation.

Most nonpoint sources discussed in this section will not be monitored directly.

Historical Data Review

Yakima River Pesticides and PCBs TMDL Study, 2007-2008 – Ecology

Wide Hollow Creek was part of a toxic contaminant study to conduct a clean-up plan (TMDL) for the Yakima River and its tributaries (Johnson et al., 2010). The chemicals include six legacy pesticides or breakdown products (DDT, DDE, DDD, dieldrin, chlordane, and alpha-BHC), two current-use insecticides (endosulfan and chlorpyrifos) and polychlorinated biphenyls (PCBs).

In the Yakima River basin, all of these chemicals have exceeded Washington State water quality criteria for protection of human health for fish consumption or criteria for protection of aquatic life. Except for endosulfan and chlorpyrifos, these pollutants are no longer produced or used in the United States.

Wide Hollow had screening samples taken quarterly (twice during irrigation season and twice during non-irrigation season from May 2007 to February 2008). The human health criteria for dieldrin and DDE were exceeded in all 4 samples. The aquatic life criterion for T-DDT was also exceeded in all 4 samples.

Additionally, storm water drains to Wide Hollow were sampled during 8 storm events and showed even higher concentrations of Total-DDT, dieldrin, endosulfan, chlorpyrifos, and Total-PCBs. Estimates of loadings are included in the analyses.

Yakima Area Creeks Bacteria TMDL Study, 2005-2006 and 2010 – Ecology

Wide Hollow Creek was part of a bacteria study to conduct a clean-up plan (TMDL) for several tributaries in the Yakima area including Cowiche Creek, Wide Hollow Creek, Moxee Drain, and their tributaries (Tarbutton, 2012). Bacteria pollution can lead to conditions that provide high illness risk to people and animals using the streams. The majority of the samples for the study were collected in 2004-06, but additional samples were also collected in 2010. During the bacteria sampling, some flow gages were installed to collect continuous flow data. Also, instant measurements of temperature, dissolved oxygen, and pH were taken, which sometimes showed impairment and led to 303(d) listings for some locations.

Water Quality BMP Implementation, 2002-03 – North Yakima Conservation District

The North Yakima Conservation District collected limited turbidity, temperature, conductivity, pH, and dissolved oxygen data at sites in Wide Hollow Creek from 2000 to 2002 (North Yakima Conservation District, 2003).

Habitat Limiting Factors Yakima River Watershed, 2001 – Washington State Conservation Commission

The Limiting Factors report assessed the conditions for channel, substrate, riparian, water quality and water quantity in Wide Hollow Creek (Haring, 2001).

Channels were found to have severe bank sloughing due to overgrazing. Pools and runs were fairly deep (>2 feet), and more frequent than riffles. Large woody debris (LWD) was generally lacking; although there is some LWD from crack willows adjacent to the stream, typically removed. Substrate was rated fair, having good coho and steelhead rearing conditions in reaches, but gravel was in short supply.

Riparian conditions were generally poor, with riparian vegetation consisting of narrow buffer with clumps of mature crack willows that provide shaded areas interspersed with sunny areas. Within areas of heavy residential development, the stream was found to be incised and very deeply shaded by dense foliage on the tops of steep banks. Restoration to a multi-age cottonwood stand was recommended.

The report rated water quality as poor/fair, citing impacts from leaking septics, stormwater runoff, and elevated pesticide concentrations from agricultural runoff, and from urban runoff. Water quality concerns were primarily associated with water temperature, toxics, and dissolved oxygen, although the influence of agricultural sources of nutrients on algal communities was also noted.

Wide Hollow Creek benthic invertebrates were found to have a very low EPT richness (<6 taxa) with no stonefly taxa, perhaps due to intensive agriculture and urbanization. EPT richness is the number of Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly) taxa in a sample. The report cited USGS data showing high turbidity.

Instream flows were cited as excellent, ranging from 20-30 cfs in the lower 4 miles, although flows were affected to a greater degree by irrigation inflow. Water from Wide Hollow Creek was being used for irrigation, domestic water supply, and stock water, with some historic non-consumptive power-related use.

The following prioritized actions were recommended to restore salmonid habitat in Wide Hollow Creek:

- Prioritize and install fish screens on unscreened water diversions
- Prioritize and correct fish passage barriers
- Preserve integrity of reaches with remaining functional floodplain
- Restore lower Wide Hollow Creek (from Bay Street to the mouth) to its pre-diversion location and channel characteristics
- Diversify riparian vegetation and restore riparian function throughout the watershed
- Implement upland agricultural and residential BMPs to reduce nutrient loading and erosion of fine sediment to the stream

- Implement a comprehensive grazing program to protect riparian vegetation and streambank stability

Quality of Water, Sediment, and Biota in Wide Hollow Creek, 1987 – Ecology

An in-depth study of Wide Hollow Creek was performed by Ecology in 1987 (Kendra, 1988). The study examined water, sediment, and biota in the creek in an effort to characterize water quality under low flow conditions, and to relate changes in water quality, sediment, and biota to point and nonpoint source effects. Water sampling took place over a 2-day period in July for the following parameters: temperature, pH, dissolved oxygen, flow, turbidity, chemical oxygen demand, nutrients, fecal coliform bacteria, hardness, and metals. Kendra noted that FC bacteria levels increased downstream, likely as the result of cumulative effects of streamside livestock pasturing, possibly contaminated pipes discharging in lower reaches, and septic system failures.

Fisheries in Wide Hollow Creek – Washington Department of Fish and Wildlife

The Washington Department of Fish and Wildlife (WDFW) have a scattered collection of notes documenting fish surveys, kills, sightings, and plantings in Wide Hollow Creek (Harvester, 2013).

In general, WDFW and the Yakima Basin Fish and Wildlife Recovery Board (YBFWRB) believe that portions of Wide Hollow Creek naturally support cold water fisheries including rainbow trout and coho salmon populations. Additionally, WDFW believes that brown trout, which were planted in the 1980s, have persisted as residents.

Wide Hollow is also known to support warmer water fisheries including numerous native cyprinids; speckled dace, redside shiner, chiselmouth, and northern pike minnow. WDFW has also documented stickleback, largescale suckers, and mountain suckers.

Goals and Objectives

Project goals

The goal of this water quality study is to provide a better understanding of the current water quality conditions in Wide Hollow Creek, particularly for water temperature, dissolved oxygen, and pH. Additionally, the biological and habitat function in Wide Hollow Creek will be assessed. This study also hopes to identify limits to better water quality attainment and to assess appropriateness of current designated aquatic life uses and supporting criteria.

Study objectives

Objectives for the study are:

- Collect a data set of sufficient quality and quantity to calibrate a water quality model of Wide Hollow Creek.
- Develop a water quality model capable of simulating continuous temperature, dissolved oxygen, and pH in Wide Hollow Creek.
- Characterize current processes governing water temperature, dissolved oxygen, and pH in Wide Hollow Creek, including the influence of tributaries, nonpoint sources, point sources, and groundwater.
- Collect and analyze the biological and habitat data in Wide Hollow Creek.
- Assess existing beneficial uses of the creek and determine whether those uses are attainable.

Study Design

Overview

The study is designed to meet the project goals and objectives by collecting an environmental data set of sufficient resolution and quality to develop and calibrate a water quality model. The model should be capable of reasonably predicting temperature, dissolved oxygen, and other water quality in the Wide Hollow Creek under dynamic flow conditions over the course of several months.

Data will be collected from July 2013 to June 2014 and include synoptic sampling surveys to characterize nutrient loads, periphyton productivity, and water quality within the study area. Additional temperature, riparian buffer, channel dimension, substrate, streamflow, groundwater, and other data will be collected to improve simulation of temperature, hydrodynamics, and water quality within the model.

Once calibrated, the model can be used to distinguish the relative contribution of different sources which account for the current water quality conditions. In addition, the model can be used to evaluate the water quality response to future watershed management decisions in Wide Hollow. Components and descriptions of the model are summarized in the following section.

Modeling and analysis framework

Ecology will be using a numerical model, QUAL2KW (Chapra et al., 2008) to simulate water quality in Wide Hollow Creek. The current version of Ecology's QUAL2KW modeling framework is a dynamic model that uses a kinematic wave (KW) method of flow routing (Chapra, 1997) for simulation of continuously changing channel velocity and depth in response to changing flows. In addition, the QUAL2KW framework will allow input of continuous changes in boundary loads and meteorology.

The QUAL2KW was selected because the dominant primary producers in Wide Hollow Creek are bottom algae. QUAL2KW is capable of dynamic simulation of river productivity when bottom algae are the dominant primary producer.

The monitoring site above 96th Avenue will serve as the upper boundary condition in the model. Located just below the confluence of Cottonwood Creek, Wide Hollow Creek, and the Yakima Valley Canal crossing, this location represents the background conditions of the upper watershed conditions. Groundwater and other inflows below 96th Avenue will be handled as diffuse or point source inputs to the model. Water quality from groundwater and other point sources will be measured directly in the field during synoptic surveys and interpolated estimates between surveys.

Within QUAL2KW, hydrodynamics for each segment are simulated based on channel characteristics and flow parameters. The KW equation is used to drive advective transport through free-flowing segments and to calculate flows, volumes, depths, and velocities resulting from variable upstream inflow. Ecology will collect travel time data from several reaches to check the hydrodynamic calculations in QUAL2KW.

QUAL2KW simulates temperature hourly, based on hourly heat transport and meteorological heat exchange processes. Accurate temperature simulation is important for productivity simulation, as temperature influences the rates of physical, chemical, and biological reactions. Other water quality variables will also be simulated hourly. The length of the simulation will depend on conditions, but it is generally expected to fall between July 2013 and June of 2014, starting with the first synoptic survey representing initial conditions.

The following QUAL2KW water quality variables will be used in the Wide Hollow model:

- ammonia
- nitrate
- organic nitrogen
- orthophosphate
- organic phosphorus
- dissolved oxygen
- CBOD
- detritus
- pH
- alkalinity
- inorganic solids
- temperature
- bottom algae biomass
- dissolved and total organic carbon

The data collection described below will provide the observed conditions to support a dynamic model calibration.

Data collection

Overview

Data collection will involve:

- Continuous hydrology, meteorology, and water quality data collection within the study area to provide continuous inputs to the water quality model.
- Monthly synoptic surveys to collect higher resolution data to characterize water quality, hydrology, and productivity in Wide Hollow Creek and its point sources.
- Continuous temperature monitoring combined with additional surveys to characterize effective shade, channel geometry, riparian vegetation, and instream habitat.
- Groundwater nutrient sampling and water quality measurements.
- Time of travel studies to determine reach-specific water velocities.
- Light extinction surveys to develop light extinction coefficients for a range of flow and turbidity conditions.
- Biological monitoring to survey aquatic life use in Wide Hollow and a survey of habitat conditions.

Sampling locations

The overall study design will consist of sampling activities at many locations (Table 5; Figure 3):

- **Mainstem locations:** about 10 mainstem sampling locations on Wide Hollow Creek.
- **Tributary locations:** all significant point sources (tributaries/pipes) that discharge directly to Wide Hollow Creek within the study area.
    - Based on previous studies, many of these sites will likely not have measureable flow and will not be sampled during some or all synoptic surveys.
    - Field staff will perform reconnaissance on these sites prior to the first synoptic survey. In the course of the synoptic surveys, any newly discovered sources may be added to the tributary network.
- **Groundwater locations:** Ecology will install up to 5 piezometers that will measure monthly groundwater levels and sample quarterly water chemistry.
- **Biological and habitat assessment:** Ecology will assess 5 sites for biological and habitat quality.
- **Continuous temperature collection:** A separate Ecology study (Dugger, 2013) will collect the continuous temperature data in Wide Hollow Creek that will be used in this study.

Table 5. Proposed sampling location for the 2013 Wide Hollow Creek Water Quality Study.

Sampling Site ID	Station Description	Latitude	Longitude
37-FW-0B***	Wide Hollow Creek below Spring Ck.	46.5400	-120.47429
37-FW-2	Spring Creek at Union Gap Public Works	46.5427	-120.4715
37-FW-2B***	Un-named creek at Union Gap Mill	46.5437	-120.4753
37-FW-0 / 37-SS-1	Wide Hollow Creek at Union Gap Public Works	46.5429	-120.4752
37-FW-1	Wide Hollow Creek at Main St. in Union Gap	46.5436	-120.4759
37-FW-1B***	Wide Hollow Creek at White St. in Union Gap	46.54957	-120.4806
37-IS-21***	Yakima City stormwater outfall west side of RR tracks		
37-FW-1C***	Place holder for Wide Hollow Creek above Fines Diversion		
37-IS-22***	Union Gap stormwater outfall (E5-41) under Ahtanum bridge west of Goodman Rd		
37-IS-12	DID #24 outfall L1 at 3rd Ave	46.5588	-120.5096
37-SS-6	City stormwater outfall at 3rd Ave	46.5589	-120.5097
37-FW-3	Wide Hollow Creek upstream of 3rd Ave bridge	46.5587	-120.5090
37-IS-13	DID #24 outfall L2; near Pioneer Ln and Cornell Ave	46.5639	-120.5159
37-IS-23***	Spring Creek Irrigation District inflow		
37-IS-24***	Yakima City stormwater outfall at 10th Ave bridge (NW corner)		
37-IS-15	DID #4 outfall at Gardner's Nursery	46.5677	-120.5228
37-IS-25***	Place holder for Hughes water right use		
37-IS-26***	Yakima City stormwater outfall at 12th Ave bridge (NE corner)		
37-IS-27***	Yakima City stormwater outfall at 12th Ave bridge (NW corner)		
37-IS-20A	Naches and Cowiche Canal near 12th Ave	46.56807	-120.52872
37-FW-4 / 37-SS-7	Wide Hollow Creek at 16th Ave	46.5685	-120.5305
37-IS-28***	Yakima City stormwater outfall SW diagonal from Wash and 16th		
37-IS-29***	Place holder for Broadway Irrigation water right use		
37-IS-30***	Yakima City stormwater outfall at Washington Ave bridge (SW corner)		
37-IS-31***	Yakima City stormwater outfall at Washington Ave bridge (NE corner)		
37-IS-32***	Place holder for JM Perry Technical Institute water right use		
37-FW-5	Wide Hollow Creek at gas station near airport upstream of 24th Ave.	46.5731	-120.5442
37-IS-20B***	Naches and Cowiche Canal near 32nd Ave	46.57532	-120.55153
37-SS-8	City storm outfall at end of 34th Ave	46.5769	-120.5542
37-IS-17	DID#40 outfall at 38th Ave and Logan Ave	46.5799	-120.5592
37-FW-6B	Wide Hollow Creek behind Bergren Screen Printing off 40th Ave	46.5786	-120.5656
37-IS-17.5 / 37-SS-9	Randall Park Pond outlet on 44th Ave	46.5800	-120.5673
37-SS-11	Wide Hollow Creek at 48th Ave/Randall Park	46.5791	-120.5723
37-IS-33***	Congdon Orchards discharge to Wide Hollow Creek		
37-SS-48	DID #48 outfall at 64th Ave	46.5833	-120.5939
37-SS-38	DID #38 outfall at 64th Ave	46.5833	-120.5939
37-SS-12	Wide Hollow Creek at 64th Ave (upstream of DID pipes)	46.5834	-120.5940

Sampling Site ID	Station Description	Latitude	Longitude
37-SS-13	Shaw Creek west of 80th Ave and north of Nob Hill	46.5868	-120.6150
37-FW-8 / 37-SS-14	Wide Hollow Creek upstream of 80th Ave (20 m?)	46.5813	-120.6146
37-SS-15	Wide Hollow Creek at 91st Ave and Wide Hollow Rd	46.5822	-120.6295
37-IS-16B***	Wide Hollow Creek below Yakima Valley Canal	46.58028	-120.64163
37-IS-16	Yakima Valley Canal Company Canal east of 101st Ave	46.5824	-120.6417
37-FW-12 / 37-SS-16	Wide Hollow Creek at Dazet Rd	46.5798	-120.6464
37-FW-13 / 37-SS-18	Cottonwood Creek at Dazet Rd	46.5792	-120.6464
37-IS-16C***	Naches River at Congdon Canal diversion	46.68379	-120.65405
37-IS-20C***	Naches River at Naches and Cowiche Canal diversion	46.63167	-120.58732

Sampling locations are tentative. Some may be moved based on whether access is available or logistically feasible.
******* Some sites are new to this study and were not included in the bacteria TMDL study. Some latitudes and longitudes of these new sites have not been established.

Figure 3. Proposed sampling locations for the 2013 Wide Hollow Creek Water Quality Study.

Meteorology and hydrology

Air temperature and relative humidity data will be recorded at two stations near Wide Hollow Creek. Meteorological data will be obtained from the NWS station at Yakima Airport and the AgWeatherNet station at Tieton. Table 6 summarizes weather stations and available data.

Table 6. Summary of weather stations, location, and available data.

Station ID	Location	Network/ Origin	Air Temp	Dew Point	Relative Humidity	Precipitation	Wind Direction	Wind Speed	Cloud Cover	Solar Radiation
KYKM	Yakima Airport	NCDC – National Weather Service	x	x	x	x	x	x	x	
Cowiche	Cowiche	Washington State University AgWeatherNet	x	x	x	x	x	x		x

Continuous hydrology data for Wide Hollow Creek will be obtained from 3 Ecology flow gages (above 96th Ave., above 40th Ave., and at Main St. in Union Gap).

Ecology will estimate continuous hydrology for other sources based on regression with gage stations or interpolation between flows measured during the synoptic surveys. Known water withdrawals will be subtracted from the flow balance. Groundwater gains (or losses) will be estimated as the residual in the flow balance.

Synoptic surveys

Ecology will collect the primary data set for model development and calibration during several synoptic surveys. Collected data will also be used for other water quality assessment. Synoptic surveys will be conducted, when possible, during periods of relatively steady-state conditions in the creek. Surveys will span a 48-hour period when several samplers collect a large amount of measurements and samples.

Approximately one survey will be conducted per month during irrigation season and several other months during non-irrigation season. Synoptic data collection will include:

- Multi-probe deployments to collect continuous diel data (at 15-minute intervals) for temperature, pH, dissolved oxygen, and specific conductance at the mainstem sites and significant point sources.
    - Deployments may be extended by a period of days to weeks, or additional deployments may occur during non-synoptic weeks, if equipment is available.

- Water sample collection at all sites for the following parameters (water sample collection at boundary conditions may be more frequent than once per month):
    - Alkalinity, ammonia, nitrite-nitrate, total persulfate nitrogen, orthophosphate (soluble reactive phosphorus), total phosphorus, dissolved and total organic carbon, chloride, total suspended solids, total non-volatile suspended solids, and turbidity.
- Streamflow measurements:
    - Manually at sites sampled when and where logistically feasible, depending on safe conditions for measurement.

Temperature, shade, and channel geometry data

In order to develop an accurate temperature model, Ecology will collect instream temperature, riparian vegetation, effective shade, channel geometry, and other data during the 2013-14 growing seasons. Data collection will include:

- Continuous temperature dataloggers (thermistors) deployment at all mainstem sites.
    - At each site 1 logger will be deployed for water temperature and 1 for air temperature. Some sites may have a data logger for relative humidity.
    - Loggers will be programmed to record temperature at 15 to 30 minute intervals.
    - Water thermistors will be deployed in the thalweg of a stream, suspended off the stream bottom, and in a well-mixed area, typically in riffles or swift glides.
- Effective shade estimates of the aerial density of vegetation shading the stream, including:
    - Hemispherical images of the sky, overhanging vegetation, and topography at stream center. These photographs will be taken at each mainstem network site and at a few reference reaches to verify existing riparian vegetation compared to aerial photos. The digital images will be processed and analyzed using the HemiView© software program (Stohr, 2008).
- Channel geometry and habitat data following Timber-Fish-Wildlife methods for thermal reach surveys (Schuett-Hames et al., 1999).
    - The surveys will be conducted during the summer of 2013 at 5 mainstem sites.
    - Measurements will consist of bankfull width and depth, wetted width and depth, substrate composition, canopy density, and channel type.
- Riparian vegetation data within 150 feet of both banks of Wide Hollow Creek (Adams, 2010; Stohr, 2008).
    - Vegetation heights will be measured in the field using a laser range/ height finder.
    - Comparing the field data collected to aerial photos, a GIS map layer will be made and will include vegetation type, general height class, and vegetation density.
    - Additional Riparian Management Zone characteristics, such as active channel width, effective shade, bank incision, and bank erosion will be recorded during the thermal reach surveys.

Continuous water quality monitoring

Ecology's Freshwater Monitoring Unit will install 3 continuous water quality stations on Wide Hollow Creek, 1 above 96th Avenue, 1 above 40th Avenue, and 1 at Main St. in Union Gap. These stations will collect continuous measurements for temperature, dissolved oxygen, pH, and specific conductance. The continuous water quality monitoring will be installed and maintained following a separate Quality Assurance (QA) Project Plan and set of protocols for Ecology's statewide ambient monitoring program (Hallock, 2009).

Groundwater data

Ecology will assess groundwater and surface-water interactions via a network of several instream piezometers. The residual from the non-irrigation, seasonal 2005-06 flow balance showed apparent groundwater inflow into Wide Hollow Creek. The gain was greater nearest to Union Gap, averaging more than 3 cfs.

Where site conditions allow, instream piezometers will be installed in the lower reach of Wide Hollow Creek to monitor surface-water and groundwater head relationships and groundwater water quality.

The piezometers are 5-foot by 1.5-inch galvanized pipes that are crimped and perforated at the bottom. The upper end of each piezometer will be fitted with a standard pipe coupler to provide a robust strike surface for installation and capping between sampling events. The piezometers will be driven into the streambed to a maximum depth of approximately 5 feet. Following installation, the piezometers will be developed using standard surge and pump techniques to assure a good hydraulic connection with the streambed sediments.

Some piezometers will be instrumented with up to 3 data logging thermistors for continuous monitoring of streambed water temperatures (Figure 4). In a typical installation, 1 thermistor will be located near the bottom of the piezometer, 1 at a depth of approximately 0.5 feet below the streambed, and 1 will be located roughly equidistant between the upper and lower thermistors. The piezometers will be accessed monthly to make temperature measurements for later validation of the thermistor data, in accordance with standard Ecology Environmental Assessment (EA) Program methodology (Ward, 2007).

During the monthly site visits, surface water stage and instream piezometer water levels will be measured using a calibrated electric well probe, a steel tape, or a manometer board (as appropriate) in accordance with standard EA Program methodology (Sinclair and Pitz, 2010). The water level (head) difference between the piezometer and the river indicates the vertical hydraulic gradient and the direction of flow between the river and groundwater. When the piezometer head exceeds the river stage, groundwater discharge into the river can be inferred. Similarly, when the river stage exceeds the head in the piezometer, loss of water from the river to groundwater storage can be inferred.

Field staff will conduct quarterly groundwater quality sampling events. Quarterly groundwater samples will be collected from instream piezometers located along gaining reaches. Water samples will be submitted to the laboratory for analysis of alkalinity, chloride, orthophosphate, total phosphorus, nitrate/nitrite, ammonia, total persulfate nitrogen, iron, and dissolved organic carbon analysis. Groundwater temperature, conductivity, pH, and dissolved oxygen will also be measured in a continuous flow cell following standard EA Program methodology (Sinclair and Pitz, 2010).

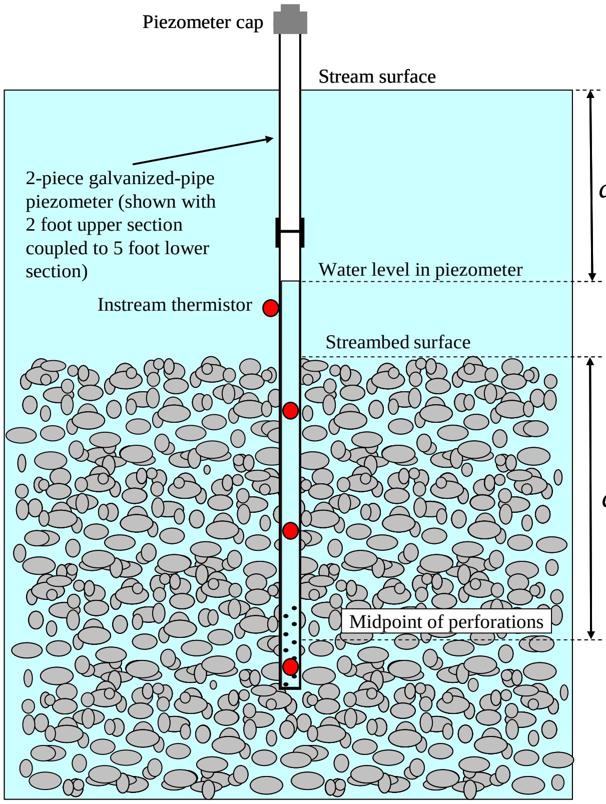

Figure 4. Instream piezometer conceptual diagram.
(diagram not to scale)

Time of travel to determine average stream velocities

Travel times will be estimated within several reaches of Wide Hollow Creek to further understand how water and pollutants move through the system and to calibrate the model. Time-of-travel studies use a small amount of fluorescent dye (20% Rhodamine WT) to trace water movement from an upstream point to a downstream point and calculate the average water velocity. Rhodamine WT dye is used by Ecology, USGS, and others to provide safe and effective time-of-travel measurements. The methods and protocols used in this survey will follow those prescribed by Kilpatrick and Wilson (1982).

Field measurements of low-level dye concentration in the stream will be made using a Hydrolab DataSonde® equipped with a rhodamine fluorometer, recording measurements every 5-10 minutes at key locations downstream from the initial point of dye release. Because only a small amount of dye is used, the dye will quickly dissipate, becoming invisible to the eye and only detectable by the fluorometer sensor.

Two time-of-travel studies will take place: 1 during irrigation flow season and 1 during non-irrigation flow season. Ecology will notify the appropriate officials before injecting the dye.

Light extinction surveys

Light limitation is a significant factor in simulation of primary production by bottom algae. Water quality models such as QUAL2KW require estimation of the light extinction coefficient to allow the model to estimate the limitation of growth that is caused by light. The light extinction coefficient is the slope of the natural log of ambient light intensity in the water versus depth.

In order to develop relationships between light extinction, turbidity, and suspended solids, we will measure the light extinction at a reference location at the downstream end of the study area where there is sufficient depth to measure profiles of light intensity. Profiles of ambient light intensity at various depths will be measured in the water column from the surface to the bottom. At the same time, samples will be collected for determination of turbidity, total suspended solids, and total nonvolatile suspended solids. This will be repeated on each of the synoptic surveys to capture a range of light variation occurring during the study period.

Biological and habitat assessment

Biological communities provide information about environmental conditions based on the range of tolerance that individual taxa have to environmental conditions. An assessment of benthic macroinvertebrate and periphyton communities will be conducted by Ecology’s Biological Monitoring staff to assess stream conditions. Also, backpack electro-fishing will be used to detect the presence and relative abundance of fish species.

Physical habitat measurements and water and sediment samples will be taken where biological samples are collected to describe the environment at the time of sampling.

Biological and habitat assessments will be conducted by Ecology’s Biological Monitoring staff following their methodology and protocols (Adams, 2010; Merritt, 2009).

Storm monitoring

This study assesses typical water quality conditions in Wide Hollow Creek during irrigation and non-irrigation seasons. Presently, Ecology is not planning to conduct targeted stormwater monitoring during infrequent runoff events. However, baseflow from municipal stormwater infrastructure may still discharge to the Wide Hollow Creek during non-runoff conditions. During the synoptic surveys, samples will be taken from storm drains with measurable flow.

Sampling and Measurement Procedures

Field sampling and measurement protocols will follow standard operating procedures (SOPs) developed by Ecology's EA Program (Table 7). Field measurements for pH, dissolved oxygen, conductivity, and temperature will be collected using a calibrated Hydrolab® data logger (Datasonde or Minisonde; Series 4 or 5). Dissolved oxygen samples will be hand-collected, using a displacement sampler, and analyzed using the Winkler titration method (APHA, 2005; Ward and Mathieu, 2011).

Table 7. Field sampling and measurement methods and protocols

Parameter	Measurement/ Sample Type	Lab Method	Field Protocol #
Water quality samples (see Table 8 for list)	Grab samples	See Table 8	EAP015 (Swanson, 2013)
Dissolved Oxygen	Displacement Sample	SM 4500 OC	EAP023 (Ward and Mathieu, 2011)
Dissolved oxygen, pH, Conductivity, ORP, Chl *a*, and Temperature	Hydrolab® multi-parameter data logger	n/a	EAP033 (Swanson, 2010)
Flow	Instantaneous	n/a	EAP024 (Sullivan, 2007) EAP055 (Shedd et al., 2008)
Continuous temperature	Thermistor/ logger	n/a	EAP044 (Bilhimer and Stohr, 2009)
Well depth/water level	In situ	n/a	EAP052 (Marti, 2009) EAP061 (Sinclair and Pitz, 2010)

Field staff will measure instantaneous flows with either a Marsh McBirney Flow-mate meter (Sullivan, 2007), Son Tek Flow Tracker handheld ADV (acoustic Doppler velocimeter), or Teledyne RDI's StreamPro ADCP (Shedd et al., 2008).

Field staff will measure light with a Licor LI-192 Underwater Light Sensor at the water surface and various depths to the stream bottom to obtain a depth profile of light. The light extinction coefficient will be calculated as the slope of the natural log of light at various depths versus the sampling depth in meters.

For continuous temperature monitoring, field staff will follow deployment, maintenance, and quality assurance/quality control (QA/QC) procedures developed by Ecology (Bilhimer and Stohr, 2009).

Field staff will collect grab samples directly into pre-cleaned/sterilized containers supplied by Manchester Environmental Laboratory (MEL) and described in their *Lab Users Manual* (MEL, 2008). Table 8 lists the sample parameters, containers, volumes, preservation requirements, and holding times. Field staff will store samples for laboratory analysis on ice and deliver to MEL within 48 hours of collection via either the Ecology courier or direct drop-off after sampling. MEL follows standard analytical methods outlined in their *Lab Users Manual* (MEL, 2008).

Biological and habitat assessments will be conducted by Ecology's Biological Monitoring staff following their methodology and protocols (Adams, 2010; Merritt, 2009).

At the end of each field visit, field staff will clean field gear in accordance with the SOP for minimizing the spread of invasive species for areas of moderate concern and extreme concern. This document is available at www.ecy.wa.gov/programs/eap/InvasiveSpecies/AIS-PublicVersion.html.

Table 8. Containers, preservation techniques, and holding times for sampled parameters.

Parameter	Sample Method	Container	Preservative	Holding Time
Alkalinity	SM 2320B	500 mL poly – NO Headspace	Cool to 0-6ºC; Fill bottle *completely*; Don't agitate sample.	14 days
Ammonia	SM4500NH3H	125 mL clear poly	H_2SO_4 to pH<2 ; Cool to 0-6°C.	28 days
Chloride	EPA300.0/ SM4110C	500 mL w/m poly bottle	Cool to ≤6°C.	28 days
Dissolved Organic Carbon	SM5310B	60 mL poly with: 0.45 um pore size filters[1]	Field filter with 0.45 um pore size filter; 1:1 HCl to pH<2; Cool to 0-6°C.	28 days
Nitrate/Nitrite	SM4500NO3I	125 mL clear poly	H_2SO_4 to pH<2; Cool to 0-6°C.	28 days
Total Persulfate Nitrogen	SM4500NO3 B	125 mL clear poly	H_2SO_4 to pH<2; Cool to 0-6°C.	28 days
Orthophosphate	SM4500PG	125 mL amber poly w/ 0.45 um pore size filters[2]	Filter in field with 0.45 um pore size filter; Cool to 0-6°C.	48 hours
Total Phosphorus	SM4500PF	60 mL clear poly	1:1 HCl to pH<2; Cool to 0-6°C.	28 days
Total Organic Carbon	SM5310B	60 mL clear poly	1:1 HCl to pH<2; Cool to 70-6°C.	28 days
Total Suspended Solids	SM2540D	1000 mL clear poly bottle	Cool to ≤6°C	7 days
Total Non-Volatile Suspended Solids	SM 540B & E	1000 mL clear poly bottle	Cool to ≤6°C	7 days
Turbidity	SM2130	500 mL w/m poly bottle	Cool to ≤6°C	48 hours

[1] Whatman PuradiscTM 25 pp or equivalent, with a polypropylene media filter designed for aqueous and organic solutions containing high debris levels and for hard-to-filter solutions.

[2] Whatman GD/X 25 mm, or equivalent, with a cellulose acetate filter membrane. A glass microfiber prefilter may be used for "hard to filter" OP samples.

A Hydrolab® multi-parameter data logger will be used to measure water conductivity, pH, dissolved oxygen, and temperature of groundwater in piezometers and the adjacent river water. Table 9 summarizes analytical methods and detection limits for groundwater sampling and measurements.

Table 9. Groundwater sampling parameters, including test methods and detection limits.

Parameter	Equipment Type and Test Method	Detection Limit
Field Measurements		
Water level	Calibrated E-tape	0.01 foot
Temperature	Hydrolab® multi-parameter sonde	0.1°C
Specific Conductance	Hydrolab® multi-parameter sonde	1 uS/cm
pH	Hydrolab® multi-parameter sonde	0.1 SU
Dissolved Oxygen	Hydrolab® multi-parameter sonde	0.1 mg/L
Laboratory Analyses		
Alkalinity	SM 2320B	5 mg/L
Chloride	EPA 300.0	0.1 mg/L
Orthophosphate[1]	SM 4500-P G	0.003 mg/L
Total phosphorus[1]	SM 4500-P F	0.005 mg/L
Nitrate+nitrite-N[1]	SM 4500 NO_3^- I	0.01 mg/L
Ammonia[1]	SM 4500-NH_3^-H	0.01 mg/L
Total persulfate nitrogen-N[1]	SM 4500NB	0.025 mg/L
Dissolved organic carbon[1]	EPA 415.1	1 mg/L

[1] Dissolved fraction.

SU: Standard units.

Quality Control Procedures

Field

Field sampling and measurements will follow quality control protocols described in Ecology's field sampling protocols (Table 7). Ecology will collect duplicate field samples, in a side-by-side manner, for 10% of all samples to assess field and lab variability. Field staff will duplicate field measurements at 10% of the sites by:

1. Allowing all parameters to equilibrate and recording an initial measurement.
2. Removing the data logger from the water for approximately 30 seconds.
3. Returning the data logger to the water near the initial location.
4. Allowing all parameters to re-equilibrate and recording a second measurement.

Prior to each synoptic survey, field staff will pre-calibrate the Hydrolabs and short term deployment probes by:

- For pH, using a two-point calibration with NIST-certified pH 7 and pH 10 standards.
- For conductivity, using a one-point calibration with NIST-certified 100 uS/cm conductivity standards. A zero conductivity check will also be performed.
- For dissolved oxygen, using the water saturated air calibration method, as recommended by manufacturer.
- For temperature, probes must be factory-calibrated. Instead of calibration, probes will be checked against a NIST-certified thermometer.

Following the survey or short term Hydrolab deployments, field staff will compare deployed probes to check probes immediately following deployment, mid-deployment, and upon retrieval. Field staff will post-check deployed data loggers against buffers, National Institute of Standards and Technology (NIST) thermometer, and 100% saturation within 24 hours of retrieval. Probes will not be calibrated during post-check.

For long term Hydrolab deployments at gage stations, field staff will follow procedures outlined by Hallock (2009). For this study, the maintenance routine will involve:

- Site visits at least twice a month that may include:
    - Removal of data logger from slant pipe and cleaning of probes.
    - Removal of any debris from station and cleaning/flushing of slant pipe.
    - Comparison with freshly calibrated check probe, buffer check, and a Winkler dissolved oxygen check (for data correction purposes).
    - Download of data.
    - Re-calibration of probes.
- If noticeable fouling is occurring during monthly visit, the frequency of service visits will be increased accordingly for the remainder of the study.
- Additional service visits will be triggered by reviewing the real-time record for suspect data. Examples of suspect data include: appearance of drift, sudden spikes or drops, and large

deviations from other data loggers in the basin. The principal investigator will review online records at least once a week.

Field staff will duplicate instantaneous streamflow measurements during each synoptic survey to check precision. If a significant difference is found between flow meters (>5% RSD), or a particular meter has a large duplicate error, the instruments will be zeroed out or not used at all. Instantaneous flows may also be compared to continuous stream gage results as an additional QA/QC measure.

The Hobo Water Temp Pro© instruments will have a calibration check both pre- and post-study in accordance with Ecology Temperature Monitoring Protocols (Bilhimer and Stohr, 2009). Ecology performs this check, using a NIST-certified reference thermometer, to document instrument accuracy at representative temperatures.

The pre-calibration check may show that the temperature datalogger differs from the NIST-certified thermometer by more than the manufacturer-stated accuracy of the instrument (range greater than ±0.2°C or ±0.4°C). A datalogger that fails the pre-study calibration check (outside the manufacturer-stated accuracy range) will not be used.

If the temperature datalogger fails the post-study calibration check, the actual measured value will be reported along with its degree of accuracy based on the calibration check results. As a result, these data may be rejected or qualified and used accordingly.

Variation for field sampling of instream temperatures and potential thermal stratification will be addressed with a field check of stream temperature at all monitoring sites upon deployment, during regular site visits, and during instrument retrieval at the end of the study period. Air temperature data and instream temperature data for each site will be compared to determine if the instream temperature instrument was exposed to the air due to stream stage falling below the installed depth of the stream temperature instrument.

Laboratory

MEL will analyze all samples for this study, with a few exceptions for biological sample identification. The MEL *Quality Assurance Manual* (MEL, 2012) documents the laboratory's quality control procedures in detail. If any of these quality control procedures are not met, the associated results will be qualified and used with caution, or not used at all. Table 13 outlines the quality objectives associated with MEL's quality control procedures.

Quality Objectives

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to address project objectives. Precision and bias together express data accuracy. Other considerations of quality objectives include representativeness and completeness. Quality objectives apply equally to laboratory and field data collected by Ecology, to data used in this study collected by entities external to Ecology, and to modeling and other analysis methods used in this study.

Field sampling procedures and laboratory analysis inherently have associated error. Measurement quality objectives (MQOs) state the allowable error for a project. Precision and bias provide measures of data quality and are used to assess agreement with MQOs.

Table 10 outlines analytical methods, expected precision of sample duplicates, and method reporting limits. The targets for precision of field duplicates are based on historical performance by MEL for environmental samples taken around the state by the EA Program (Mathieu, 2006). The reporting limits of the methods listed in the table are appropriate for the expected range of results and the required level of sensitivity to meet project objectives.

Table 10. Measurement quality objectives for laboratory analysis parameters.

Analysis	Method	Method Lower Reporting Limit[2]	Lab Blank Limit	Check Standard (% recovery limits)	Matrix Spikes (% recovery limits)	Precision – Lab Duplicates (RPD)	Precision – Field Duplicates (median)[1]
Total Alkalinity	SM2320	5 mg/L	<½ RL	80-120%	n/a	20%	10% RSD
Chloride	EPA 300.0	0.1 mg/L	<MDL	90-110%	75-125%	20%	5% RSD
Dissolved Oxygen (Winkler)	SM4500OC	0.05 mg/L	n/a	n/a	n/a	n/a	± 0.1 mg/L
Dissolved Organic Carbon	SM5310B	1 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Organic Carbon	SM5310B	1 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Persulfate Nitrogen	SM4500NO3B	0.025 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Ammonia	SM4500NH3H	0.01 mg/L	<½ RL	80-120%	75-125%	20%	10% RSD
Nitrate/Nitrite	SM4500NO3I	0.01 mg/L	<½ RL	80-120%	75-125%	20%	10% RSD
Orthophosphate	SM4500PG	0.003 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Phosphorus	SM4500PF	0.005 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Turbidity	SM2130	0.5 NTU	< 1/10th RL	90-105%	n/a	20%	15% RSD
Total Suspended Solids	SM2540D	1 mg/L	±0.3 mg	80-120%	n/a	20%	15% RSD

RL: reporting limit
MDL: method detection limit
DW: dry weight

[1] field duplicate results with a mean of less than or equal to 5X the reporting limit will be evaluated separately

[2] reporting limit may vary depending on dilutions

Table 11 summarizes field MQOs for precision and bias, as well as the manufacturer's stated accuracy, resolution, and range for the equipment used in this study.

Table 11. Measurement quality objectives and resolution for field measurements and equipment.

Parameter	Equipment/ Method	Bias (median)	Precision–Field Duplicates (median)	Equipment Accuracy	Equipment Resolution	Equipment Range	Expected Range
Water Quality Measurements							
Water Temperature	Hydrolab®	See Table 12	± 0.2°C	± 0.1°C	0.01° C	-5 to 50° C	0 to 30° C
Specific Conductance	Hydrolab®	See Table 12	5% RSD	± (0.5% + 1 uS/cm)	1 uS/cm	0 to 100,000 uS/cm	20 to 500 uS/cm
pH	Hydrolab®	See Table 12	± 0.2 s.u.	± 0.2 units	0.01 s.u.	0 to 14 s.u.	6 to 10 s.u.
Dissolved Oxygen – Luminescent (LDO)	Hydrolab®	See Table 12	5% RSD	± 0.1 mg/L at <8 mg/L; ± 0.2 mg/L at 8 to <20 mg/L[b]	0.01 mg/L	0 to 60[c] mg/L	0.1 to 15 mg/L
Dissolved Oxygen – Clark Cell	Hydrolab®	See Table 12	5% RSD	± 0.2 mg/L at <20mg/L[b]	0.01 mg/L	0 to 50[c] mg/L	0.1 to 15 mg/L
Flow Measurements							
Streamflow	EAP SOP#024	n/a	10% RSD	n/a	n/a	n/a	0.01 to 2,000 cfs
Velocity	Marsh McBirney	±0.05 ft/s[e]	n/a	±2% + zero stability[d]	0.01 ft/s	-0.5 to +20 ft/s	0.01 to 10 ft/s
Velocity	StreamPro ADCP	n/a	n/a	±1.0% or ±0.007 ft/sc	0.003 ft/s	-16 to +16 ft/s	0.01 to 10 ft/s
Continuous Temperature Monitoring							
Water Temperature	Hobo Water Temp Pro v2	n/a	n/a	±0.2°C at 0° to 50°C[b,e]	0.02°C at 25°C	-40° to +50°C	0 to 30°C
Air Temperature	Hobo Water Temp Pro v2 or v1	n/a	n/a	±0.2°C at 0° to 50°C[b,e]	0.02°C at 25°C	-40° to 70°C	-5 to 40°C
Relative Humidity	Hobo Pro	n/a	n/a	±3%	0.03%	0.03% to 100%	30% to 100%
Light Extinction Measurements							
Light	Licor LI-192	n/a	n/a	±2%	0.01 umol/s/m^2	0-10,000 umol	0-5,000 umol

[a] sum of bias due to fouling bias and calibration bias
[b] accuracy is diminished outside of listed range
[c] greater than natural range
[d] zero stability check criteria, not a measurement of bias
[e] also the MQO for accuracy assessed by pre and post deployment water bath checks

Precision

Precision is defined as the measure of variability in the results of duplicate measurements due to random error. Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures). Precision for duplicates will be expressed as %RSD and assessed following the MQOs outlined in Tables 10 and 11.

Bias

Bias is defined as the difference between the population mean and true value of the parameter being measured. Field and laboratory QC procedures, such as blanks, check standards, and spiked samples, provide a measure of any bias affecting sampling and analytical procedures. Field staff will minimize bias in field measurements and samples by strictly following measurement, sampling, and handling protocols.

EA Program staff will assess bias in field samples by submitting field blanks. Field staff will prepare blanks in the field by:

- For most water quality samples, filling the bottles directly with deionized water. For filtered parameters, deionized water will be filtered through a new syringe and filter into the sample bottle.
- Handling and transporting the filtering equipment and blank samples to MEL in the same manner that the rest of the samples are processed.

For field measurements, EA staff will:

- Minimize bias in the Hydrolab® data logger field measurements by pre-calibrating before each run.
- Assess any potential bias from instrument drift in probe measurements by:
    - For pH and conductivity, post-checking the probes against NIST-certified pH and conductivity standards.
    - For dissolved oxygen, post-checking the probe against 100% saturation and comparing Winkler dissolved oxygen samples to field measured dissolved oxygen values.
    - For temperature, checking the probe's temperature readings before and after each run using an NIST-certified thermometer.
- Assess bias from instrument fouling by:
    - Collecting a final measurement upon retrieval of a deployed data logger,
    - Then immediately cleaning the sensors at the site,
    - And finally taking another measurement immediately after cleaning.

In general, field staff will follow procedures outlined by Wagner (2006) to assess bias. Any data corrections applied to the continuous data will be applied following procedures outlined in Wagner (2006).

Table 12 contains the data quality bias objectives for both instrument drift and fouling checks.

Table 12. Measurement quality objectives for Hydrolab post-deployment and fouling checks.

Parameter	Units	Accept	Qualify	Reject
pH	std. units	< or = ± 0.2	> ± 0.2 and < or = ± 0.8	> ± 0.8
Conductivity*	uS/cm	< or = ± 5%	> ± 5% and < or = ± 15%	> ± 15%
Temperature	° C	< or = ± 0.2	> ± 0.2 and < or = ± 0.8	> ± 0.8
Dissolved Oxygen**	% saturation	< or = ± 5%	> ± 5% and < or = ± 15%	> ± 15%

* Criteria expressed as a percentage of readings: for example, buffer = 100.2 uS/cm and Hydrolab = 98.7 uS/cm; (100.2-98.7)/100.2 = 1.49% variation, which would fall into the acceptable data criteria of less than 5%.
**When Winkler data is available, it will be used to evaluate acceptability of data in lieu of % saturation criteria.

Corrected data will be assigned an accuracy rating based on combined fouling and calibration corrections applied to the record (Table 13). Data assigned a *poor* rating will not be used in data analysis. For qualified data where a data correction could not be confidently applied, the project manager may choose to exclude the data from data analysis based on a thorough QC review.

Table 13. Ratings of accuracy for data corrections based on combined fouling and calibration drift corrections applied to record.

Measured field parameter	Ratings of accuracy for data corrections			
	Excellent	Good	Fair	Poor
Water temperature	≤ ± 0.2 °C	> ± 0.2 – 0.5 °C	> ± 0.5 – 0.8 °C	> ± 0.8 °C
Specific conductance	≤ ± 3%	> ± 3 – 10%	> ± 10 – 15%	> ± 15%
Dissolved oxygen	≤ ± 0.3 mg/L or ≤ ± 5%, whichever is greater	> ± 0.3 – 0.5 mg/L or > ± 5 – 10%, whichever is greater	> ± 0.5 – 0.8 mg/L or > ± 10 – 15%, whichever is greater	> ± 0.8 mg/L or > ± 15%, whichever is greater
pH	≤ ± 0.2 units	> ± 0.2 – 0.5 units	> ± 0.5 – 0.8 units	> ± 0.8 units

Comparability

Comparability to previously collected Ecology data will be established by strictly following EA Program protocols and adhering to data quality criteria.

Representativeness

The study is designed to collect enough measurements and samples to adequately assess spatial and temporal variability of the measured parameters throughout the study area. Sample locations are distributed along the river and throughout the watershed strategically to represent different conditions and land uses. The representativeness of a sample location will be assessed by periodic measurements across both width and depth of channel. A sample location will be considered representative if it meets the *accept* criteria in Table 12.

Completeness

The U.S. Environmental Protection Agency (EPA) has defined completeness as a measure of the amount of valid data needed to be obtained from a measurement system (Lombard and Kirchmer, 2004). The goal for this study is to correctly collect and analyze a minimum of 95% of the samples and measurements for all sites. Problems occasionally arise during sample collection that cannot be controlled, including flooding, stagnant or no flow during dry periods, equipment failure, or samples damaged in transit.

If equipment fails or samples are damaged, Ecology will attempt to recollect the data the following day, if possible. In general, the study is designed to accommodate some data loss and still meet project goals and objectives.

Quality objectives for modeling or other analysis

Sensitivity analyses will be run to assess the variability of the model results. Model resolution and performance will be measured using the root-mean-square-error (RMSE), a commonly used measure of model variability (Reckhow, 1986). The RMSE is defined as the square root of the mean of the squared difference between the observed and simulated values.

Model bias will be assessed either mathematically or graphically. Bias is the systematic deviation between a measured (i.e., observed) and a computed value. Bias in this context could result from uncertainty in modeling or from the choice of parameters used in calibration. Mathematically, bias is calculated as % RPD. This statistic provides a relative estimate of whether a model consistently predicts values higher or lower than the measured value.

$RPD = (| Pi – Oi | *2) / (Oi + Pi)$, where
Pi = ith prediction
Oi = ith observation

QUAL2KW graphically represents observed and measured values along the length of the modeled stream segment. Therefore, bias will also be evaluated by observing modeled trends and over- or under-prediction between computed vs. measured values.

Data Management Procedures

Field measurement data will be entered into a field book with waterproof paper in the field and then entered into Excel® spreadsheets (Microsoft, 2001) as soon as practical after returning from the field. Alternatively, Ecology will collect some field data electronically using a rugged, hand-held field computer. Data will be combined into an Excel database that will be used for preliminary analysis and to create a table to upload data into Ecology's Environmental Information Management (EIM) System.

Sample result data received from MEL by Ecology's Laboratory Information Management System (LIMS) will be exported prior to entry into EIM and added to a cumulative spreadsheet for laboratory results. This spreadsheet will be used to informally review and analyze data during the course of the project.

An EIM user study (JICA0002) has been created for this study and all monitoring data will be available via the internet once the project data has been validated. The URL address for this geospatial database is: www.ecy.wa.gov/eim/. All data will be uploaded to EIM by the EIM data engineer once it has been reviewed for quality assurance and finalized.

All spreadsheet files, paper field notes, and GIS software products created as part of the data analysis will be kept with the project data files.

Audits and Reports

Audits on field work and data analysis may be conducted at any time during the course of the project, by supervisors for the project team. The project manager will be responsible for submitting quarterly reports, if necessary, as well as the draft technical sections of the technical study according to the project schedule.

Data Verification and Validation

MEL will provide verification for laboratory-generated data. Data reduction, review, and reporting will follow the procedures outlined in the MEL *QA Manual* (MEL, 2012). Lab results will be checked for missing or improbable data. Variability in lab duplicates will be quantified using the procedures outlined in the MEL *QA Manual* (MEL, 2012). Any estimated results will be qualified and their use restricted as appropriate. A standard case narrative of laboratory QA/QC results will be sent to the project manager for each set of samples.

Field notebooks will be checked for missing or improbable measurements before leaving each site. The Excel® Workbook file containing field data will be labeled "DRAFT" until data verification and validation are completed. Data entry will be checked against the field notebook data for errors and omissions.

Field duplicate sample results will be compared to quality objectives in Table 14. Data requiring additional qualifiers will be reviewed and verified by the project manager.

The project manager will additionally verify data received from LIMS by:

- Checking for omissions against the “Request for Analysis” forms.
- Checking result values against expected range of results and data from previous surveys.

After data verification is complete, all field, laboratory, and flow data will be entered into Ecology’s EIM system. An independent data reviewer will validate the EIM data by checking for errors following standard EA Program protocols.

Once the EIM data has been verified, the project manager will compile all project data in a data summary report. Internal (within Ecology) and external (project stakeholders) reviewers will provide validation of the report.

Data Quality (Usability Assessment)

Study data usability

The project manager will verify that all measurement and data quality objectives have been met for each monitoring station. If the objectives have not been met (such as the %RSD for sample duplicates exceeds the MQO), then the project manager will decide how to qualify the data and how it should be used in the analysis or whether it should be rejected. Documentation of the data quality assessment will be summarized in the final report and all assessment files will be archived with the project data.

During data analysis, the project manager will evaluate the adequacy of the study design, based on the results, to draw conclusions and make recommendations.

The project manager will handle any non-detects (sample results below the reporting limit) using methods described in Chapter 13, “Methods for Data Below the Reporting Limit,” of Helsel and Hirsch (2002).

Usability of results from modeling or other analysis

The usability of the results from the QUAL2KW model will be assessed by the project manager by comparison of predicted model results to observed values, comparison of calibrated model parameters and rates to those from other studies, and other techniques.

External data usability

Any water quality data from outside this study that is used in the analysis must meet the requirements of the agency’s credible data policy. See Water Quality Policy1-11 Chapter 2 at www.ecy.wa.gov/programs/wq/303d/policy1-11.html. This requirement does not apply to data such as flow or meteorological data.

The final report will include an assessment of data quality for any outside data used for analysis, and certification that the data meets a level of quality acceptable for use. The data quality assessment would include one or all of the following elements:

- Reference to a peer-reviewed and published QA Project Plan
- Demonstration that the data collected yielded results of comparable quality to the study (based on data quality objectives and requirements in this QA Project Plan).
- Documentation that the objectives of the QA Project Plan or equivalent quality assurance procedures were met and that the data are suitable for water quality-based actions. The assessment of the data must consider whether the data, in total, fairly characterize the quality of the water body at that location at time of sampling.
- Documentation of the planning, implementation, and assessment strategies used to collect the information, including:
    - Documentation of the original intended use of the information gathered (e.g., chemical/physical data for TMDL analyses)
    - Description of the limitations on use of the data (e.g., these measurements only represent storm-event conditions).
    - Complete data sets, that is, not censored to include only part of the data results from the project.

Project Organization

Table 14 lists the people and agencies involved in this project as well as corresponding titles and responsibilities.

Table 14. Organization of project staff and responsibilities.

Staff (EAP staff unless noted otherwise)	Agency/ Organization	Title	Responsibilities
Laine Young Water Quality Program Central Regional Office Phone: 509-575-2642	Ecology	Client; Water Quality Program TMDL Lead	Coordinates information exchange. Forms technical advisory team and organizes meetings. Reviews the QAPP and technical report. Assists on sampling team.
Jim Carroll Eastern Operations Section	Ecology	EAP Project Manager	Co-authors the QAPP. Analyzes data. Co-authors the technical sections of the report. Oversees model development, calibration, and application.
Eiko Urmos-Berry Eastern Operations Section Phone: 509-575-2397	Ecology	EAP Principal Investigator	Co-authors the QAPP. Coordinates field surveys, oversees field sampling and transportation of samples to the laboratory. Conducts QC review of data, analyzes and interprets data, and enters data into EIM. Co-authors the technical sections of the draft report and final study report. Assists with model development, calibration, and application.
Kirk Sinclair Groundwater Forests and Fish Unit – Statewide Coordination Section Phone: 360-407-6557	Ecology	EAP Staff Hydrogeologist	Provides hydrogeologic assistance with study design including interpretation of historical geology and groundwater data in the basin, groundwater data collection, and data QC review.
Chris Coffin Water Quality Program Central Regional Office Phone: 509-575-2821	Ecology	Unit Supervisor of Water Quality Lead / Client	Reviews and approves the QAPP, staffing plan, technical study budget, and the technical sections of the technical report.
Charlie McKinney Water Quality Program Central Regional Office Phone: 509-457-7107	Ecology	Section Manager of Water Quality Lead / Client	Approves technical report.
Tom Mackie Eastern Operations Section Phone: 509-454-4244	Ecology	EAP Section Manager of Project Manager	Reviews and approves the QAPP, staffing plan, technical study budget, and the technical sections of the report.
Joel Bird Manchester Environmental Laboratory Phone: 360- 871-8800	Ecology	Laboratory Director	Provides laboratory staff and resources, sample processing, analytical results, laboratory contract services, and quality assurance/quality control (QA/QC) data. Approves the QAPP.
William R. Kammin Phone: 360-407-6964	Ecology	Ecology Quality Assurance Officer	Provides technical assistance on QA/QC issues. Reviews the draft QAPP and approves the final QAPP.

EAP: Environmental Assessment Program
EIM: Environmental Information Management system
QAPP: Quality Assurance Project Plan

Project Schedule

Table 15. Proposed schedule for completing field and laboratory work, data entry into EIM, and reports.

Field and laboratory work	Due date	Lead staff
Field work completed	June 2014	Eiko Urmos-Berry
Laboratory analyses completed	July 2014	
Environmental Information System (EIM) database		
EIM user study ID	JICA0002 – as of publication date WHM_WHB as of April 2017	
Product	Due date	Lead staff
EIM data loaded	September 2014	Eiko Urmos-Berry
EIM quality assurance	October 2014	TBD
EIM complete	November 2014	Eiko Urmos-Berry
Final Technical Study report		
EAP author lead	Jim Carroll	
Schedule		
Draft due to technical/policy peer reviewers	November 2014	
Draft due to external reviewer(s)	November 2014	
Draft due to EAP publications coordinator (all reviews and author revisions complete)	January 2015	
Final Technical Study report		
EAP publications coordinator transmits technical study report or WQIR to WQP; report marked as complete in Project Tracker	February 2015	

EIM: Environmental Information Management database
EAP: Environmental Assessment Program
WQIR: Water Quality Improvement Report
WQP: Water Quality Program

Laboratory Budget

Table 16. Tentative lab budget.

This budget assumes 42 sites per survey; actual number of sites sampled could be more or less.

Parameter/analysis	Sites	Surveys	Field Dupes	Field Blanks	Total Samples	$/sample	Subtotal
Synoptic Surveys							
Turbidity	42	9	36	9	423	$11.92	$5,042
TSS + TNVSS	42	9	36	9	423	$26.02	$11,006
Alkalinity	42	9	36	9	423	$18.43	$7,796
Chloride	42	9	36	9	423	$14.09	$5,960
Total Persulfate Nitrogen (TPN)	42	9	36	9	423	$18.43	$7,796
Ammonia	42	9	36	9	423	$14.09	$5,960
Nitrite/Nitrate NO2/NO3	42	9	36	9	423	$14.09	$5,960
Orthophosphate (SRP)	42	9	36	9	423	$16.26	$6,878
Total Phosphorus (TP)	42	9	36	9	423	$19.50	$8,249
Dissolved Organic Carbon	42	9	36	9	423	$38.98	$16,489
Total Organic Carbon	42	9	36	9	423	$35.77	$15,131
Copper (dissolved and total)	4	6	6	6	36	$135.00	$4,860
Hardness	12	9	8	9	125	$23.84	$2,980
						Subtotal =	**$104,106**
Groundwater Sampling							
Alkalinity	5	4	4	4	28	$18.43	$534
Chloride	5	4	4	4	28	$14.09	$409
Total Persulfate Nitrogen (TPN)	5	4	4	4	28	$18.43	$534
Ammonia	5	4	4	4	28	$14.09	$409
Nitrite/Nitrate NO2/NO3	5	4	4	4	28	$14.09	$409
Orthophosphate (SRP)	5	4	4	4	28	$16.26	$471
Total Phosphorus (TP)	5	4	4	4	28	$19.50	$566
Dissolved Organic Carbon	5	4	4	4	28	$38.98	$1,131
						Subtotal =	**$4,462**
						Total =	**$108,568**
Biological Sampling							
Macroinvertebrate Identification	5	1	0	0	5	$295.00	$1,475
Periphyton AFDW and Identification	5	1	0	0	5	$300.00	$1,500
Fish Identification	5	1	0	0	5	$200.00	$1,000
Water Total Suspended Solids	5	1	1	0	6	$11.92	$72
Water Chloride	5	1	1	0	6	$14.09	$85
Water Total Persulfate Nitrogen (TPN)	5	1	1	0	6	$18.43	$111

Parameter/analysis	Sites	Surveys	Field Dupes	Field Blanks	Total Samples	$/sample	Subtotal
Water Total Phosphorus (TP)	5	1	1	0	6	$19.50	$117
Sediment Metals (As, Cu, Pb, Zn)	5	1	0	0	5	$108.00	$540
Sediment PAH	5	1	0	0	5	$396.00	$1,980
Sediment Total Organic Carbon	5	1	0	0	5	$45.52	$228
						Subtotal =	**$7,106**

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Appendix. Glossary, Acronyms, and Abbreviations

Glossary

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Critical conditions: When the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or designated water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 flow event unless determined otherwise by the department.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each water body or segment, regardless of whether or not the uses are currently attained.

Diel: Of, or pertaining to, a 24-hour period.

Effective shade: The fraction of incoming solar shortwave radiation that is blocked from reaching the surface of a stream or other defined area.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform bacteria are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100 mL).

Glide: A shallow stream reach without surface turbulence, often found in the transitional area between a pool and a run. Typically, a glide has a maximum depth that is 5% or less of the average stream width and a water velocity less than 0.65 ft/sec.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (analyte).

Periphyton: A complex mixture of algae, cyanobacteria, heterotrophic microbes, and detritus that is attached to submerged surfaces.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Riffle: A **s**hallow stream reach, with visible surface turbulence, where water flows swiftly over rough streambed substrates.

Riparian: Relating to the banks along a natural course of water.

Salmonid: Fish that belong to the family *Salmonidae*. Any species of salmon, trout, or char. www.fws.gov/le/ImpExp/FactSheetSalmonids.htm

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Thalweg: The path of a stream that follows the deepest part of the channel.

Total Maximum Daily Load (TMDL): A distribution of a substance in a water body designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Wasteload allocation: The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality-based effluent limitation.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every ten years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

Acronyms and Abbreviations

EA	Environmental Assessment (Program)
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GIS	Geographical Information System
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
NPDES	(See Glossary above)
QA	Quality assurance
QC	Quality control
RSD	Relative standard deviation
SOP	Standard operating procedure
TMDL	(See Glossary above)
USGS	United States Geological Survey
WAC	Washington Administrative Code
WQA	Water Quality Assessment

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams.
kg/d	kilograms per day
m	meter
mm	milliliter
mg	milligrams
mgd	million gallons per day
mg/L	milligrams per liter (parts per million)
mL	milliliters

NTU	nephelometric turbidity units
s.u.	standard units
ug/L	micrograms per liter (parts per billion)
uS/cm	microsiemens per centimeter, a unit of conductivity