Hangman Creek Watershed Dissolved Oxygen and pH Total Maximum Daily Load

Water Quality Study Design (Quality Assurance Project Plan)

By Joe Joy

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Federal Clean Water Act 2004 303(d) Listings Addressed in this Study

Waterbody	Parameter	Listing ID	Location
Hangman Creek	Dissolved Oxygen	41985	Section 29 T20N R46E
Hangman Creek	Dissolved Oxygen	41987	Section 16 T22N R44E
Hangman Creek	pH	11391	Section 23 T25N R42E
Rock Creek	Dissolved Oxygen	41990	Section 23 T23N R44E

Waterbody Numbers: WA-56-1010, -1500, -1600, -1900, -2040, -2050

Cover photo: Hangman Creek, July 2006, taken by Joe Joy.

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Abstract

Each study conducted by the Washington State Department of 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 completion of the study, a final report describing the study results will be posted to the Internet.

Hangman Creek has been the subject of Total Maximum Daily Load (TMDL) evaluations for fecal coliform bacteria, temperature, and turbidity.

Phosphorus loads also have been evaluated to assess seasonal impacts for the *Spokane River/ Lake Spokane Dissolved Oxygen TMDL.* However, the possible role of phosphorus in Hangman Creek watershed pH and dissolved oxygen (DO) criteria violations has not been assessed because data were lacking. The pH and DO violations observed in the watershed are thought to be the result of inadequate shade, low streamflows, and excessive nitrogen or phosphorus loads.

TMDL investigations planned for 2008 and 2009 will fill the data gaps to complete the pH and DO TMDLs in the watershed. Data collection will include synoptic surveys during the summer and fall low-flow season, monitoring nutrient and chemical reference conditions in four ecoregions, and monitoring Washington/Idaho border nutrient loads. Data collected also will supply water quality models and statistical analysis to determine load and wasteload allocations.

What is a Total Maximum Daily Load (TMDL)?

Federal Clean Water Act requirements

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

Every two years, states are required to prepare a list of waterbodies – lakes, rivers, streams, or marine waters – that do not meet water quality standards. This list is called the 303(d) list. To develop the list, the Washington State Department of Ecology (Ecology) compiles its own water quality data along with data submitted by local, state, and federal governments; tribes; industries; and citizen monitoring groups. All data are reviewed to ensure that they were collected using appropriate scientific methods before the data are used to develop the 303(d) list. The 303(d) list is part of the larger Water Quality Assessment.

The Water Quality Assessment is a list that tells a more complete story about the condition of Washington's water. This list divides waterbodies into five categories:

Category 1 – Meets standards for the parameter (or parameters) for which it has been tested.

Category 2 – Waters of concern.

Category 3 – Waters with no data available.

Category 4 – Polluted waters that do not require a TMDL because:

- 4a. – Has a TMDL approved and it is being implemented.
- 4b. – Has a pollution control plan in place that should solve the problem.
- 4c. – Is impaired by a non-pollutant such as low water flow, dams, culverts.

Category 5 – Polluted waters that require a TMDL – on the 303d list.

TMDL process overview

The Clean Water Act requires that a TMDL be developed for each of the waterbodies on the 303(d) list. The TMDL identifies pollution problems in the watershed and specifies how much pollution needs to be reduced or eliminated to achieve clean water. Then Ecology works with the local community to develop an overall approach to control the pollution, called the Implementation Strategy, and a monitoring plan to assess effectiveness of the water quality improvement activities. Once the TMDL has been approved by the U.S. Environmental Protection Agency (EPA), a *Water Quality Implementation Plan* must be developed within one year. This Plan identifies specific tasks, responsible parties, and timelines for achieving clean water.

Elements required in a TMDL

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and of the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can be discharged to the waterbody and still meet standards (the loading capacity) and allocates that load among the various sources.

If the pollutant comes from a discrete (point) source such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation*. If the pollutant comes from a set of diffuse (nonpoint) sources such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation*.

The TMDL must also consider seasonal variations and include a margin of safety that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A reserve capacity for future loads from growth pressures is sometimes included as well. The sum of the wasteload and load allocations, the margin of safety, and any reserve capacity must be equal to or less than the loading capacity.

Identification of the contaminant loading capacity for a waterbody is an important step in developing a TMDL. EPA defines the loading capacity as "the greatest amount of loading that a waterbody can receive without violating water quality standards" (EPA, 2001). The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a waterbody into compliance with standards. The portion of the receiving water's loading capacity assigned to a particular source is a load or wasteload allocation. By definition, a TMDL is the sum of the allocations, which must not exceed the loading capacity.

TMDL = Loading Capacity = sum of all wasteload allocations + sum of all load allocations + margin of safety.

What Part of the Process Are We In?

The Hangman Creek pH and DO TMDL is in the data gathering stage of developing TMDLs. Previous work has provided some data, but more is needed to define the causes and remedies for pH and DO criteria violations in the watershed. From the data analyses, load allocations for nonpoint sources and wasteload allocations for point sources will be recommended.

Why is Ecology Conducting a TMDL Study in This Watershed?

Overview

Ecology is conducting a TMDL study in this watershed because Hangman Creek watershed has documented pH and dissolved oxygen (DO) water quality problems. Past water quality studies have shown that Washington State standards are not met for fecal coliform bacteria, turbidity, temperature, pH, and DO in several locations in the watershed (SCCD, 1994, 1999, 2000; Ecology, 2008a). A previous TMDL study addressed fecal coliform bacteria, temperature, and turbidity issues in the watershed (Joy et al., 2008).

The causes of pH and DO problems are difficult to sample and analyze. Dissolved oxygen and pH problems can be caused by direct wastewater discharges, but are often related to excessive algae or plant growth in the stream. The excessive growth is the result of too much nitrogen, phosphorus, light, or heat without enough water for significant dilution. The problems also can be the result of wetland inputs or groundwater sources. Too high or too low pH, and too little DO, harm aquatic organisms.

Phosphorus, ammonia nitrogen, and biochemical oxygen demand (BOD) loads from Hangman Creek to the Spokane River are of concern for Lake Spokane water quality (Cusimano, 2004; Ecology, 2008b), but pH and DO criteria violations within the Hangman Creek watershed have not been examined. The effects of nitrogen, phosphorus, and BOD loads from various sources within the watershed on pH levels and DO concentrations need to be explored. If nutrient and BOD limits are required to protect Hangman Creek organisms from excessive pH and DO concentrations, these limits will be considered in the final Lake Spokane TMDL load allocations.

Study area

Hangman Creek (also known as Latah Creek) is a trans-boundary watershed that begins in the foothills of the Rocky Mountains of northern Idaho, extends over the southeastern portion of Spokane County, Washington (Figure 1), and is a tributary to the Spokane River. It encompasses over 689 square miles (approximately 430,000 acres). Portions of Rock Creek, Little Hangman Creek, and upper Hangman Creek lie in the Coeur d'Alene Reservation in Idaho. The watershed is dominated by dryland farming but, like other eastern Washington watersheds, is experiencing increases in urbanization and changes in land use practices.

The TMDL evaluation is limited to the 446 square miles of watershed within Washington. Major tributaries included in the study area are California Creek, Rock Creek, Marshall Creek, Spangle Creek, and Little Hangman Creek. Reaches in these sub-watersheds also have pH and DO criteria violations, and are of interest. Nutrient loads from sub-watershed areas across the Idaho border will be limited to data collected at border sites. Monitoring in the Spokane River is not planned for this TMDL.

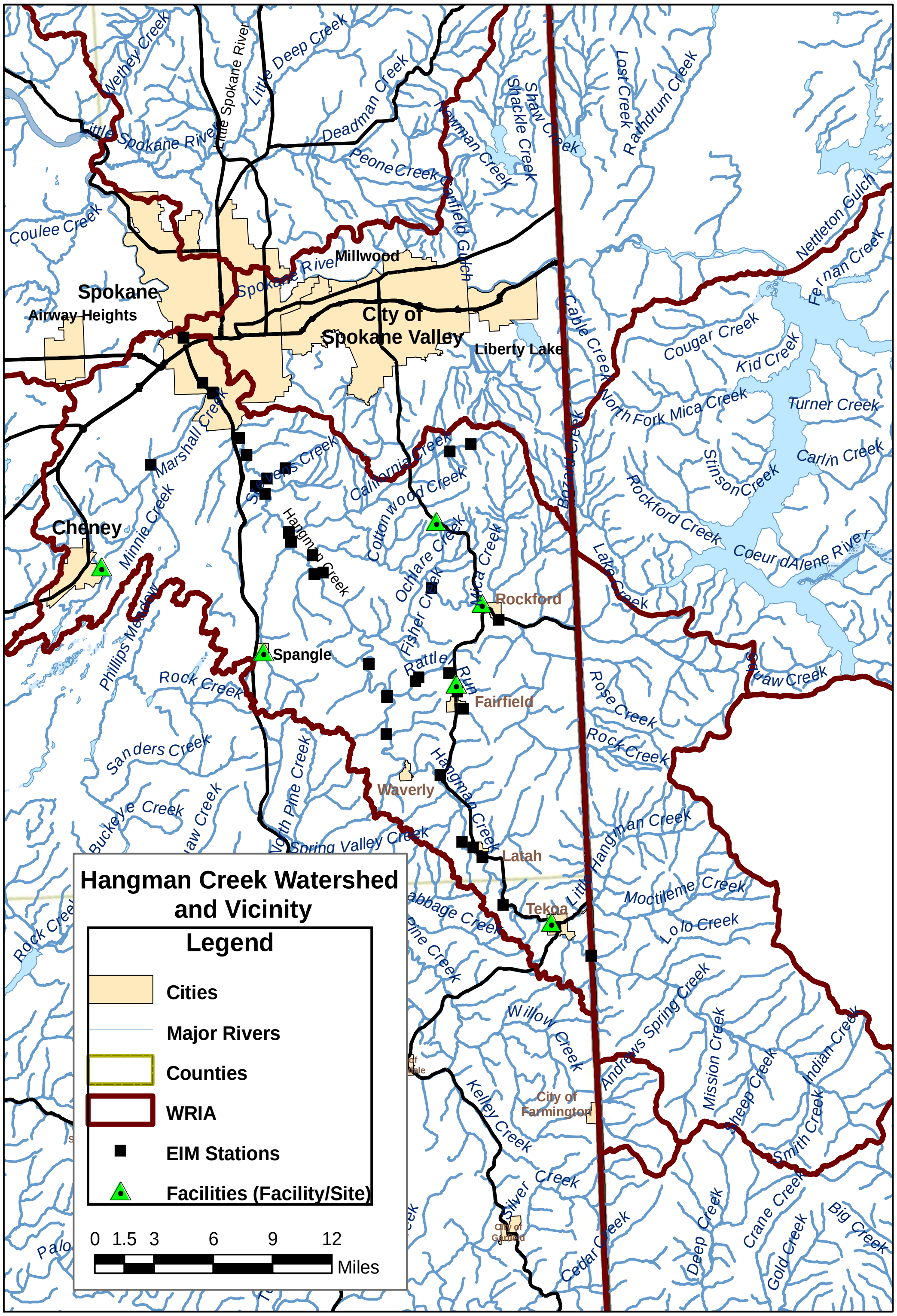

Figure 1. Study area for the Hangman Creek pH and dissolved oxygen Total Maximum Daily Load study.

Pollutants addressed by this TMDL

This TMDL addresses pH and DO criteria violations of Washington State criteria in the Hangman Creek watershed. The violations can be the result of other pollutants or poor stream conditions. Excessive nutrients and BOD, high water temperatures, poor channel conditions from erosion and sedimentation, and low streamflows are possible contributors to pH and DO problems. Nitrogen and phosphorus are likely limiting nutrients that may be surrogate TMDL allocation parameters. The temperature TMDL that was conducted earlier can provide system potential shade requirements to limit light as much as possible (Joy et al., 2008). Also, phosphorus, BOD, and ammonia nitrogen loads to the Spokane River will address load allocations from the *Spokane River/Lake Spokane Dissolved Oxygen TMDL.*

Impaired beneficial uses and waterbodies on Ecology's 303(d) List of impaired waters

The main beneficial use to be protected by this TMDL is aquatic habitat in the Hangman Creek watershed and the Spokane River. Hangman Creek has not been identified as having special populations of salmon to protect (Table 602 of WAC 173-201A-602). However, according to watershed assessments of current and historical fish populations (SCCD, 2005b):

> *Fish habitat and distribution throughout the watershed has radically changed over the last one hundred years. Hangman Creek once had viable populations of native redband trout and healthy runs of salmon and steelhead. The removal of riparian vegetation, channel alterations, and heavy sedimentation has significantly reduced the spawning and rearing habitat on Hangman Creek. The primary species now found in the stream are adapted to warmer, slower waters and considered undesirable as gamefish. Resident trout populations are severely depressed.*

California Creek, Rock Creek, and Marshall Creek have remnant populations of redband trout (Western Native Trout Initiative, 2007; Lee, 2005). However, there is no major effort to re-establish anadromous (sea-run) salmon or steelhead in the Hangman Creek watershed because of downstream barriers in the Spokane River system. But improving water quality conditions would be a necessary step for enhancing and protecting all aquatic communities, including cold water fisheries. Proper levels of DO and pH are essential for healthy fish and macroinvertebrate populations.

Monitoring prior to 2003 detected four areas with DO and pH that did not meet Washington State water quality criteria that would support beneficial uses (Table 1). Further monitoring in 2003 and 2004 documented pH and DO violations in other areas suitable for Category 2 and 5 listings in the candidate 2008 Water Quality Assessment (Table 2).

Table 1. Hangman Creek study area waterbodies on the 2004 303(d) list for pH and dissolved oxygen impairments (Category 5).

Waterbody	Parameter	Listing ID	Township	Range	Section
Hangman Creek at Stateline	DO	41985	20N	46E	29
Hangman Creek at Bradshaw Road	DO	41987	22N	44E	16
Hangman Creek at mouth	pH	11391	25N	42E	23
Rock Creek at Jackson Road	DO	41990	23N	44E	23

Table 2. Hangman Creek study area waterbodies with pH and dissolved oxygen listings in Category 5 (impaired) and 2 (water of concern) for the 2008 Water Quality Assessment.

Waterbody	Parameter	Proposed Category	Listing ID	Township	Range	Section
Spangle Creek at mouth	pH	5	50382	22N	40E	16
Hangman Creek at Duncan Road	pH	5	50421	23N	43E	11
Hangman Creek at mouth	DO	5	11390	25N	42E	23
Cove Creek at Highway 27	DO	5	47036	21N	45E	30
Hangman Creek at Roberts Road	DO	5	47123	21N	44E	01
Hangman Creek at state line	pH	2	50425	20N	46E	29
Hangman Creek below Tekoa	DO	2	8448	20N	45E	14
Hangman Creek below Tekoa	DO	2	8450	20N	45E	13
Rock Creek at mouth	pH	2	50377	23N	43E	12
Rock Creek at Rockford	pH	2	50378	23N	45E	33
Hangman Creek at Duncan Road	DO	2	47120	23N	43E	11
Hangman Creek at River Mile 21	pH	2	50422	23N	43E	13
Cove Creek at Highway 27	pH	2	50343	21N	45E	30
Little Hangman Creek near mouth	DO	2	8451	20N	45E	24
Little Hangman Creek at mouth	DO	2	41988	20N	45E	13
Marshall Creek at mouth	DO	2	41989	25N	43E	31
Marshall Creek at mouth	pH	2	50417	25N	43E	31
Marshall Creek at McKenzie Road	DO	2	47118	24N	42E	22

Why are we doing this TMDL now?

The Hangman Creek pH and DO TMDLs are an extension of Ecology's water quality cleanup work in the Hangman Creek watershed and Spokane River basin. Data from previous Hangman Creek TMDLs for temperature and suspended sediment will be used. But Ecology is collecting more water quality data to make a quantitative assessment of sources and possible solutions to the pH and DO problems.

The water quality of the Hangman Creek watershed is important to the local community and communities downstream, along the Spokane River and Lake Spokane. Residents would enjoy aesthetic and recreational benefits from improved water quality in the creek.

Water quality work in the Spokane River basin is ongoing. The potential role of phosphorus, ammonia nitrogen, and BOD in DO and pH problems in the Hangman Creek watershed also has importance for the Spokane River and Lake Spokane.

The Spokane River/Lake Spokane TMDL recommended seasonal phosphorus, ammonia, and BOD load limits on Hangman Creek (Ecology, 2008b). The limits are needed to prevent harmfully low DO concentrations in the Spokane River and Lake Spokane. Initial Hangman Creek phosphorus load modeling and analyses demonstrated that some difficulty remains in determining 'background' or 'natural' loads from nonpoint source loads. More monitoring is needed to specifically address those types of loads on so that more accurate pollutant reduction requirements can be estimated.

Phosphorus or nitrogen may be a limiting nutrient for the pH and DO problems reported in the Hangman Creek watershed; however, other factors could be limiting. Light and heat exposure, and substrate type, can influence excessive algae or macrophyte growth that cause pH and DO problems. Additional data and analyses are needed to explore where and why pH and DO criteria violations are occurring in the watershed. Then, Ecology can work with the local community to remove or reduce the problem.

Finding the reasons for the DO and pH problems in Hangman Creek will provide water quality managers with information for managing sources of excessive nutrients such as phosphorus. It will also help managers understand the role of background or natural conditions in the watershed compared to manageable point and nonpoint sources contributing to the problem. In addition, upstream sources of nutrient loads across the Idaho border must be addressed for trans-boundary agreements and implementation plans.

How will the results of this study be used?

A TMDL study identifies how much pollution needs to be reduced or eliminated to achieve clean water. This is done by assessing the situation and recommending practices to reduce pollution and by establishing limits for facilities that have permits. Since the study may also identify the main sources or source areas of pollution, Ecology and local partners use these results to figure out where to focus water quality improvement activities. Or sometimes the study suggests areas for follow-up sampling to further pinpoint sources for cleanup.

Water Quality Standards and Beneficial Uses

Dissolved oxygen

Aquatic organisms are very sensitive to reductions in the level of DO 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, Washington 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 waterbody.

In the Washington State water quality standards, freshwater aquatic life use categories are described using key species (salmonid versus warmwater species) and life-stage conditions (spawning versus rearing). Minimum concentrations of DO are used as criteria to protect different categories of aquatic communities [WAC 173-201A-200; 2003 edition]. Hangman Creek has not been designated for protection of any special population of fish. Therefore, the following statewide default designated aquatic life use and criteria are to be protected:

> *(3) 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.*

The criterion described above is used to maintain conditions where a waterbody is naturally capable of providing full support for its designated aquatic life uses. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. When a waterbody 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.

While the numeric criteria generally apply throughout a waterbody, the criteria are not intended to apply to discretely anomalous areas such as in shallow stagnant eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason, the standards direct that one take measurements from well-mixed portions of rivers and streams. For similar reasons, do not take samples from anomalously oxygen rich areas. For example, in a slow moving stream, focusing sampling on surface areas within a uniquely turbulent area would provide data that are erroneous for comparing to the 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 carbon dioxide from bicarbonate in the water to be directly lethal to fish.

The state established pH criteria in the Washington State water quality standards primarily to protect aquatic life. The criteria also serve to protect waters as a source for domestic water supply. 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 of the distribution system.

In the state's water quality standards, two pH criteria are established to protect six different categories of aquatic communities [WAC 173-201A-200; 2003 edition]. Since Hangman Creek watershed has not been designated with a special category, the pH criterion is the state-wide default for Salmonid spawning, rearing and migration:

(2) 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.

Nutrients

Eutrophication is a condition for a lake or stream where plant growth and lower water quality are associated with a high dissolved nutrient input. It can be a natural process that takes hundreds of years as lakes become wetlands and rivers fill valleys with sediment to become slow and marshy. Plants are stimulated by plenty of light and nutrients, low streamflows, and elevated temperatures. Human activity can reduce shade along streams, add nutrients, withdraw water, and increase temperatures. When human-caused acceleration of the plant stimulation is present from nutrient inputs and other changes, it's called *cultural eutrophication*.

Cultural eutrophication probably affects periphyton (algae that grow on submerged rocks, plants, and debris) and macrophyte (large aquatic plants) growth in the Hangman Creek during the summer low-flow period. Observed local pH and DO criteria violations are probably associated with the excessive aquatic plant growth. Major portions of the creek channel become choked with aquatic weeds, emergent grasses, filamentous algae, and periphyton in the summer. Besides affecting habitat and aesthetics in a negative way, the excessive plant growth can cause oxygen supersaturation during the day through photosynthesis, and oxygen deficits at night from respiration. The pH values over the day can swing beyond safe levels for fish and macroinvertebrates.

Nutrients such as nitrogen and phosphorus do not have numeric state or federal standards for running freshwater systems such as Hangman Creek. In this TMDL, nutrients may be key pollutants for pH and DO criteria violations. So they are called *surrogate parameters*. Nutrient concentrations that cause these problems can be very site-specific. Older EPA guidelines (EPA, 1986) of 0.1 mg/L phosphorus have proven ineffective in preventing eutrophication in most watersheds.

More recent EPA ecoregional nutrient guidelines suggest a more region-specific approach (EPA, 2000a, 2000b). Regions of similar geology, climate, soils, and vegetation should have similar background concentrations of nutrients. The EPA ecoregions are broken into different levels. Four Level IV ecoregions (EPA, 2000a, 2000b) subdivide the watershed:

- Northern Rockies ecoregion (15).
  - Northern Idaho Hills (15v).
  - Spokane Valley Outwash Plain (15s).
- Columbia Plateau ecoregion (10).
  - Palouse Hills (10h).
  - Channeled Scablands (10a).

The headwaters of Hangman Creek and Rock Creek lie along the boundary between the Northern Idaho Hills (15v) and the Palouse Hills (10h). The creek transits through the Palouse Hills to the Channeled Scablands (10a) before entering the Spokane Valley Outwash Plain (15s). The ecoregions suggest that there may be distinctive characteristics in soils and vegetation that could be important for evaluating pollutant loading and transport.

Not enough data have been collected at Level IV, but samples combined from state and federal agencies at Level III are available to estimate a reference condition (Table 3). The reference concentrations are based on the median of four seasonal 25th percentile values of all data reported across the ecoregion. The EPA (2000a; 2000b) suggests the 25th percentile is a starting reference concentration until local governments and entities can analyze samples from designated reference streams.

Table 3. EPA Level III ecoregion reference concentrations relevant to Hangman Creek.

Parameter	Northern Rockies Ecoregion 15		Columbia Basin Ecoregion 10	
	Number of Samples	25th percentile	Number of Samples	25th percentile
Total Phosphorus (mg/L)	150	0.0078	127	0.030
Nitrate + Nitrite Nitrogen (mg/L)	133	0.020	71	0.072

However, research has not been performed to evaluate the effect of the reference nitrogen and phosphorus concentrations on resident aquatic communities. For example, work has not been done for checking if reference concentrations support all beneficial uses and maintain water quality criteria such as DO and pH.

Watershed Description

Hangman Creek and its tributaries, Rock Creek and Little Hangman Creek, originate in Idaho and flow northwest into Washington. Headwaters in Idaho lie at 3,600 ft mean sea level. Hangman Creek watershed covers 689 square miles and is a tributary to the Spokane River (Figure 1). The confluence of the Spokane River and Hangman Creek is within the Spokane city limits at 1,700 ft mean sea level.

The Hangman Creek watershed land use is estimated at 73% agriculture and rangeland, 22% forest, and 5% residential. The watershed has been intensely developed for dryland farming since the 1870s. Irrigation is very limited. Most farming occurs along the Hangman and Rock Creek valleys and to the west. Small agriculture-based communities also lie along the main valley and tributaries. Forested areas are primarily at higher elevations to the southeast. Most of the residential development has occurred in the lower watershed near the cities of Spokane and Cheney.

Agriculture has been the dominant land use in the Hangman Creek watershed since the early 1900s. By the early 1920s, a significant portion of the farmable land had been cleared and cultivated for the production of wheat, barley, peas, and lentils. Thousands of acres of forest and riparian areas were cut and cleared. Miles of stream channel were straightened and new ditches were dug to quickly move water off wetlands and the farm fields.

These modifications, along with stream meander cutoff by roads, changed the watershed's hydrological response. The system became stressed with heavy sediment loading, poor water quality, and accelerated streambank erosion. The altered hydrology produces flashy, and sometimes damaging, streamflows during the winter and spring (Figure 2). Peak winter and spring flows (December through May) are generally 4,000 to 10,000 cubic feet per second (cfs), with flows up to 20,000 cfs. During the summer (July through September), the baseflow decreases significantly, and the creek becomes a series of slow-moving pools. Daily average flows of less than one cfs have been recorded at the mouth of Hangman Creek.

Two major areas of streamflow are at opposite ends of the watershed. Previous analyses estimate that 50% of the annual streamflow comes from across the Idaho border (Joy et al., 2008). The streamflow volumes across the border are highly seasonal with many large winter and spring streamflows from the Rock Creek and upper Hangman drainages drying up in the summer low-flow period. In the last ten miles to the mouth of Hangman Creek, streamflow volumes double during the low-flow period, as groundwater and subsurface flows enter from Marshall Creek and Garden Springs areas.

In 2003, the Spokane County Conservation District (SCCD) conducted an assessment of the functional status of riparian corridor and wetlands along the mainstem of Hangman Creek within Washington (SCCD, 2005b). The results indicated that 50% of the 58-mile corridor was non-functional, and 34% was rated as functional-at-risk condition. Only 15% was rated as properly functional that would adequately support physical and biological benefits. A properly functioning riparian corridor is essential to provide protection from streamflow extremes, reduce erosion and pollutant transport, and enhance fish production.

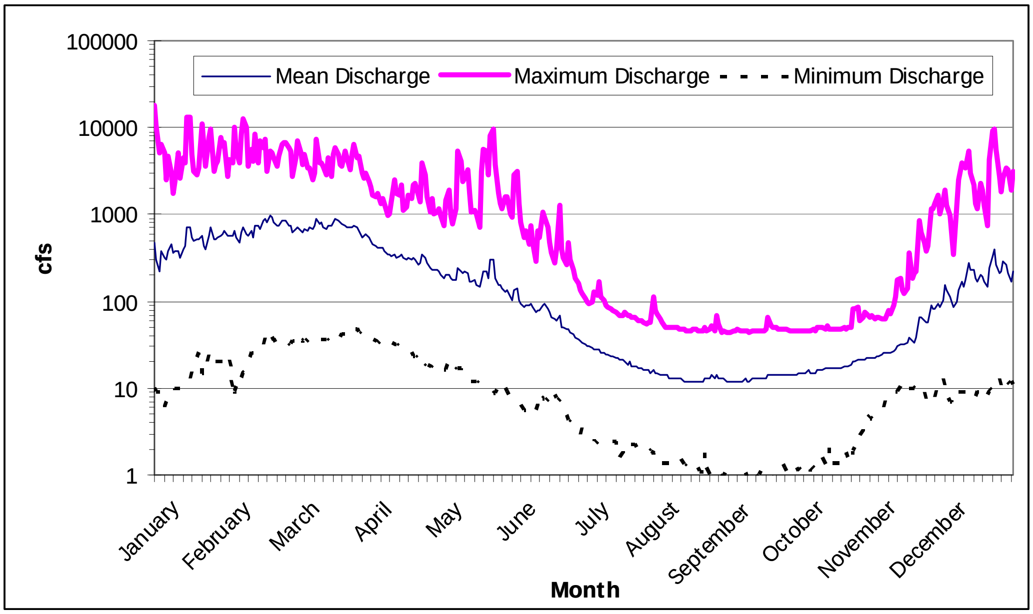

Figure 2. Daily maximum, mean, and minimum discharge for the mouth of Hangman Creek based on measurements from 1948 through 2007 at USGS site 12424000.

The four Level IV ecoregions mentioned in the previous section have very distinct geologic and vegetation characteristics within the Hangman Creek watershed that have defined land use patterns (Figure 3).

- Palouse Hills (10h) soils in the heart of the watershed are especially rich in organic matter and productive. Their presence has made wheat and small grain farming a dominant land use.
- Pine and fir forests of the Northern Idaho Hills (15v) and Spokane Valley Outwash Plains (15s) supplied easily accessible timber for building. Development in the well-drained and lower elevation Spokane Valley has steadily grown over the past century.
- The Channeled Scablands (10a) are more rugged, and were the last areas to be settled in the watershed.

Hangman Creek has cut through the easily erodible soils of the Palouse Hills and Spokane Valley Outwash Plains. Where these soils remain unprotected with vegetative cover, erosion becomes a major problem. Sediment from the eroded banks and uplands find their way into stream channels of Hangman Creek and its tributaries. The Spokane River also receives a substantial sediment load from Hangman Creek, especially during the spring run-off or winter rain-on-snow events.

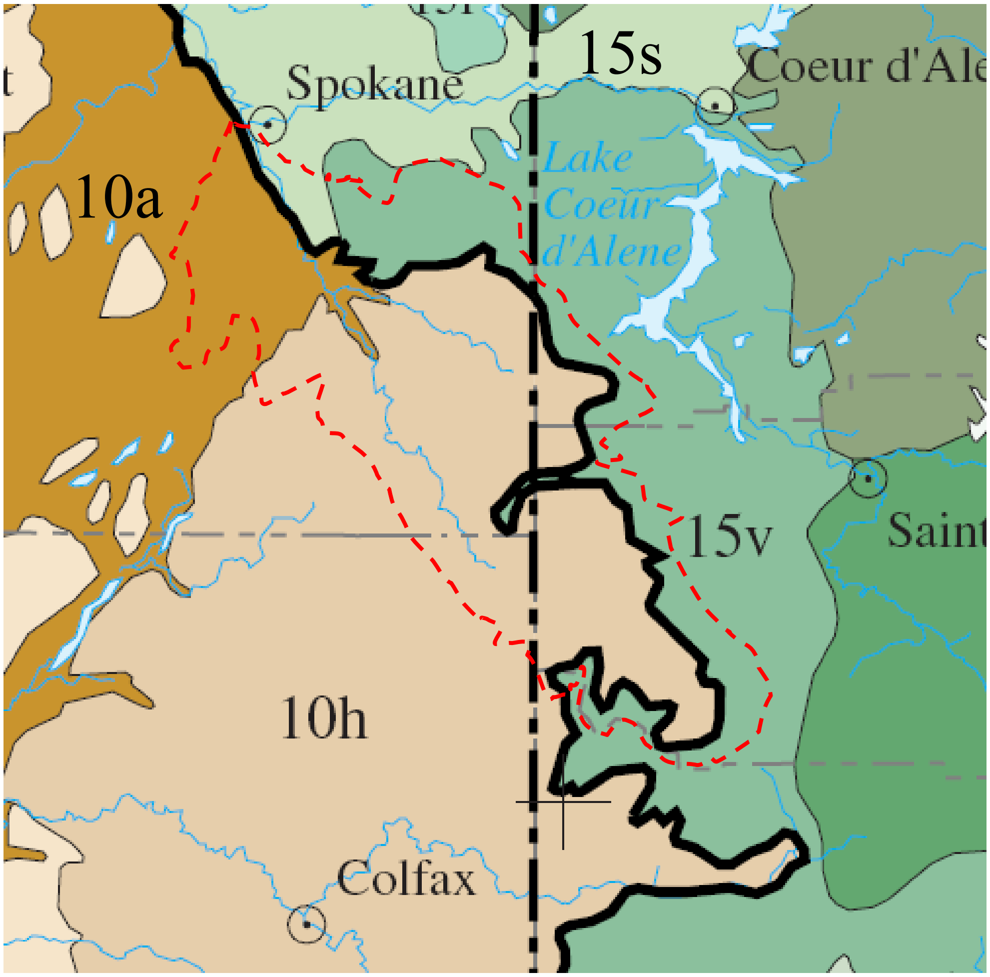

Figure 3. Map showing EPA Level 4 ecoregions in the Hangman Creek watershed (red outline). The ecoregions are: 15v (Northern Idaho Hills), 15s (Spokane Valley Outwash Plains), 10h (Palouse Hills), 10a (Channeled Scablands).

Permit holders (point sources)

The Hangman Creek watershed contains ten permitted facilities in Washington. Four of these facilities (Badger Lake Estates, Liberty School District, Hangman Hills, and Upper Columbia Academy) have Washington State wastewater discharge permits to discharge to ground or wetlands. The six remaining wastewater treatment plants (WWTPs) have NPDES permits to discharge to surface water (Table 4).

Table 4. Wastewater facilities with permits to discharge to Hangman Creek.

Facility	City	Permit Number	Discharges to
Cheney WWTP	Cheney	WA0020842C	Wetland drains to Minnie Creek
Fairfield WWTP	Fairfield	WA0045489C	Rattler Run Creek
Freeman School District	Rockford	WA0045403C	Little Cottonwood Creek
Rockford WWTP	Rockford	WA0044831C	Rock Creek
Spangle WWTP	Spangle	WA0045471B	Spangle Creek
Tekoa WWTP	Tekoa	WA0023141C	Hangman Creek

Only Tekoa and Spangle WWTPs discharge throughout the year. Rockford WWTP can only discharge to Rock Creek when a specific dilution ratio is present. Fairfield and Freeman School District lagoon systems have enough capacity to hold effluent during the late-summer and early-fall low streamflow season. Cheney WWTP currently does not have a surface discharge to Minnie Creek.

All of the permitted municipal WWTPs have effluent limits for BOD and suspended solids. Ammonia effluent limits have been established for Rockford, Tekoa, Spangle, Cheney, and Fairfield. Only Cheney has a phosphorus effluent limit. Spangle monitors its effluent for total phosphorus twice a month.

Hangman Creek and Rock Creek receive effluent from three additional wastewater facilities located across the Washington border on the Coeur d'Alene Reservation. Tensed WWTP is located on the mainstem Hangman Creek upstream of Tekoa. Worley and the Coeur d'Alene Casino have wastewater facilities that discharge to Rock Creek. Their nutrient loads will not be specifically evaluated, but are included in loads measured at the border.

Three jurisdictions within the watershed are covered by the Municipal Stormwater Permit. This NPDES permit regulates pollutants carried to waterbodies by stormwater. Spokane County, the City of Spokane, and the Washington Department of Transportation are all Phase 2 municipal separate stormwater sewer system (MS4) permit holders. Stormwater permits do not have specific permit limits, but jurisdictions are required to create stormwater management plans that meet specific management requirements.

Six facilities hold general industrial permits for handling rock, sand, and gravel: Mutual Materials Mica, Mutual Materials Pottraz, Mutual Materials Fruin Mine, Spokane County Public Works at Rockford and at Cutoff, and Seubert Excavators at Pottraz. One facility, M&M Trucking, holds an industrial stormwater permit. Visits may be arranged to assess if these facilities have potential impacts on surface water pH and DO conditions.

Nonpoint sources

Nonpoint sources of pH and DO problems in the watershed include diffuse sources of nutrients, BOD, eroded sediments, and areas with a lack of riparian shade. The watershed has extensive areas of farming. Some farming practices are potential sources of nutrients and eroded sediments rich in phosphorus. Some growers have also eliminated riparian vegetation to gain a few more feet of arable land. Channel area exposed to long periods of sunlight can become choked with periphyton, grasses, and aquatic plants when nutrients are plentiful in the water column or in bed sediments.

Some livestock access areas have been observed in the previous TMDL surveys. Poor livestock management in riparian corridors can be sources of nutrients and oxygen-demanding manures. None of the livestock populations appear to qualify as confined area feeding operations that would require a permit.

Eroding banks may be enriched with nutrients or may have native nutrient concentrations high enough to stimulate algae growth in the stream channels. As mentioned earlier, soils and geologic factors in much of the watershed leave unprotected banks and uplands susceptible to erosion. Land uses and channelization have destabilized streambanks in the watershed. Several bank restoration projects have been undertaken in the watershed, but miles of streambank remain in poor condition.

Residential and urban areas supply nutrients through run-off and tend to have denuded riparian areas. Fertilizers, on-site septic systems, and pets can be sources of nutrients and BOD. Riparian areas with bank-side development often lack shade and are subject to channelization or streambank erosion.

Historical Data Review

Carey (1989) recorded some of the first DO data used for 303(d) listings during an August 1988 receiving water study upstream and downstream of the Tekoa WWTP. Early morning DO concentrations were as low a 1.2 mg/L below the WWTP outfall and less than 6 mg/L upstream of the outfall. Carey also noted the nitrogen-to-phosphorus ratio above the outfall suggested a nitrogen limitation. This became more pronounced below the outfall and characteristic of a hypereutrophic condition often found in freshwater bodies with heavy loads of effluent nutrients.

Ecology ambient stations at the mouth of Hangman Creek (56A070) and at Bradshaw Road (56A200) have also recorded instantaneous pH and DO measurements beyond criteria. When the long-term site, 56A070, was monitored in the morning, summer DO concentrations often fell below 8 mg/L (usually at DO saturation levels of 55% to 85%). When the site was monitored in the late afternoon, pH values exceeded 8.5 in the summer or fall. Bradshaw Road was only sampled during the 1999 water year and during the morning hours. The DO concentrations at the site in July and August were 4.8 mg/L and 6.1 mg/L, respectively. Dissolved oxygen saturation levels were 55% and 69.5%, respectively. Summer and fall pH values at the site were 7.8 to 8.4, somewhat elevated for morning readings.

Nitrogen loading to the lower reaches of Hangman Creek is evident during the low-flow season compared to upstream sites. Nitrogen depletion occurred at the Bradshaw Road site (RM 32.9) in October and November of 1998 and July through September of 1999. SCCD data show that nitrogen also became depleted at several sites from RM 18 upstream to the Idaho border in July 2004 (SCCD, 2005a). Meanwhile, nitrogen concentrations at the mouth (Ecology Station 56A070) were not depleted during these periods (Ecology, 2008a), and nitrogen-to-phosphorus ratios suggested the system could become phosphorus-limited if some other factor like light or substrate were not more limiting.

The additional nitrogen loading below RM 10 is thought to come from groundwater and spring sources. Streamflows during the low-flow season are greatly enhanced in the lower reaches of the creek by springs and subsurface inputs (Figure 4). The sources of nitrogen could be related to residential, commercial, and recreational land uses in the area or to legacy use of fertilizers when the area was small farms.

Other pH and DO listings were the result of SCCD watershed studies in the past and water quality monitoring conducted in 2004 (SCCD, 1994; 1999; 2000; 2005a). Although diel measurements were not taken, instantaneous measurements of pH and DO taken during the 2004 surveys were compared to Washington State criteria in Table 5 (SCCD, 2005a). Several mainstem and tributary sites exceeded the criteria enough times to qualify for Category 5 or Category 2 status (Tables 1 and 2). The 2004 low DO concentrations were associated with low-flow periods in winter and summer, but especially when temperatures increased. The non-compliant pH values did not meet upper and lower criteria, depending on the season and location. Both decomposing and productive environments are thought to be involved.

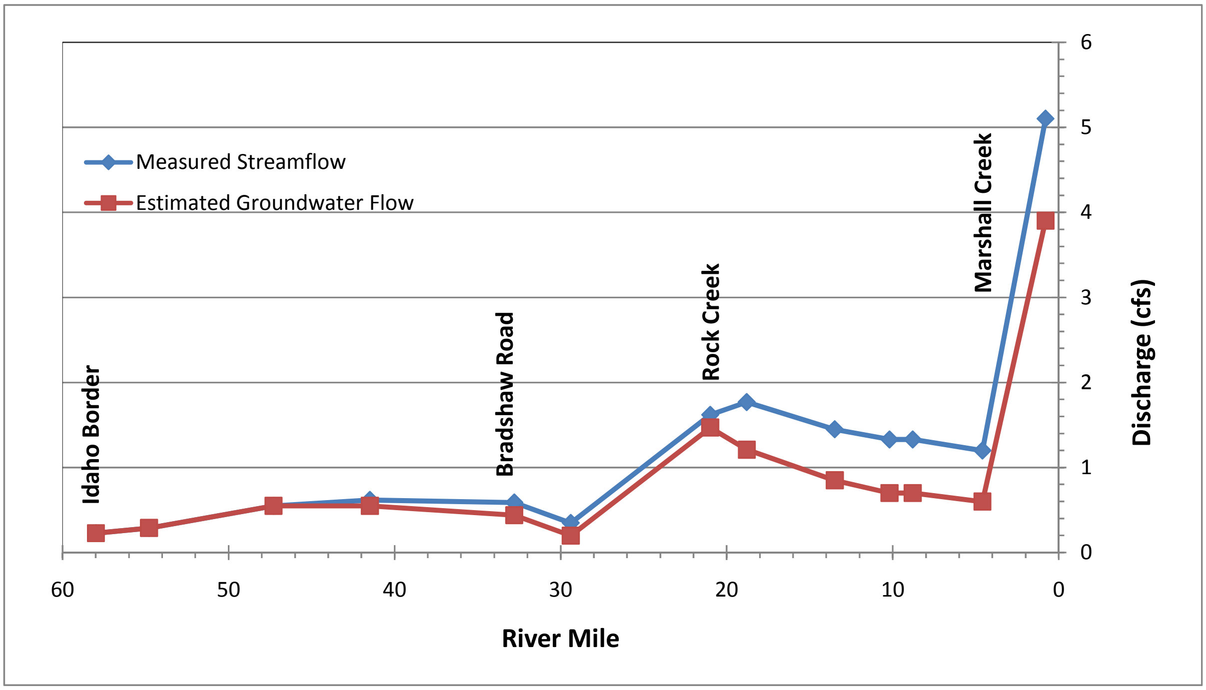

Figure 4. Hangman Creek groundwater and streamflow measurements collected during a September 2001 synoptic survey by Spokane County Conservation District (SCCD, 2005a).

Although a comprehensive survey of all areas in the watershed has not been undertaken, the results of these Ecology and SCCD studies indicate that pH and DO criteria violations are common throughout the watershed during the summer and fall. The previous watershed planning studies (SCCD, 2005b) and TMDL evaluations for temperature and turbidity (Joy et al., 2008) demonstrated the difficulties caused by low streamflows, poor riparian cover, and shallow, wide, sediment-filled channels. All of these conditions are wide-spread in the watershed and exacerbate temperature, pH, and DO problems.

In the interest of evaluating the Spokane River/Lake Spokane TMDL recommended total phosphorus loads for Hangman Creek, an assessment of total phosphorus loads was conducted as an initial task of the previous Hangman Creek TMDL. The landscape model and statistical load analyses suggested total phosphorus loads were primarily event-based and seasonal (Cadmus and CDM, 2007; Joy, unpublished data).

The Watershed Analysis and Risk Management Framework (WARMF) model was developed for Hangman Creek to evaluate sediment and phosphorus delivery from various land uses and sources (Cadmus and CDM, 2007; Joy et al., 2008; Joy, unpublished data). Not enough long-term and diel ambient data or specific source data were available to simulate instream DO concentrations and pH values in WARMF.

Table 5. The number of pH, DO and temperature measurements collected at several sites in the Hangman Creek watershed that do not meet Washington State water quality criteria. Measurements were taken by the Spokane County Conservation District from December 2003 to August 2004 (SCCD, 2005a). mg/L = milligrams per liter; RM = river mile.

Site Location	Number of Samples	Number of Exceedances		
		pH Units (<6.5 or >8.5)	Dissolved Oxygen (<8 mg/l)	Temperature (>18 °C)
Hangman Creek at Stateline	11	1	3	1
Cove Creek	11	2	3	1
Hangman Creek at Roberts Rd	11	1	4	2
Rock Creek at Rockford	11	2	0	1
Rock Creek at the mouth	11	3	0	2
Hangman Creek at RM 21.0	11	2	0	2
Hangman Creek at Duncan	11	4	2	4
California Creek near Marsh Rd	11	1	0	0
California Creek at the mouth	11	0	0	0
Spangle Creek at the mouth	7	3	0	0
Marshall Creek at McKenzie Rd	11	0	2	0
Marshall Creek at the mouth	11	0	0	0

According to WARMF output, agriculture and streambank erosion were major sources of total phosphorus. The small WWTPs also contributed a small, but identifiable, load. Loads in Idaho were also significant, so any significant reductions in phosphorus or suspended sediment would require cross-border cooperation. The analysis also suggested that soil and soil-water concentrations of phosphorus may be higher than estimated by the Spokane River TMDL assumptions. The Spokane River TMDL assumed Hangman Creek background phosphorus concentrations were similar to Little Spokane River's, but the ecoregional make-up of the two watersheds is quite different.

These data and Ecology ambient monitoring data have provided a basis for observed water quality violation listings and consequent watershed improvement plans (Ecology, 2008a; Joy et al., 2008). The data will be used to direct monitoring and investigate data gaps so that the pH and DO TMDL can be correctly targeted and implemented.

Project Goals and Objectives

The project goals are (1) to complete a technical analysis for DO and pH TMDLs in Hangman Creek and its tributaries, and (2) better define phosphorus loading from Hangman Creek to the Spokane River. The following objectives are necessary to accomplish these goals:

- Collect nutrient and diurnal pH and DO data from the 2004 303(d) listed and contributing areas, and from the proposed 2008 Category 2 and Category 5 areas (Table 2).
- Estimate the time-of-travel through the watershed during critical seasons (summer and fall) so that QUAL2Kw modeling of pH and DO has accurate hydrological properties.
- Conduct two synoptic water quality surveys during the low-flow season (July – September)
- Collect additional ambient pH, DO, and nutrient data in the watershed at:
    - Reference sites in the four Level IV ecoregions.
    - The Idaho border in the Rock Creek, Little Hangman Creek, and upper Hangman Creek sub-watersheds.
    - Wastewater treatment plants and other point sources.
    - Key watershed sites during run-off events.
- Enter data in Ecology's EIM system and organize into spreadsheets or a database.
- Write a detailed data summary report and TMDL technical report.

The data need to be collected in a manner useful for the QUAL2K and WARMF models and other analytical tools for TMDL development. Therefore, temperature, discharge measurements, and physical characteristics of the creek channels will be needed as well.

Study Design

Overview

The project objectives will be met by collecting data to (1) refine the current landscape model of the Hangman Creek watershed, and (2) develop a numerical water quality model for DO and pH analysis during the low-flow summer period. Data will be collected by Ecology staff with assistance from SCCD staff in accordance with requirements of this Quality Assurance Project Plan. Additional data from USGS and Spokane County Conservation District streamflow gages will be obtained. Data collection is organized as four monitoring tasks: a reconnaissance survey, synoptic surveys, border load monitoring, and reference area monitoring.

Field and laboratory data collected during this 2008-09 study will be used in two major modeling efforts:

1. Seasonal and annual nutrient loads will be addressed by monthly border, point source, reference area, and run-off event monitoring for use in a landscape model delivery model.
2. Critical season (summer and fall) pH and DO dynamics will be addressed with data from synoptic surveys for use in a steady-state water quality model.

Seasonal and annual nutrient loads from various locations and sources in the watershed need to be assessed. The Watershed Analysis and Risk Management Framework (WARMF) model was developed for Hangman Creek to evaluate sediment and phosphorus delivery from various land uses and sources (Cadmus and CDM, 2007; Joy et al., 2008; Joy, unpublished data). The WARMF model uses climate, soil, slope, and land use data to generate loading rates to waterbodies and the transport through the waterbody network (see *Data Analyses and Use*). Additional nutrient, streamflow, and channel characteristic data are needed for model calibration and source loading evaluations.

More site-specific data are required under near steady-state, summer low-flow conditions to understand the spatial distribution and characteristics of pH and DO dynamics. The data collected will help develop and calibrate a QUAL2Kw model for pH and DO analyses. The QUAL2Kw model simulates diel patterns of DO and pH under steady-state conditions (see *Data Analyses and Use*).

Parameters, equipment, and the number of sites estimated for the synoptic survey, border load, and reference condition monitoring tasks are summarized in Table 6. The reconnaissance survey will allow the Ecology team to familiarize themselves with the project area and to collect some preliminary data for laboratory and analytical comparisons. The synoptic survey task has three sub-tasks: time-of-travel tests, 48-hour diel pH and DO monitoring, and synoptic productivity monitoring. The border and reference survey tasks are a foundation network for expanded geographic coverage during runoff events. Details of the monitoring tasks follow.

Table 6. An activity summary describing synoptic, border load, and reference site monitoring tasks in the Hangman Creek watershed in preparation for pH, dissolved oxygen (DO), and nutrient TMDLs.

Task	Parameter	Type	Equipment	Hangman Creek	Rock Creek
48-hr diel pH and DO	Air temperature	Continuous	TidBit	4 stations	2 stations
	Relative humidity	Continuous	RH probe	4 stations	2 stations
	DO, pH, temperature, conductivity	Deployment of 48-hrs or more	Hydrolab DataSonde	10 -12 stations	3 stations
Synoptic Productivity	Total nitrogen and total phosphorus, TOC, alkalinity, chloride , BOD5	Grab samples, unfiltered	(laboratory)	25 stations*	5 stations
	DOC, nitrate+nitrite, ammonia nitrogen, orthophosphate	Grab samples, filtered	(laboratory)	25 stations*	5 stations
	DO, pH, temperature, conductivity	Instantaneous grab	Hydrolab surveyor	25 stations	5 stations
	Macrophyte estimate	Measurement	(field)	10 stations	5 stations
	Periphyton	Grab samples	(see *Methods*)	3 stations	-
	Discharge	Instantaneous in situ	Flow meter & rod or staff gage	stations	stations
Synoptic Flow and Travel Time	Tracer concentration	Slug	Fluorometer	4-5 release and 4-5 monitoring stations	3 release and 3 monitoring stations
	Channel surveys	Measurement	(field)	As needed	As needed
Border Loads	Dissolved nutrients (nitrate+nitrite, ammonia nitrogen, orthophosphate)	Grab samples, filtered	(laboratory)	2 stations	3 stations
	DO, pH, temperature, conductivity	Grab sample	Field methods	2 stations	3 stations
	Total nitrogen, total phosphorus, alkalinity, TOC, TSS	Grab samples, unfiltered	(laboratory)	2 stations	3 stations
	Discharge	Seasonally - Continuous	Gage station	2 stations	3 stations
Reference Sites	DO, pH, temperature, conductivity	Instantaneous grab	Hydrolab surveyor	4-8 stations	-
	DO, pH, temperature, conductivity	Deployment of 24-hrs or more	Hydrolab DataSonde	4-8 stations	-
	Air temperature	Continuous	TidBit	4 stations	-
	Relative humidity	Continuous	RH probe	4 stations	-
	DOC, nitrate+nitrite, ammonia nitrogen, orthophosphate	Grab samples, filtered	(laboratory)	4-8 stations	-
	Total nitrogen and total phosphorus, alkalinity, TOC, chloride	Grab samples, unfiltered	(laboratory)	4-8 stations	-
	Discharge	Instantaneous in situ	Flow meter & rod or staff gage	4-8 stations	-
Run-off Events	Dissolved nutrients (nitrate+nitrite, ammonia nitrogen, orthophosphate)	Grab samples, filtered	(laboratory)	12 stations	4-5 stations
	DO, pH, temperature, conductivity	Grab sample	Field methods	12 stations	4-5 stations
	Total nitrogen, total phosphorus, alkalinity, TOC, TSS, CBOD	Grab samples, unfiltered	(laboratory)	12 stations	4-5 stations
	Discharge	Continuous	Gage station	12 stations	4-5 stations

* Includes eight sites on seven tributaries: Stevens, Marshall, California, Spangle, Cove, and Little Hangman Creeks and Rattler Run.

Sampling is distributed over a year commencing in September 2008 and ending in September 2009 (Table 7). Reconnaissance surveys are planned for September 2008, and a full water year (October to September) of border and reference site sampling is planned. Synoptic surveys and run-off event surveys are not firmly scheduled since they depend on local streamflow and weather conditions.

Table 7. Proposed temporal distribution of border and reference-network, synoptic low-flow, and run-off event sampling surveys.

<table>
<tr><th>Survey</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th></tr>
<tr><td>Border and Reference Network</td><td></td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>2</td><td>2</td><td>2</td><td>2</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Synoptic low-flow event</td><td colspan="10"></td><td>1</td><td></td><td>1</td></tr>
<tr><td>Run-off event</td><td colspan="3"></td><td colspan="2">1*</td><td></td><td colspan="4">2 – 3*</td><td colspan="3"></td></tr>
<tr><td>Reconnaissance survey</td><td>1</td><td colspan="12"></td></tr>
</table>

*Run-off or storm events sampled in the winter months and during the spring snowmelt.

Low-flow critical season

Synoptic surveys are needed to build and calibrate a QUAL2Kw water quality model for temperature, pH, and DO during the low-flow critical season. To properly conduct a synoptic survey, a set of time-of-travel studies will provide the information to properly calibrate water velocities, longitudinal water balances, and check physical channel data estimates. The studies will also help determine scheduling for field teams to reasonably collect the synoptic survey samples under plug-flow conditions. In other words, how many days will field teams require to follow blocks of water from the upper Hangman Creek and Rock Creek watersheds to the mouth of Hangman Creek?

Synoptic surveys capture a detailed 'snapshot' of water quality based on well-timed, intensive sampling. The data from synoptic surveys are important for water quality model calibration and verification, especially to simulate daily maximum and minimum values. Model interpretation requires an accurate simulation of watershed water balances and hydrology during relatively steady-state conditions. Proper calibration of chemical, physical, and biological elements of the water quality model depends on this foundation. Bracketing the range of temperature, pH, and DO conditions collected from two synoptic surveys during the July to September critical part of the growing season will provide the most essential model input.

Time-of-travel surveys

Two methods are available to conduct time estimates: (1) calculations based on extensive channel and discharge measurements, and (2) monitoring slugs of dye along sections of the watershed network. A mix of the two methods is recommended for this study. Some additional data review is necessary to determine which method should be effectively used for what parts of the watershed. For example, the SCCD and Coeur d'Alene Tribe Natural Resources staff may have channel data to avoid dye work in many areas of the watershed.

The mainstem of Hangman Creek downstream of the Washington/Idaho border has undergone a series of habitat and shade surveys which may provide adequate channel and discharge data to make time-of-travel estimates (SCCD, 2005b). In addition, flow analysis of recent data from the two USGS continuous recording stations near Tekoa (12422990) and at the mouth (12424000) may provide an estimate of time-of-travel under various discharge levels as well. Unfortunately, the slow pools during the low-flow period (July- September) complicate gage data analysis over 57 miles.

Rock Creek may not have the channel data and may require more extensive dye studies than other areas. Dye studies are recommended in reaches of the mainstem where channel and discharge data are lacking and similar representative reaches elsewhere in the watershed are not known.

Based on map data and Manning's equation, time-of-travel in the main channel of Hangman Creek from the Washington border to the mouth was roughly estimated to be from 8 to 82 days (Table 8). Conducting dye studies over an extensive period of time would be an unnecessary expenditure of resources. Dye testing representative reaches would provide estimates to extrapolate to similar reaches and estimate total time-of-travel. Dye testing through all or parts of the following sections of Hangman and Rock Creeks is planned:

- Border (RM 57) to Latah (RM 47).
- Latah (RM 47) to Bradshaw Road (RM 33).
- Bradshaw Road (RM 33) to Rock Creek (RM 20).
- Rock Creek (RM 20) to the mouth (RM 0).
- Confluence of North and South Forks Rock Creek (RM 15) to Jackson Road (RM 9).
- Jackson Road (RM 9) to confluence with Hangman Creek (RM 0).

Dye studies should be undertaken using USGS-type standard operating procedures since Ecology's procedures have not been approved (described below). If possible, two dye surveys should be conducted prior to synoptic surveys in the July and September critical season to bracket flows of pH and DO criteria violations.

Table 8. Channel characteristics for travel time study estimates.

From	Elevation (m)	To	Elevation (m)	Length (mi)	Slope	Low-flow Discharge[1] (ft/s)	Travel Time (range of day)[2]
Reservation Boundary	840	Lolo Creek	769	13	0.003394	--	--
Lolo Creek	769	State line	762	4	0.001088	0.29	1 – 8
State line	762	Latah	738	10.8	0.001381	0.55	2 – 22
Latah	738	Bradshaw Road	700	13.7	0.001724	0.59	2 – 28
Bradshaw Road	700	Keevy Road	665	3.5	0.006215	0.35	0.2 – 2
Keevy Road	665	Rock Creek	593	9.2	0.004864	1.62	1 – 8
Rock Creek	593	RM 10.5	560	9.7	0.002114	1.33	0.7 – 7
RM 10.5	560	USGS Gage	525	9.7	0.002243	5.10	0.7 – 7

[1] Based on a single day September 2001 seepage run.
[2] Assuming 10 times range of velocity to account for pools.

Synoptic surveys

Once the time-of-travel is estimated, synoptic surveys can be conducted to measure longitudinal and diel changes in water quality from the Washington border to the Spokane River, especially for parameters affecting pH and DO. The maximum and minimum daily water quality values obtained from the monitoring will provide model calibration data.

Monitoring on two occasions is needed during the critical low-flow period of July through September. Proposed monitoring sites are listed in Table 9 and shown in Figure 5. The first survey is planned for September 2008 and the second for July 2009. The interval will allow time for QUAL2Kw models of Hangman and Rock Creeks to be constructed and calibrated before the second survey. Any unforeseen data deficiencies in model input can be remedied in planning for the second survey.

Discharge and in-situ measurements and chemical sampling requirements are summarized in Table 6. In-situ measurements and samples for laboratory analysis will be collected twice each day for two days at each site. Samples will be taken early in the morning and again in the late afternoon. Field teams will record all field data and ship laboratory samples after each day's set of surveys.

Table 9. Potential synoptic survey sites for the 2008 and 2009 Hangman Creek pH and dissolved oxygen TMDL data collection study.

Site Name	River Mile	Water Sampling & Measurements	Discharge	Periphyton	48-hr Diel
Hangman Cr at state line	57.4	x	USGS	x	x
Hangman Cr above Tekoa	54.6	x	x		
Hangman Cr below Little Hangman Cr	53.7	x			
Tekoa WWTP	53.6	x	Tekoa		
Hangman Cr below Tekoa	52	x			x
Hangman Cr at Fairbanks Rd	50.4	x			
Hangman Cr at Marsh Rd	47.3	x	x		
Hangman Cr at Chapman Rd	46	x			
Hangman Cr at Roberts Rd	41.5	x	x		x
Hangman Cr at Bradshaw Rd	32.9	x	SCCD	x	x
Hangman Cr at Keevy Rd	29.4	x	x		
Hangman Cr at Latah Cr Rd	21	x	x		
Hangman Cr at Duncan	18.8	x	SCCD	x	x
California Cr at mouth	Ca C 0	x	x		
Stevens Cr at mouth	St C 0	x	x		
Hangman Cr at HV Golf	13.8	x	x		
Hangman Cr at Campion Park	6.4	x	x		x
Hangman Cr at Chestnut Street	1.8	x	x		
Hangman Cr at mouth	0.4	x	USGS	x	x
Little Hangman Cr at Hwy 27	LHC 0.1	x			
Little Hangman Cr at mouth	LHC 0	x	SCCD		x
Cove Cr at Hwy 27	CC 0.4	x	x		x
Rattler Run above WWTP	RR 5.7	x	x		
Fairfield WWTP effluent	RR 5.0	x	Fairfield		
Rattler Run at mouth	RR 0	x	SCCD		
Spangle WWTP	SC 6.2	x	Spangle		
Spangle Cr below WWTP	SC 5.2	x	x		
Spangle Cr at mouth	SC 0	x	x		x
Cheney WWTP seepage	MC	x			
Marshall Cr at McKenzie	MC 5.3	x	x		
Marshall Cr at mouth	MC 0.1	x	x		x
Rock Cr at N/S Fork	RC 15.5	x	x	x	x
Rock Cr at Rockford	RC 13.5	x	x		
Rockford WWTP drain	RC 13	x	Rockford		
Rock Cr at Jackson Rd	RC 8.9	x	x	x	x
Rock Cr at mouth	RC 0.0	x	SCCD		x

Depending on the time-of-travel results, the watershed may be separated into sub-units for staggered longitudinal sampling. For example, in the upper watershed, field teams may begin at the border, sample Little Hangman, Tekoa WWTP, and the Tekoa area, then advance sampling step-wise to sites downstream over a few days (Figure 5). Another field team would start along Rock Creek in a similar manner, so both teams would meet at the Hangman/Rock Creek confluence.

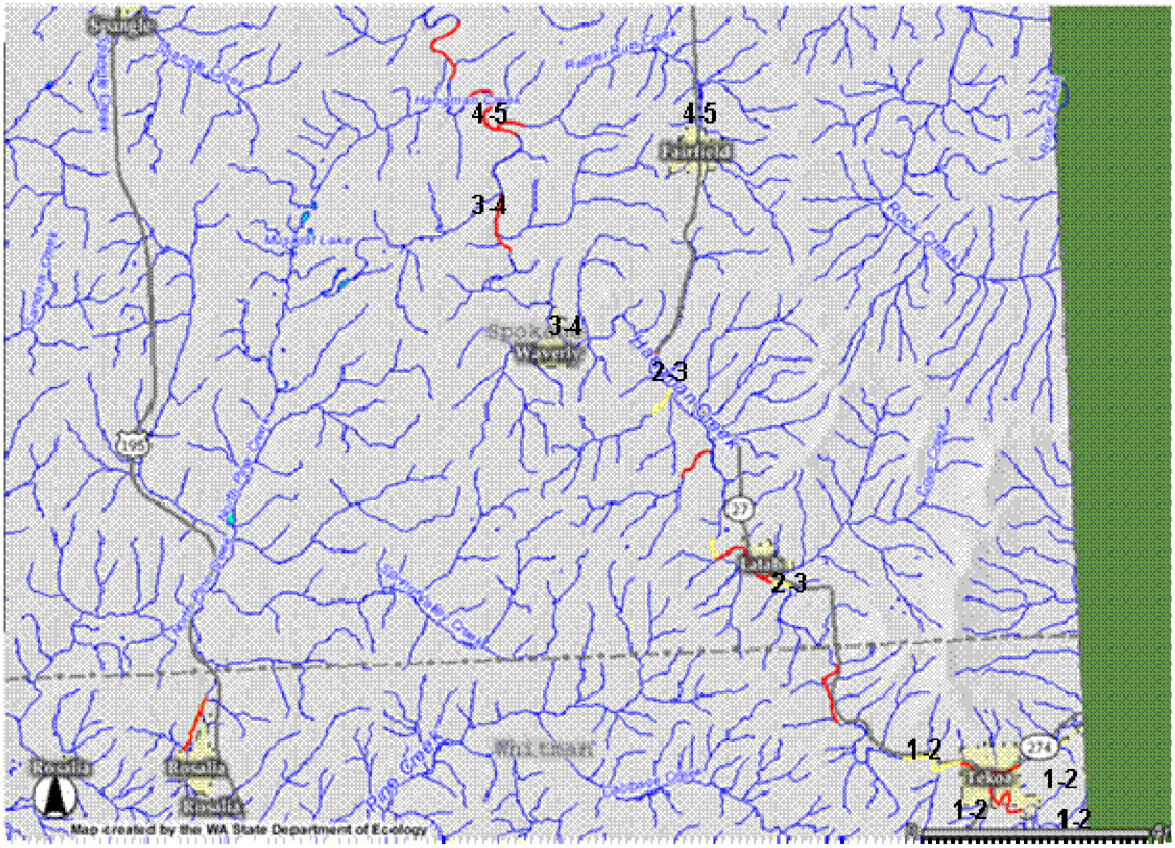

Figure 5. An example of a possible site sampling progression in upper Hangman Creek. Numbers indicate progressive timing of days to visit each site twice in a synoptic manner.

Field crews will collect samples for nitrate-nitrite, ammonia, total nitrogen, dissolved phosphorus, total phosphorus, alkalinity, total organic carbon, and dissolved organic carbon.

Crews will estimate the channel bed coverage of macrophytes and periphyton at all sites on Hangman and Rock Creeks. Periphyton samples for chlorophyll and ash-free dry weight analyses will be collected at approximately four Hangman sites and two Rock Creek sites. Methods are described in the *Sampling and Measuring Procedures* section.

During the synoptic surveys, diel measurements of pH, DO, temperature, and conductivity will be recorded over 48 hrs at approximately 14 sites using Hydrolab DataSonde® monitoring equipment. The deployment at a site should coincide with at least one of the two-day water quality sampling visits. Standard Environmental Assessment Program procedures for calibrating and deploying the equipment will be followed.

Washington/Idaho border monitoring

Rock Creek, Little Hangman Creek, and the upper Hangman Creek have substantial portions of their watersheds upstream of the Washington border, primarily in the Coeur d'Alene Reservation. Together these portions constitute 35% of the Hangman Creek area, and supply up to 60% of the annual streamflow. Flow and load estimates from the WARMF model have been based on only a few observed data. Additional data over a full year are needed to better calibrate the WARMF model to obtain better estimates of the nutrient and sediment loads coming across the border.

Previous work in the Hangman Creek watershed indicates that most loading across the border probably occurs during high-flow events in the winter and spring (SCCD, 1999, 2005a; Joy et al., 2005). Efforts will be made to obtain samples during periods of high flows by sampling twice a month during March, April, May, and June 2009. Special run-off sampling runs from an expanded monitoring network is also planned and may substitute for one of the twice-a-month sampling runs (see *Run-off Monitoring*, below). Streamflows may be reduced in the summer and fall to levels inadequate for sampling. Also, ice cover, common in the coldest part of winter, may limit sampling. However, when possible, samples will be collected on a monthly basis (October 2008 - September 2009) at the following sites:

- Hangman Creek at State Line Road.
- Little Hangman Creek near Willard (may need CdA Tribe permission).
- Rock Creek at S. Idaho Road north of Truax Road.
- Rose Creek at Chatcolet Road.
- North Fork Rock Creek at Hoxie Road.

Total and dissolved nitrogen, phosphorus and carbon, suspended solids, and alkalinity are recommended for laboratory analysis (Table 6). Methods of collection are described in the *Sampling and Procedures* section. Instantaneous measurements of DO, pH, temperature, and conductivity are also recommended for baseline information and chemical data interpretation. Streamflow data are available at the site, Hangman at state line, from a USGS station (#12422990). If possible, continuous discharge monitoring equipment will be installed at the other four sites to record winter and spring discharge volumes. If not, then surveyed staff gages should be established and instantaneous discharge measurements collected over the range of flows.

Reference conditions monitoring

The allocation of nutrients, sediment, and other chemicals to *natural background,* as compared to those generated by *nonpoint,* sources is very important to water quality management in the Hangman Creek watershed and Spokane River basin. Obtaining natural background data in the Hangman Creek watershed is difficult since direct and indirect human influences have touched all parts of the watershed over 150 years or more.

The term *reference condition* can have multiple meanings: from natural and undisturbed, through minimally and least disturbed, to best potential condition (www.epa.gov/bioindicators/html/reference_condition_types.html) (Table 10). The plan is to screen sites and choose the highest level of reference condition available among the natural, minimally disturbed, and best potential categories. The least disturbed category will be used only when all other options are exhausted.

Table 10. Some definitions of sample sites often referred to as reference conditions.

Type	Availability	Attributes	Uses
Natural	Usually theoretical	No historical or current human activity	Goal for 'naturalness'.
Minimally Disturbed	Rare	Human activity is limited to such actions as atmospheric deposition	Reference.
Least Disturbed	Most common	Least amount of human disturbance compared to similar waterbodies in the area of interest. May not meet water quality criteria.	Comparative to criteria and application of best management practices.
Best Potential	Variable	Best conditions achievable with proper best management practices in place.	Often a 'compromise' condition better than Least Disturbed, but not quite Minimally Disturbed.

Four ecoregions (Figure 3) make the hunt for reference areas more difficult. The Palouse Hills will be the most difficult ecoregion type because of its highly desirable farming characteristics. Sites will be proposed, visited, and chosen in August and September 2008. Sites out of the watershed may be selected if none of the sites within the Hangman Creek watershed are acceptable. The following areas hold some promise for potential reference conditions:

- Northern Idaho Hills – Upper California Creek.
- Spokane Valley Outwash Plains – (unidentified – may be in Little Spokane River watershed).
- Palouse Hills – (unidentified – may be Palouse River watershed).
- Channeled Scablands – Turnbull National Wildlife Area.

Native riparian vegetation and limited channel structure disturbance would be highly desirable for any site chosen. Most areas near perennial streams have been developed, so intermittent streams may be the only ones available. Another site option, commonly reported as better than 'least disturbed', may be sites downstream of areas where best management practices have been installed and maintained for five years or more. Some 'minimally disturbed' areas of appropriate ecoregions may be in neighboring watersheds that do not drain to the Spokane River.

Habitat, channel, and surrounding land use will be documented and photographed at established sites. Total and dissolved nitrogen, phosphorus and carbon, suspended solids, and alkalinity are recommended for laboratory analysis (Table 6). A full year of monitoring is needed to address seasonal loading questions. Methods of collection are described in the *Sampling and Procedures* section. Reference sites will also be part of the run-off monitoring network (see *Run-off Monitoring*, below).

Run-off monitoring

The purpose of run-off monitoring is to better characterize potential sources of suspended sediment and phosphorus loading in the Hangman Creek watershed. Historical data and WARMF model output show higher loading during rain-on-snow or rainstorm events in winter and spring. Resources and weather patterns permitting, run-off sampling will occur in December and January, and in March through June. If sufficient runoff does not occur during these months, the schedule will be adjusted. Runoff from Idaho, reference areas, major tributaries, and key mainstem sites will be targeted where possible.

Three to four events will be sampled, with a run-off event defined as an order of magnitude 'spike' in streamflow over a 24-hour period (e.g., at 100 cfs a spike to 1000 cfs). The USGS gaging stations at State Line and at the mouth provide real-time data to identify these events. The spike definition may vary according to the existing discharge level in the creek and the interval since the last spike. The rainfall and temperature patterns in the watershed are sometimes more localized, but watershed-wide events will be targeted so all sites can respond.

Timing will vary with the timing and intensity of the run-off event. For example, if a strong storm occurs when the creek is already flowing above the seasonal average, sites will need to be visited as quickly as possible. However, if the event occurs when initial flows are low, some sites may be collected on Day 1 and downstream sites on Day 2. Storm sampling will consist of at least two teams of two people sampling all sites. If possible, two visits to each site over the duration of the event will be conducted to catch a rising and falling limb of the hydrograph.

Streamflow will be measured or estimated using stage and rating curves or relationships with other monitoring locations when grab samples are collected. Daily rainfall data will be obtained from local sources.

The run-off event sampling sites will include all border and reference network sites plus major tributaries, municipal WWTPs, and significant stormwater outfalls under NPDES Phase II permits. Stormwater NPDES permits are required to have corresponding wasteload allocations set in TMDL studies. Therefore, this study must determine any limiting nutrient wasteload allocations for each permit holder (i.e., for each Phase II permit jurisdiction). Spokane County, the City of Spokane, and the Washington State Department of Transportation hold stormwater permits.

After regular monitoring has commenced and land use has been characterized more thoroughly, adjustments to the storm monitoring schedule and site locations may be necessary. Any significant adjustments will be addressed through an addendum to the Quality Assurance Project Plan and sent to the appropriate parties. The ability to quickly and safely access some sites and obtain a representative sample will be a challenge. Permission to sample runoff at some locations is still required.

Sites may be added or removed from any part of the sampling plan, depending on access and new information provided during the Quality Assurance Project Plan review, field observations, and preliminary data analysis.

Sampling Procedures

Field sampling protocols for synoptic surveys, border monitoring, and reference data collections will follow Environmental Assessment Program (EAP) approved Standard Operating Procedures www.ecy.wa.gov/programs/eap/quality.html:

- EAP013 Determining Global Positioning System coordinates.
- EAP015 Grab sampling – Fresh Water.

Some protocols are in provisional or scheduled status. But they have draft descriptions or well-established procedures described in previous TMDL studies that are available:

- EAP047 Channel geometry studies conducted for a temperature TMDL study.
- EAP048 Riparian vegetation surveys conducted for a temperature TMDL study.

Finally, some protocols described by other agencies have been through peer review and are in common use in the scientific community. In this study the following referenced protocols will be used:

- USGS, 2006. Equal-width increment depth integrated sampling.
- Stevenson and Bahls, 2007. EPA rapid bioassessment periphyton protocols.

All samples collected for surveys in this set of studies will be collected from effluents and stream channels in a representative manner. Equal-width increment (EWI) depth-integrated samples (USGS, 2006) will be preferred for samples submitted for laboratory analyses, but grab samples may be collected as necessary. Grab samples will be collected from the thalweg, within free-flowing stream sections, and away from channel boundaries. Grab sampling handling and techniques will follow EAP protocols.

Equipment for EWI samples will be examined for adhering material, cleaned, and then rinsed in distilled water prior to moving to the next site. At the next site, equipment will be rinsed in local water before a pre-cleaned integration bottle is inserted.

Data and documentation for all surveys will be kept orderly, legible, and secure. Field observations and measurements will be recorded immediately in non-smearing ink or dark pencil on Rite-in-the-Rain® paper as they occur. Sheets will be numbered consecutively from the start of the survey run. The following will be recorded:

- The name of the study, station identification number or name, date, time, personnel names, and weather conditions of each site will be clearly noted in a consistent location on the sheets.
- Grab or EWI method of sample collection will be noted.
- For sites with continuous DataSonde recording, instrument identification number, calibration data (or location of data), start and end time of deployment, download file name, time and value of check samples, and specific placement descriptions will be recorded.

- Identification numbers used for lab analysis samples will be recorded. Replicate sample identification numbers will be recorded as well. All information on the sample tag will be recorded in the field notes.
- The identification number of the Hydrolab surveyor, Minisonde, or other equipment used for instantaneous DO, pH, temperature, and conductivity measurements will be noted.
- Staff gage readings or discharge measurement data will be clearly labeled and neatly recorded.

Sample tags will be filled out completely with waterproof pen, dark pencil, or pre-printed ink. Tags or labels will be securely attached to samples. Information will be transferred to the 'Laboratory Analysis Required' form. Tag information will follow Manchester Environmental Laboratory requirements that include:

- Study name
- Pre-assigned lab number
- Sample collection location
- Date and time
- Sampler's initial
- Parameter
- Preservatives

The 24-hour reference area deployments and 48-hour meter deployments of Hydrolab Multi-probe meters during the synoptic surveys will collect pH, DO, temperature, and conductivity data at 10-minute intervals. Data will be downloaded to a secondary portable computer as soon as possible and preferably before the next deployment. Care will be given to deployment of meters to prevent theft or damage while maintaining representative data collection. Meters should be hidden from easy view, secured with cable, and locked to a permanent structure whenever possible. Meters should not be deployed if a rapid increase in streamflow is possible.

Water samples for synoptic, border, and reference surveys will be treated in a similar manner. Grab samples will be collected into pre-cleaned containers supplied by MEL as prescribed in the MEL User's Manual (2005). Sample matrix, container, preservation method, and holding time for each parameter are summarized in Table 11. EWI-type samples will be dispensed into the MEL pre-cleaned containers as well. All samples will be placed in the dark, on ice, and received by MEL within 48 hours.

Effluent samples from wastewater treatment facilities during synoptic surveys will be collected by time-weighted composite samplers. Compositor jugs will be pre-cleaned and kept iced throughout the sampling period to maintain the composite at 4ºC. The compositor jug will be thoroughly and continually mixed as aliquots are drawn for samples into pre-cleaned containers from MEL. All samples will be placed in the dark, on ice, and received by MEL within 48 hours.

Periphyton field sampling protocols are adapted from EPA Rapid Bioassessment Protocols (Stevenson and Bahls, 2007). Periphyton biomass samples will be collected by scraping material from a measured surface area on representative rocks. Three samples will be collected at each site. Periphyton biomass samples are collected for laboratory analysis of chlorophyll *a* and ash-free dry weight. Samples will not be collected for speciation. Benthic area coverage by periphyton or macrophytes will be estimated for each site using a grid and random sampling technique. Notes on general periphyton and macrophyte types will be taken (e.g., filamentous, diatoms, reed canary grass, emergent weeds).

Table 11. Containers, preservation methods, and holding times for samples (MEL, 2005) collected from the Hangman Creek watershed for the pH, DO, and nutrient TMDL data surveys.

Parameter	Sample Matrix	Container	Preservative	Holding Time
Chloride	Surface water, WWTP effluent, & runoff	500 mL poly	Cool to 4ºC	28 days
Total Suspended Solids	Surface water, WWTP effluent, & runoff	1000 mL poly	Cool to 4ºC	7 days
Alkalinity	Surface water, WWTP effluent, & runoff	500 mL poly – No Headspace	Cool to 4°C; Fill bottle *completely*; Don't agitate sample	14 days
Ammonia	Surface water, WWTP effluent, & runoff	125 mL clear poly	H_2SO_4 to pH<2; Cool to 4ºC	28 days
Dissolved Organic Carbon	Surface water, WWTP effluent, & runoff	60 mL poly with: Whatman Puradisc™ 25PP 0.45um pore size filters	Filter in field with 0.45um pore size filter; 1:1 HCl to pH<2; Cool to 4°C	28 days
Nitrate/Nitrite	Surface water, WWTP effluent, & runoff	125 mL clear poly	H_2SO_4 to pH<2; Cool to 4ºC	28 days
Total Persulfate Nitrogen	Surface water, WWTP effluent, & runoff	125 mL clear poly	H_2SO_4 to pH<2; Cool to 4ºC	28 days
Orthophosphate	Surface water, WWTP effluent, & runoff	125 mL amber poly w/ Whatman Puradisc™ 25PP 0.45um pore size filters	Filter in field with 0.45um pore size filter; Cool to 4°C	48 hours
Total Phosphorus	Surface water, WWTP effluent, & runoff	125 mL clear poly	1:1 HCl to pH<2; Cool to 4°C	28 days
Total Organic Carbon	Surface water, WWTP effluent, & runoff	60 mL clear poly	1:1 HCl to pH<2; Cool to 4°C	28 days
Biochemical Oxygen Demand	Surface water & WWTP effluent	1 gallon cubitainer	Cool to 4ºC in dark	48 hours
Chlorophyll *a* and Ash-Free Dry Weight	Periphyton	500 mL amber poly	Cool to 4ºC; 24 hrs to filtration	28 days after filtering

All samples for laboratory analysis will be stored in the dark, on ice, and delivered to MEL within 48 hours of collection. The principle investigator will be responsible for finding airline freight schedules, establishing a field collection schedule that meet flight departure times, contacting EAP or MEL couriers, and informing MEL staff of impending sample arrivals. The principle investigator will confirm arrival of samples to MEL the day after collection.

Measurement Procedures

Field

Field measurements will follow approved EAP standard operating procedures (SOPs):

- EAP013 Determining Global Positioning System Coordinates.
- EAP011 Instantaneous Measurement of Temperature in Water.
- EAP023 Winkler Determination of Dissolved Oxygen.
- EAP024 Estimating Streamflow.
- EAP031 Measurement of pH in Freshwater.
- EAP032 Measurement of Conductivity in Freshwater.
- EAP033 Hydrolab® DataSonde and MiniSonde Multiprobes.
- EAP035 Measurement of Dissolved Oxygen in Surface Water.

Sampling sites will be located on maps, and deviations will be recorded in field notes. Deviations farther than 100 yards will be given a new site number. If the site location does not have easily recognizable landmarks, a Global Positioning System (GPS) unit reading will be taken to obtain accurate latitude and longitude. Reading will follow EAP standard operating procedures.

Methods and targets for various field parameters are summarized in Table 12. Hydrolab® Multi-probe meters require daily calibration or daily checks (for deployed DataSondes) to meet precision targets. Care should be taken when using multi-probe meters in shallow water that sediment is not disturbed and that probes are completely submerged. Slow velocities also usually require a longer probe equilibration period. During high flows, a look-out for debris may be needed to prevent damage to meters.

Samples collected for Winker titration should be collected as close to the meter unit as possible and with the least disturbance and air entrainment. Methods of sample collection may vary by local conditions. Multiple samples are recommended if field staff lack confidence that an undisturbed sample can be collected. Samples should be acid-fixed and titrated at the end of the survey day.

Instantaneous flow measurements will be performed at all sites, not co-located with a gage. Gage flow volumes will be calculated from continuous stage-height records and curves developed prior to, and during, the project. Ecology-installed pressure transducers will measure stage height by data logger every 15 minutes. Pressure transducer data will be downloaded monthly. Staff gages may be installed at other sites. Streamflows will be measured or staff gage readings taken at all sites during all field surveys.

Table 12. Targets for precision and reporting limits for Hangman Creek measurements and sample analyses.

Analysis	Method	Expected Range of Values	Duplicate Samples Relative Standard Deviation (RSD)	Method Reporting Limits and/or Resolution
Velocity[1]	Marsh McBirney Flow-Mate Flowmeter	<0.1 – 10 ft/s	0.1 ft/s	0.01 ft/s
Water Temperature[1]	Hydrolab MiniSonde®[3]	1.0 - 30° C	+/- 0.1° C	0.01° C
Water Temperature[1]	Onset TidBit®	1.0 - 30° C	+/- 0.2° C	0.01° C
Specific Conductivity[2]	Hydrolab MiniSonde®	50 – 500 umhos/cm	+/- 0.5%	0.1 umhos/cm
pH[1]	Hydrolab MiniSonde®	6.0 – 9.0 su	0.05 SU	1 to 14 SU
Dissolved Oxygen[1]	Hydrolab MiniSonde®	1.0 – 12 mg/L	5% RSD	0.1 - 15 mg/L
Dissolved Oxygen[1]	Winkler Titration	1.0 – 12 mg/L	+/- 0.1 mg/L	0.01 mg/L

[1]as units of measurement, not percentages.
[2] as percentage of reading, not RSD.
[3] same for both the MiniSonde and DataSonde style of meters.

Dye studies follow USGS procedures (Kilpatrick and Wilson, 1989). The procedures include the following elements:

- Survey planning, resource, and dye requirement calculations.
- Dye procedures, equipment, and data collection descriptions.
- Directions for press releases and notification of authorities.
- Data analysis and presentation suggestions.

Ecology uses Rhodamine WT dye and deploys Hydrolab DataSonde® with Rhodamine WT detectors instead of shore-side sampling. The technique reduces the number of staff needed for sampling, and eliminates the need for generators and creek access close to equipment vehicles.

Hydrolab equipment will be programmed with accurate date and time. Sensitivity to low concentrations (~1 part per billion) of Rhodamine WT will be checked. Calibration to a set of dye standards will not be necessary. Deployment and meter identification information will be recorded in the field notebooks (see details later in this section). The meter's program will record measurements at not more than five-minute intervals. Dye measurements will be recorded until the dye peak has passed. Data will be downloaded to a secondary portable computer as soon as possible, preferably before deployment to the next site.

Field measurements and descriptions of shade, riparian vegetation, and channel geometry characteristics for reference monitoring sites will be conducted. Temperature TMDL protocols (EAP047 and EAP048) will be used for these measurements (Stohr, in progress).

Laboratory

Samples will undergo MEL standard analytical techniques (Table 13) with standard laboratory quality control procedures (MEL, 2006).

Table 13. Targets for precision and reporting limits for Hangman Creek measurements and sample analyses. Duplicate laboratory sample error values include laboratory and field variability. Higher end of range predicted for municipal effluent and storm event samples.

Analysis	Method	Expected Range of Concentrations	Duplicate Samples Relative Standard Deviation (RSD)	Method Reporting Limits and/or Resolution
Chloride	EPA 300.0	0.3 – 100 mg/L	5% RSD[1]	0.1 mg/L
Total Suspended Solids	SM 2540D	1 – 10,000 mg/L	10% RSD[1]	1 mg/L
Turbidity	SM 2130	<1 – 7,000 NTU	10% RSD[1]	1 NTU
Alkalinity	SM 2320	20 – 200 mg/L as $CaCO_3$	10% RSD[1]	10 mg/L
Ammonia	SM 4500-NH_3H	<0.01 – 30 mg/L	10% RSD[1]	0.01 mg/L
Dissolved Organic Carbon	SM 5310B	<1 – 20 mg/L	10% RSD[1]	1 mg/L
Dissolved Nitrate/Nitrite	4500-NO_3I	<0.01 – 30 mg/L	10% RSD[1]	0.01 mg/L
Total Persulfate Nitrogen	SM 4500-NO_3B	0.5 – 50 mg/L	10% RSD[1]	0.025 mg/L
Dissolved Orthophosphate	SM 4500-P G	0.01 – 5.0 mg/L	10% RSD[1]	0.003 mg/L
Total Phosphorous	SM 4500-P F	0.01 – 10 mg/L	10% RSD[1]	0.005 mg/L
Total Organic Carbon	SM 5310B	<1 – 20 mg/L	10% RSD[1]	1 mg/L
Biochemical Oxygen Demand	SM 5210B	<1 – 14 mg/L	25% RSD	2 mg/L
Chlorophyll a	SM 10300	1 – 1000 mg/m^2	30% RSD	1 mg/m^2
Ash-free Dry Weight	SM 10300	1 – 1000 mg/m^2	30% RSD	1 mg/m^2

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

SM = Standard Methods for the Examination of Water and Wastewater, 20th Edition (APHA, AWWA and WEF, 1998).

EPA = EPA Method Code.

Additional pre-processing of periphyton chlorophyll *a* samples is needed (Stevenson and Bahls, 2007). Once received by MEL, these steps should be followed:

1. Homogenize the sample with a tissue homogenizer.
2. Record the initial volume of the sample.
3. Stir the sample on a magnetic stirrer and subsample. Take at least two aliquots from the sample for the chlorophyll *a* subsample.
4. Record the volume of the chlorophyll *a* subsample.
5. Concentrate the chlorophyll *a* on a glass fiber filter.
6. Continue with Standard Methods 10300 procedure to measure chlorophyll *a* content.

Data Quality Objectives

The Hangman Creek watershed surveys require data for subsequent pH and DO TMDL development, and refinement of phosphorus load estimates from areas of the watershed. Previous water quality surveys and data analysis conducted in the watershed have provided useful information for the pH and DO assessments:

- Water temperature patterns
- Seasonal and historical streamflow patterns
- Land and channel erosion impacts on channel sedimentation and turbidity
- Nonpoint and point source phosphorus loading
- Instantaneous pH and DO measurements in several areas of the watershed

The pH and DO TMDLs require association with relevant Washington State criteria, and identification and allocation to sources of water quality impairment. As previously mentioned, the pH and DO criteria are single event maximums or minimums (Table 14). Data collection and analyses must compare criteria to the spatial distribution and range of pH and DO values, especially in 303(d) listed areas. In turn, the mechanisms controlling pH and DO values must be understood, and the causes of impairment need to be quantitatively described. Nonpoint and point sources, climate and hydrology, and physical attributes of the creek need to be assessed for daily, seasonal, and annual effects on pH and DO.

Table 14. A summary of Washington State Water Quality Criteria applicable to Hangman Creek and tributaries for DO and pH.

1997 Standards Classification	Water Quality Parameter	1997 Criteria[1]	2006 Use Revision	2006 Criteria[1]
Class A	Dissolved Oxygen	8.0 mg/l 1-DMin[2]	Salmonid Spawning, Rearing, and Migration	8.0 mg/l 1-DMin[2]
	pH	6.5 to 8.5 units	Salmonid Spawning, Rearing, and Migration	6.5 to 8.5 units

[1] Criteria have been established in the existing water quality standards for specific waterbodies that differ from the general criteria shown in the above table. These special conditions can be found in WAC 173-201A-130 of the 1997 version, and WAC 173-201A-602 of the 2003 version, of the standards.
[2] 1-DMin means the lowest annual daily minimum oxygen concentration occurring in the waterbody.

QUAL2Kw models for Hangman Creek and Rock Creek with point inputs from major tributaries and operating wastewater treatment plants need to simulate the following:

- hydrology
- temperature
- nutrients
- dissolved oxygen
- pH

The QUAL2Kw model requires data for calibrations of longitudinal changes and diurnal ranges during the summer-fall critical season. These data must be accurate to definitively address pH and DO water quality criteria that address daily extremes. The model requires reach-specific data for physical channel and riparian structure, biomass, and chemistry. Calibration data are most helpful for critical condition evaluation when weather conditions are 'warm and sunny' and streamflows are 'low and stable'. These conditions do not always fit survey schedules, but surveys may need to be rescheduled if severe storm or unseasonable conditions are present.

Routine and event monitoring during all seasons are needed to (1) produce improved estimates of cross-border nutrient data for loading analyses, and (2) refine previous WARMF model estimates (Joy, unpublished data). Nutrient load data from upstream of the Washington border needs to be collected from two branches of Rock Creek, Little Hangman Creek, and the Hangman Creek mainstem.

The data need to be of sufficient quality and quantity to derive seasonal and annual load estimates using a multiple regression statistical model (Cohn, 2002) or a Beales ratio-estimator load statistical method (Dolan at al., 1981). Daily average discharge data are necessary for the multiple regression statistical model. Monthly or seasonal average flows with sample coincidental flows are needed for the ratio-estimator method. Nutrient sample data require various levels of precision and accuracy (addressed in *Sampling Procedures* section). Calibration of the WARMF model has the same data requirements.

Also, water quality characterization to estimate 'natural' or 'background' values is needed for nutrient load allocation estimates. The reference area monitoring is complicated by the multiple ecoregions in the watershed that may have unique characteristics. The task will require care in locating appropriate sites in the four EPA Level IV Ecoregions (Figure 3):

- 15v Northern Idaho Hills.
- 15s Spokane Valley Outwash Plains.
- 10h Palouse Hills.
- 10a Channeled Scablands.

The exact boundaries between ecoregions are not known. Undisturbed sites within each area may be difficult to locate and/or to gain access. Data from reference sites require care in being representative spatially and temporally so that seasonal error bounds can be determined. Nutrient samples, and physical and associated chemical measurements, will be needed for all seasons for background load allocation assessment.

Quality Control

Measurement quality objectives

Measurement quality objectives (MQOs) refer to the performance or acceptance criteria for individual data quality indicators such as precision, bias, and lower reporting limit. MQOs provide the basis for determining the procedures that should be used for sampling and analysis.

Field studies are designed to generate data adequate to reliably estimate the temporal and spatial variability of that parameter. Sampling, laboratory analysis, and data evaluation steps have several sources of error that should be addressed by MQOs. Accuracy in laboratory measurements can be more easily controlled than field sampling variability. Analytical bias needs to be as low and precision as high as possible in the laboratory. Sampling variability can be controlled somewhat by strictly following standard procedures and collecting quality control samples, but natural spatial and temporal variability can contribute greatly to the overall variability in the parameter value. Resources limit the number of samples that can be taken at one site spatially or over various time intervals. Finally, laboratory and field errors are further amplified by estimate errors in loading calculations and model results.

Precision is the degree of agreement between replicate analyses of a sample under identical conditions and is a measure of the random error associated with the analysis, usually expressed as Relative Percent Difference (RPD) or Relative Standard Deviation (RSD) (Lombard and Kirchmer, 2004).

Accuracy is the measure of the difference between an analytical result and the true value, usually expressed as percent. The accuracy of a result is affected by both systematic errors (bias) and random errors (imprecision).

Bias is the systematic or persistent distortion of a measurement process that causes errors in one direction. Some bias can be assessed using blanks, spikes, and check standards.

Precision, *accuracy*, and *bias* for water quality data may be measured by one or more of the following quality control procedures: method blanks, matrix spikes, certified reference materials, replicates, positive controls, and negative controls. These are discussed in following sections.

Representativeness expresses the degree to which sample data accurately and precisely represent a characteristic of a population, parameter variations at the sampling point, or an environmental condition. Samples for analysis will be collected from stations with pre-selected coordinates to represent specific site locations. Sample collection procedures are assigned to minimize variations, potential contamination, and other types of degradation in the chemical and physical composition of the water. Following standard field protocols will ensure that samples are representative. Laboratory representativeness is achieved by proper preservation and storage of samples along with appropriate sub-sampling and preparation for analysis.

Completeness is defined as the total number of samples analyzed for which acceptable analytical data are generated, compared to the total number of samples collected. Sampling at stations with known position coordinates in favorable conditions and at the appropriate time points, along with adherence to standardized sampling and testing protocols, will aid in providing a complete data set for this project. The goal for completeness is 100%.

Comparability is a qualitative parameter expressing the confidence with which one data set can be compared with another. This goal is achieved through using standardized techniques to collect and analyze representative samples, along with standardized data validation and reporting procedures.

Field and laboratory quality control

Continuous or instantaneous Hydrolab meter measurements collected at each sampling event will conform to the quality control parameters in Table 15. Quality control measurements will be taken at intervals summarized in Table 16. Meter DO measurements may be compared to Winkler samples or a second meter that has been allowed to equilibrate to local conditions. The meter pH, temperature, and conductivity measurements may be compared to standard solutions, a hand-held thermometer reading, or a second meter. Pre- and post-deployment calibration checks will be conducted and recorded with survey data.

Table 15. Hydrolab® equipment individual probe quality control requirements.

Parameter	Replicate Samples	Field Calibration Check Standards	Calibration Drift End Check
Dissolved Oxygen	RPD ≤ 20%	Not applicable	± 4 %
Temperature	± 0.3 °C	Not applicable	Not applicable
Conductivity	RPD ≤ 10%	± 10 %	± 10 %
pH	± 0.2 pH units	± 0.2 pH units	± 0.2 pH units

A second multiprobe meter or DO Winkler samples and independent pH and conductivity field meters will be used to verify calibration of Hydrolab Multiprobes as directed under the SOP EAP033. Total variability for laboratory analysis will be assessed by collecting replicate samples. Sample precision will be assessed by collecting replicates for 10-20% of samples in each survey (Table 16). Field blanks and filter blanks will be submitted with each sampling run to assess some areas of bias. MEL routinely duplicates sample analyses in the laboratory (Lab Duplicate) to determine laboratory precision. The difference between field variability and laboratory variability is an estimate of the sample field variability.

MEL will inform the project manager or principle investigator as soon as possible if any sample is lost, damaged, has a lost tag, or gives an unusual result.

Table 16. Summary of field and laboratory quality control samples and intervals.

Analysis	Field Replicates	Lab Check Standard	Lab Method Blank	Lab Duplicate	Matrix Spikes
Field Measurements					
Velocity/Discharge	1/day	N/A	N/A	N/A	N/A
Temperature	1/10 samples	N/A	N/A	N/A	N/A
Dissolved Oxygen	1/10 samples	N/A	N/A	N/A	N/A
Specific Conductivity	1/10 samples	1/run	N/A	N/A	N/A
pH	1/10 samples	1/10 samples	N/A	N/A	N/A
Laboratory Analyses					
Dissolved Oxygen (Winkler)	1/10 samples	N/A	N/A	N/A	N/A
Chlorophyll a (periphyton)	1/5 samples	N/A	N/A	1/5 samples	N/A
Biochemical Oxygen Demand (5-day)	1/10 samples	Sugar check	1/batch	1/20 samples	N/A
Chloride	1/10 samples	1/batch	1/batch	1/20 samples	1/20 samples
Total Organic Carbon	1/10 samples	1/batch	1/batch	1/20 samples	1/20 samples
Dissolved Organic Carbon	1/10 samples	1/batch	1/batch	1/20 samples	1/20 samples
Alkalinity	1/10 samples	1/batch	N/A	1/20 samples	N/A
Total Nitrogen	1/10 samples	1/batch	1/batch	1/20 samples	1/20 samples
Ammonia Nitrogen	1/10 samples	1/batch	1/batch	1/20 samples	1/20 samples
Nitrate + Nitrite Nitrogen	1/10 samples	1/batch	1/batch	1/20 samples	1/20 samples
Orthophosphate	1/10 samples	1/batch	1/batch	1/20 samples	1/20 samples
Total Phosphorus	1/10 samples	1/batch	1/batch	1/20 samples	1/20 samples
Ash-free Dry Weight (periphyton)	1 /5 samples	1/batch	1/batch	1/5 samples	N/A

Model quality control

WARMF and QUAL2Kw models and other mathematical analyses will be developed to simulate observed seasonal, annual and daily critical conditions. Model time-steps will be appropriate for the data collected and simulated. Daily time-steps will be used to simulate critical conditions in this watershed for nutrient and BOD loadings that are typically run-off events and seasonally high streamflows. Critical conditions for DO and pH are characterized by a period of low-flow and high-water temperatures (July – September) but require hourly time steps.

Sensitivity analysis 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) or Nash-Sutcliffe coefficient. The RMSE is a commonly used measure of model variability (Reckhow et al., 1986). The RMSE is defined as the square root of the mean of the squared difference between the observed and simulated values. Nash-Sutcliffe coefficient of efficiency (Nash and Sutcliffe, 1970) measures model errors in estimating the mean or variance of the observed data sets. It is more sensitive to outliers in continuous simulation output than the RMSE.

Synoptic surveys will provide calibration and verification runs to ensure the QUAL2Kw model is robust. Unless a defensible reason for simulation differences can be presented, rates and coefficients for the model may need to be adjusted to a 'compromise' value to provide the best match to observed data from both surveys. Inputs will closely match observed values and calculated estimates, e.g., tributary streamflows calculated from upstream and downstream mainstem differences. Rates and coefficients will be verified that they are within the range of literature and research values.

Data Management Procedures

Field measurement data will be entered from the field book into EXCEL® spreadsheets (Microsoft, 2007) as soon as practical after returning from the field. Hydrolab recovered data and gage recording data likewise will be downloaded into a central database. This database will be used for preliminary analysis and to create a table to upload data into Ecology's Environmental Information Management (EIM) System. The database will be held in a computer space with a daily automatic back-up routine to a remote/separate computer.

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.

All continuous data will be stored in a project database that includes station location information and data quality assurance information. This database will facilitate summarization and graphical analysis of the pH and DO data and also create a data table to upload the data to Ecology's statewide EIM geospatial database.

An EIM user study ID (JJOY0005) has been created for this TMDL 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: apps.ecy.wa.gov/eimreporting. All data will be uploaded to EIM by the EIM engineer after all data have been reviewed for quality assurance and finalized.

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

Audits and Reports

The project manager will be responsible for submitting semi-annual reports and the final technical study report to Ecology's Eastern Regional Office Water Quality Program TMDL coordinator for this project, according to the project schedule. MEL will supply quality assurance statements with paper copies of the laboratory data as it is entered into LIMS.

Data Verification

Laboratory-generated data reduction, review, and reporting will follow the procedures outlined in the MEL Users Manual (MEL, 2005). Lab results will be checked for missing and improbable data. Variability in lab duplicates will be quantified using the procedures outlined in the MEL Users Manual (MEL, 2005). Any estimated results will be qualified and their use restricted as appropriate. A standard case narrative of laboratory quality assurance/quality control 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 is complete. Data entry will be checked against the field notebook data for errors and omissions. Missing or unusual data will be brought to the attention of the project manager for consultation. Valid data will be moved to a separate file labeled FINAL.

Data received from LIMS will be checked for omissions against the Request for Analysis forms by the field lead. Data can be in EXCEL® spreadsheets (Microsoft, 2007) or downloaded tables from EIM. These tables and spreadsheets will be located in a file labeled DRAFT until data verification is completed. Field replicate sample results will be compared to quality objectives in Table 13. Data requiring additional qualifiers will be reviewed by the project manager.

After data verification and data entry tasks are completed, all field, laboratory, and flow data will be entered into a file labeled FINAL and then into the EIM system. EIM data will be independently reviewed by another EAP field assistant for errors at an initial 10% frequency. If significant entry errors are discovered, a more intensive review will be undertaken.

At the end of the field collection phase of the study, the data will be compiled in a data summary. Semi-annual reports will be available during the data collection period of the project.

Data Usability, Analyses, and Use

The field lead will verify which measurement and data quality objectives have been met for each monitoring station. For example if the objectives have not been met, such as if the %RSD for phosphorus replicates exceeds the MQO or a Hydrolab shows signs of malfunctioning, then the field lead and project manager will decide whether to delete non-credible data or how to qualify the data. All data considered credible will be available in EIM and for use in the analyses with appropriate qualifiers and comments taken into account. Data may be eliminated from statistical or graphical analysis after careful consideration of all quality control processes.

The field investigator will produce a data summary and quality assurance report that will include at a minimum: site descriptions, data quality assurance notes, calculations of quality assurance measures and comparison to Quality Assurance Project Plan MQOs, and graphs of all continuous data.

Once quality steps have been completed, data are fit for analysis. Data analysis will include evaluation of data distribution characteristics and, if necessary, appropriate distribution of transformed data. Estimation of univariate statistical parameters and graphical presentation of the data (box plots, time series, and regressions) will be made using WQHYDRO (Aroner, 2003) and EXCEL® (Microsoft, 2007) software.

Means, maximums, minimums, and 90th percentiles will be determined from the raw data collected at each monitoring location. Estimates of groundwater inflow will be calculated by constructing a water mass balance from continuous and instantaneous streamflow data with time-of-travel calculations taken into consideration.

Water quality modeling will be conducted using QUAL2Kw (Pelletier and Chapra, 2003) and Watershed Analysis Risk Management Framework (WARMF).

QUAL2Kw will be used for critical pH and DO condition modeling tasks. The model uses kinetic formulations for simulating DO and pH in the water column similar to those shown in Figure 4 and Table 17. QUAL2Kw will be used to analyze the fate and transport of water quality variables relating to nutrients, periphyton, DO, and pH interactions in the water column. The water quality model will be developed to simulate dynamic variations in water quality of Hangman Creek and Rock Creek. The water quality model will be calibrated and corroborated using data collected during the two synoptic surveys and any other historical data collected to the extent possible.

QUAL2K will be applied by assuming that flow remains constant (i.e., steady flows) for a given condition such as a 7-day or 1-day period (using daily average flows), but key variables other than flow will be allowed to vary with time over the course of a day. For QUAL2K temperature simulation, the solar radiation, air temperature, relative humidity, headwater temperature, and tributary water temperatures are specified or simulated as diurnally varying functions.

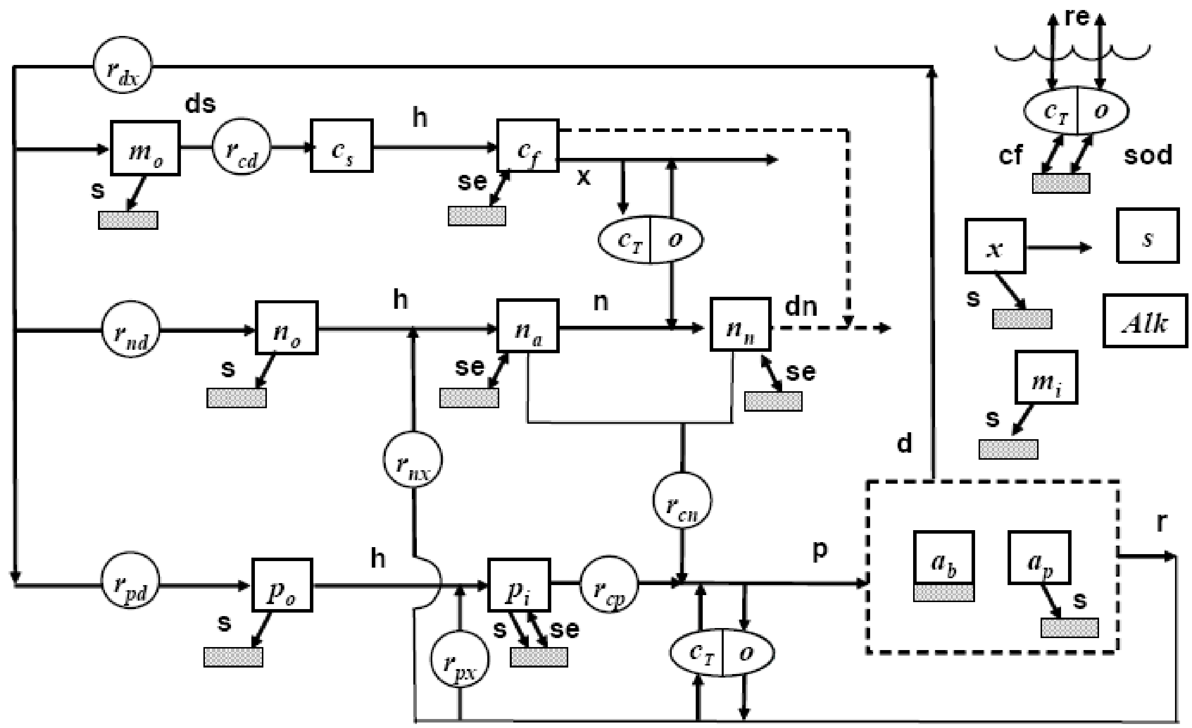

Figure 4. Model kinetics and mass transfer processes in QUAL2Kw and GEMSS.

The state variables are defined in Table 8.

Kinetic processes are dissolution (ds), hydrolysis (h), oxidation (x), nitrification (n), denitrification (dn), photosynthesis (p), death (d), and respiration/excretion (r).

Mass transfer processes are reaeration (re), settling (s), sediment oxygen demand (SOD), sediment exchange (se), and sediment inorganic carbon flux (cf).

Note that the subscript x for the stoichiometric conversions stands for chlorophyll a (a) and dry weight (d) for phytoplankton and bottom algae, respectively. For example: r_{px} and r_{nx} are the ratio of phosphorus and nitrogen to chlorophyll a for phytoplankton, or the ratio of phosphorus and nitrogen to dry weight for bottom algae; rdx is the ratio of dry weight to chlorophyll a for phytoplankton or unity for bottom algae; r_{nd}, r_{pd}, and r_{cd} are the ratios of nitrogen, phosphorus, and carbon to dry weight.

Table 17. Model state variables.

Variable	Symbol	Units*	Measured as
Conductivity	s	μmhos	COND
Inorganic suspended solids	m_i	mgD/L	TSS-VSS
Dissolved oxygen	o	mgO_2/L	DO
Slow-reacting CBOD	c_s	mg O_2/L	-
Fast-reacting CBOD	$c_{f,}$	mg O_2/L	r_{oc} * DOC or CBODU
Organic nitrogen	n_o	μgN/L	TN – NO3N NO2N– NH4N
Ammonia nitrogen	n_a	μgN/L	NH4N
Nitrate nitrogen	n_n	μgN/L	NO3N+NO2N
Organic phosphorus	p_o	μgP/L	TP - SRP
Inorganic phosphorus	p_i	μgP/L	SRP
Phytoplankton	a_p	μgA/L	CHLA
Detritus	m_o	mgD/L	r_{dc} (TOC – DOC)
Alkalinity	Alk	mg$CaCO_3$/L	ALK
Total inorganic carbon	c_T	mole/L	Calculation from pH and alkalinity
Bottom algae biomass	a_b	gD/m^2	Periphyton biomass dry weight
Bottom algae nitrogen	IN_b	mgN/m^2	Periphyton biomass N
Bottom algae phosphorus	IP_b	mgP/m^2	Periphyton biomass P

* mg/L ≡ g/m^3
D=dry weight
A=chlorophyll a
roc = stoichiometric ratio of oxygen for hypothetical complete carbon oxidation (2.69)

The following are measurements that are needed for comparison with model output:

TEMP = temperature (^{o}C)

TKN = total kjeldahl nitrogen (μgN/L) or TN = total nitrogen (μgN/L)

NH4N = ammonium nitrogen (μgN/L)

NO2N = nitrite nitrogen (μgN/L)

NO3N = nitrate nitrogen (μgN/L)

CHLA = chlorophyll *a* (μgA/L)

TP = total phosphorus (μgP/L)

SRP = soluble reactive phosphorus (μgP/L)

TSS = total suspended solids (mgD/L)

VSS = volatile suspended solids (mgD/L)

TOC = total organic carbon (mgC/L)

DOC = dissolved organic carbon (mgC/L)

DO = dissolved oxygen (mgO_2/L)

PH = pH

ALK = alkalinity (mg$CaCO_3$/L)

COND = specific conductance (μmhos/cm)

The WARMF model has been previously used in the Hangman Creek watershed for phosphorus and suspended sediment load evaluations (Joy et al., 2008; Joy, unpublished data). Depending on the outcome of the limiting nutrient evaluation, nitrogen load analyses may be added. The WARMF model has been calibrated, but datasets from these surveys will allow calibration to additional sites and verification/correction of background input values. The WARMF model output will be used to compare loads from various source types and geographic locations. The output is also instructive for evaluating pollutant transport times through the watershed.

Project Organization

The following people are involved in this project. All are employees of the Washington State Department of Ecology.

Table 18. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Elaine Snouwaert Water Quality Program Eastern Regional Office (509) 329-3503	Overall Project Lead	Acts as point of contact between EAP staff and interested parties. Coordinates information exchange. Forms technical advisory team and organizes meetings. Reviews the QAPP and technical report. Prepares and implements TMDL report for submittal to EPA.
David T. Knight Water Quality Program Eastern Regional Office (509) 329-3590	Unit Supervisor of Project Lead	Approves TMDL report for submittal to EPA.
Joe Joy Eastern Operations Section EAP (360) 407-6486	Project Manager	Writes the QAPP, coordinates field surveys with principal investigator, analyzes and interprets data, enters data into EIM, and writes the technical sections of the draft report and final TMDL report.
Tighe Stuart Eastern Operations Section EAP (509) 329-3476	Principal Investigator	Oversees field operations, recruits field assistants, and coordinates with the laboratory, conducts QA review of data, collects field samples and records field information, and writes data summary under the supervision of the project manager.
Gary Arnold Eastern Operations Section EAP (509) 454-4244	Section Manager of Project Manager	Approves the QAPP and technical sections of the TMDL report.
Stuart Magoon Manchester Environmental Laboratory, EAP (360) 871-8801	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 EAP (360) 407-6964	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 19. Proposed schedule for completing field and laboratory work, data entry into EIM, and reports.

Field and laboratory work	
Field work completed	October 2009
Laboratory analyses completed	November 2009
Environmental Information System (EIM) system	
EIM data engineer	Dan Sherratt
EIM user study ID	JJOY0005
EIM study name	Hangman Creek Dissolved Oxygen and pH TMDL
Data due in EIM	February 2010
Semi-annual and Data reports	
Author lead	Joe Joy or Tighe Stuart
Schedule	
1st semi-annual report	June 2009
2nd semi-annual report	December 2009
Data Summary	February 2010
Final report	
Author lead	Joe Joy
Schedule	
Draft due to supervisor	June 2010
Draft due to client/peer reviewer	June 2010
Draft due to external reviewer	August 2010
Final report due on web	October 2010

Laboratory Budget

The estimated laboratory budget and lab sample load in Table 20 is based on the proposed schedule in Table 19. Costs are approximately $58,700 for FY09 and $34,800 for FY10. The project manager and principle investigator will communicate closely with MEL so that monthly and weekly laboratory sample loads will not overload MEL capacity.

The greatest uncertainty in the laboratory load and cost estimate is with the number of reference sites, the number of dry channel (no sample) events, and the run-off survey work. Efforts will be made to keep the submitted number of samples within the estimate. However, because the reference and runoff survey sites have not been selected yet, this is an estimate only.

Table 20. The number of monthly sample submittals for each analysis, an estimate of the monthly analytical costs, and the total analytical cost estimate[1] for the project.

Type of Survey		No. of sites	QA samples survey	Price ($)	Total per Survey ($)	No. of surveys	Analysis cost/task ($)
Border & Reference Sites	10 (4 border & 6 reference)						
Alkalinity		10	2	16	192	16	3,072
Nutrients (5)		10	2	79	948	16	15,168
Chloride		10	2	12	144	16	2,304
TSS		10	2	10	120	16	1,920
TOC		10	2	30	360	16	5,760
DOC		10	2	32	384	16	6,144
					2,148		*34,368*
Synoptic Surveys	35 (30 ambient & 5 WWTP-related)						
Nutrients (5)		70	8	79	6,162	2	12,324
Chloride		70	8	12	936	2	1,872
BOD5		4	1	50	250	2	500
TOC		70	8	29	2,262	2	4,524
DOC		70	8	29	2,262	2	4,524
Alkalinity		70	8	14	1,092	2	2,184
Periphyton	Ash-free dry weight	18	2	12	240	2	480
	Chlorophyll a	18	2	48	960	2	1,920
					14,164		*28,328*
Run-off Event Monitoring							
Nutrients (5)		50	5	79	4,345	3	13,035
Chloride		50	5	12	660	3	1,980
TSS		50	5	10	550	3	1,650
TOC		50	5	30	1,650	3	4,950
BOD5		8	2	50	500	3	1,500
					7,705		*23,115*
Reconnaissance Survey	22 (20 ambient & 2 WWTP-related)						
Nutrients (5)		44	2	79	3,634	1	3,634
Chloride		44	2	12	552	1	552
BOD5		2	1	50	150	1	150
TOC		44	2	29	1,334	1	1,334
DOC		44	2	29	1,334	1	1,334
Alkalinity		44	2	14	644	1	644
					7,648		*7,648*
						Total for Study	**93,459**

[1] Costs include 50% discount for Manchester Laboratory

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Appendix. Glossary and Acronyms

Ambient monitoring: A strategy of collecting samples from a fixed network of stations to determine existing conditions.

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 condition: 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 waterbody or segment, regardless of whether or not the uses are currently attained.

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

Dilution factor: The relative proportion of effluent to stream (receiving water) flows occurring at the edge of a mixing zone during critical discharge conditions as authorized in accordance with the state's mixing zone regulations at WAC 173-201A-100. apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-020

Diurnal: Of, or pertaining to, a day or each day; daily. (1) Occurring during the daytime only, as different from nocturnal or crepuscular, or (2) Daily; related to actions which are completed in the course of a calendar day, and which typically recur every calendar day (e.g., diurnal temperature rises during the day, and falls during the night).

Load allocation: The portion of a receiving waters' loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading capacity: The greatest amount of a substance that a waterbody can receive and still meet water quality standards.

Margin of safety: Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving waterbody.

Municipal separate storm sewer systems (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains): (1) owned or operated by a state, city, town, borough, county, parish, district, association, or other public body having jurisdiction over disposal of wastes, storm water, or other wastes and (2 designed or used for collecting or conveying stormwater; (3) which is not a combined sewer; and (4) which is not part of a Publicly Owned Treatment Works (POTW) as defined in the Code of Federal Regulations at 40 CFR 122.2.

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.

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: Such 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 is 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.

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

Salmonid: Any fish that belong to the family *Salmonidae*. Basically, 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.

Synoptic sampling: A strategy of collecting samples in an intensive network of sites to define and characterize a particular event or condition.

System potential: The design condition used for TMDL analysis.

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from 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.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report.

BMP	best management practices
BOD	biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
CdA	Coeur d'Alene Tribe
cfs	cubic feet per second
DO	dissolved oxygen
DOC	dissolved organic carbon
EAP	Environmental Assessment Program
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
MEL	Manchester Environmental Laboratory
NAF	New Approximation Flow
NPDES	National Pollution Discharge Elimination System
NSDZ	near-stream disturbance zones
RM	river mile

RSD	relative standard deviation
SCDD	Spokane County Conservation District
SOP	standard operating procedure
SU	standard unit
TIR	thermal infrared radiation
TMDL	Total Maximum Daily Load (water cleanup plan)
TOC	total organic carbon
TSS	total suspended solids
USFS	United States Forest Service
USGS	United States Geological Survey
WAC	Washington Administrative Code
WARMF	Watershed Analysis and Risk Management Framework
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resources Inventory Area
WWTP	wastewater treatment plant