Quality Assurance Project Plan

Lower Yakima River Temperature and Eutrophication Modeling

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

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Federal Clean Water Act 1996 303(d) Listings Addressed in this Study. See Section 3.3.

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Cover photo: Yakima River below Chandler Power Plant. Photo by Paul Pickett.

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Signatures are not available on the Internet version.
TMDL: Total Maximum Daily Load
WQP: Water Quality Program
EAP: Environmental Assessment Program

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2.0 Abstract

Monitoring of the lower Yakima River has found impairment of water quality conditions for temperature, dissolved oxygen, and pH. Between 2004 and 2007, the United States Geological Survey conducted an eutrophication study of the lower Yakima River, collecting an extensive data set. This Quality Assurance Project Plan describes the study design and quality assurance measures for developing a water quality model of the lower Yakima River for the impaired parameters based on this data set. Modeling results will be used to support future water quality restoration work in the lower Yakima River.

3.0 Background

3.1 Introduction and problem statement

Data collected over decades show that the lower Yakima River does not meet Washington State's water quality aquatic life criteria for temperature, dissolved oxygen (DO), and pH. Because of these impairments, the Washington State Department of Ecology's (Ecology's) Water Quality Program (WQP) requested that Ecology's Environmental Assessment Program develop a water quality model of the lower Yakima River for these parameters.

Over the last several years, Ecology participated with federal agencies, tribes, environmental groups, and irrigators in developing the *Yakima River Basin Integrated Water Resources Management Plan* (YBIP[1]). The focus of the YBIP is on municipal and agricultural water supply and on the restoration of fisheries in the basin. This study presents an opportunity to (1) develop an analytical tool for assessing pollution impacts and the potential effects of water pollution program reduction actions and (2) predict potential changes to water quality in the lower Yakima River from changes in water and land use management. The goal of the pollution reduction projects in the lower Yakima River is restoration of water quality, guided by overall regional efforts to restore fisheries.

3.2 Study area and surroundings

The Yakima River basin drains the east slopes of the Cascade Mountains and enters the Columbia River near the cities of Richland and Kennewick (Figure 1 – see Section 16 for figures). The upper basin lies in Kittitas County, the central basin in Yakima County, and the lower basin in Benton County. Ellensburg, Yakima, and Richland are the largest municipalities in the basin, and there are many other smaller cities. The Reservation of the Confederated Tribes and Bands of the Yakama Nation (Yakama Nation, or YN) lies on the west bank of the Yakima River from Ahtanum Creek near Union Gap to Mabton, and the river in this reach flows mostly within the boundaries of the Yakama Nation Reservation (Figure 2).

Figure 2 shows the study area for this project is the lower Yakima River, which in this context extends from Selah Gap above the Naches River to a few miles upstream of the Yakima River's

[1] http://www.ecy.wa.gov/programs/wr/cwp/YBIP.html; Reclamation and Ecology, 2011

confluence with the Columbia River near Richland, a distance of 112 river miles. The river runs through a region of highly productive agricultural lands, renowned in particular for fruit tree crops, wine grapes, and hops. The urban areas of Yakima and Richland lie at the upper and lower ends, respectively, of the study area. The highest elevations of the Yakima River watershed are forested, mostly National Forest and Yakama Nation Reservation lands, and the surrounding hills are scrub steppe grasslands.

The Yakima River is a highly managed system. The U.S. Bureau of Reclamation owns and operates five major reservoirs in the system: Keechelus Reservoir (Yakima River), Kachess Reservoir (Kachess River), and Cle Elum Reservoir (Cle Elum River) at the upstream end of the upper Yakima Valley; and Bumping Lake (Bumping River) and Rimrock Lake (Tieton River) on tributaries to the Naches River (Figure 3). Although these five reservoirs are all outside the study area, they are the dominant drivers of flows entering the lower Yakima River.

Flows in the lower Yakima River are also significantly affected by the operations of many irrigation districts. The largest of these are:

- Roza Irrigation District
- Selah-Moxee Irrigation District
- Sunnyside Valley Irrigation District
- Wapato Irrigation Project
- Kennewick Irrigation District
- Columbia Irrigation District

3.2.1 History of study area

Water use and control within the Yakima River basin are of primary interest to people working in community development, agricultural irrigation, and restoration of fish runs to the river. Increasing development of agriculture and demand of expanding populations since the 1870s has focused attention on expanding the withdrawal and use of Yakima River water. During the first half of the 20th century, federal projects created reservoirs, cleared habitat, and built levees to support agricultural and municipal development.

Management of water volumes for human uses has changed the distribution of water throughout the year in the Yakima River from natural and historical conditions. Original conditions flowed highest during the spring snowmelt and lowest during summer. Because irrigation water delivery has been mandated by Congress and court adjudications, water volumes now flow high during summer in the Yakima.

In the latter decades of the century, Congress and the courts have mandated that fishery concerns be addressed, including defining minimum flows levels in the lower Yakima River. Driven by these fishery mandates and agricultural losses during drought years, more than 35 government and stakeholder groups met for 12 years, culminating in 2010 with the YBIP. The YBIP plans for large-scale projects designed to ensure additional flow volumes to support fish and increase supply during drought years. It also has a component for restoration of the watershed, riparian areas, and fish habitat.

3.2.2 Summary of previous studies and existing data

Pickett (2016) provides a detailed summary of past studies and data. Relevant past studies have included modeling of Yakima River temperatures; modeling of DO and pH in the lower Yakima River below Prosser; numerous studies of hydrogeology, groundwater, flood plain morphology, and thermal regimes; routine ambient monitoring; and a reconnaissance survey during the summer of 2015. The most relevant studies are described below. Past studies and data described in that memorandum represent supporting information to meet the goals of this Quality Assurance Project Plan (QAPP).

Of particular interest to this study is the United States Geological Survey (USGS) study of eutrophication in the lower Yakima River (USGS, 2009). Figure 2 shows the study area for that study. Given the central role of the USGS study in this proposed modeling study, its abstract is provided here:

> *In response to concerns that excessive plant growth in the lower Yakima River in south-central Washington was degrading water quality and affecting recreational use, the U.S. Geological Survey and the South Yakima Conservation District conducted an assessment of eutrophication in the lower 116 miles of the river during the 2004–07 irrigation seasons (March–October). The lower Yakima River was divided into three distinct reaches based on geomorphology, habitat, aquatic plant and water-quality conditions. The Zillah reach extended from the upstream edge of the study area at river mile (RM) 116 to RM 72, and had abundant periphyton growth and sparse macrophyte growth, the lowest nutrient concentrations, and moderately severe summer dissolved oxygen and pH conditions in 2005. The Mabton reach extended from RM 72 to RM 47, and had sparse periphyton and macrophyte growth, the highest nutrient conditions, but the least severe summer dissolved oxygen and pH conditions in 2005. The Kiona reach extended from RM 47 to RM 4, and had abundant macrophyte and epiphytic algae growth, relatively high nutrient concentrations, and the most severe summer dissolved oxygen and pH conditions in 2005.*
>
> *Nutrient concentrations in the lower Yakima River were high enough at certain times and locations during the irrigation seasons during 2004–07 to support the abundant growth of periphytic algae and macrophytes. The metabolism associated with this aquatic plant growth caused large daily fluctuations in dissolved oxygen concentrations and pH levels that exceeded the Washington State water-quality standards for these parameters between July and September during all 4 years, but also during other months when streamflow was unusually low. The daily minimum dissolved oxygen concentration was strongly and negatively related to the preceding day's maximum water temperature—information that could prove useful if a dissolved oxygen predictive model is developed for the lower Yakima River.*
>
> *Periphytic algal growth generally was not nutrient-limited and frequently reached nuisance levels in the Zillah reach, where some surface-water nutrient concentrations were below the reference concentrations suggested by the U.S. Environmental Protection Agency. Although lowering nutrient concentrations in this reach might limit periphytic algal growth enough to improve dissolved oxygen and pH conditions, groundwater inflow at some locations might still provide an adequate supply of nutrients for periphytic algal growth.*

Macrophyte growth in the Kiona reach was dominated by water stargrass (Heteranthera dubia), was far greater compared to the other two reaches, varied greatly between years, and was negatively related to greater spring runoff due to lower light availability. Lowering nutrient concentrations in the Kiona reach might not impact the level of macrophyte growth because macrophytes with extensive root systems such as water stargrass can get nutrients from river sediment. In addition, the results from this study did not indicate any nutrient uptake by the macrophytes from the water column (nutrient uptake from the sediment was not examined). Creating the prolonged turbid and deep conditions during spring necessary to suppress macrophyte growth in this reach would not be possible in years with low streamflow. In addition, because of the relatively stable substrate present in much of this reach, the macrophyte root systems would likely not be disturbed under all but the most extremely high streamflows that occur in the lower Yakima River.

Other studies provide useful information that could support model development and quality assessment:

- USGS developed a temperature model for the Yakima River, based on monitoring (USGS, 2008). The SNTEMP modeling framework was used, and the study domain was from the Roza Dam to the Prosser Dam. SNTEMP is a steady-state model that calculates daily average temperatures, and then estimates daily maximum temperatures from a separate algorithm. The USGS SNTEMP model was applied in several other studies, including a decision-support system to evaluate flow and temperature in the Yakima River.
- Carroll and Joy (2001) modeled the lower Yakima River with the QUAL2E model from above Prosser Dam to the Highway 182 bridge 5 miles above the mouth. Modeling of DO was limited by the fact that phytoplankton alone could not explain the DO diurnal variations, so they used a simple assumption (negative SOD) to estimate periphyton DO productivity. The study did not evaluate pH.
- USGS developed a basin-wide groundwater model (USGS, 2011). The model is based on the MODFLOW modeling framework. The model includes tributaries, agricultural drains, recharge, and pumpage. The model was calibrated to conditions for October 1959 to September 2001, and provides a 42-year record of monthly water budgets.

3.2.3 Parameters of interest and potential sources

This study focuses on temperature, DO, and pH. All of these parameters play an important role in providing healthy habitat for salmonids and other aquatic life.

Of these three parameters, temperature has received the most attention from the fishery restoration efforts in the Yakima. High temperatures in the lower Yakima River are known to reach levels in the summer that are lethal to salmonids, creating a barrier to migration. As part of Yakima River water management, a volume of reservoir water has been set aside to be released at the call of fishery managers to create a cold water pulse during a period of cool summer weather. The sudden and rapid migration of salmon during this pulse is well documented.

Studies have shown that the primary causes of high temperatures in the lower Yakima include:

- Hot air temperatures combined with dry, clear days in the summer. The mouth of the river is located in the area with the hottest summer temperatures in Washington.
- A wide, shallow river with little riparian vegetation to provide shade. Historical evidence suggests that this may be a natural state in parts of the river, such as downstream of Prosser.
- Loss of floodplain and riparian functions due to channelization; development on the flood plains; disconnection of the floodplain by levees and other structures; and reductions in spring flood flows due to reservoir management.
- Low flows due to water diversions. However, it’s likely that, compared to pre-development hydrology, flows now are higher in much of the river during the summer due to reservoir releases. In addition, fishery needs are being addressed by current water management, which requires minimum flows in critical locations, such as below Parker and below Prosser.

Low DO and high pH are primarily driven by productivity in the river, as noted in the abstract above from USGS (2009). The most likely sources of nutrient loading are from agriculture return flows and wastewater discharges, while stormwater may also be a factor. However, given the dense growths of aquatic macrophytes observed in the river, internal cycling of nutrients between the plants and sediment is likely also a process of interest. Also noted by USGS (2009) are the effects of sediment loading, such as scour and light limitation, which may also be factors in macrophyte growth.

There are 265 facilities in the upper and lower Yakima River basins that are covered by a National Pollutant Discharge Elimination System (NPDES) or State Waste Discharge permit. These include individual permits and several general permits. NPDES municipal wastewater treatment plants that discharge into (or near) the lower Yakima River study area include:

- Selah (Selah Ditch)
- Yakima
- Buena (unnamed tributary)
- Zillah
- Toppenish (E. Toppenish Cr.)
- Granger
- Sunnyside (Joint Drain 334, Sulfur Cr.)
- Wapato (Marion Drain)
- Harrah (Marion Drain)
- Mabton
- Grandview
- Prosser
- Benton City
- Richland
- West Richland

The USGS eutrophication study (USGS, 2009) sampled 30 tributaries, wastewater discharges, and agricultural drains.

3.2.4 Regulatory criteria or standards

Washington water quality standards and 303(d) listings

Ecology, under its delegated Clean Water Act (CWA) authority, has established water quality standards as state regulations (Ecology, 2011). These standards identify designated uses for the state's waters, establish numeric criteria to protect those beneficial uses, and describe mechanisms to implement the standards, such as setting pollution limits and providing goals for water cleanup projects. The criteria that apply for temperature, DO, and pH in the lower Yakima River are summarized in Table 1.

Table 1. Water Quality Criteria for the study area.

Reach	Dates	Criteria		pH[3]
		Temperature[1]	DO[2]	
Yakima River from Cle Elum River to the mouth	Annual	21°C	8.0 mg/L	6.5 to 8.5

[1] When natural conditions exceed the criterion or are within 0.3 °C of the criterion, no temperature increase of greater than 0.3 °C is allowed. When background conditions are below the criterion, other limitations to heating apply.

[2] When natural conditions are below the criterion or within 0.2 mg/L of the criterion, human conditions considered cumulatively may not cause the DO of the water to decrease by more than 0.2 mg/L.

[3] Human-caused variation within this range shall be less than 0.5 units.

Every two years, states are required to prepare a list of water bodies that do not meet water quality standards. This list is called the CWA 303(d) list. In Washington State, this list is part of the Water Quality Assessment (WQA) process. WQA listings are placed in categories according to their status. Category 5 is the CWA 303(d) list: water bodies where data have shown impairment by pollutants. The CWA requires Ecology to complete a TMDL analysis and develop a water cleanup plan for Category 5 waters.

Table 2 shows the seven 303(d) listings for temperature, DO, and pH impairment in the lower Yakima River. Each of these listings corresponds with a section of the river that does not meet water quality standards for these parameters. This study is focused on these listings and will not address other listings other than to note where opportunities for coordination may exist. These are likely not the only locations that fail to meet standards at times, and this study will evaluate all three parameters throughout the lower Yakima River study area.

Yakama Nation water quality standards

The Yakama Nation (YN) and Ecology share jurisdiction over the regulation of water quality in 28 miles of the Yakima River. The YN has established water quality standards for the waters within their reservation boundaries. However, at this time EPA has not granted YN "Treatment as a State" authority and has not approved their water quality standards. EPA has an oversight role for CWA regulatory decisions in YN waters.

Table 2. Temperature, dissolved oxygen, and pH Category 5 (303[d] list) listings in the lower Yakima River.

View Listing	Water Resource Inventory Area	Waterbody Name	Parameter	Map Link	Category
8311	37 - Lower Yakima	Yakima River	Temperature	8311	5
6734	37 - Lower Yakima	Yakima River	pH	6734	5
11195	37 - Lower Yakima	Yakima River	pH	11195	5
50588	37 - Lower Yakima	Yakima River	pH	50588	5
8309	37 - Lower Yakima	Yakima River	DO	8309	5
11177	37 - Lower Yakima	Yakima River	DO	11177	5
47277	37 - Lower Yakima	Yakima River	DO	47277	5

This QAPP proposes the development of a water quality model that includes reaches of the Yakima River that flow through YN lands. The project as described by this QAPP is fundamentally a scientific study and makes no attempt to make policy calls or interpret treaties, laws, or regulation regarding the shared waters. Ecology will offer to work with the YN to collaborate on technical work supporting modeling of these shared waters.

Regulatory challenges

In 2008, the National Marine Fisheries Service (now NOAA Fisheries) and the U.S. Fish and Wildlife Service issued Biological Opinions for EPA's approval of Ecology's revised water quality standards (NMFS, 2008; USFWS, 2008). The TMDL process was noted in several places as the mechanism to ensure compliance with Water Quality Standards to determine the "natural thermal potential" of water bodies.

The Biological Opinions specifically note temperature barriers in the Yakima River, and they comment that the special conditions criterion of 21°C for the mainstem Yakima River below the Cle Elum River was not changed and therefore not reviewed. The Biological Opinions cite an Ecology letter to EPA (Ecology, 2008). In that letter, Ecology notes that "…a temperature water quality improvement report (total maximum daily load) for the mainstem…will model the thermal potential of the Yakima mainstem and should provide the basis for a discussion of the special condition criteria."

A key challenge to addressing the CWA requirements in the Yakima River basin is the high level of water management in the basin. The river is used as a water delivery system from the five Bureau of Reclamation reservoirs to downstream irrigators. At the same time, the YBIP is working on a variety of projects, including conservation, system infrastructure improvements, and aquatic habitat restoration, that will share the benefits of water management improvements between agriculture, communities, and environmental services. For these reasons, the Bureau of Reclamation is a key stakeholder for providing input and interpreting results of modeling.

Given the difficulties in interpreting CWA regulatory tools, both in this regulatory context and in the context of overall Yakima River management, this project does not propose a specific regulatory endpoint for applying the model. The model will provide a tool to help evaluate and interpret the policy choices for addressing compliance with the CWA in the Yakima River.

3.2.5 Global climate change

Changes in climate are expected to affect both water quantity and quality in the Pacific Northwest (Casola et al., 2005). Factors affecting these changes include climate influences at both annual and decadal scales and air temperature increases. When air temperatures increase, more precipitation falls as rain rather than snow, which melts of the winter snowpack earlier.

Projected changes in seasonal precipitation are expected to have a particularly strong impact on the Yakima River basin, where a shift from snow to rain regime impacts water management. This was demonstrated in 2015, when normal rainfall combined with warm temperatures reduced snowpack to record low levels, and irrigation districts that depend on Bureau of Reclamation’s water deliveries were reduced to less than 50% proration.

Ten climate change models were used to predict the average rate of climatic warming in the Pacific Northwest (Mote et al., 2005). The average warming rate is expected to be in the range of 0.1-0.6°C (0.2-1.0°F) per decade, with a best estimate of 0.3°C (0.5°F) (Mote et al., 2005). Eight of the 10 models predicted proportionately higher summer temperatures, with three indicating summer temperature increases at least two times higher than winter increases. Summer streamflows are also predicted to decrease as a consequence of global climate change (Hamlet and Lettenmaier, 1999).

The changes in weather patterns expected in the Yakima River watershed highlight the importance of protecting and restoring the mechanisms that help keep stream temperatures cool. Stream temperatures can be improved, both across the channel and in cold water refuges, by growing mature riparian vegetation along stream banks, restoring channel and flood plain complexity, and enhancing summer baseflows. This action can restore the resiliency of the aquatic environment to weather extremes and may help offset the changes expected from global climate change.

It will take considerable time, however, to implement these restoration actions. The sooner these actions begin and the more complete they are, the more effective we will be in offsetting some of the detrimental effects of climate variability on our stream resources.

As global climate change progresses, the thermal regime of the Yakima River will likely change due to reduced summer streamflows and increased air temperatures. Watershed and aquatic habitat restoration efforts may not be sufficient to ensure that streams will meet the numeric temperature criteria everywhere or in all years. However, these efforts will maximize the extent and frequency of healthy temperature conditions, creating long-term and crucial benefits for fish and other aquatic species.

Ecology is conducting this study based on current and historic patterns of climate. Changes in stream temperature associated with global climate change may require further analysis in the future. However, the best way to preserve and restore our aquatic resources would be to begin now to protect as much of the thermal health of our streams as possible.

4.0 Project Description

This purpose of this project is to develop a water quality model for temperature, DO, and pH for the lower Yakima River from Selah Gap to just above the Columbia River confluence. The model will be developed using existing data from the USGS eutrophication study (USGS, 2009) and from other sources of data for the same study period, 2004-2007.

4.1 Project goal

The goal of this project is to develop a water quality model for the lower Yakima River to simulate temperature, DO, and pH.

This model is intended to be a useful analytical tool that is the first step in (1) bringing the lower Yakima River into compliance with State water quality standards and (2) managing water quality as part of YBIP fishery goals. This model can provide information on water quality to support fish restoration and evaluate the effects of water management decisions. The model also can help identify data gaps and build a foundation of knowledge for developing more sophisticated and comprehensive future models.

4.2 Project objectives

The following project objectives will support the goals of this project:

- Obtain, analyze, and process data from the USGS eutrophication study and other sources to support model development.
- Using the QUAL2Kw framework and other modeling tools, assemble and calibrate a working water quality model for the lower Yakima River.
- Conduct a quality assessment of the model to quantify model uncertainty and assess the model's ability to meet project goals.
- Identify future uses of the model and data needs for model improvement.
- Develop a project report that describes model development and results and also provides recommendations for future work, including model applications, data collection for model improvements, and other analyses to support overall project goals.

4.3 Information needed and sources

Development of the model will be based on existing data. Sources expected to be used include:

- USGS eutrophication study (USGS, 2009)
- Ecology ambient monitoring network (http://www.ecy.wa.gov/programs/eap/fw_riv/index.html)
- USGS Surface-Water Data for Washington (https://waterdata.usgs.gov/wa/nwis/sw)
- U.S. Bureau of Reclamation Yakima Project Hydromet System (https://www.usbr.gov/pn/hydromet/yakima/index.html)

- Yakima River RiverWare model (http://wa.water.usgs.gov/projects/yakimawarsmp/warsmp/riverware.htm)
- USGS Yakima River basin groundwater model (USGS, 2011)
- Meteorological data from:
  - National Weather Service (available through a variety of outlets, such as the National Climatic Data Center, Weather Underground, or UW GraySkies)
  - Washington State University AgWeatherNet (http://weather.wsu.edu/index.php?p=88650)
  - RAWS (http://www.raws.dri.edu/index.html

Current and relevant external data sets that are useful and applicable for water quality impairment studies are also presented in Ecology's Programmatic Quality Assurance Project Plan for Water Quality Impairment Studies (Ecology, 2017), Appendix A (Table A-1), with a description of the organization and availability and usability of appropriate data. The table indicates established quality assurance (QA) or quality control (QC) programs to ensure credible data sources.

4.4 Tasks required

The tasks required to meet project objectives are described within this QAPP.

4.5 Systematic planning process used

This QAPP represents the systematic planning process and includes the key elements:

- Description of the project, goals, and objectives (Section 4).
- Project organization, responsible personnel, and schedule (Sections 5 and 12).
- Procurement of data and study design to support the project goals and objectives (Sections 7, 8 and 9).
- Specification of quality assurance/quality control (QA/QC) activities to assess the quality performance criteria (Sections 6, 10 and 11).
- Analysis of data (Sections 13 and 14).

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 3. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Laine Young WQP Central Regional Office Phone: 509-575-2642	TMDL Lead	Clarifies scope of the project. Provides internal review of the QAPP and approves the final QAPP.
Paul J. Pickett EAP Eastern Operations Section Phone: 360-407-6882	Technical Lead/ Principal Investigator	Writes the QAPP. Conducts quality review of data. Develops, calibrates, and conducts quality assessment of the model. Analyzes and interprets model results. Writes the draft report and final report.
George Onwumere EAP Eastern Operations Section Phone: 360-407-6596	Supervisor for the Technical Lead	Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP.
Mark Peterschmidt WQP Central Regional Office Phone: 509-457-7107	Unit Supervisor for the Study Area	Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP.
David Bowen WQP Central Regional Office Phone: 509-457-7107	Section Manager for the Study Area	Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP.
William R. Kammin Phone: 360-407-6964	Ecology Quality Assurance Officer	Reviews and approves the draft QAPP and the final QAPP.

EAP: Environmental Assessment Program
WQP: Water Quality Program
QAPP: Quality Assurance Project Plan

Because the Yakima River is shared waters with the Yakama Nation (YN), coordination and collaboration with YN is a critical element of this project. Ecology's Water Quality Program (WQP) staff will manage relations with the YN.

The U.S. Bureau of Reclamation is a partner with Ecology and YN in managing the river. WQP staff will coordinate with staff from Ecology's Office of Columbia River to manage relations with Reclamation.

In general, the WQP will manage external relations and communication, in consultation with the Office of Columbia River.

5.2 Special training and certifications

The Technical Lead/Principle Investigator is a licensed Professional Engineer and specialist in water quality modeling.

5.3 Organization chart

Not applicable - See Table 3.

5.4 Proposed project schedule

Table 4. Proposed schedule for completing modeling and reports.

Model Development	**Due date**
Model calibration	June 2018
Model quality assessment	August 2018
Final report	
Schedule	
Draft due to supervisor	October 2018
Draft due to client/peer reviewer	November 2018
Draft due to external reviewer(s)	December 2018
Final (all reviews done) due to publications coordinator	March 2019
Final report due on web	May 2019

The Technical Lead/Principle Investigator is responsible for all tasks.

5.5 Budget and funding

All work will be conducted by salaried staff. No laboratory or contract services are anticipated.

6.0 Quality Objectives

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to meet project objectives. Precision and bias together express data accuracy. Other considerations of quality objectives include representativeness, completeness, and comparability. Quality objectives apply to data collected by entities external to Ecology and also to the results of modeling and other analysis methods.

6.1 Data quality objectives

Data quality objectives for this project that will guide the data used for model development and the quality assessment of model results are defined in Sections 6.3 and 6.4.

6.2 Measurement quality objectives

Data will not be collected for this study, so no measurement quality objectives are defined.

6.2.1 Targets for precision, bias, and sensitivity

Not applicable.

6.2.2 Targets for comparability, representativeness, and completeness

Not applicable.

6.3 Acceptance criteria for quality of existing data

Potential data sources for this study are listed in Section 4.3. The nature of modeling is to use the best data available, assess the quality of that data, and then assess the effects of data quality on model quality. In the course of model development, additional data sources may be identified. The Programmatic QAPP (Ecology, 2017) is a resource for assessing data from the sources listed in Appendix A of that document. For other data, a process of quality assessment will be followed.

Assessment of data used for model inputs and quality assessment will follow these steps:

1. The source of the data will be investigated for documented data quality procedures.
2. Any qualifications or other metadata provided with the data set will be documented and evaluated.
3. The data intended for use will be evaluated for outliers or unusual trends that may suggest data quality problems. Based on the evaluation of the data, which would include investigation of unusual environmental or logistical conditions at the time of data collection, suspect data may be either censored, qualified, or accepted.
4. An overall assessment of the variability and uncertainty of each data set will be conducted and documented in the project report.

5. As part of model quality assessment, the effect of data variability or uncertainty on model results will be (1) evaluated, either qualitatively or through a quantitative analysis such as a sensitivity or uncertainty analysis, and (2) documented in the project report.

The major source of data for this study, USGS (2009), followed the rigorous QC procedures that are standard practice for USGS. QC for laboratory data included field blanks, replicate samples, and laboratory splits, for about 15% of discrete samples.

- Field blank results showed some sporadic detections, with some concern for nitrogen compounds. However no systematic contamination was indicated.
- Relative percent difference (RPD) values between replicates were mostly at reasonable levels, with a few exceptions. Chlorophyll a and periphyton showed some higher levels, but still reasonable for those parameters. Ecology (2006) evaluated RPD for multiple studies, and the USGS data fall within the ranges found in those studies. Nutrients met recommended average RPD target values of 10%, except for ammonia which had an average RPD of 11%. Chlorophyll a was well within the target value of 20% RPD.

The quality of this data set is acceptable for use in model development, with the observed variability and qualifications of results taken into consideration.

6.4 Model quality objectives

Model quality results should be comparable to other models used in similar water quality impairment modeling studies to meet the project goals and objectives. A summary of results for comparison is available in *A Synopsis of Model Quality from the Department of Ecology's Total Maximum Daily Load Technical Studies* (Sanderson and Pickett, 2014). Sensitivity analyses will also be conducted to assess the variability of the model results to specific parameters.

Model quality includes the following considerations (discussed in detail in Section 13.4), all of which are important and must be balanced with one another,

- **Goodness-of-fit:** The accuracy with which the model is able to predict observed data. This can be described by statistics such as Root Mean Squared Error (RMSE) and overall Bias, or assessed visually using plots of modeled and observed values.
- **Accurate representation of processes**: Mechanistic models should achieve accurate predictions by invoking basically correct explanations of observed data, and reasonably simulating real-world processes. For example, a model might accurately predict low stream temperatures by incorrectly invoking groundwater instead of shade. Such a model might have good goodness-of-fit but for the wrong reasons.
- **Sensitivity to key inputs**: Models should accurately predict the sensitivity of water body response to key inputs, such as the sensitivity of temperature to shade or of DO to nutrients.

More specific qualitative objective goals for the model developed in this project include:

- For channel geometry, as applicable, accurately represent depth, width, and velocity across a range of flows that correspond to the critical period for the parameters of interest.
- For instream flow, patterns and levels of flow should predict a reasonable representation of observed conditions and, in particular, capture the critical periods for water quality conditions.
- For temperature, simulate observed temperatures and accurately represent spatial and temporal patterns. These temperature simulations require substantially correct explanations for observed patterns, such as the correct combinations of channel geometry, shade, groundwater, and hyporheic flow characteristics.
- For DO and pH, simulate observed trends and accurately represent spatial and temporal patterns. These simulations should represent the overall balance of processes, such as algal productivity, respiration, and reaeration. These simulations should also represent the sensitivity of algal growth to nutrient concentrations.
- For nutrients, accurately simulate nutrient concentrations by correctly accounting for nutrient sources, such as groundwater, tributaries, runoff, and point sources, and nutrient sinks, such as groundwater recharge and algal uptake.

For this modeling work, the primary quality objective is that the assumptions, limitations, goodness-of-fit, and uncertainty are characterized. This is so natural resource managers, stakeholders, and policy makers can evaluate the level of quality and uncertainty of model results against the magnitude of the potential decision or regulatory actions to determine which decisions the model results can support. Therefore, it is critical that this study provides a clear, accurate, and thorough job communicating each of these aspects of the model.

The model developed in this project may be used in future regulatory actions, such as the development of pollutant total maximum daily loads (TMDLs). Water quality data used in modeling will be evaluated and documented for compliance with state laws and agency policies on credible data (http://www.ecy.wa.gov/programs/wq/qa/policies.html), including Water Quality Program-Environmental Assessment Program Policy 1-11, Chapter 2.

7.0 Study Design

7.1 Study boundaries

The study area is described in Section 3.2. No collection of new data is planned.

7.2 Field data collection

Not applicable.

7.2.1 Sampling locations and frequency

Not applicable.

7.2.2 Field parameters and laboratory analytes to be measured

Not applicable.

7.3 Modeling and analysis design

7.3.1 Analytical framework

Temperature, DO, and pH by their nature are variable in time, both diurnally and on a day-to-day basis because of weather and flow conditions. Therefore, the preference for a modeling platform will be a dynamic model.

The QUAL2Kw model is the preferred modeling platform for this study (Pelletier et al., 2006; Pelletier and Chapra, 2008). This model appears to be well-suited to make use of the USGS eutrophication study data set.

Figure 4 illustrates the general study design, including the data, tools, and models that will be used and how they are related to each other. The sampling design for this project is primarily driven by the data needs for the models that will be used to perform the TMDL analysis.

The main tools and models that will be used are described in more detail below, followed by a description of the field data collection that will support model development and calibration.

Shade Model

Ecology's Shade model will be used to evaluate solar radiation and effective shade. The Shade model is a Microsoft Excel spreadsheet (Shade.xls), and is available for download at http://www.ecy.wa.gov/programs/eap/models.html (Ecology, 2003).

The Shade model was adapted from a program that Oregon Department of Environmental Quality (ODEQ) developed as part of its HeatSource model version 6. The Shade model calculates shade using one of two methods. The first is ODEQ's original method from the HeatSource model version 6 (documentation of ODEQ's HeatSource model is located at http://www.deq.state.or.us/wq/tmdls/tools.htm). The second is Chen's method, based on the HSPF SHADE FORTRAN program, (Chen et al., 1998a and Chen et al., 1998b).

The Shade model quantifies the potential daily solar load and generates percent effective shade at user-specified longitudinal distances along the river channel. Effective shade is the fraction of shortwave solar radiation that does not reach the stream surface because of interception with vegetative cover and topography. Effective shade is influenced by latitude/longitude, time of year, stream geometry, topography, and vegetative buffer characteristics such as height, width, overhang, and density.

The riparian vegetation coverage inputs into the Shade model will contain three specific attributes: vegetation height, vegetation overhang, and average canopy density. The Ttools application (http://www.ecy.wa.gov/programs/eap/models.html) will be used to develop input data. LiDAR data and aerial orthophotos are available for the study area, and will be used, to the extent allowed by the existing data sets, to develop inputs to the Shade model. Riparian shading information is available from the USGS temperature modeling report (USGS, 2008), which can be used to assess shade modeling results.

The Shade model will be used to generate longitudinal effective shade profiles. Reach-averaged integrated hourly effective shade (i.e., the fraction of potential solar radiation blocked by topography and vegetation) will be used as input into the QUAL2Kw model.

RMA Model

The River Metabolism Analyzer (RMA) is a simplified modeling tool developed by Ecology (Pelletier, 2013) that can be used to solve for gross primary production, ecosystem respiration, reaeration, and limitation due to light, temperature, and nutrients. It is available for download at: http://www.ecy.wa.gov/programs/eap/models.html.

The data required to run RMA include:

- Diel DO, pH, and temperature data
- Alkalinity data
- Concentration of the limiting nutrient
- Depth of water where data were collected

Continuous data collected by deployed probes during the USGS eutrophication study will be used in RMA to analyze reach-scale productivity and respiration. The primary application of the RMA tool for this project will be to (1) understand reach-scale water quality dynamics and (2) estimate the sediment oxygen demand (SOD). Hobson et al. (2014) suggests that the SOD can be estimated by subtracting the gross primary productivity from ecosystem respiration – both of which are outputs of the RMA tool. This SOD can then be used directly in the QUAL2Kw model.

QUAL2Kw Water Quality Model

Ecology's QUAL2Kw modeling framework (Pelletier et al., 2006; Pelletier and Chapra, 2008) will be used in this study for detailed evaluation of temperature and DO under critical flow and weather conditions.

The original version of Ecology's QUAL2Kw model was a steady-flow model. A new version is now available (http://www.ecy.wa.gov/programs/eap/models.html), which can simulate non-steady, non-uniform flow using kinematic wave (KW) flow routing. The KW approach is described in more detail by Chapra (1997) and allows for a continuous simulation of the river with continuously changing channel velocity and depth in response to changing flows, and time-varying boundary conditions (e.g., tributary loading and meteorology) for periods of up to one year.

Incorporating KW transport and continuous boundary forcing will allow QUAL2Kw to be used in this project to simulate continuous changes in water quality throughout the summer low-flow period rather than for a single day at a time.

The QUAL2Kw model was selected because it can simulate continuous changes in temperature, nutrients, algal/macrophyte biomass, and DO over the entire growing season, including representation of diel variations. Other features of this model that support the project objectives include:

- One dimensional. The channel is well-mixed vertically and laterally. Also includes up to two optional transient storage zones connected to each main channel reach (surface and hyporheic transient storage zones).
- Dynamic heat budget. The heat budget and temperature are simulated as a function of meteorology on a continuously varying time scale. Parameters included that affect stream temperature are effective shade, solar radiation, air temperature, cloud cover, relative humidity, headwater and tributary temperature, and hyporheic flow temperature.
- Dynamic water quality kinetics. All water quality state variables are simulated on a continuously varying time scale for biogeochemical processes.
- Heat and mass inputs. Point and non point loads and abstractions are simulated.
- Two algal species in the water column: phytoplankton and bottom algae (periphyton). The USGS eutrophication study found that the "Zillah Reach" of the river (Figure 2) was periphyton-dominated, the "Kiona Reach" was dominated by macrophytes, while conditions in the "Mabton Reach" were uncertain. For this project, different rate constants will be applied to the periphyton modeling compartment to simulate either periphyton or macrophytes, depending on which are known to be the dominant growth in a given reach.
- Variable stoichiometry. Luxury uptake of nutrients by the bottom algae (periphyton) is simulated with variable stoichiometry of nitrogen and phosphorus.
- Sediment diagenesis and heterotrophic metabolism in the hyporheic zone are simulated.
- Automatic calibration. Includes a genetic algorithm to automatically calibrate the kinetic rate parameters.
- Monte Carlo simulation.

Aquatox

Staff planning this modeling anticipate that the capabilities of QUAL2Kw will be adequate to meet project objectives. However, given the complexity of the system, attempts to calibrate QUAL2Kw may reveal shortcomings to that modeling platform. Specifically, QUAL2Kw is limited in its ability to model phytoplankton, periphyton, and aquatic macrophytes together.

If this proves to be the case, the Aquatox modeling platform will be considered for advanced modeling (https://www.epa.gov/exposure-assessment-models/aquatox). Some of the characteristics of Aquatox include:

- Simulation model that links pollutants to aquatic life
- Integrates fate and ecological effects
  - Fate & bioaccumulation of organics
  - Food web & ecotoxicological effects
  - Nutrient & eutrophication effects
- Predicts effects of multiple stressors
  - Nutrients, organic toxicants, temperature, suspended sediment, flow, salinity
- Peer reviewed by independent panel and in published model reviews
- EPA distributed and supported

Aquatox provides a more complex platform for modeling nutrients, algae, and aquatic plants; it can also include toxics, aquatic invertebrates, and fish. This could have some future benefits to address 303(d) listings for toxics and to more closely align the model to Yakima River fishery management. Aquatox has been used for modeling nutrients for the lower Boise River TMDL, which suggest it could be applied to the Yakima River as well, given the similarities of the two systems.

Model input needs for Aquatox are similar to QUAL2Kw. A key feature of Aquatox is its ability to model multiple compartments of algae, periphyton, and aquatic macrophytes. The USGS (2009) study has much of the information needed to use this more complex feature of Aquatox. QUAL2Kw would still be needed to model temperature, so it would be logical to use it first and determine its capabilities before deciding if developing an Aquatox model was warranted.

7.3.2 Model setup and data needs

Flows in the Yakima River are highly managed and well monitored. Figure 5 illustrates the agricultural diversions and return flows in the lower Yakima River.

In addition, the U.S. Bureau of Reclamation developed a water management model based on the RiverWare software package that provides a detailed analysis of dynamic flow in the river from the storage reservoirs downstream. Therefore, the flow analysis will occur outside of the water quality model, and flow time series will be provide for the model.

Regarding the season to be monitored, historic data from Ecology and USGS point to the following seasons when water quality criteria may not be met in the lower Yakima River:

- Temperature: May through September
- DO: April through October
- pH: February through December (more commonly March through October)

The USGS eutrophication study (USGS, 2009) collected a large body of data from 2004 through 2008. The most complete body of data is available for March through September in 2005 and 2006. USGS conducted a synoptic survey July 26-29, 2004. Therefore modeling will address, at a minimum, the following seasons:

- Temperature: March through September, 2004, 2005, 2006
- DO and pH: July and August 2004

After the data are more fully evaluated and model construction initiated, expanding the model to the additional or longer periods will be explored.

Table 5 presents a summary of input and calibration data needed for the model. The model will begin near the city of Selah and extend to just above the mouth of the Yakima River, for a length of approximately 112 miles, or 175 kilometers (km). Based on segment lengths of 1 km per segment, the model would contain approximately 175 segments. The final number of segments used in the model will be adjusted during model development.

The first step of modeling will be to simulate temperature continuously, with a time step on the order of minutes. Tributary inflows, groundwater inflows/outflows, agricultural drains, and point source inflows will be handled as boundary inputs to the mainstem model. Nutrient loads from diffuse inputs such as groundwater, and direct inputs such as tributaries, will be estimated based on the results of the USGS synoptic surveys. Some loads may be estimated based on interpolation, where appropriate.

Once calibrated, the QUAL2Kw model will be subjected to a quality assessment. Based on the results of the quality assessment, recommendations will be developed for:

- Additional model improvements
- Data collection to support model improvements
- Potential scenarios that could be supported by the model

Table 5. Model input and calibration data needed for QUAL2Kw.

Parameter	Source of Data	Description
Model Input Data		
Channel geometry	From channel surveys and the RiverWare model	Average velocity, depth, and width or rating curve information relating channel width, depth, and velocities.
Effective shade and solar radiation	From Shade model	Shade model will be run continuously for the study period to generate continuous outputs of effective shade. LiDAR and orthophoto data are available for the Yakima River to support the shade analysis.
Meteorology	USGS and nearby weather stations	Meteorological data include air temperature, dew point temperature, cloud cover, wind direction, wind speed, and solar radiation.
Headwater and tributary flows	USBR and USGS gages, RiverWare model	The Yakima River basin has an extensive network of flow gages, which have been used to develop the RiverWare model
Headwater and tributary temperatures	USGS eutrophication study and long-term monitoring sites	Extensive water temperature data were collected during the 2004-2008 eutrophication study period.
Headwater and tributary water quality variables	USGS eutrophication study and long-term monitoring sites	Extensive water quality data were collected during the 2004-2008 eutrophication study period.
Groundwater flow, temperature, and water quality	USGS eutrophication study, RiverWare model, USGS groundwater model	Estimates of groundwater inflows for the 2004-2008 eutrophication study period are available from several sources. The USGS eutrophication study evaluated groundwater inflow quality.
Model Calibration Data		
Travel time and velocities	USGS eutrophication study and RiverWare model	Values will be estimated indirectly from existing data.
Instream temperatures	USGS eutrophication study and long-term monitoring sites	Extensive water temperature data were collected during the 2004-2008 eutrophication study period.
Instream water quality variables	USGS eutrophication study and long-term monitoring sites	Extensive water quality data were collected during the 2004-2008 eutrophication study period.
Groundwater interactions/ hyporheic exchange	USGS eutrophication study, RiverWare model, USGS groundwater model	Estimates of groundwater inflows for the 2004-2008 eutrophication study period are available from several sources.
Bottom algae biomass	USGS eutrophication study	Biomass data was determined by the USGS eutrophication study.
Macrophyte biomass	USGS eutrophication study	Biomass data was determined by the USGS eutrophication study.

7.4 Assumptions in relation to objectives and study area

Modeling work contains inherent assumptions when representing a water body through a simplified mathematical-representation that is not able to account for each variable and element influencing the system. Modeling assumptions include:

- Conservative assumptions used in the development and application of the model will be sufficient to implicitly build a margin of safety into the model.
- Data used in the model are representative of the spatial and temporal variation within the sampling location.
- River flows for simulations are representative of the system.
- Aquatic macrophytes, algae, and bacteria (bottom algae, phytoplankton, and heterotrophic biofilm) are primarily limited by a single limiting nutrient at any given time (phosphorus, nitrogen, or carbon).

- Simplifying assumptions used to model phytoplankton, periphyton, and aquatic macrophyte growth rates.
- Assumed or calibrated process kinetics and rate constants of the model are accurate and appropriate.
- Water quality constants and kinetics determined within calibrated model would be similar under different environmental conditions used in simulations of alternative scenarios.
- The QUAL2Kw model is one dimensional, which means that it assumes that the modeled sections are vertically and laterally well-mixed.

Data limitations such as data gaps, limitations in boundary conditions and calibration data, and measurement error may also influence modeling assumptions underlying design.

7.5 Possible challenges and contingencies

7.5.1 Logistical problems

Logistical problems are minimal for this study, given there is no data collection involved.

Obtaining existing data and organizing data by time and location is expected to be complex and time-consuming.

7.5.2 Practical constraints

The constraints on this project are primarily related to the resources available for the project and the context of the project.

- The modeling process is highly uncertain and must be balanced with the time available to the project lead.
- The focus on existing data creates constraints on model development, since model development may need to deal with data gaps and uncertainty.
- The model represents conditions at the time of data collection, which included a drought year (2015), so the model will most likely not be representative of the full range of potential conditions.
- Given that the modeling period is a decade or more in the past, the age of the data and difficulty in accessing supporting data may present challenges.
- It will be difficult to draw conclusions about current practices from a model based on older information.

In the broader context of the project, numerous factors could represent constraints, such as coordination with the Yakama Nation, being responsive to the needs of the YBIP, and uncertainties around how to proceed with Clean Water Act compliance given the unusual and complex water management challenges in the Yakima River basin.

7.5.3 Schedule limitations

Changes in project prioritization and workload for both Ecology's Environmental Assessment Program (EAP) and Water Quality Program (WQP) could affect the project schedule. Factors that can cause delays to the proposed project schedule include:

- Time required for QAPP review and approval.
- The need for additional technical analysis work or the need for policy decisions.
- Addressing comments from reviewers, both internal and external, that may lead to additional work required.
- Changes to the schedule based on current needs and available resources from EAP and WQP.

Management of the schedule will require frequent communication between the technical lead, supervisor, and WQP staff to adapt to emerging issues, both related to model development challenges and coordination with Yakima River basin partners and stakeholders.

8.0 Field Procedures

8.1 Invasive species evaluation

Not applicable.

8.2 Measurement and sampling procedures

Not applicable.

8.3 Containers, preservation methods, holding times

Not applicable.

8.4 Equipment decontamination

Not applicable.

8.5 Sample ID

Not applicable.

8.6 Chain-of-custody

Not applicable.

8.7 Field log requirements

Not applicable.

8.8 Other activities

Not applicable.

9.0 Laboratory Procedures

9.1 Lab procedures table

Not applicable.

9.2 Sample preparation methods

Not applicable.

9.3 Special method requirements

Not applicable.

9.4 Laboratories accredited for methods

Not applicable.

10.0 Quality Control Procedures

10.1 Table of field and laboratory quality control

Not applicable.

10.2 Corrective action processes

A fundamental premise of this project is that this model, developed with existing information, will be useful to Ecology but inherently limited in certainty. A critical element of the project will be to understand uncertainties in the model as fully as possible, and then to use that information to inform WQP staff and determine future activities. As an understanding of the level of success and uncertainty emerges, the project lead will work closely with WQP staff to evaluate that information and make adjustments to the project's emphasis, scope, or direction.

11.0 Management Procedures

11.1 Data recording and reporting requirements

All final spreadsheet files, modeling files, documentation, and final products created as part of the model development and quality assessment process will be kept with the project data files.

11.2 Laboratory data package requirements

Not applicable.

11.3 Electronic transfer requirements

Not applicable.

11.4 EIM/STORET data upload procedures

Not applicable.

11.5 Model information management

Data management for modeling work ranges from data analysis spreadsheets to software control and input files.

Ecology will maintain and provide the final version of the model, including input, output, and executables for archiving at the completion of the task. Electronic copies of the data, GIS, and other supporting documentation (including records documenting model development) will be saved and stored as appropriate for agency policies on records retention practices. Ecology will maintain copies in a task subdirectory, subject to regular system backups, and on disk for a maximum of 3 years after task termination, unless otherwise directed by agency management. The underlying data used for the model are organized prior to the public comment phase of the project so that it can be easily shared upon request.

The importance of routinely archiving work-assignment data files from hard drive to compact disc or server storage is recognized. Information will be stored on Ecology servers that are routinely backed up. Screening for viruses on electronic files loaded on microcomputers or the network is standard agency policy. Automated screening systems are updated regularly to ensure that viruses are identified and destroyed. Annual maintenance of software is performed to keep up with evolutionary changes in computer storage, media, and programs.

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

Not applicable.

12.2 Responsible personnel

Not applicable.

12.3 Frequency and distribution of reports

Status reports on the progress of the project will be provided to the WQP staff monthly, or when requested.

A peer-reviewed technical report will be completed and published to Ecology's website. The final report also will be distributed to all managers, clients, tribes, municipalities, and other stakeholders, involved or interested in the study as determined by consultation between EAP and WQP.

Model documentation may be accomplished in one document at the end of the project. The amount of detail provided in the model documentation should be sufficient as to allow for an independent recreation of the results by someone who is experienced and technically proficient with the model.

The use of models in the regulatory sense requires more detailed documentation than is found in scientific journals. In addition, a model that underlies a decision (such as a TMDL or NPDES permit) is subjected to the same public comment process as the regulatory action, even in cases when the model was previously peer-reviewed. The expected sequence of the documentation process should be considered in the project scoping and schedule.

12.4 Responsibility for reports

The technical lead is responsible for writing the final technical report and for working with support staff to format and publish the report on the Ecology website.

The EAP section manager is responsible for assigning a peer reviewer with the appropriate expertise for the technical report. Depending on the type of final report, there may be an internal and external review process. The peer reviewer is responsible for completing EAP's peer review form and working with the report author to resolve or clarify any issues with the report.

As the project proceeds, the EAP section manager and WQP clients may determine that an additional peer review is needed. More information can be found regarding the peer review process within the *Guidance on the Development, Evaluation, and Application of Environmental Models* (CREM, 2009). This more detailed peer review would help to ensure the work used "Best Available Science" including credible data, information, and literature (WAC 365-195-905, RCW 90.48.580). These projects will include information about how "Best Available Science" was established within the project-specific QAPP.

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

Not applicable.

13.2 Laboratory data verification

Not applicable.

13.3 Validation requirements, if necessary

Not applicable.

13.4 Model quality assessment

Model performance will be assessed both quantitatively and qualitatively to evaluate the quality of model calibration and model results. Because of uncertainty and lack of available literature on model performance criteria, inherent error in input and observed data, and the approximate nature of model formulations, absolute criteria for model acceptance or rejection are usually not appropriate, and will not be established for this project.

13.4.1 Calibration and validation

Environmental simulation models are simplified mathematical representations of complex real world systems. Models cannot accurately depict the multitude of processes occurring at all physical and temporal scales. Models can, however, make use of known interrelationships among variables to predict how a given quantity or variable would change in response to a change in an interdependent variable or forcing function. In this way, models can be useful frameworks for investigating how a system would likely respond to a perturbation from its current state.

To provide a credible basis for predicting and evaluating water quality scenarios and management options, the ability of the model to represent real-world conditions should be optimized and evaluated through a process of model calibration and, if appropriate, through validation (CREM, 2009).

Model calibration is necessary because of the inherent uncertainty of water quality models. The water quality models used are mechanistic, based on physical, chemical, and biological processes. However, they use kinetics derived from previous research or applications to mathematically quantify these processes. Model calibration is the method of adjusting model parameters and kinetics to achieve an optimal match between the predicted trends of the model to the observed conditions. Model calibration involves a qualitative graphical comparison and basic statistical methods that are used to compare model predictions and observations.

The values of the kinetics used within the model are typically found from scientific literature and other water quality impairment studies in similar water bodies. However, in some cases, the need for kinetic values outside the range found in associated literature is necessary to accurately represent the modeled system; these situations will be justified and documented within the model report.

There are two general approaches to calibration/validation:

- Use all available observed data to calibrate and improve the model. Under this scenario, validation/corroboration is less formal and involves evaluating model fitness and how well the mechanistic processes are captured under varying conditions in the model.
- Use one observed data set to calibrate the model, and reserve a second "blind" observed data set to "validate" the model.

For this project, calibration with all existing data will be employed. Calibration will focus on the most critical time period and areas of the waterbody, based on the availability of calibration data.

Once calibration is completed, model validation may then occur if appropriate data are available. (Different terms are sometimes used for validation, such as "verification" or "corroboration".) EPA defines model validation as "subsequent testing of a pre-calibrated model to additional field data, usually under different external conditions, to further examine the model's ability to predict future conditions" (USEPA 1997). This process occurs through using the same model calibration framework for a separate field data set within the same waterbody, without adjusting any rates or coefficients. The matching of observed versus predicted trends in a second simulation helps validate the accuracy of the model. This type of validation also provides a direct measure of the degree of uncertainty that can be expected when the model is applied to conditions outside the calibration series.

A "blind" validation for this model with new data is a possible recommendation for future work that results from this study.

The quality of model performance will be evaluated using statistical tests. Model performance statistics are used, not as absolute criteria for acceptance of the model, but as guidelines to supplement the visual inspection of model-data plots and to determine appropriate endpoints for calibration and corroboration of the model. This section lists a suite of tests that are used during model quality assessment. The exact statistical tests will be determined during model calibration and may include any of the following. In addition, if determined necessary and appropriate, additional tests of model fit may be applied.

13.4.1.1 Precision

Precision is a measure of the variability in the model results relative to measured values. Model resolution and performance are measured using the root-mean-square-error (RMSE), a commonly used measure of model variability (Reckhow, 1986). The RMSE is defined as the square root of the mean of the squared difference between observed and simulated values. Other metrics that might be used to assess precision include the Coefficient of Determination, the Nash-Sutcliffe Coefficient of Model Efficiency, absolute mean error, and relative error.

Root-Mean-Square Error Statistic (RMSE). The root-mean-square error (E_{rms}) is defined as

$$E_{rms} = \sqrt{\frac{\sum (O - P)^2}{n}}$$

where,
O = observation
P = model predication at same location and time as the observation
n = number of observed-predicted pairs
E = mean error

A RMSE of zero is ideal. The RMSE error is an indicator of the deviation between model predictions and observations. The E_{rms} statistic is an alternative to (and is usually larger than) the absolute mean error. It tends to emphasize large errors, so that a few large errors can greatly increase the E_{rms} statistic even if most errors are small.

However, an important consideration of the RMSE approach is that when it is used to assess time series diel or continuous model outputs, it severely penalizes the model for small phase shifts in timing. One approach that can be used to address this is to establish a time window, calculate the range of model predictions for the time window, then count a deviation from prediction only if the observation falls outside this range within this time window. Another approach is to compare only the daily minimum, maximum, and/or average.

Coefficient of Determination. The coefficient of determination (R^2) is defined as

$$R^2 = \frac{\sum_{i=1}^{n}(P_i - \bar{O})^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

where,
P_i = i^{th} prediction
O_i = i^{th} observation

where the overbar indicates the mean of the n observed values. The coefficient of determination varies between 0 and 1 and indicates the proportion of the total variation in observations explained by the model.

Nash-Sutcliffe Coefficient of Model Fit Efficiency. The coefficient of model fit efficiency or Nash-Sutcliffe coefficient (E_{ns}) is particularly useful for evaluating model fit to continuous data, taking into account both the difference between model and observed values and the variance of the observations. The statistic is defined as

$$E_{NS} = 1.0 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

The resulting coefficient ranges from minus infinity to 1.0, with higher values indicating better agreement. At a value of zero, the test indicates that the model is a good predictor of the observed mean, while negative values indicate that the model is a better predictor of the observed mean.

Absolute Mean Error. The absolute mean error (E_{abs}) between model predictions and observations is defined as

$$E_{abs} = \frac{\sum |(O - P)|}{n}$$

An absolute mean error of zero is ideal. The magnitude of the absolute mean error indicates the average deviation between model predictions and observed data. Unlike the mean error, the absolute mean error cannot give a value less than zero.

13.4.1.2 Bias

Bias is the systematic deviation or difference between the modeled and observed (i.e., measured) values. Bias in this context could result from uncertainty in modeling or from the choice of parameters used in calibration. Mathematically, bias is evaluated through use of standard metrics such as the mean error, relative error, or relative percent difference (%RPD). The %RPD provides a relative estimate of whether a model consistently predicts values higher or lower than the measured value.

Relative Percent Difference. The %RPD is defined as

$$RPD = \left[\frac{|P_i - O_i| * 2}{O_i + P_i}\right] * 100$$

Mean Error Statistic. The mean error (E) or overall bias between model predictions and observations is defined as

$$E = \frac{\sum(O - P)}{n}$$

A mean error of zero is ideal. A non-zero value is an indication that the model might be biased toward either over- or under-prediction, and typically represented by either a plus or negative sign (e.g., +0.5 or -0.5). Mean error can also be expressed as a relative statistic by dividing it by the average observed value.

Relative Error Statistics. The relative error statistics (*RE*) between model predictions and observations can be calculated by dividing the RMSE (E_{rms}) and/or absolute mean error (E_{abs}) statistics by the mean of the observations. A relative error statistic of zero is ideal. When it is non-zero, it represents the percentage of deviation between the model prediction and observation.

13.4.1.3 Representativeness

Model results will be assessed to determine how representative they are of the population of interest, the model-specified population boundaries. Representativeness can be assessed narratively by examining the ranges, distributions, trends, and other patterns in model results, and their congruence with known or likely characteristics of the modeled water body. The representativeness analysis for this project will consider factors such as model approach, input and calibration data collection methods, seasonality, time of day, flow conditions, and weather.

13.4.1.4 Qualitative assessment

Graphical assessment and spatial assessments with GIS will be used to provide a qualitative assessment of the goodness-of-fit to supplement the quantitative methods.

Model results (for hydrology and water quality) will be compared with associated observed measurements using graphical presentations. Such visual comparisons are extremely useful in evaluating model performance over the appropriate temporal and spatial range. For example, continuous monitoring data can be compared with continuous modeling results to ensure diurnal variation and minimum/maximum values are well represented.

Model performance can also be assessed through comparison with similar projects. There are several existing temperature models and water quality models (described in Pickett, 2016) that can be useful for this evaluation.

13.4.2 Analysis of sensitivity and uncertainty

This study will evaluate the level of model uncertainty and potential sources of that uncertainty. The methods described below use appropriate spatial and temporal pooling of data to help provide a more comprehensive understanding of model uncertainty.

The technical analysis also will use the evaluation of model uncertainty and sensitivity to determine potential uses of the model that are appropriately supported by the quality of the model results. Uncertainty and sensitivity results will be presented in the final report using a combination of tables and plots, such as time series plots, histograms, and box plots.

Modelers qualitatively assess the sensitivity of model parameters through parameter perturbation. Another sensitivity analysis includes testing the response of key model outputs to changes in key model inputs (e.g., testing the model outputs of DO sensitivity to nutrient inputs or temperature sensitivity to shade). A summary of any model sensitivity analyses will be included in the final modeling report. Details may include the variables modified for model calibration, the percent modification (e.g., ± 10%) or modified value, the change in the modeling or model-fitness results, and the normalized sensitivity coefficient (Brown and Barnwell, 1987).

Normalized sensitivity coefficient (NSC) is defined as,

$$NSC = \frac{\Delta Y_O / Y_O}{\Delta X_i \,/\, X_i}$$

where,

ΔY_o = Change in the output variable Y_o

ΔX_i = Change in the input variable X_i

Algorithmic techniques for sensitivity and uncertainty assessment also may be used and are available through several water quality modeling programs (Monte Carlo Simulation, first-order error analysis, or automated objective function optimization).

For advanced sensitivity and uncertainty analysis, EAP typically uses YASAIw - A Monte Carlo simulation add-in for Microsoft Excel (http://www.ecy.wa.gov/programs/eap/models.html). This add-in is a free open-source framework for Monte Carlo simulation in Excel. YASAIw is a modification of the original YASAI add-in that was developed by Rutgers University. The modified version (YASAIw) adds several new features including more distributions, correlated random variables, sensitivity analysis, and the ability to run user-defined macros during simulation.

Uncertainty analysis is the terminology associated with the examination of how the lack of knowledge in model parameters, variables, and processes propagates through the model structure as model output or forecast error. Sources of model uncertainty are characterized by EAP during the initial stages of planning in order to better understand how the model input data and parameters would potentially influence model output and prediction. Potential sources of model uncertainty include:

- Estimated model parameter values.
- Observed model input data.
- Model structure and forcing functions.
- Numerical solution algorithms.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

The final report will include:

- An assessment of the data quality for external data sources used in the analysis, including those which do not have readily available QA/QC information, and
- Documentation of the data quality and its effect on meeting project objectives.

The data quality assessment will include one or more of the following elements:

- Reference to a peer-reviewed and published QAPP.
- Documentation that the objectives of the QAPP or equivalent quality assurance procedures were met and that the data are suitable for water quality-based actions. The assessment of the data must consider whether the data, in total, fairly characterize the quality of the water body at that location at time of sampling.
- Documentation of the planning, implementation, and assessment strategies used to collect the information, including:
  - Documentation of the original intended use of the gathered information (e.g., chemical/physical data for TMDL analyses)
  - Description of the limitations on use of the data (e.g., these measurements only represent storm-event conditions).

14.2 Treatment of non-detects

Any non-detects will be included in the study analysis. Depending on the circumstances and the parameter, non-detects will be treated in one of several ways:

1. Non-detect may be replaced with half the detection limit,
2. Non-detect may be replaced with a raw laboratory instrument value, or
3. Non-detect may be treated as an indeterminate value between zero and the detection limit. For example, when comparing model predictions to observed data where the observed data is a non-detect, any predicted value less than the detection limit would be considered an exact match.

For summary statistics, methods such as regression on-order statistics (ROS) or Kaplan-Meier may be used.

14.3 Data analysis and presentation methods

Data will be analyzed before they are summarized or used for modeling. Model calibration and quality assessment results, and any other relevant and interesting data analysis results, will be presented in the final report using a combination of tables and plots of various kinds, such as time series plots, histograms, and box plots.

14.4 Sampling design evaluation

14.4.1 Modeling and analysis design evaluation

Existing data is expected to be sufficient for the selected modeling tools. The process of using the data to develop and calibrate the model(s) will automatically involve the evaluation of the original sampling design for external data. It is expected that these modeling tools, used with existing data, will be satisfactory to meet project goals and objectives. The success of the data collection design used by modeling will be assessed as part of the quality assessment for the model.

Written documentation will be prepared and included in the final report addressing the calibrated model's ability to meet the project goals and objectives, how the model might be useful for addressing future questions, and recommendations for future improvements in the model. Appropriate uses of the model will be determined by the project team on the basis of an assessment of the types of decisions to be made, the model performance, and the available resources.

If the project team determines that the quality of the model is insufficient to address the project goal and study objectives, the project team will consult with peers, experts, and partners (from Ecology, EPA, and other team members, as appropriate) as to whether, given the levels of uncertainty present in the models, which user requirements can be met, and any actions needed to address the issue.

14.5 Documentation of assessment

In the final report or memo, the Technical Lead will include a summary of the model quality evaluation findings. The final report will also provide the results of data analysis, model calibration, and sensitivity and uncertainty analysis.

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16.0 Figures

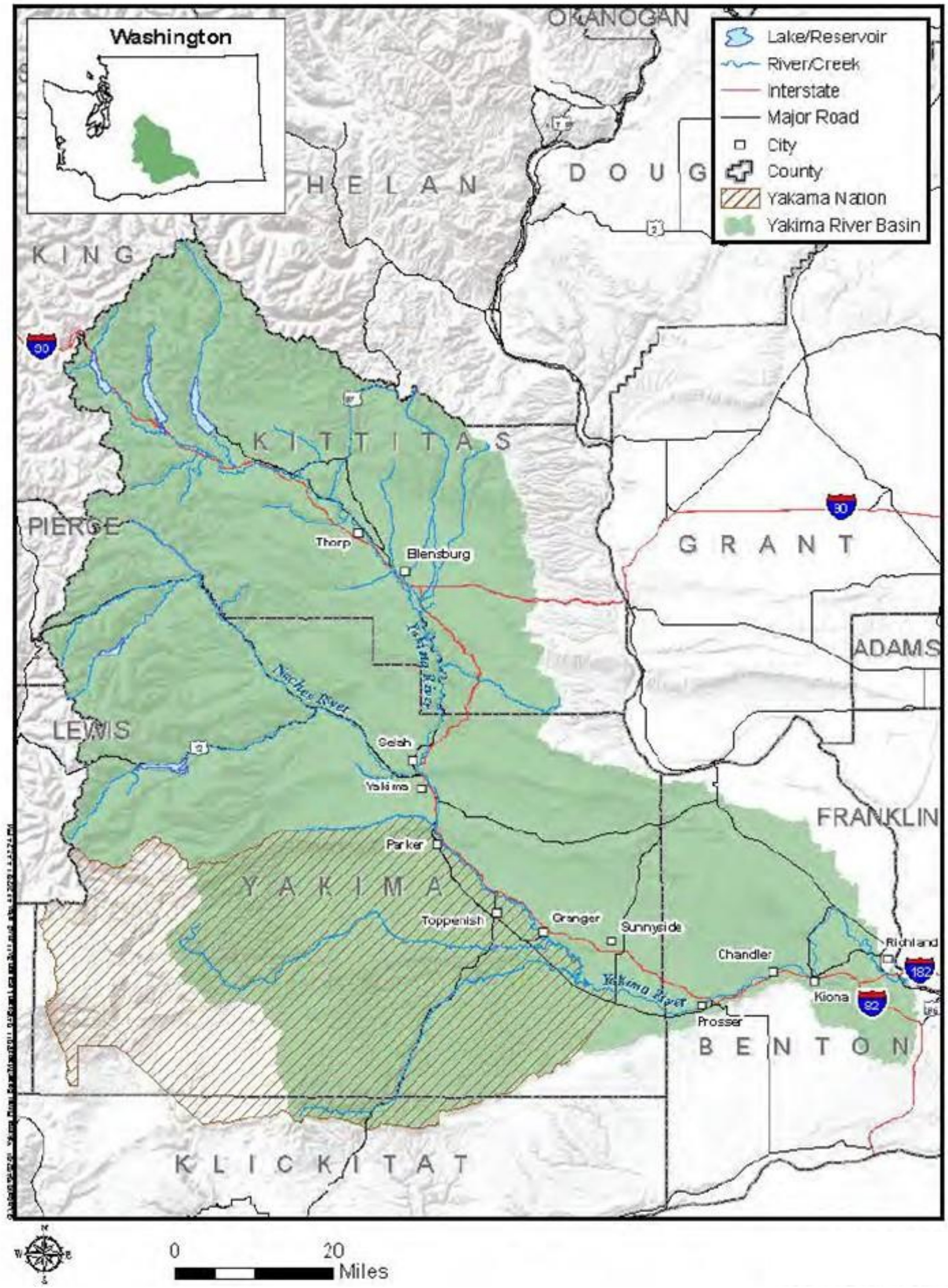

Figure 1. Yakima River basin (Reclamation and Ecology, 2011).

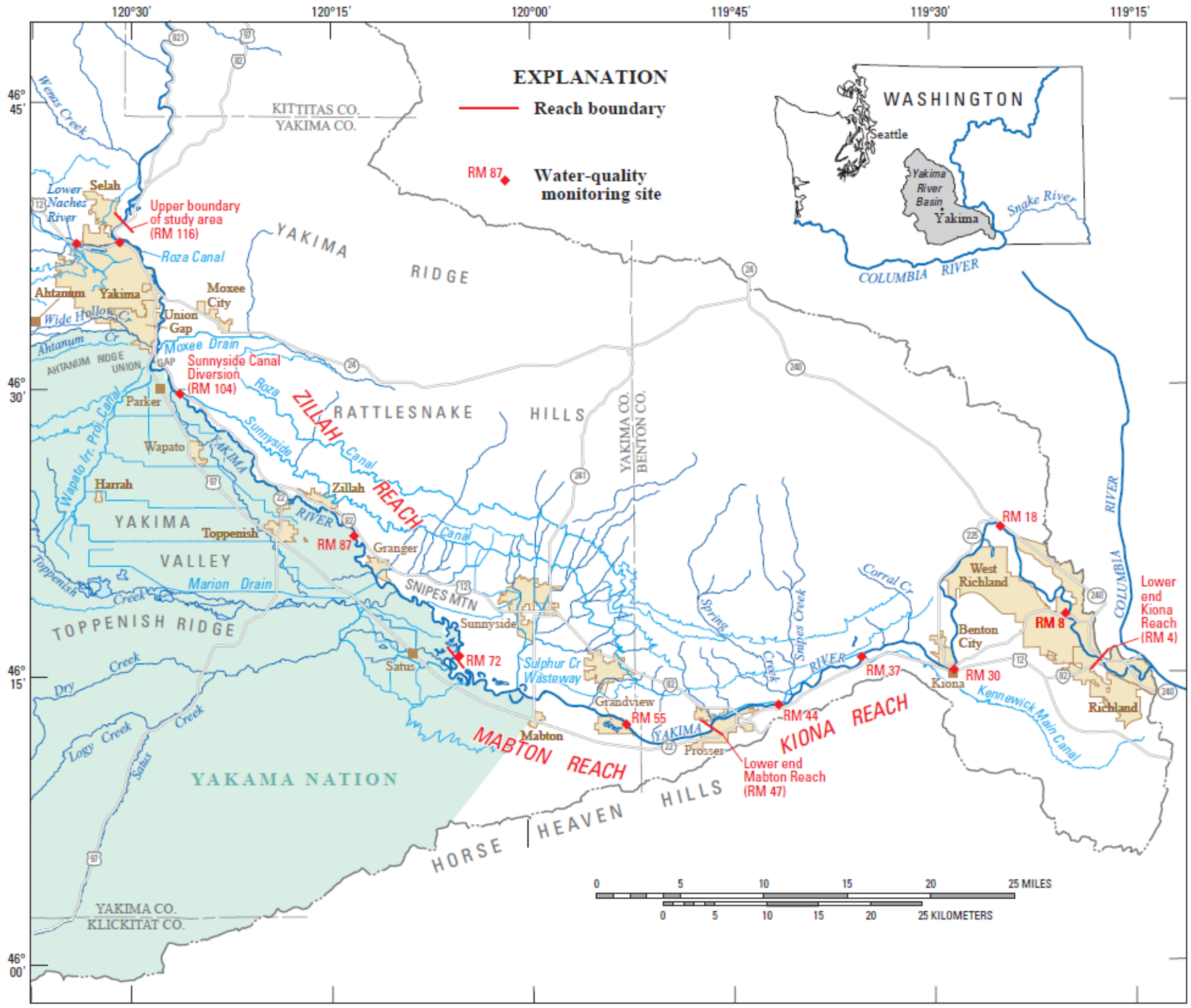

Figure 2. Study area with reaches (USGS, 2009).

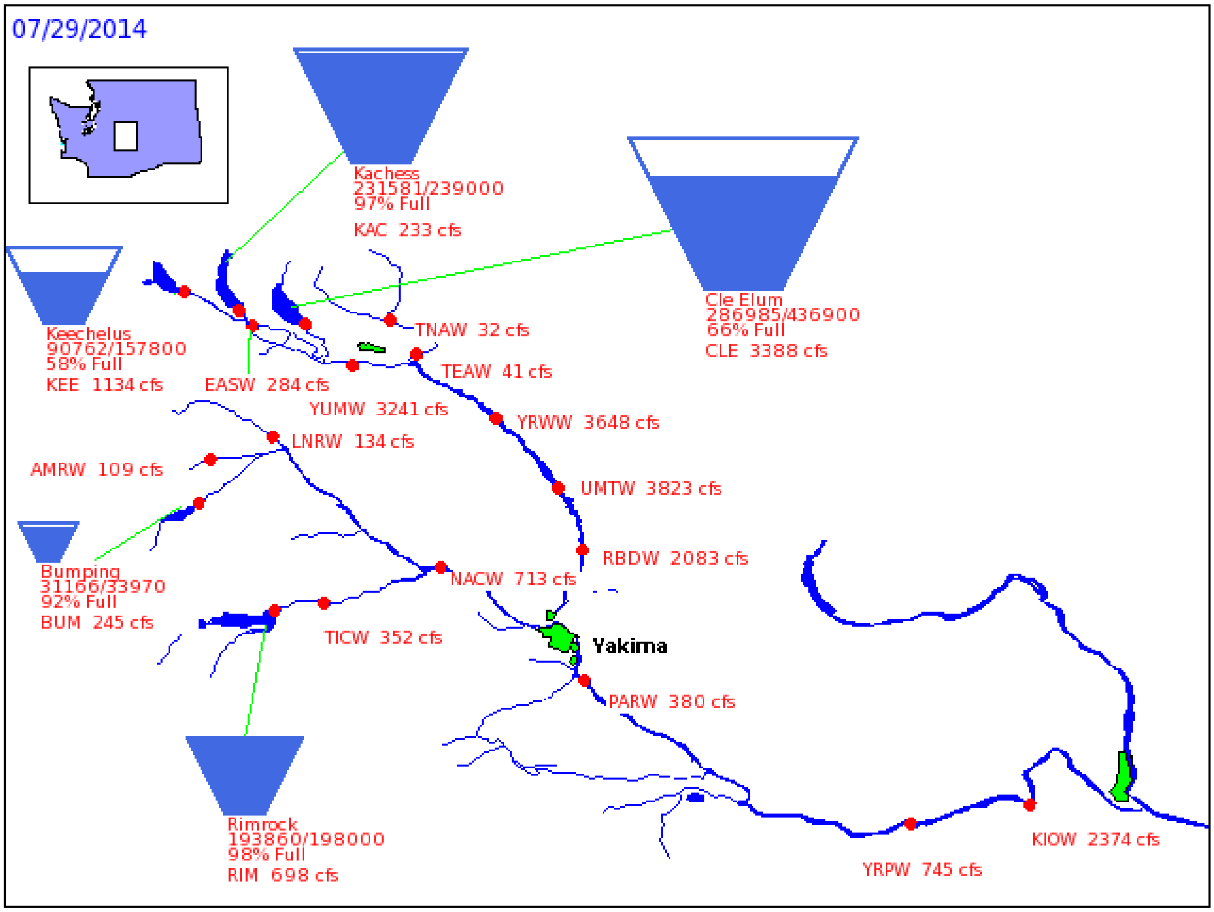

Figure 3. Yakima River basin water management system
(from: http://www.usbr.gov/pn/hydromet/yakima/yaktea.html).

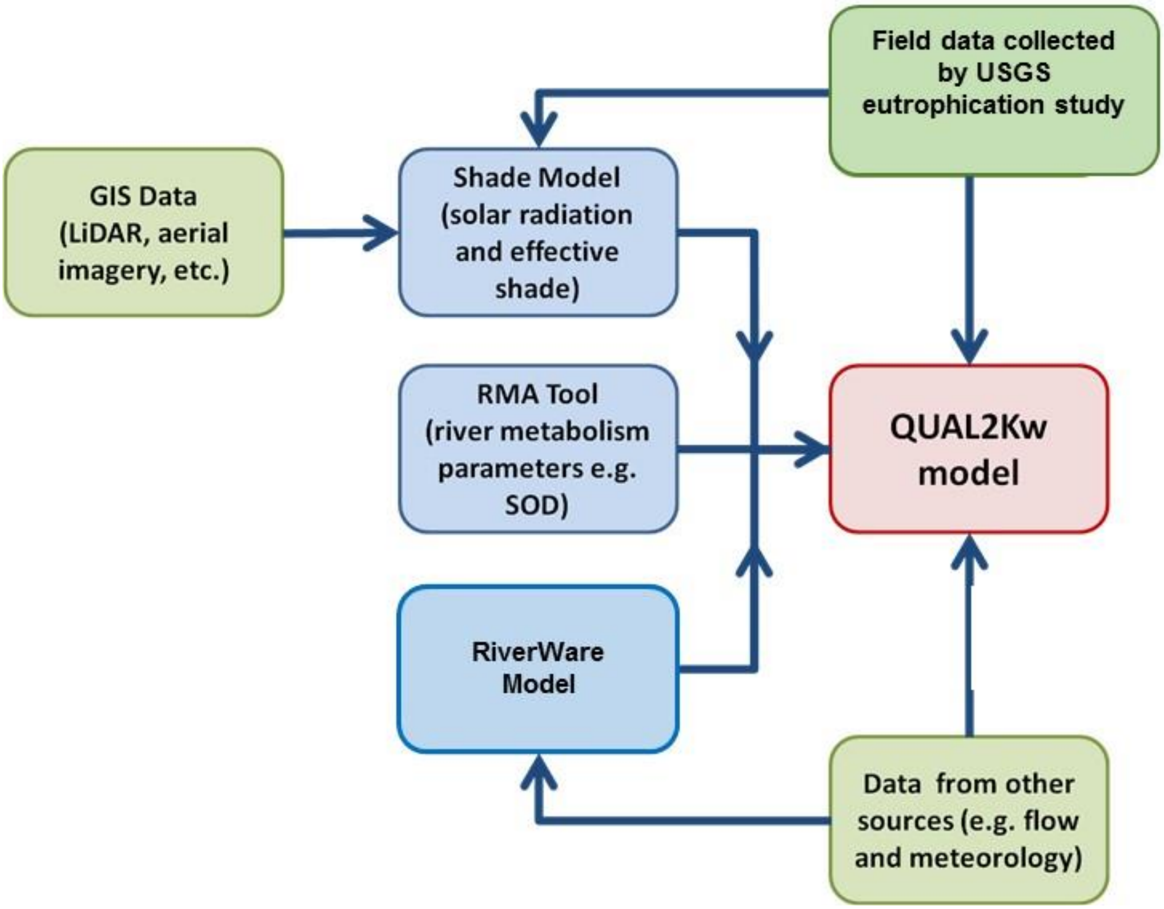

Figure 4. Schematic of modeling analysis framework.

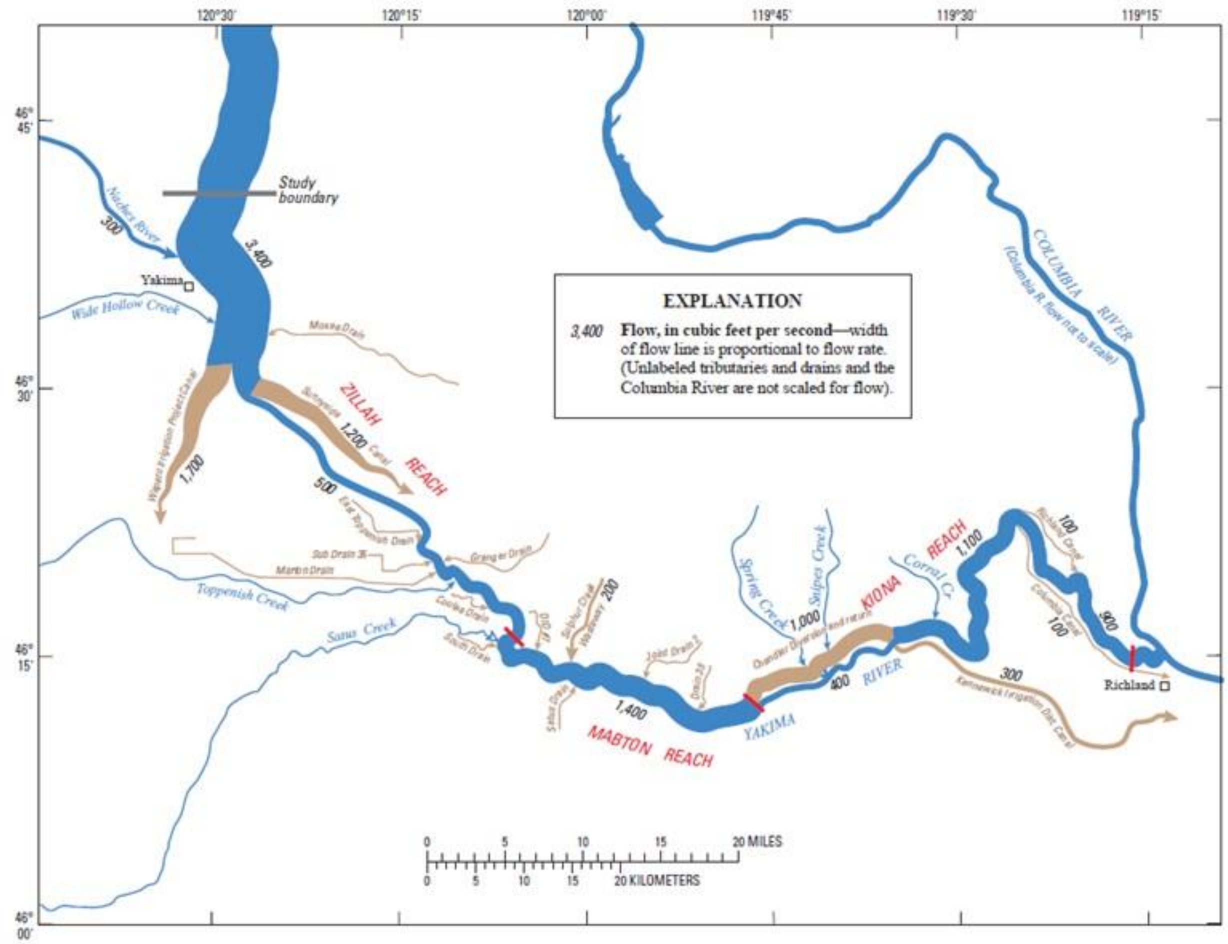

Figure 5. Typical irrigation-season streamflow and canal discharge for the lower Yakima River basin (from: USGS, 2009).

17.0 Appendix. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

Ambient: Background or away from point sources of contamination. Surrounding environmental condition. Commonly used to refer to Ecology's statewide long-term monitoring program.

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.

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

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

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).

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

Eutrophication: The process of nutrient enrichment and cycling in the aquatic environment that produces high primary productivity and algal and plant biomass.

Hyporheic: The area beneath and adjacent to a stream where surface water and groundwater intermix.

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.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Source of pollution that discharges 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 where more than 5 acres of land have been cleared.

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

Reach: A specific portion or segment of a stream.

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

Salmonid: Fish that belong to the family *Salmonidae*. Any species of salmon, trout, or char.

Sediment: Soil and organic matter that is covered with water (for example, river or lake bottom).

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.

Streamflow: Discharge of water in a surface stream (river or creek).

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Synoptic survey: Data collected simultaneously or over a short period of time.

Total Maximum Daily Load (TMDL): A distribution of a substance in a water body designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual waste load 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 waste load determination. A reserve for future growth is also generally provided.

Turbidity: A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

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, requiring 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.

Acronyms and Abbreviations

CWA	Clean Water Act
DO	(see Glossary above)
e.g.	For example
Ecology	Washington State Department of Ecology
EAP	Environmental Assessment Program
EPA	U.S. Environmental Protection Agency
et al.	And others
GIS	Geographic Information System software
i.e.	In other words
MQO	Measurement quality objective
NPDES	(See Glossary above)
QA	Quality assurance
QC	Quality control
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOD	Sediment oxygen demand
TIR	Thermal infrared radiation
TMDL	(See Glossary above)
USBR	U.S. Bureau of Reclamation
USGS	United States Geological Survey
WAC	Washington Administrative Code
WQA	Water Quality Assessment
WQP	Water Quality Program
WWTP	Wastewater treatment plant
YBIP	Yakima River Basin Integrated Water Resources Management Plan
YN	Confederated Tribes and Bands of the Yakama Nation

Units of Measurement

°C	degrees centigrade
ft	feet
g	gram, a unit of mass

kg	kilograms, a unit of mass equal to 1,000 grams
km	kilometer, a unit of length equal to 1,000 meters
m	meter
mg	milligram
mg/L	milligrams per liter (parts per million)
mL	milliliter

Quality Assurance Glossary

Accreditation: A certification process for laboratories, designed to evaluate and document a lab's ability to perform analytical methods and produce acceptable data. For Ecology, it is "Formal recognition by (Ecology)…that an environmental laboratory is capable of producing accurate analytical data." [WAC 173-50-040] (Kammin, 2010)

Accuracy: The degree to which a measured value agrees with the true value of the measured property. USEPA recommends that this term not be used, and that the terms precision and bias be used to convey the information associated with the term accuracy. (USGS, 1998)

Analyte: An element, ion, compound, or chemical moiety (pH, alkalinity) which is to be determined. The definition can be expanded to include organisms, e.g., fecal coliform, Klebsiella. (Kammin, 2010)

Bias: The difference between the population mean and the true value. Bias usually describes a systematic difference reproducible over time, and is characteristic of both the measurement system, and the analyte(s) being measured. Bias is a commonly used data quality indicator (DQI). (Kammin, 2010; Ecology, 2004)

Blank: A synthetic sample, free of the analyte(s) of interest. For example, in water analysis, pure water is used for the blank. In chemical analysis, a blank is used to estimate the analytical response to all factors other than the analyte in the sample. In general, blanks are used to assess possible contamination or inadvertent introduction of analyte during various stages of the sampling and analytical process. (USGS, 1998)

Calibration: The process of establishing the relationship between the response of a measurement system and the concentration of the parameter being measured. (Ecology, 2004)

Check standard: A substance or reference material obtained from a source independent from the source of the calibration standard; used to assess bias for an analytical method. This is an obsolete term, and its use is highly discouraged. See Calibration Verification Standards, Lab Control Samples (LCS), Certified Reference Materials (CRM), and/or spiked blanks. These are all check standards, but should be referred to by their actual designator, e.g., CRM, LCS. (Kammin, 2010; Ecology, 2004)

Comparability: The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a data quality indicator. (USEPA, 1997)

Completeness: The amount of valid data obtained from a project compared to the planned amount. Usually expressed as a percentage. A data quality indicator. (USEPA, 1997)

Continuing Calibration Verification Standard (CCV): A QC sample analyzed with samples to check for acceptable bias in the measurement system. The CCV is usually a midpoint calibration standard that is re-run at an established frequency during the course of an analytical run. (Kammin, 2010).

Control chart: A graphical representation of quality control results demonstrating the performance of an aspect of a measurement system. (Kammin, 2010; Ecology 2004)

Control limits: Statistical warning and action limits calculated based on control charts. Warning limits are generally set at +/- 2 standard deviations from the mean, action limits at +/- 3 standard deviations from the mean. (Kammin, 2010)

Data integrity: A qualitative DQI that evaluates the extent to which a data set contains data that is misrepresented, falsified, or deliberately misleading. (Kammin, 2010)

Data Quality Indicators (DQI): Commonly used measures of acceptability for environmental data. The principal DQIs are precision, bias, representativeness, comparability, completeness, sensitivity, and integrity. (USEPA, 2006)

Data Quality Objectives (DQO): Qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.
(USEPA, 2006)

Data set: A grouping of samples organized by date, time, analyte, etc. (Kammin, 2010)

Data validation: An analyte-specific and sample-specific process that extends the evaluation of data beyond data verification to determine the usability of a specific data set. It involves a detailed examination of the data package, using both professional judgment, and objective criteria, to determine whether the MQOs for precision, bias, and sensitivity have been met. It may also include an assessment of completeness, representativeness, comparability and integrity, as these criteria relate to the usability of the data set. Ecology considers four key criteria to determine if data validation has actually occurred. These are:

- Use of raw or instrument data for evaluation.
- Use of third-party assessors.
- Data set is complex.
- Use of EPA Functional Guidelines or equivalent for review.

Examples of data types commonly validated would be:

- Gas Chromatography (GC).
- Gas Chromatography-Mass Spectrometry (GC-MS).
- Inductively Coupled Plasma (ICP).

The end result of a formal validation process is a determination of usability that assigns qualifiers to indicate usability status for every measurement result. These qualifiers include:

- No qualifier, data is usable for intended purposes.
- J (or a J variant), data is estimated, may be usable, may be biased high or low.
- REJ, data is rejected, cannot be used for intended purposes (Kammin, 2010; Ecology, 2004).

Data verification: Examination of a data set for errors or omissions, and assessment of the Data Quality Indicators related to that data set for compliance with acceptance criteria (MQOs). Verification is a detailed quality review of a data set. (Ecology, 2004)

Detection limit (limit of detection)**:** The concentration or amount of an analyte which can be determined to a specified level of certainty to be greater than zero. (Ecology, 2004)

Duplicate samples: Two samples taken from and representative of the same population, and carried through and steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variability of all method activities including sampling and analysis. (USEPA, 1997)

Field blank: A blank used to obtain information on contamination introduced during sample collection, storage, and transport. (Ecology, 2004)

Initial Calibration Verification Standard (ICV): A QC sample prepared independently of calibration standards and analyzed along with the samples to check for acceptable bias in the measurement system. The ICV is analyzed prior to the analysis of any samples. (Kammin, 2010)

Laboratory Control Sample (LCS): A sample of known composition prepared using contaminant-free water or an inert solid that is spiked with analytes of interest at the midpoint of the calibration curve or at the level of concern. It is prepared and analyzed in the same batch of regular samples using the same sample preparation method, reagents, and analytical methods employed for regular samples. (USEPA, 1997)

Matrix spike: A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias due to interference or matrix effects. (Ecology, 2004)

Measurement Quality Objectives (MQOs)**:** Performance or acceptance criteria for individual data quality indicators, usually including precision, bias, sensitivity, completeness, comparability, and representativeness. (USEPA, 2006)

Measurement result: A value obtained by performing the procedure described in a method. (Ecology, 2004)

Method: A formalized group of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, data analysis), systematically presented in the order in which they are to be executed. (EPA, 1997)

Method blank: A blank prepared to represent the sample matrix, prepared and analyzed with a batch of samples. A method blank will contain all reagents used in the preparation of a sample, and the same preparation process is used for the method blank and samples. (Ecology, 2004; Kammin, 2010)

Method Detection Limit (MDL): This definition for detection was first formally advanced in 40CFR 136, October 26, 1984 edition. MDL is defined there as the minimum concentration of an analyte that, in a given matrix and with a specific method, has a 99% probability of being identified, and reported to be greater than zero. (Federal Register, October 26, 1984)

Percent Relative Standard Deviation (%RSD): A statistic used to evaluate precision in environmental analysis. It is determined in the following manner:

$$\%RSD = (100 * s)/x$$

where s is the sample standard deviation and x is the mean of results from more than two replicate samples. (Kammin, 2010)

Parameter: A specified characteristic of a population or sample. Also, an analyte or grouping of analytes. Benzene and nitrate + nitrite are all "parameters." (Kammin, 2010; Ecology, 2004)

Population: The hypothetical set of all possible observations of the type being investigated. (Ecology, 2004)

Precision: The extent of random variability among replicate measurements of the same property; a data quality indicator. (USGS, 1998)

Quality assurance (QA): A set of activities designed to establish and document the reliability and usability of measurement data. (Kammin, 2010)

Quality Assurance Project Plan (QAPP): A document that describes the objectives of a project, and the processes and activities necessary to develop data that will support those objectives. (Kammin, 2010; Ecology, 2004)

Quality control (QC): The routine application of measurement and statistical procedures to assess the accuracy of measurement data. (Ecology, 2004)

Relative Percent Difference (RPD): RPD is commonly used to evaluate precision. The following formula is used:

$$[Abs(a-b)/((a + b)/2)] * 100$$

where "Abs()" is absolute value and a and b are results for the two replicate samples. RPD can be used only with 2 values. Percent Relative Standard Deviation is (%RSD) is used if there are results for more than 2 replicate samples (Ecology, 2004).

Replicate samples: Two or more samples taken from the environment at the same time and place, using the same protocols. Replicates are used to estimate the random variability of the material sampled. (USGS, 1998)

Representativeness: The degree to which a sample reflects the population from which it is taken; a data quality indicator. (USGS, 1998)

Sample (field): A portion of a population (environmental entity) that is measured and assumed to represent the entire population. (USGS, 1998)

Sample (statistical): A finite part or subset of a statistical population. (USEPA, 1997)

Sensitivity: In general, denotes the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit. (Ecology, 2004)

Spiked blank: A specified amount of reagent blank fortified with a known mass of the target analyte(s); usually used to assess the recovery efficiency of the method. (USEPA, 1997)

Spiked sample: A sample prepared by adding a known mass of target analyte(s) to a specified amount of matrix sample for which an independent estimate of target analyte(s) concentration is available. Spiked samples can be used to determine the effect of the matrix on a method's recovery efficiency. (USEPA, 1997)

Split sample: A discrete sample subdivided into portions, usually duplicates (Kammin, 2010)

Standard Operating Procedure (SOP): A document which describes in detail a reproducible and repeatable organized activity. (Kammin, 2010)

Surrogate: For environmental chemistry, a surrogate is a substance with properties similar to those of the target analyte(s). Surrogates are unlikely to be native to environmental samples. They are added to environmental samples for quality control purposes, to track extraction efficiency and/or measure analyte recovery. Deuterated organic compounds are examples of surrogates commonly used in organic compound analysis. (Kammin, 2010)

Systematic planning: A step-wise process which develops a clear description of the goals and objectives of a project, and produces decisions on the type, quantity, and quality of data that will be needed to meet those goals and objectives. The DQO process is a specialized type of systematic planning. (USEPA, 2006)

References for QA Glossary

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