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QAPP Addendum: Soos Creek Bioassessment TMDL Modeling and Analysis

Addendum to:

Modeling Quality Assurance Project Plan for Soos Creek Watershed Temperature and Dissolved Oxygen TMDL Technical Analysis

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EAP: Environmental Assessment Program
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1.0 Table of Contents

Page

1.0 Table of Contents 2
2.0 Abstract 6
3.0 Background 7
3.1 Introduction and problem statement 7
3.2 Study area and surroundings 7
3.2.1 History of study area 9
3.2.2 Summary of previous studies and existing data 9
3.2.3 Parameters of interest and potential sources 11
3.2.4 Regulatory criteria or standards 11
3.3 Water quality impairment studies 12
3.3.1 What is a TMDL? 12
3.3.2 Why is Ecology conducting a TMDL study in this watershed? 16
3.3.3 Water Quality Standards and Numeric Targets 17
4.0 Project Description 21
4.1 Project goals 21
4.2 Project objectives 21
4.3 Information needed and sources 22
4.3.1 GIS data 22
4.3.2 Hydrology data 23
4.3.3 Sediment data 26
4.3.4 Bioassessment/B-IBI data 29
4.4 Tasks required 32
4.5 Systematic planning process used 32
5.0 Organization and Schedule 33
5.1 Key individuals and their responsibilities 33
5.2 Special training and certifications 33
5.3 Organization chart 34
5.4 Proposed project schedule 34
5.5 Budget and funding 34
6.0 Quality Objectives 35
6.1 Data quality objectives 35
6.2 Measurement quality objectives 35
6.3 Model quality objectives 35
7.0 Study Design 37
7.1 Study boundaries 37
7.2 Field data collection 37
7.3 Modeling and analysis design 37
7.3.1 Statistical analysis 37
7.3.2 GIS analysis 39
7.3.3 HSPF modeling 40

7.3.4 Model setup and data needs 43
7.3.5 Potential approaches to establishing TMDL targets 48
7.4 Assumptions in relation to objectives and study area 50
7.5 Possible challenges and contingencies 50
7.5.1 Logistical problems 50
7.5.2 Practical constraints 50
7.5.3 Schedule limitations 51
9.0 Laboratory Procedures 51
10.0 Quality Control Procedures 52
10.1 Table of field and laboratory quality control 52
10.2 Corrective action processes 52
11.0 Management Procedures 53
11.1 Data recording and reporting requirements 53
11.2 Laboratory data package requirements 53
11.3 Electronic transfer requirements 53
11.4 EIM/STORET data upload procedures 53
11.5 Model information management 53
12.0 Audits and Reports 54
12.1 Field, laboratory, and other audits 54
12.2 Responsible personnel 54
12.3 Frequency and distribution of report 54
12.4 Responsibility for reports 54
13.0 Data Verification 55
13.1 Field data verification, requirements, and responsibilities 55
13.2 Laboratory data verification 55
13.3 Validation requirements, if necessary 55
13.4 Model quality assessment 55
13.4.1 Hydrologic calibration and validation process 56
13.4.2 Sediment calibration and validation process 56
13.4.3 Calibration and validation assessment 58
13.4.2 Analysis of sensitivity and uncertainty 60
14.0 Data Quality (Usability) Assessment 62
14.1 Process for determining if project quality objectives were met 62
14.1.1 Data usability 62
14.2.1 Model usability 64
14.2 Treatment of non-detects 64
14.3 Data analysis and presentation methods 64
14.4 Sampling design evaluation 64
14.5 Documentation of assessment 64
15.0 References 65
16.0 Appendix. Glossaries, Acronyms, and Abbreviations 72

List of Figures

Page

Figure 1. Map of the Soos Creek watershed/study area. 8

Figure 2. Map of active King County precipitation and streamflow gages in and near the Soos Creek watershed. 25

Figure 3. Monitoring locations in the Soos Creek watershed for sediment grain size, TSS, and turbidity data collected by King County's ambient streams and sediment monitoring programs, the Muckleshoot Indian Tribe (MIT), and the Regional Stormwater Monitoring Program/Stormwater Action monitoring 28

Figure 4. Monitoring locations in the Soos Creek watershed for B-IBI measurements collected by various entities from 1999-2013 and used in the stressor ID analysis 30

Figure 5. Range of linear correlation coefficients (R) and coefficients of determination (R^2) for general assessment of HSPF model performance for daily and monthly flows (source: Duda et al., 2012) 36

Figure 6. Map identifying the HSPF catchment delineations for this study 44

List of Tables

Page

Table 1. Category 5 listings for bioassessment impairments in the Soos Creek watershed (as per the 2014 Water Quality Assessment) 17

Table 2. Active King County precipitation gages in or near the Soos Creek watershed. 23

Table 3. Active King County streamflow gages in the Soos Creek watershed..................24

Table 4. Available TSS, turbidity, and sediment grain size data collected in the Soos Creek watershed from 2001-2015. 27

Table 5. List of B-IBI sampling sites within the Soos Creek watershed used in EPA's stressor identification study..31

Table 6. Organization of Ecology project staff and responsibilities..................................33

Table 7. Proposed schedule for completing analysis and reports 34

Table 8. Project budget and funding 34

Table 9. General range of percent difference between simulated and observed values that can be used for evaluation of HPSF model performance (source: Donigian, 2000)...36

Table 10. List of HSPF catchments that have field sampling sites for flow, TSS, grain size, and B-IBI...45

Table 11. Statistical calculations that we plan to use to assess the quality of HSPF model calibration and validation. 59

Table 12. Information about datasets we plan to use in this study, organizations who collected these data, and relevant data quality information................................63

2.0 Abstract

The Soos Creek watershed is located in King County, in western Washington State, within Water Resource Inventory Area 9 (WRIA 9). It includes the mainstem Big Soos Creek as well as these four main tributaries: Little Soos, Soosette, Jenkins, and Covington Creeks. The watershed covers an area of just under 70 square miles.

The Soos Creek watershed has been the focus of several monitoring, modeling, and other studies over the years. Several sections of the creeks within the watershed have been monitored to assess water quality and the aquatic/benthic communities. Monitoring data show that these creeks do not meet Washington State's surface water quality standards for temperature, dissolved oxygen, and bioassessment/aquatic health. When water bodies do not meet criteria, the Washington State Department of Ecology (Ecology) must conduct a Total Maximum Daily Load (TMDL) study and develop a water cleanup plan.

Temperature and dissolved oxygen impairments have already been addressed in a separate Quality Assurance Project Plan (QAPP), and that analysis is also underway. This is a QAPP addendum specifically focused on bioassessment impairments. A separate analysis determined that these bioassessment impairments are predominantly a result of three stressors: sediment, flow alteration in the form of high flows, and physical habitat degradation.

The purpose of this study is to understand the flow and sediment delivery processes in the Soos Creek watershed using a watershed model called HSPF (Hydrologic Simulation Program – Fortran). Ecology will start by (1) using an existing calibrated HSPF model of the watershed that simulates the watershed's hydrologic processes and (2) adding the simulation of sediment processes to this model. The model will be used to help us understand the dominant watershed activities and processes that govern the delivery of flow and sediment to the creeks and to predict flow and sediment loading throughout the watershed.

To help determine load reduction targets, statistical analysis will be conducted to explore the relationships between flow metrics, sediment loading, and biotic integrity. The model, in combination with statistical analysis, will be used to determine the TMDL load allocations and wasteload allocations needed to address biological impairments in the watershed.

3.0 Background

3.1 Introduction and problem statement

Soos Creek and tributaries in the Soos Creek watershed have several water quality impairments for temperature, dissolved oxygen (DO), and bioassessment (aquatic health). Over the last ten years, there has been a cooperative effort involving multiple agencies and organizations to address these impairments via a Total Maximum Daily Load (TMDL) study. A significant amount of technical analysis has already been done as part of this TMDL.

This Quality Assurance Project Plan (QAPP) addendum is specifically focused on the TMDL analysis that will be done to address bioassessment impairments in the watershed. There is an existing QAPP which already covers some of the modeling analysis that has been conducted in the watershed to address the temperature and DO impairments (TetraTech, 2012).

3.2 Study area and surroundings

The Soos Creek watershed is located in the Puget Sound lowlands, in western Washington State, inside Water Resource Inventory Area 9 (WRIA 9). The Soos Creek system drains about 66 square miles and includes four main tributaries: Little Soos, Soosette, Jenkins, and Covington Creeks. These all drain into the mainstem Big Soos Creek, which then drains into the Middle Green River near Auburn at River Mile (RM) 33.7. The watershed includes the city of Covington and parts of the cities of Auburn, Black Diamond, Kent, Maple Valley, and Renton, and also unincorporated King County (Figure 1).

The relatively moderate climate of the study area is typical of other Puget Sound lowland watersheds and is characterized by warm, dry summers and cool, wet winters. The hydrograph is also typical of rain-dominated western Washington streams which reflect high precipitation in the form of rain during the winter and relatively low precipitation during the summer.

The Soos Creek headwaters originate in a rolling low-gradient glacial outwash plain, and the watershed has an extensive system of interconnected lakes, wetlands, and infiltrating soils (King County, 2000). Land use/cover in the watershed is a mix of forest/forest practices, rural agriculture/pasture, rural residential, low- to high-density urban residential areas as well as high-density commercial areas. Other features of the study area are described in Section 1.2 of the original QAPP (Tetra Tech, 2012a).

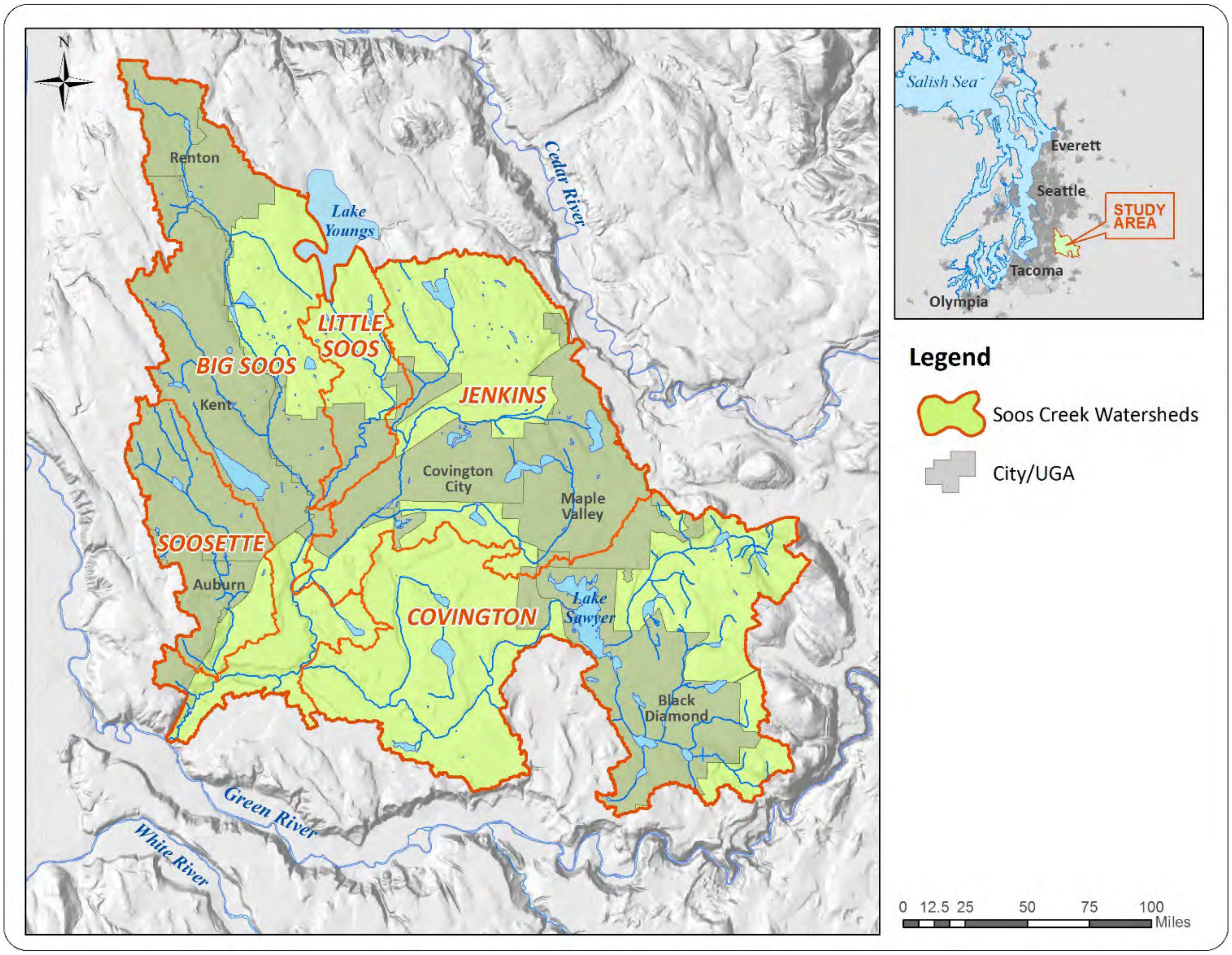

Figure 1. Map of the Soos Creek watershed/study area.

UGA: Urban Growth Area

3.2.1 History of study area

Historically, the Soos Creek watershed has supported all five species of North American Pacific salmon (chinook, coho, chum, pink, and sockeye) as well as steelhead and cutthroat trout (King County, 2008). Chinook salmon and steelhead are listed as threatened on the Endangered Species List (NOAA, 2016).

Over the years, the watershed has experienced significant changes in land use. Portions of the watershed experienced some of the most rapid suburban residential development in King County between 1917 and 1970 (King County, 2000). The basin now consists of rural and urban residential, agriculture, and highly urban commercial areas. The northern and western portions of Soosette and Big Soos subbasins have the highest density of urban subdivisions, commercial retail centers, and scattered single-family residences. The western area in east Renton, Kent, and Auburn, and the central area in Covington, in particular have been subject to heavy urbanization in recent years. There is also development pressure in the eastern part of the watershed.

This evolution of land use from old growth forest to commercial timber production, agriculture, and urbanization has had significant and adverse effects on water quality and stream habitat. Erosion and sediment have been identified as a problem and habitat-limiting factor in the watershed over several studies conducted by King County since the 1990s (King County, 2000).

3.2.2 Summary of previous studies and existing data

Studies in the Soos Creek watershed

Extensive analysis and study has been done in the Soos Creek watershed by multiple groups towards the development of this TMDL study. Organizations involved to date include the Washington State Department of Ecology (Ecology), King County, Muckleshoot Indian Tribe (MIT), U.S. Environmental Protection Agency (EPA), and Tetra Tech (as a consultant to EPA).

Below is a brief timeline of the relevant studies and work already done related to this TMDL effort.

Year(s)	Description of study/analysis done
2007-2009	Ecology, King County, and others initiated a cooperative effort to develop a temperature and DO TMDL study. King County wrote a Sampling and Analysis Plan and conducted field work during 2007 summer low-flow conditions (King County, 2009).
2012	Tetra Tech QAPP on Bioassessment monitoring and Analysis (Tetra Tech, 2012b[1]).
2012-2013	Tetra Tech QAPP on temperature and DO modeling (Tetra Tech, 2012a), and subsequent modeling work using the Shade Model and the QUAL2kW model.
2003-2013	Aqua Terra Consultants originally developed the HSPF model for King County for the whole of WRIA 9 (which includes the Soos Creek watershed) and documented this work in an unpublished report. King County further developed this model for retrofit planning and documented their work in a final report (King County, 2013). The unpublished report, however, is available and contains more details on Soos Creek model development and is referenced here as Aqua Terra (2003).
2012-2015	Muckleshoot Indian Tribe refinement of the above King County's HSPF model to more accurately represent groundwater flows and water withdrawals in order to improve baseflow predictions (Carlson and Massmann, 2015).
2013	Tetra Tech report on bioassessment monitoring and analysis, including a description of stressor identification analysis (Tetra Tech, 2013a[2]).
2013-2016	EPA refinement of the QUAL2Kw model for temperature and DO modeling begun by Tetra Tech. Model calibration was completed, and several model scenarios were also run. This work still needs to be completed, including running a few more modeling scenarios and documenting the findings in a final TMDL report which specifies load and wasteload allocations.
2015-current	Detailed bioassessment and stressor identification statistical analysis by EPA and Ecology – a final publication is expected in 2018.

[1] This was a combined QAPP for bioassessment monitoring in Soos Creek and Squalicum Creek (located in Whatcom County)
[2] This was a combined QAPP for Soos Creek and Squalicum Creek (located in Whatcom County)

Existing Data

A range of data has been collected in the Soos Creek watershed by various entities (mainly Ecology, King County, and MIT). The data relevant to this study and that will be used for modeling, are described in more detail in Section 4.3: *Information needed and sources.*

3.2.3 Parameters of interest and potential sources

The following parameters are of interest in this study:

- **Bioassessment/aquatic health –** represented by B-IBI (Benthic Index of Biotic Integrity) scores.
- **Total Suspended Solids (TSS) –** the concentration of sediment in the water, sometimes also called total suspended sediment.
- **Flow alteration metrics –** various ecologically relevant metrics will be used to describe the hydrologic regime and alteration.
- **Turbidity –** a measure of water clarity. Suspended material in the water column contributes to turbidity.

Section 3.3.3 describes bioassessment and how it relates to the above parameters of interest in more detail.

Potential sources of TSS and turbidity, and factors that contribute to flow alteration include:

- **Land-use activities**: existing and new development and related changes to the land surface (e.g. increases in impervious surfaces associated with inadequate stormwater treatment and flow control) can change the natural hydrologic and sediment processes in the watershed and increase stormwater runoff and flashiness. Agricultural activities, non-permitted earth moving activities, deforestation, and tree removal can increase sediment erosion.
- **Permitted sources**: construction, phase I and phase II municipal stormwater, sand and gravel, individual, and industrial permittees.
- **Channel morphological changes**: riparian channel reconfiguration, floodplain detachment, loss of channel complexity, channel incision, loss of riparian buffers, and impacts to wetlands.

3.2.4 Regulatory criteria or standards

The regulatory standards relevant to this study are Washington State's Water Quality Standards, which are described in the *Section 3.3.3 Water Quality Standards and Numeric Targets*.

3.3 Water quality impairment studies

This QAPP addendum supports the development of a TMDL. A TMDL study helps us determine what needs to be done in the Soos Creek watershed in order to meet the federal Clean Water Act mandate to restore and maintain the chemical, physical, and biological integrity of the Soos Creek watershed.

3.3.1 What is a TMDL?

A TMDL is a numerical value representing the highest pollutant load a surface water body can receive and still meet water quality standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

Federal Clean Water Act requirements

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

The Water Quality Assessment (WQA) and the 303(d) List

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

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

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

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

Category 2 – Waters of concern.

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

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

- 4a. – Have an approved TMDL being implemented.
- 4b. – Have a pollution-control program in place that should solve the problem.
- 4c. – Are impaired by a non-pollutant such as low water flow, dams, culverts.

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

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

The Clean Water Act requires that a TMDL study be developed for each of the water bodies on the 303(d) list.

TMDL process overview

Ecology uses the 303(d) list to prioritize and initiate TMDL studies across the state. The TMDL study identifies pollution problems in the watershed, and it specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology, with the assistance of local governments, tribes, agencies, and the community then develops a strategy to control and reduce pollution sources and a monitoring plan to assess effectiveness of the water quality improvement activities. Together, the study and implementation strategy comprise the *Water Quality Improvement Report and Water Quality Implementation Plan* (WQIR/WQIP).

Ecology submits the WQIR/WQIP to the U.S. Environmental Protection Agency (EPA) for approval. EPA approves the WQIR portion of the document, then Ecology and stakeholders begin implementing the WQIP, which identifies specific tasks, responsible parties, and timelines for reducing or eliminating pollution sources and achieving clean water.

Who should participate in this TMDL?

Nonpoint source pollutant load targets will likely be set in this TMDL. Because nonpoint pollution comes from diffuse sources, all upstream watershed areas have potential to affect downstream water quality. Therefore, all potential nonpoint sources in the watershed must use the appropriate best management practices to reduce impacts to water quality. Similarly, all point source dischargers in the watershed must also comply with the TMDL. The area that will be subject to the TMDL is shown in Figure 1.

During the development and implementation of the Soos Creek TMDL, Ecology anticipates active participation by the Muckleshoot Indian Tribe, King County, Washington State Department of Transportation (WSDOT), Public Health of Seattle/King County, King Conservation District, various nonprofit environmental groups, municipal jurisdictions, and also possible participation by local water and sewer districts. The municipal jurisdictions in the Soos Creek watershed include the cities of Auburn, Black Diamond, Covington, Kent, Maple Valley, and Renton as well as unincorporated King County. The cities are all Phase II municipal stormwater permittees, while King County falls under the Phase I municipal permit; both permits include stormwater management programs that help control pollutants in stormwater. The Covington Water District, Cedar Water and Sewer District, and King County Water District #111 can contribute to water management practices that may beneficially affect stream baseflows.

Elements the Clean Water Act requires in a TMDL

Loading Capacity, Allocations, Seasonal Variation, Margin of Safety, and Reserve Capacity

A water body's *loading capacity* is the amount of a given pollutant that a water body can receive and still meet water quality standards. The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a water body into compliance with the standards.

The portion of the receiving waters loading capacity assigned to a particular source is a *wasteload* or *load* allocation. If the pollutant comes from a discrete (point) source subject to a National Pollutant Discharge Elimination System (NPDES) permit, such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation*. If the pollutant comes from diffuse (nonpoint) sources not subject to an NPDES permit, such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation*.

The TMDL must also consider *seasonal variations*, and include a *margin of safety* that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A *reserve capacity* for future pollutant sources is sometimes included as well.

Therefore, a TMDL is the sum of the wasteload and load allocations, any margin of safety, and any reserve capacity. The TMDL must be equal to or less than the loading capacity.

Surrogate measures

When an impairment cannot be attributed to a single pollutant, a surrogate pollutant is often used. Surrogate measures can also be more helpful for designing and tracking improvements and progress during TMDL implementation. EPA regulations [40 CFR 130.2(i)] as well as a report of the Federal Advisory Committee on the TMDL program (FAC, 1998), support the use of surrogates in a TMDL and provide the following guidance on the use of surrogate measures for TMDL development:

> *When an impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional "pollutant," it is appropriate to use another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgement where they are not…*
>
> *If used, surrogate environmental indicators should be clearly related to the water quality standard that the TMDL is designed to achieve. Use of a surrogate environmental parameter should require additional post-implementation verification that attainment of the surrogate parameter results in elimination of the impairment. If not, a procedure should be in place to modify the surrogate parameter or to select a different or additional surrogate parameter and to impose additional remedial measures to eliminate the impairment. (p. G-3)*

If the bioassessment impairments cannot be attributed to a single pollutant (e.g. sediment), Ecology may develop a surrogate in order to provide more meaningful and measurable pollutant loading targets. Flow alteration metrics are being considered as a surrogate for this TMDL because flow-induced physical alteration has been correlated with biological impairment and is thus of primary importance for this bioassessment TMDL. Biological alteration is usually a result of multiple stressors and, therefore, an unimpaired hydrologic regime does not guarantee healthy benthic communities when other habitat stressors are present.

However, physical integrity is a key foundational requirement for a healthy benthic community, and the connection between flow and the alteration of a stream's physical properties (and the subsequent effects on benthic organisms and aquatic health) is well-established in existing federal and state laws and regulations, as well as Ecology guidance and policy:

- Section 101 of the 1972 Federal Clean Water Act (33 U.S.C. §1251 et seq.) mandates us to restore and maintain the chemical, physical, and biological integrity of the Nation's waters.
- Chapter 173-201A of the WAC describes the water quality standards for surface waters of Washington State, and defines "pollution" as including "contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state…"
- The State Water Pollution Control Act (Chapter 90.48 RCW) uses the same definition of "pollution" as that in WAC 173-201A above.
- Ecology's Fact Sheet for Phase 1 NPDES permits (Ecology, 2006) describes how urbanization increases the "quantity and peak flows of runoff, which in turn cause hydrologic impacts such as scoured streambed channels, instream sedimentation and loss of habitat."
- The Volume 1, Chapter 1-2.5.7 of the Stormwater Manual for Western Washington (Ecology, 2014a) discusses how the duration of high flow events need to be minimized in order to reduce the energy associated with flows that is capable of moving sediments in the stream.
- Ecology's Phase I Municipal NPDES Stormwater permit requires certain counties to perform watershed-scale stormwater planning to "identify a stormwater management strategy or strategies that would result in hydrologic and water quality conditions that fully support *existing uses*, and *designated uses* as those terms are defined in WAC 173-201A-020, throughout the stream system."
- In appeals to the Pollution Control Hearings Board (PCHB), the PCHB has upheld Ecology's authority to retain flow control requirements within Ecology's 2007 stormwater permit in order to prohibit violations of the water quality standard (e.g. PCHB No. 07-021-023,-026 through -030 and -037).
- EPA has a webpage that provides some resources on developing stormwater-source TMDLs, which also includes a list of innovative TMDLs that use flow or impervious cover as surrogates for stormwater pollutants in streams listed for biological impairment[3].
- EPA (2010a) recognizes the benefit of using flow (e.g. stormwater flow volume) as a surrogate in TMDLs where stormwater sources are the primary source of impairment. The memo states that in this case, the TMDL "demonstrate the linkage between the surrogate parameter and the documented impairment (e.g. biological degradation)."
- Ecology policy explicitly recognizes that since water quality impairments can be caused by various factors related to stormwater, "it is logical to use surrogate indicators when developing wasteload allocations for stormwater" as long as there is a direct correlation

[3] Impaired Waters and Stormwater webpage: https://www.epa.gov/tmdl/impaired-waters-and-stormwater

between the surrogate and the pollution problem, and that "Ecology may establish a wasteload allocation that uses stormwater flow as a surrogate measure to address biological impairments as defined in the surface water quality standards.[4]"

- Previous published studies have shown that hydrologic alteration is correlated to observed biological impairments in urban streams, and discuss how hydrologic alteration limits the characteristics (e.g. abundance, richness, diversity, or individual taxa) of macroinvertebrates assemblages (Konrad et al. 2008; Booth and Bledsoe, 2009; DeGasperi et al. 2009; and Horner, 2013).
- Finally, the connections between flow alteration, fine sediment, and biological impairments in the Soos Creek watershed have already been established through a stressor ID analysis.

In this TMDL, we are considering the use of flow alteration metrics as a surrogate for pollution, since flows can alter the physical and biological properties of streams and deliver sediment to the stream. Flow and/or sediment might therefore be used to develop TMDL allocations to address bioassessment impairments in the Soos Creek watershed. Sections 7.3.1, 7.3.3, and 7.3.4 describe the statistical analysis, modeling, and potential target setting approaches (respectively) we are proposing for this TMDL study to assess the relationship between bioassessment impairments, sediment, and flow alteration. The results of these analyses will be used to determine whether or not sediment allocations alone are sufficient to address bioassessment impairments, or if flow alteration surrogates will be used in addition to, or instead of, sediment allocations.

3.3.2 Why is Ecology conducting a TMDL study in this watershed?

Ecology is conducting a TMDL study in this watershed because of temperature, DO, and bioassessment impairments that have resulted in several 303(d) listings in the watershed. The beneficial and designated uses protected in the Soos Creek watershed are defined in WAC 173-201A-600 as: core summer salmonid habitat, primary contact recreational uses, water supply, wildlife habitat, harvesting, commerce/navigation, boating, aesthetics, and as a habitat for aquatic species. The water quality criteria for temperature and DO, and associated listings, are described in Section 1.2 of the original QAPP (TetraTech, 2012). This QAPP addendum addresses only the additional work that will be done to address bioassessment impairments and related stressors.

Within the Soos Creek watershed, there are seven Category 5 listings for bioassessment identified by the Washington State 2014 Water Quality Assessment (Table 1).

[4] TMDLs, Surrogates, and Stormwater:
https://ecology.wa.gov/DOE/files/6b/6b7f13df-06ac-438c-afa7-465f3420a029.pdf

Table 1. Category 5 listings for bioassessment impairments in the Soos Creek watershed (as per the 2014 Water Quality Assessment).

Listing ID	Assessment Unit ID	Waterbody Name
70181	17110013000097	BIG SOOS CREEK
70186	17110013000483	BIG SOOS CREEK
70161	17110013000168	JENKINS CREEK
70162	17110013000493	JENKINS CREEK
70187	17110013002281	LITTLE SOOS CREEK
70150	17110013000171	RAVENSDALE CREEK
70183	17110013000484	MERIDIAN VALLEY CREEK

3.3.3 Water Quality Standards and Numeric Targets

The water quality criteria for temperature and DO are described in Section 1.2 of the original QAPP. Bioassessment and the related stressors (fine sediment, flow alteration, and physical habitat alteration) are discussed below.

Bioassessment

The Benthic Index of Biotic Integrity (B-IBI) is used in the bioassessment process and to assess the biological condition/aquatic health of streams. A B-IBI score is calculated by sampling macroinvertebrates (benthic organisms) in the stream and analyzing the species composition in that sample. The B-IBI score takes into account the overall diversity and richness of species present, as well as the types of species that are either absent or present. The prevalence of specific species that are more tolerant of poor aquatic habitat/water quality conditions, and the absence of species that require more pristine aquatic habitat/water quality conditions, indicate that the macroinvertebrate community is impaired. The B-IBI score takes all this into account: the lower the B-IBI score, the poorer the aquatic health of the stream where the measurement is made.

Impairment of biota is recognized as a violation of the State's Surface Water Quality Standards, within the narrative protection criteria described in WAC 173-201A-260 and the Tier I anti-degradation rules in WAC 173-201A-300 (see *References* for link to WAC 173-201A). Chapter 1 of Ecology's Water Quality Policy 1-11 also describes (1) guidance for bioassessment using science-based numeric standards and (2) how waterbody segments will be assessed to determine attainment with surface water quality standards and listing criteria.

Ecology's current thresholds for bioassessment scores are based on a rationale developed for the 2014 Water Quality Assessment submittal to EPA (Ecology, 2014b), in combination with determinations made in Adams (2010), EPA Guidance (EPA 2000a), Karr et al. (1986), and Morley (2000).

The current numeric targets for listings are based on the 5th and 25th percentiles of the distribution of B-IBI scores at reference sites. These scores were used in the 2014 Water Quality Assessment for listing:

- Category 5 – listings that indicate biological impairment, which is when the B-IBI score calculated from the two most recent years of available macroinvertebrate assemblage data is less than or equal to 27.
- Category 2 – listings that are “waters of concern”, with scores that fall between 28 and 37, and more information is needed to determine impairment status.
- Category 1 – measurements that show no impairment, indicated by B-IBI scores equal to or higher than 38.

Ecology Policy 1-11 (Ecology, 2012) describes the use of science-based numeric targets for bioassessment and for establishing the B-IBI numeric thresholds used to characterize the listings above. At the time this QAPP addendum is being prepared, Ecology is in the process of updating Policy 1-11 as part of the 2016 revision. These updates include moving from the 10-50 B-IBI scale to a 0-100 B-IBI scale, reevaluating the numeric targets for bioassessment, and considering regional (rather than statewide) targets for listing criteria. These changes will not affect existing Category 5 listings in the Soos Creek watershed, but may change the B-IBI scores for getting off the 303(d) list, since the new policy will be adopted before our study is complete. Any changes in these scores/thresholds will be stated in the final TMDL report.

Because bioassessment is an indicator of aquatic health or biotic integrity, stressors that cause low B-IBI scores first need to be identified in order to determine what needs to be done to improve B-IBI scores in the watershed. EPA and Ecology conducted a stressor ID analysis to evaluate which stressors correlated to low B-IBI scores found in the Soos Creek watershed (Marshalonis and Larson, 2018).

This stressor ID analysis used a weight-of-evidence approach to identify the potential stressors that contribute to the low B-IBI scores observed in the watershed. The analysis identified fine sediment, flow alteration (described by high pulse count, or HPC), and physical habitat alteration as the three main stressors that contribute to low B-IBI scores in the Soos Creek watershed. Each of these are described in more detail below.

Fine sediment, TSS, and turbidity

While sediment is integral to channel morphology, excess sediment loading, particularly fine sediment, can negatively affect aquatic life. It can smother gravel beds used for fish spawning and egg incubation, smother fish gills, bury aquatic insects that provide food for fish, and cover plants that produce oxygen. Sediment also clogs or widens streams and wetlands which increases flooding and reduces the pollution reduction capacities of wetlands. Organic sediment fractions, and sediment that has adsorbed nutrients, can also contribute to DO and pH problems. Urbanization, agriculture, and deforestation can all contribute to an increase in the watershed sediment yield and, combined with alterations in flow regime, contribute to an increase in sediment loading to receiving waterbodies via runoff. Instream channel erosion of the side banks and the streambed, which is a symptom of urbanization and flows in urban watersheds, also contribute additional sediment loading to streams (Russel et al., 2017).

While excess fine sediment is more problematic to water quality than TSS, measurements of sediment in streams are usually made in terms of TSS. Excess sediment is regulated under WAC 173-201A-260 as a “deleterious material.” Ecology does not set numeric thresholds for TSS in Chapter 173-201A WAC but may establish site-specific expectations for sediment levels as part of its TMDL program.

Turbidity is also a parameter of interest since it is a measure of water clarity, and TSS contributes to higher turbidity values. In fresh waters, regulation of TSS can be done in conjunction with the state criteria for turbidity in WAC 173-201A-200(1)(e). The Soos Creek watershed is Core Summer Salmonid Habitat where turbidity shall not exceed 5 nephelometric turbidity units (NTU) when the background is 50 NTU or less, or a 10% increase in turbidity when the background turbidity is more than 50 NTU.

Flow alteration

Flow alteration refers to changes in the hydrologic regime relative to undisturbed or reference conditions. Bunn and Arthington (2002) and Poff and Zimmerman (2010) have summarized the literature of biological responses to altered flows, which include overall reductions in the abundance and diversity of macroinvertebrates.

Studies have also found that there is a high degree of flow alteration when comparing fully forested conditions to urbanized conditions. Rosburg et al. (2017) analyzed 25+ years of flow data in Puget Sound-area streams to show changes in flow-duration curves over time with increased urbanization, including an increase in the magnitude of flow and flashiness. In addition, several other studies have compared modeled pre-developed/forested flows to current flows, and found relationships between urbanization/increases in impervious areas and increases in peak flows, stream flashiness, more unstable stream channels, and a reduction in the quality of stream habitat (Booth et al., 1997; Booth et al., 2002; King County, 2013; and Horner, 2013). Changes in flow regime due to urbanization increase the supply of fine sediment to downstream water bodies (Russel et al., 2017). Lastly, Vietz et al. (2012) highlight how flashy affects the physical form of streams, and considers what kind of flow regimes are necessary to sustain the desired geomorphology.

Flow alteration metrics (also referred to as hydrologic indicators) allow us to characterize stream flow patterns and analyze how human activities and land use/land cover affect these patterns. In addition, since stream ecosystems depend on certain flow and hydrologic patterns to maintain and preserve ecological function, these metrics can also be correlated to ecological metrics such as B-IBI scores.

DeGasperi et al. (2009) found eight flow metrics (1 through 8 listed below) to be significantly correlated with B-IBI scores and potentially biologically relevant in urbanizing basins in the Puget Sound lowland. Cooper (1996) found an additional potentially relevant metric (number nine below), which Horner (2011) also suggested as having potential to be a useful flow-ecology metric. This list of flow metrics use the same definitions as in Attachment A of Horner (2011):

1. **Low pulse count (LPC) –** Number of days each calendar year that discrete low flow pulses occur. A low-flow pulse is defined as the occurrence of daily average flows that are equal to or less than a low-flow threshold set at half (50%) of the long-term mean daily flow rate.

2. **Low pulse duration (LPD) –** Mean number of days per occurrence that the daily time-step hydrograph is below the low-flow threshold (defined in #1 above) for each calendar year.
3. **High pulse count (HPC) –** Number of days each calendar year that discrete high flow pulses occur. A high-flow pulse is defined as the occurrence of daily average flows that are equal to or greater than a high-flow threshold set twice the long-term mean daily flow rate.
4. **High pulse duration (HPD) –** Mean number of days per occurrence that the daily time-step hydrograph is above the high-flow threshold (defined in #3 above) for each calendar year.
5. **High pulse range (HPR) –** Range in days between the start of the first high flow pulse and the end of the last high flow pulse during a year.
6. **Flow reversals (FR) –** Number of times per water year that a trend change occurred in the daily time-step hydrograph (rising to falling limb or falling to rising limb, except for minor variations [<2 percent]).
7. **TQmean (T_{Qmean}) –** Fraction of time in each water year that the daily time-step hydrograph exceeds the annual mean discharge for year.
8. **Richards-Baker Index (R-B) –** Mean daily rate of change (absolute value) of daily time-step hydrograph for each water year.
9. **Peak 2-yr: Winter Baseflow Ratio (PK2YR) –** Ratio of the peak flow rate with a 2-year return frequency to the mean baseflow rate during the period October 1 – April 30.

While the focus of this TMDL is on flow alteration in general, the stressor ID analysis found that HPC in particular had a statistically significant correlation to B-IBI scores in the Soos Creek watershed; as high pulse counts increase in frequency, B-IBI scores decrease.

HPC is a measure of stream flashiness and also a reflection of urbanization and impervious cover in the watershed. Flashiness in general adversely affects waterbodies in several ways. First, they can transport various pollutants (including sediment) from roads, lawns, fields, impervious surfaces, and other land areas within the watershed and then deliver these pollutants to surface waters during storm events. Second, the physical force and 'flashiness' of HPC flows can scour and erode stream banks, result in channel incision, dislodge benthic organisms, and degrade and alter stream channels.

Physical habitat alteration

Physical habitat alteration can be a result of a variety of changes in watershed activities and instream processes. Both fine sediment loading and flow alteration contribute to alteration and degradation of physical habitat (e.g. erosion of the stream channel during flow events, and changes to the sediment bed composition). Reducing fine sediment loading and limiting flow alteration would ameliorate some of the degradation of physical habitat; therefore, this TMDL will indirectly address those components of physical habitat alteration by setting sediment and/or flow alteration targets. The TMDL Implementation Plan may also recommend other actions to improve physical habitat.

4.0 Project Description

4.1 Project goals

The main goals of this project are to:

1. Develop and use a calibrated sediment HSPF model of the Soos Creek watershed to understand, identify, and quantify the various sources and processes that influence sediment transport and delivery, as well as flow alteration in the watershed.
2. Use a combination of modeling and statistical tools to determine the sediment reduction targets and/or flow alteration targets needed to alleviate the effect of these stressors on the biological community and address bioassessment impairments in the creeks.
3. Use the results of statistical and modeling analysis to set TMDL load and wasteload allocations, make TMDL recommendations, and determine the implementation actions needed to meet these targets.

4.2 Project objectives

Specific project objectives and tasks include:

- Analyze and understand patterns in existing sediment data, particularly between fine sediment and TSS, which have been collected in the watershed to establish a link between the stressor (fine sediment) and the modeled output (TSS).
- Use existing data and known relationships and correlations in published literature and studies (Horner, 2013; King County, 2012 and 2017; Snohomish County, 2017) and conduct new statistical analysis between B-IBI scores, flow alteration metrics (such as HPC), and sediment loads. Synthesize the results of this analysis to establish the targets needed to improve B-IBI scores in the watershed to meet the water quality standards.
- Quantify land-use changes in the watershed since 2007 using existing land-use change maps. While we do not anticipate the need to update land use from the 2007 characterizations used in the existing HSPF model, this quantification of the level of land-use change in the watershed in the last 10 years will help us determine whether the changes are within the noise of the model resolution.
- Extend the hydrology model simulation of the existing HSPF model of the Soos Creek watershed through Water Year (WY) 2015, verify whether the original hydrology calibration parameters are still valid, and recalibrate if necessary.
- Add the sediment module to the HSPF model of the Soos Creek watershed, and calibrate the model for sediment for the years 2001-2015. The objective is to use the sediment parameter values from King County's WRIA 9 (King County, 2013) sediment modeling effort as much as possible, but fine-tune the calibration as needed for the Soos Creek watershed.
- Analyze relevant data and modeling results to determine the relationships between sediment and hydrology/flow events, what TSS loading and hydrologic patterns were like under forested conditions, and the human contribution to TSS loading and changes to hydrologic patterns.

- Combine the results of modeling and statistical analysis to establish the load reductions needed to meet both sediment and/or flow targets, which can then be used to inform the implementation plan.
- Review model output to determine whether any attributes of source areas can be highlighted for action during the implementation phase.
- Make recommendations on whether or not the technical approach used for this study is/is not applicable to other bioassessment TMDLs in Washington State.

4.3 Information needed and sources

This study does not involve the collection of any new data; it will rely on existing data to develop and calibrate the HSPF model. These data are described in the following sections. More details about these data (e.g. reference to relevant QA procedures) are provided in Section 14.1.1.

4.3.1 GIS data

The existing HSPF model involved the use and analysis of various GIS datasets, including topography, surficial geology, delineated stream networks, delineated sub-watersheds, and land use (described in King County, 2013). Since information from these data sources have already been incorporated into the development of the HPSF model, these data are not needed again for the baseline scenario/calibration process. Additional land-use GIS data may be needed for specific TMDL scenarios.

The existing model is based on 2007 land-use conditions and is calibrated for hydrology for WYs 2001-2008. We are now extending the hydrology simulation through WY 2015. Except for land use, the other GIS datasets are relatively static in time and are still relevant for extending the simulation to more recent years.

Depending on the degree of land use and land cover (LULC) change that has occurred in the Soos Creek watershed since 2007, we may or may not need to change how land use is represented and characterized in the model. To determine this, we will use results of the Washington Department of Fish and Wildlife (WDFW)'s High Resolution Change Detection (HRCD) analysis which includes all WRIAs in Puget Sound. This analysis included an assessment of high-resolution aerial imagery to calculate the percent change in LULC categories over the following time windows: 2006-2009, 2009-2011, and 2011-2013.

The HRCD datasets are all available through Ecology's GIS data repository. All three change analysis datasets will be evaluated to (1) assess the percent change in LULC categories (% forested, % developed, % agriculture, % total effective impervious area) since 2007, and (2) determine whether or not the degree of change in the Soos Creek is within the noise of the model. The decision on whether or not an update the model's land use will also consider other sources of uncertainty that might confound more accurate land use representation (e.g. stormwater mitigation efforts that have also been implemented over the time period) and other relevant factors.

4.3.2 Hydrology data

Hourly precipitation and daily evaporation data (weather data) are the two primary drivers to the hydrology component of the HSPF model. Streamflow data are needed to compare model predictions to observations and is the primary metric to assess model quality and calibration. All three data types (evaporation, precipitation, streamflow) will be needed to extend the model simulation through WY 2015. Figure 2 shows the location of available hydrologic monitoring data, each of which are described in more detail in the following sections.

Evaporation

The closest weather station with evaporation data is the Washington State University (WSU) Puyallup station, which has daily data available since June 1995 (data have been quality assured since January 2003). This same station was used by King County in developing the original HSPF model will be used in this analysis to extend the model evaporation inputs through 2015. Data can be downloaded one month at a time through the WSU AgWeatherNet website http://weather.wsu.edu/index.php?p=92950 or by email request for a longer-time series.

Precipitation

Table 2 lists the precipitation gages located inside and near the model domain that will be used to update the necessary model hydrology input files in order to run the model through WY 2015. All data can be downloaded from King County's Hydrologic Information Center Data Download webpage at http://green2.kingcounty.gov/hydrology/Data.aspx.

Table 2. Active King County precipitation gages in or near the Soos Creek watershed.

Site Code	Site Name	Data Availability	Location
09V*	Covington Cr. Rain Gauge below Lake Sawyer	2004 - present	inside model domain
26u*	Jenkins Creek Rain Gauge	1991 - present	inside model domain
32u	Lower Green River Rain Gauge	1988 - present	inside model domain
54v*	Soos Creek Rain Gauge	1991 - present	inside model domain
BDIA	Black Diamond I&I Rain Gage	2000 - present	inside model domain
KANG	Kent-Kangley I&I Rain Gage	2000 - present	inside model domain
SEQU	Sequoia JR High School I&I Rain Gage	2000 - present	outside, but near model domain
03u	Panther Creek Precipitation	1988 - present	outside, but near model domain
31w2	Peterson Rain 2	2013 - present	outside, but near model domain
31Y2	Fairwood Rain Gage	2009 - present	outside, but near model domain

*These three gages were used by King County to create a composite precipitation time-series input for the HSPF model for the Soos Creek watershed.

Streamflow within the Soos Creek watershed

Streamflow is the primary parameter needed to compare model predictions with observations in order to evaluate the model's ability to represent hydrologic processes in the model (i.e. to assess hydrologic calibration). Table 3 lists King County streamflow gages in the watershed that will be used to evaluate whether the existing model calibration remains valid for the extended model simulation period (WYs 2009-2015). This process will focus comparisons of model-predicted streamflows to observed flows at the most downstream locations of each creek in the watershed. We may not need to use all these data in Table 3 to evaluate whether the existing model calibration remains valid. Figure 2 illustrates the location of all hydrologic monitoring stations in/near the Soos Creek watershed. All data can be downloaded from King County's Hydrologic Information Center Data Download webpage at http://green2.kingcounty.gov/hydrology/Data.aspx.

Table 3. Active King County streamflow gages in the Soos Creek watershed.

Site Code	Site Name	Data Availability
09a	Covington Creek near Mouth	Jan. 1988 - present
09b	Rock Creek near Lake Sawyer	2015 – 2017 (data available for only 2-5 months each year)
09d	Ravensdale Creek (Lake Sawyer Inflow)	Feb. 2015 – present
26a	Jenkins Creek near Mouth	Dec. 1987 – present
54a/12112600*	Soos Creek at Mouth/Big Soos Creek above hatchery near Auburn	Nov. 1960 – present
54h	Soosette Creek Above SR-18	Dec. 1993 – present
54i	Little Soos Creek at SE 272nd	Oct. 1995 – present
54J	Soos Creek at Kent-Black Diamond RD	Dec. 2010 – present

*This is a USGS streamflow gage, but is also a King County monitoring site for other parameters.

Streamflow in other Puget Lowland watersheds

Additional streamflow data from USGS, King County, and other jurisdictions (e.g. county and city) collected outside the Soos Creek watershed and throughout the Puget Lowlands region will also be used to calculate flow alteration metrics, such as HPC. This larger dataset of paired streamflow and co-located B-IBI data will be used to create a larger database for analyzing, identifying, and exploring statistical relationships between the two.

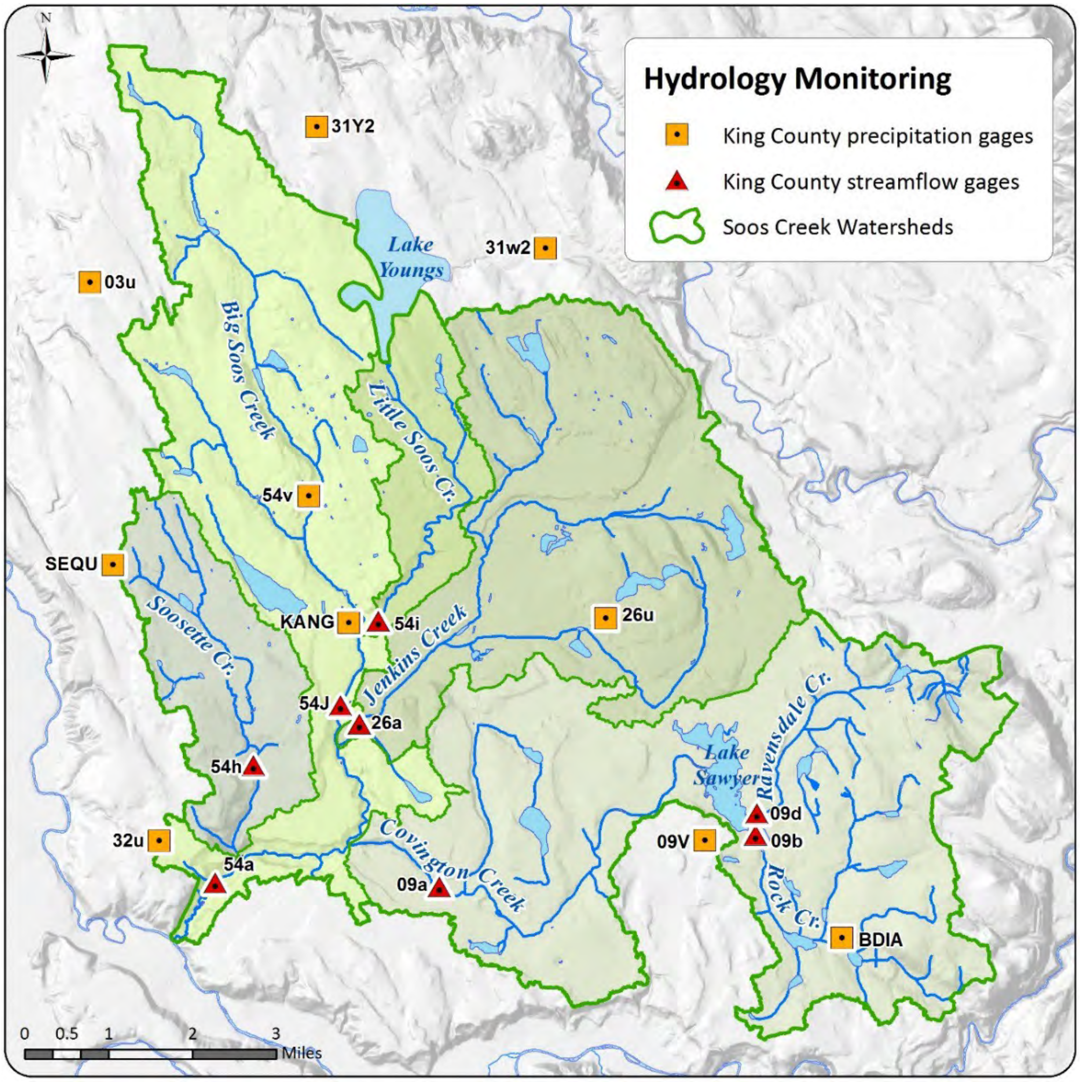

Figure 2. Map of active King County precipitation and streamflow gages in and near the Soos Creek watershed.

Groundwater withdrawal data

Information and data on the quantity of water withdrawals are needed to accurately simulate the water balance within the model. Muckleshoot Indian Tribe (MIT) has already compiled groundwater withdrawals within the watershed (which reduce summertime baseflow) and found that while there are 14 individual Group A and 288 Group B systems, approximately 98% of the total groundwater withdrawal volume was from the following three Group A systems: Kent Water Department, Covington Water District, and King County Water District #111 (Carlson and Massmann, 2015). Groundwater withdrawal data from years 2000 to 2008 were incorporated into the HSPF model by MIT and used to represent withdrawals between 2001-2008. Errors in the Kent Water Department data, and limited data available for the other two systems, meant that some estimation needed to occur.

Groundwater withdrawals for the same three water systems will be updated for the 2009 to 2015 time period with help from MIT. More data are available now than in 2008, when the initial modeling effort was started. Monthly metered data are available for the Kent Water Department and for the Covington Water District. King County Water District 111 will soon provide metered monthly data as well. The monthly data will be disaggregated into daily time steps and imported into a time-series water data management file (WDM) that can be used by the model.

4.3.3 Sediment data

Different types of sediment data will be used in this study. TSS will be the primary parameter needed to evaluate sediment calibration and the model's ability to predict sediment concentrations in the stream, particularly at the downstream outlet of each major tributary in the watershed. Turbidity data will also be used, as needed, since it is often correlated with TSS. Sediment grain size data will be used to specify the fraction of sand, silt, and clay within each reach of the model. Table 4 lists the agencies/monitoring programs that have collected TSS, turbidity, and sediment grain size data, and Figure 3 illustrates the location of these monitoring sites in the watershed.

Available instream TSS and turbidity data include:

- King County's Routine Ambient and Wet Weather Streams Monitoring Program which collects grab samples for TSS and turbidity approximately once per month. Data can be downloaded at: http://green2.kingcounty.gov/streamsdata/DataDownload.aspx.
- The MIT Fisheries Division, the City of Covington, and Tetra Tech collaboratively developed a stormwater monitoring plan for the Soos Creek watershed. This involved collection of TSS and turbidity (and other parameters not relevant to this study) by Tetra Tech in 2013, 2014, and 2015 in creeks and stormwater outfalls. These data have already been provided to us at Ecology electronically.
- King County conducted continuous turbidity monitoring as part of a wider effort to provide data to refine calibration of watershed hydrologic and water quality models in WRIA 9. Monitoring included the deployment of four turbidity probes/sondes in the Soos Creek watershed during WY 2011, and the data have been provided to us by King County.
- King County sampled TSS and turbidity during 13 storm and baseflow events at two sites in the Soos Creek watershed as part of the Green-Duwamish River Water Quality Assessment (GDWQA). Sampling included collection of discrete grab samples, auto-sequential sampling, and auto-composite sampling between 2001 and 2003.
- The Regional Stormwater Monitoring Program/Stormwater Action Monitoring is a collaborative program administered by Ecology in Puget Lowland Ecoregion streams, and includes TSS and turbidity data collected by municipal stormwater permittees. These data are available via Ecology's online EIM database.

Table 4. Available TSS, turbidity, and sediment grain size data collected in the Soos Creek watershed from 2001-2015.

Monitoring Agency/Program	No. of Sites	Number of simultaneous TSS and turbidity samples per year												
		2001-2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
King County - Ambient Streams Monitoring	6		51	54	48	48	48	24	24	8	6	46	54	70
MIT[3] - Soos Creek Stormwater Monitoring - Pipe/Outfall sites	8												33	14
MIT[3] - Soos Creek Stormwater Monitoring - River/Stream sites	23											93	138	88
King County - Green-Duwamish Watershed Water Quality Assessment[1]	2	52[2]												
King County – WRIA 9 data collection for stormwater retrofit planning[2]	4								continuous[3]					
Regional Stormwater Monitoring Program	3												26	
	No. of Sites	Number of sediment grain/particle size samples per year												
		2000-2009							2010	2011	2012	2013	2014	2015
King County - Sediment Monitoring	24	1 per year							11		13			
Regional Stormwater Monitoring Program	3													7

1. Monitoring was conducted by King County from 2001-2003, and the report/assessment was done by Herrera Environmental Consultants, Inc.
2. Monitoring included two sites in the Soos watershed (A320 and Y320) sampled during 13 storm-flow events and 13 and baseflow events at each site, so: (13+13) x 2 = 52. However, sample collection included discrete grab samples, auto-sequential sampling, and auto-composite sampling. Therefore, total number of data points are actually larger than 52 since the auto-sequential sampling involved collecting a sample every 4 hours over a 20-40-hour period, resulting in 6 to 10 samples per duration of the storm or baseflow event.
3. Continuous measurements of turbidity were made using a probe or sonde for several (but not all) months of WY 2011 at four sites in the Soos Creek watershed.
4. MIT = Muckleshoot Indian Tribe. Monitoring was done by Tetra Tech under a collaborative effort between MIT Fisheries Division, City of Covington, and Tetra Tech.

King County has also collected sediment grain/particle-size data (percent clay, silt, sand, and gravel in the stream bottom) at some of these same stations as part of their sediment monitoring program. These data are mostly collected about once per year. One site on the mainstem Big Soos (close to the outlet of the watershed) has been monitored once a year from 2000-2012, while a more focused sampling effort in 2010 and 2012 had a total of 11 and 13 sampling locations, respectively, within the Soos watershed. These sampling locations are illustrated in Figure 3.

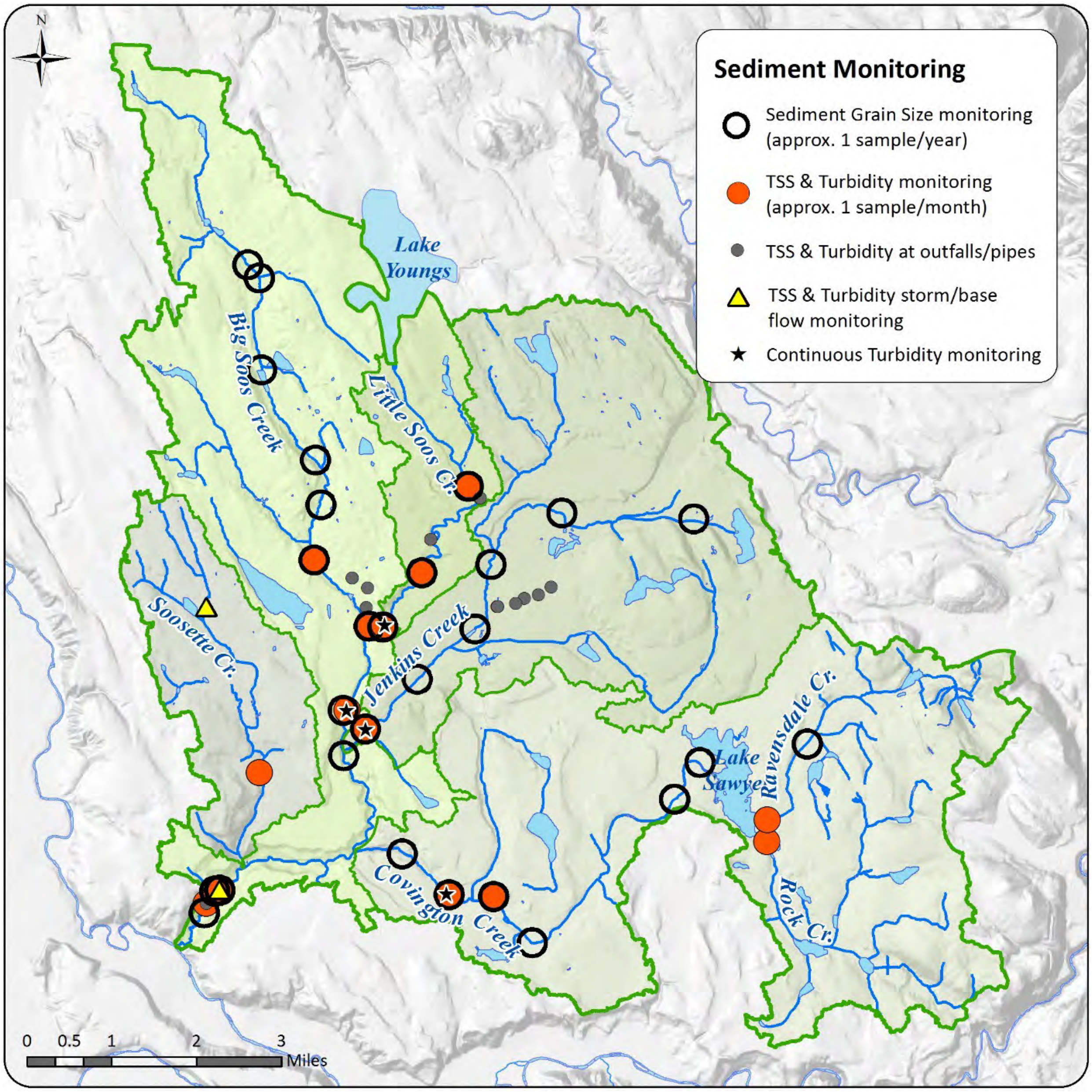

Figure 3. Monitoring locations in the Soos Creek watershed for sediment grain size, TSS, and turbidity data collected by King County's ambient streams and sediment monitoring programs, the Muckleshoot Indian Tribe (MIT), and the Regional Stormwater Monitoring Program/Stormwater Action monitoring.

In addition, another King County effort measured sediment particle size distribution in suspended sediment (as opposed to the stream bottom) at 13 sites in the Bear Creek watershed in 2015 and 2016, during two storm and two baseflow events. These TSS size fractions were generally consistent with standard practices for fractions, and potentially useful/applicable to the Soos Creek watershed in the absence of site-specific data.

TSS and turbidity data will be used to primarily compare to *instream* predictions of TSS loads and concentrations. However, literature data on sediment *loading to streams* will be used to estimate the possible range of sediment-delivery ratios and unit-area loads by land-use category, and also to compare these values with model-simulated loadings. Loadings of sediment loading by land-use categories have been estimated from literature data by Horner et al. (1994), Burton and Pitt (2002), and Shaver et al. (2007), as well as from local sources by King County (2007).

4.3.4 Bioassessment/B-IBI data

Bioassessment/B-IBI data are available online through the Puget Sound Stream Benthos (PSSB) Database: http://pugetsoundstreambenthos.org. Data are uploaded to this database by multiple entities throughout the Puget Sound region. B-IBI data collected within the Soos Creek watershed that were used in the Stressor ID analysis are illustrated in Figure 4 and listed in Table 5. These included data collected from 1999-2013 acquired from the PSSB as well as data collected in 2012 by Tetra Tech (contracted by EPA/Ecology) specifically for this TMDL. The B-IBI was developed using data from a variety of streams throughout the Puget Lowlands, and enough data have now been collected from around the state to make meaningful comparisons in order to start improving conditions.

For this study, we will query the PSSB database to acquire newer data and also data from other locations outside the Soos Creek watershed but within the Puget Sound Lowlands region. These B-IBI data will be used for statistical analysis together with hydrologic metrics and also sediment data.

These data will also be used to identify areas of the watershed to target for protection if there are areas that fall within Category 2 (waters of concern) and Category 1 (non-impaired) listings. Category 2 listings need to be prioritized for potential implementation and restoration actions to prevent further degradation, while Category 1 areas need to be prioritized for protection.

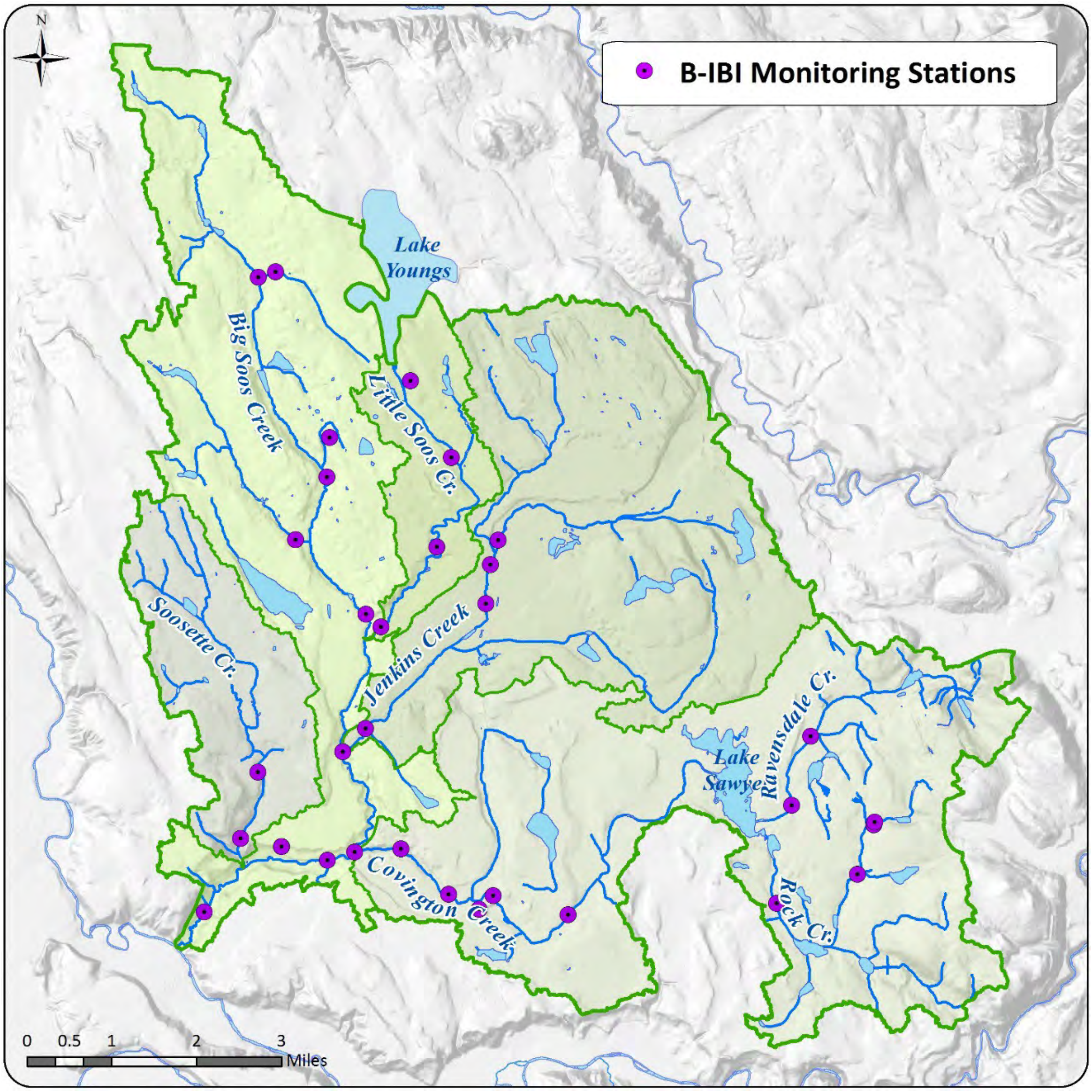

Figure 4. Monitoring locations in the Soos Creek watershed for B-IBI measurements collected by various entities from 1999-2013 and used in the stressor ID analysis.

Table 5. List of B-IBI sampling sites within the Soos Creek watershed used in EPA's stressor identification study.

*Sites in **bold** are where benthic data collected at that site resulted in a 303(d) listing.*

Agency	Project	Site Code	Latitude	Longitude	# Samples
King County - DNRP	Ambient Monitoring	09COV1165	47.31934	-122.1316	11
King County - DNRP	Ambient Monitoring	09COV1418	47.30933	-122.0777	10
King County - DNRP	Ambient Monitoring	09COV1753	47.31199	-122.0254	1
King County - DNRP	Ambient Monitoring	09COV1756	47.32877	-122.0221	11
King County - DNRP	Ambient Monitoring	09COV1798	47.34064	-122.0176	9
King County - DNRP	Ambient Monitoring	09COV1862	47.31721	-122.0052	9
King County - DNRP	Ambient Monitoring	09COV1864	47.32576	-122.0013	8
King County - DNRP	Ambient Monitoring	09DEE2163	47.28230	-121.9327	11
King County - DNRP	Ambient Monitoring	09SOO0943	47.30855	-122.1690	11
King County - DNRP	Ambient Monitoring	09SOO1020	47.32125	-122.1603	2
King County - DNRP	Ambient Monitoring	09SOO1022	47.33264	-122.1563	10
King County - DNRP	Ambient Monitoring	09SOO1040	47.41720	-122.1588	1
King County - DNRP	Ambient Monitoring	09SOO1130	47.31778	-122.1384	11
King County - DNRP	Ambient Monitoring	09SOO1134	47.33641	-122.1351	11
King County - DNRP	**Ambient Monitoring**	**09JEN1318**	**47.36222**	**-122.0999**	**10**
King County - DNRP	**Ambient Monitoring**	**09JEN1357**	**47.36890**	**-122.0989**	**11**
King County - DNRP	**Ambient Monitoring**	**09JEN1358**	**47.37313**	**-122.0972**	**9**
King County - DNRP	**Ambient Monitoring**	**09SOO1106**	**47.37249**	**-122.1480**	**7**
King County - DNRP	**Ambient Monitoring**	**09SOO1144**	**47.38331**	**-122.1405**	**7**
King County - DNRP	**Ambient Monitoring**	**09SOO1209**	**47.35787**	**-122.1261**	**9**
King County - DNRP	**Ambient Monitoring**	**09SOO1283**	**47.37174**	**-122.1126**	**11**
King County - Roads	ESA Water Quality	E216	47.34047	-122.1295	7
King County - Roads	ESA Water Quality	E234	47.41812	-122.1545	7
King County - Roads	ESA Water Quality	E242	47.38703	-122.1093	7
King County - Roads	ESA Water Quality	E333	47.32620	-122.0011	12
King County - Roads	ESA Water Quality	E349	47.31235	-122.0966	5
King County - Roads	ESA Water Quality	E3516	47.31240	-122.1078	7
King County - Roads	ESA Water Quality	E365/366	47.28565	-121.9237	7
Ecology/Tetra Tech	TMDL Studies	Soos Cr & SR 58 Crossing Kent-Black Diamond R	47.31000	-122.1000	1
Ecology/Tetra Tech	TMDL Studies	Soos Creek at 148th Ave SE	47.39000	-122.1400	1
Ecology/Tetra Tech	TMDL Studies	Soos Creek at 164th Ave SE	47.40000	-122.1200	1
Ecology/Tetra Tech	TMDL Studies	Soos Creek at 168th Way	47.32000	-122.1200	1
Ecology/Tetra Tech	TMDL Studies	Soos Creek at 272nd St	47.36000	-122.1300	1
Ecology/Tetra Tech	TMDL Studies	Soos Creek Near SR 58	47.32000	-122.1500	1

DNRP = Department of Natural Resources and Parks
ESA = Endangered Species Act

4.4 Tasks required

The specific tasks required to meet project objectives are mostly technical and focused on model development, calibration, and application. These tasks are discussed in Section 7.3.

4.5 Systematic planning process used

This QAPP addendum represents the systematic planning process for this project.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 6. Organization of Ecology project staff and responsibilities.

Staff (All EAP except client)	Title	Responsibilities
Joan Nolan Water Quality Program Northwest Regional Office Phone: 425-649-4425	EAP Client/TMDL Lead	Clarifies scope of the project. Provides internal review and approval of the QAPP addendum. Writes final TMDL Implementation Plan and serves as a liaison with stakeholders.
Ralph Svrjcek Watershed Unit Northwest Regional Office Phone: 425-649-7165	Unit Supervisor for the TMDL Lead	Reviews and approves the draft and final QAPP addendum, technical memo and TMDL report. Provides an advisory role as the project progresses.
Teizeen Mohamedali Modeling and TMDL Unit Western Operations Section Phone: 360-715-5209	Principal Investigator/ Project Manager	Authors the QAPP addendum. Conducts technical analysis and modeling. Synthesizes results, writes the draft and final technical memo and TMDL report.
Cristiana Figueroa-Kaminsky Modeling and TMDL Unit Western Operations Section Phone: 360-407-7392	Unit Supervisor for the Project Manager	Reviews and approves the draft and final QAPP addendum, technical memo and TMDL report, and approves the budget. Provides technical advice and oversight.
Dale Norton Western Operations Section Phone: 360-407-6596	Section Manager for the Project Manager & Study Area	Reviews the project scope and budget, tracks progress, reviews and approves final QAPP addendum.
William R. Kammin Phone: 360-407-6964	Ecology Quality Assurance Officer	Reviews and approves the draft and final QAPP addendum.

EAP: Environmental Assessment Program
QAPP: Quality Assurance Project Plan

5.2 Special training and certifications

The principal investigator for this project has taken an intensive week-long training on HSPF, including model theory, parameters and processes simulated by the model, hydrology and sediment model development, calibration, model evaluation, etc., and now has the skills to use and apply this model for this project. A licensed professional engineer also will review this QAPP addendum and subsequent technical reports that document the technical analysis and modeling work that is done.

5.3 Organization chart

In addition to Ecology staff identified in Table 6, this project has a technical advisory team that includes staff from EPA, the Muckleshoot Indian Tribe, and King County. These staff will be provided the opportunity to be involved in the project during key decision making points (e.g. when we select what model scenarios to run, when establishing LA and WLAs) and also to provide input on the draft technical memo and the TMDL report before it gets disseminated to the public.

5.4 Proposed project schedule

Table 7. Proposed schedule for completing analysis and reports.

Technical Memo – Sediment/Bioassessment Modeling & Analysis	
Author lead / Support staff	Teizeen Mohamedali
Schedule	
Draft due for internal review	October 2019
Draft due for project team review	December 2019
Final Technical Memo*	January 2020

This technical memo will be folded into the final TMDL report. The final TMDL report will also include temperature and DO components of the TMDL.

5.5 Budget and funding

Table 8. Project budget and funding.

Budget Item	**Amount**
Salary, benefits, and indirect/overhead	$239,200
Modeling contactor support - consultant fees for reviewing HSPF model set up, calibration, and scenarios*	$20,000
Travel and other	$1,000

*Modeling contractor support is contingent on funding.

6.0 Quality Objectives

6.1 Data quality objectives[5]

This project does not involve the collection of any new field data, or analysis of lab data, but relies on existing data that have already been collected in the watershed. The main Data Quality Objective (DQO) for this project is to ensure that existing data meet certain data quality criteria (see Section 4.3 and 14.1.1) for the development and calibration of the sediment HSPF model.

6.2 Measurement quality objectives

Not applicable. No new field data will be collected, and there is no laboratory analysis for this project.

6.3 Model quality objectives

Absolute criteria for model acceptance or rejection are usually not appropriate 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. However, model performance will be evaluated using quantitative and qualitative metrics to determine the relative quality of model calibration and model results.

In watershed modeling, the ‘weight-of-evidence’ approach is rapidly becoming the standard practice (Donigian, 2002; EPA, 2006; Duda et al., 2012; Brown and Caldwell, 2013; and USACE, TNC and IC, 2013). This approach uses a combination of quantitative/statistical and qualitative/graphical methods to determine the quality of model calibration. The specific methods that will be used for this study to assess model quality are outlined in Section 13.4.

Within the HSPF modeling community, thresholds for specific model metrics are sometimes used to communicate the *general* quality of model calibration. Figure 5 and Table 9 provide examples of how these thresholds can be used to gauge the level of accuracy (e.g. from poor to very good) expected from HSPF model application.

[5] DQO can also refer to ***Decision*** Quality Objectives. The need to identify Decision Quality Objectives during the planning phase of a project is less common. For projects that do lead to important decisions, DQOs are often expressed as tolerable limits on the probability or chance (risk) of the collected data leading to an erroneous decision. And for projects that intend to estimate present or future conditions, DQOs are often expressed in terms of acceptable uncertainty (e.g., width of an uncertainty band or interval) associated with a point estimate at a desired level of statistical confidence.

R	←0.75 ——— 0.80 ——— 0.85 ——— 0.90 ——— 0.95 ——→
R^2	←——— 0.6 ——— 0.7 ——— 0.8 ——— 0.9 ——→
Daily Flows	Poor Fair Good Very Good
Monthly Flows	Poor | Fair | Good | Very Good

Figure 5. Range of linear correlation coefficients (R) and coefficients of determination (R^2) for general assessment of HSPF model performance for daily and monthly flows (source: Duda et al., 2012).

Table 9. General range of percent difference between simulated and observed values that can be used for evaluation of HPSF model performance (source: Donigian, 2000).

	% Difference between Simulated and Observed Values*		
	Very Good	**Good**	**Fair**
Hydrology/flow	< 10	10 to 15	15 to 25
Sediment	< 20	20 to 30	30 to 45

*CAVEATS:

1. Relevant to monthly and annual mean values only; storm peaks may differ more (i.e. individual events or observations may show larger differences and still be acceptable).
2. Level of agreement depends on site and application-specific conditions, including the quality and detail of input and calibration data.
3. Ranges may vary depending on the purpose of model application.
4. If time and resources are available, use of additional/alternative assessment procedures are recommended, and could meet study objectives.

These thresholds will be calculated over the simulation period for five subbasins in the Soos Creek watershed (i.e. averaged for all calibration stations within each subbasin): Big Soos, Little Soos, Soosette, Jenkins, and Covington Creeks.

Determining where within these thresholds the model performance lies provides only a coarse and initial assessment of model quality. If model metrics fall within the 'Poor' or 'Fair' category, it would indicate that model performance is likely inadequate. However, even if a model falls within the 'Good' to 'Very Good' range, the thresholds alone are insufficient to decide whether to accept or reject the model since these thresholds are based on a limited number of performance metrics and do not provide a holistic way to assess model performance or model skill. We plan to use the thresholds in Figure 5 and Table 9 to assess the quality of our model at a coarse level. We will then combine this with a much more extensive model calibration assessment process (outlined in Section 13.4.3) to determine whether the model quality is adequate for its application in this TMDL.

7.0 Study Design

7.1 Study boundaries

The study boundaries are defined by the Soos Creek watershed boundary, which includes five subbasins: Big Soos, Little Soos, Soosette, Jenkins, and Covington. Figure 1 shows a map of the study area, and Figure 6 delineates the individual reaches within the Soos Creek watershed as they are represented in the HSPF model.

7.2 Field data collection

Not Applicable. There is no new field work associated with this project.

7.3 Modeling and analysis design

This study will involve a combination of statistical analysis, HSPF modeling, and GIS analysis. These are described in more detail below.

7.3.1 Statistical analysis

The main statistical analysis to be conducted in this study will be to demonstrate, analyze, and establish relationships between B-IBI, hydrologic metrics, fine sediment, and TSS in order to support flow and/or TSS targets and thresholds. The statistical methods that we plan to use to establish relationships between the different parameters of interest include:

Simple regression

Linear regression, log-linear regression, and exponential regression are used to achieve the best-fit among the data (e.g. between flow alteration metrics and B-IBI scores). It is important to emphasize that benthic communities respond to a number of dynamic environmental variables, and simple regression relationships might show correlation but do not imply causation. Simple regressions are useful for identifying relationships, but we cannot rely on them alone to associate cause and effect in nature because of the complexity of conditions that may modify or obscure a causal relationship.

Quantile regression

Quantile regression estimates relationships between variables for all portions of a probability distribution. The approach involves first separating your dataset (in this case, B-IBI scores) into quantiles and calculating different regression parameters (e.g. intercept and slope) for the subsets of data that fall within each quantile. The result is a variable intercept and slope for different quantiles of data that each have different functional responses to the predictor variable. The approach is useful for ecological data that have unequal variations to predictor variables; this is described in more detail in Cade and Noon (2003) and Schmidt et al. (2012). It has been applied in the analysis of flow alteration and bioassessment to determine the biological status that could be achieved as flow alteration increases or decreases away from a baseline condition (USACE, TNC and IC. 2013). This statistical method aims to address some of the limitations of simple regression techniques in its application to analyze and identify ecological responses to specific collinear environmental variables and various limiting factors.

Conditional probability

Conditional probability could be used, for example, to determine the probability that B-IBI scores would improve to a score at or above a specific threshold value if a specific condition (e.g. reduction in HPCs, a change in the level of flow alteration, or a reduction in fine sediment) is met. It has also been applied in the analysis of flow alteration and biometrics (USACE, TNC and IC. 2013).

One or more of the above statistical methods will be applied to:

Analyze the relationships between fine sediment and TSS, and turbidity and TSS

The link between fine sediment and TSS is critical since fine sediment is one of the identified stressors, but TSS is the parameter that is being modeled, and the parameter that is usually measured in the field. Similarly, establishing a relationship between turbidity and TSS could help us determine if the turbidity water quality standard could be used as a basis of TSS allocations.

Analyze relationships between flow and B-IBI scores

The relationship between flow and benthic community response is a fundamental part of this study. Statistical analysis will be used to analyze the response of B-IBI to changes in flow due to urbanization, and identify the targets/thresholds needed to maintain B-IBI scores over a specific threshold value (e.g. a score of 38 is what is currently needed to get of the Category 5 list). This requires paired measurements of streamflow and B-IBI scores. However, paired flow and B-IBI data collected only within the Soos Creek watershed does not produce a large enough dataset for all the statistical methods we plan to use.

We therefore plan to:

1. **Use measured flow and B-IBI data collected throughout the Puget Sound lowlands ecoregion.**

   Regional B-IBI data collected within the Puget lowlands provide context for data collected within the Soos Creek watershed, and also allow for the interpretation of local conditions and trends relative to regional patterns. These data also increase our sample size and ability to perform statistical analysis in a regional context. In addition, B-IBI data from regional reference or 'minimally impacted' sites allow us to see what we would should expect under 'minimal human impact.' This helps us to determine where the 'biological health' of a site exists along a gradient of unimpaired (excellent biological health) to highly impaired (poor biological health).

   B-IBI from the online PSSB database collected since 2000 will be retrieved and paired with a limited number of flow alteration metrics that have already been identified in previous studies to be ecologically relevant (listed in Section 3.3.3). Since benthic sampling does not always occur at the same locations where streamflow gages exist, we will establish criteria to identify co-located streamflow data that are close to B-IBI sites. These criteria will include comparing the level of development/urbanization within the drainage area for each B-IBI sampling location with that in the drainage area for the closest flow gage (e.g. by comparing percent impervious area, population density, and/or road density).

The B-IBI and flow datasets will be averaged over the same time period before performing statistical analysis. A recent analysis by Snohomish County (2017) averaged both flow metrics and B-IBI data over a four-year period and found stronger statistical regressions between the two than previous analysis by DeGasperi et al. (2009). This previous analysis used single-year B-IBI values and averaged hydrologic metrics for the three years (preceding, but including the calendar year in which the B-IBI sample was collected). However, the analysis by Snohomish County also removed two ‘outliers’ from the dataset, which contributed to stronger correlations. The basis of the selected averaging period we use for this study, and any decisions to remove outliers, will be documented in the final report.

2. **Use modeled flow and B-IBI data collected within the Soos Creek watershed**

   Calculate flow metrics from the flows simulated by the HSPF model (as opposed to measured flows) at the locations within the Soos Creek watershed where we have B-IBI data. This step was already done for the stressor ID analysis but will be repeated to bring all the analysis into a consistent time-period (i.e. through 2015). It will also include more recent data and may provide us with a larger dataset.

   An additional advantage of using simulated streamflow is that it would allow us to also calculate the *difference* between hydrologic metrics under existing/baseline conditions and forested/reference conditions (i.e. the percent of flow alteration[6]). We could then perform statistical analysis between B-IBI scores and flow alteration metrics (e.g. percent alteration in HPC or flashiness) due to anthropogenic/human activities. This is constructive because the eventual goal cannot be better than forested conditions.

   For this part of the analysis, we will not need to find ‘co-located’ stream gages with similar drainage areas since we will simply use simulated streamflow from the model reach where B-IBI samples were taken. The same hydrologic metrics will be used as above. These will be averaged over the same time period as B-IBI data to create pairs of stream flow metrics and B-IBI scores, except that the hydrologic metrics will be calculated from model simulated streamflow under both existing/baseline and forested conditions.

7.3.2 GIS analysis

This study will also involve some GIS analysis. Examples of GIS analysis include:

- Analyzing change in land use in the watershed between 2007 and 2015. This analysis will specifically focus on increases in impervious cover, in order to determine whether land use needs to be updated in the existing HSPF model.

[6] See Section 7.3.4 (‘Potential model scenarios’) for a definition of forested conditions in terms of how this is defined for modeling purposes.

- Evaluating criteria for ‘co-locating’ streamflow and B-IBI sites by analyzing the relative level of urbanization in the drainage areas for each paired site.
- Analyzing land uses in different parts of the watershed (e.g. identifying wetlands, existing riparian buffer zones, and possible sources of sediment).
- Identifying least-disturbed and forested areas in the watershed where ‘good’ or ‘excellent’ B-IBI scores have been measured. Studies have shown that benthic invertebrates can recolonize restored sections of a stream that formerly had poor benthic assemblages, but that connectivity and proximity to these source populations is important (Pander et al., 2016; Winking et al., 2016). These upstream/pristine areas, as well as the connectivity between them and downstream/degraded areas, will need to be conserved, as indicated in the implementation plan.

7.3.3 HSPF modeling

This study will start with an existing Hydrologic Simulation Program-FORTRAN (HSPF) model of the Soos Creek watershed. The model has been calibrated for hydrological parameters for WYs 2001-2008, using 2007 land-use conditions. The development and calibration of the original HSPF model for the Soos Creek watershed is described in detail in Aqua Terra (2003). This version of the model was further developed and documented in a final report by King County (2013), and then refined by the MIT to improve baseflow predictions (Carlson and Massmann, 2015). This refined version of the HSPF model will be the starting point for this study. All model files have been provided to Ecology. The model will first be extended through WYs 2009-2015, sediment simulation will be added to the model.

The model simulation begins in 1998 to allow time for the model to spin up and stabilize by the year 2001. Model spin up is a way to ‘warm up’ the model for a certain amount of time until model results are not as sensitive to initial conditions.

The HSPF is a process-based watershed model. The User’s Manual (Bicknell et al., 2005) describes HPSF as “*a set of codes that can simulate the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams*”. The model simulates runoff processes and instream interactions and is capable of simulating sub-daily dynamic time-series of runoff and pollutant loads and concentrations. The model has been used extensively by EPA, USGS, and the academic community, and maintains a strong scientific basis. Locally, it has been used extensively and applied by King County in watersheds within their jurisdiction for stormwater retrofit planning and other studies.

The model simulates fundamental hydrologic processes that make up the water budget, including precipitation, evaporation, evapotranspiration, interception, surface runoff, interflow, infiltration, as well as various components of groundwater flow and storage. It is typically run at an hourly time step. Additional modules (e.g. sediment and water quality) can be added once the hydrology has been calibrated.

The processes and algorithms within the model have been developed from theory, lab experiments, and empirical watersheds (Duda et al., 2012). These processes are controlled by associated rates and parameters which the user specifies for the pervious (referred to as PERLNDs) and impervious (referred to as IMPLNDs) land areas within the watershed, within the PWATER and IWATER submodules, respectively. The submodule HYDR then simulates instream hydraulic processes, which keeps track of the water balance within each reach, including reach-level precipitation, evaporation, and all other inflows and outflows.

The sediment module in HSPF simulates the detachment, removal/wash off (i.e. erosion), and accumulation of sediment on both pervious and impervious surfaces. Erosion is primarily a function of runoff, which is affected by land use, land cover, land slope, soil disturbance, and transport properties of soil (EPA, 2006). The sediment loading rate from different types of land uses is a calibrated parameter. The submodule SEDMNT simulates the production and removal of sediment from pervious land segments; the submodule SOLIDS simulates the accumulation and removal of solids by runoff and other means from impervious land segments.

This sediment load that is eroded from the land surface is transported from the watershed/land surfaces, and then divided into user-specified fractions of sand, silt, and clay, before being delivered to the stream channel/stream reach (referred to as RCHRES). From here, the SEDTRN module simulates the instream sediment fate and transport of sediment.

The SEDTRN module has two submodules: SANDLD and COHESV. The SANDLD submodule simulates the deposition, scour, and transport of the sand fraction of inorganic sediment within the stream. Whether sand is deposited, scoured, or transported downstream is determined by comparing the sand transport carrying capacity and the actual sand transport rate, which are functions of stream velocity. The COHESV submodule simulates the deposition, scour, and transport of silt and clay (also known as cohesive sediments) as a function of advection and bed shear stress.

The algorithms used to simulate the hydrologic and sediment processes described above are described in more detail in the User's Manual (Bicknell et al., 2005) as well as by Donigian and Love (2003) and Duda et al. (2012).

The modeling phase of this study will involve the following steps:

1. Extend the HSPF hydrology simulation from the existing WYs 1998-2008 to WY 2015. This might require two separate simulation periods, each representing a different land use period: WYs 2001-2008 and WYs 2009-2015 (with WYs 1998-2000 being the spin up time). The second simulation can either use the outputs of the first simulation period for initial conditions, or it can have its own spin-up period. The most streamlined approach of these two will be selected.
2. Validate the existing HSPF model by checking if the calibrated model parameters adequately simulate the flow regime over the new time-period, WYs 2009-2015 (i.e. without changing any model parameters). If not, re-calibrate hydrology as needed.

3. Add the sediment module to the model and calibrate the model for sediment between WYs 2001-2015. The plan is to use the sediment parameter values from King County's WRIA 9 (King County, 2013) sediment modeling effort as much as possible but fine-tune these parameters as needed for the Soos Watershed.
4. Perform sediment model validation over the WYs 2001-2015. Since sediment observations are sparser, we do not plan to have a separate validation time period. Instead, a random subset of available sediment data will be removed and not used for calibration, so that these data can be used in this step for model validation.
5. Use the final, fully calibrated hydrology and sediment model to calculate and compare hydrologic metrics and TSS loads under existing conditions, forested conditions, and other relevant scenarios.
6. Model scenarios to predict what TSS load would be associated with meeting the flow/HPC targets established from statistical analysis (see 'Statistical Analysis' below for details).

Hardware and software needs

Existing computer hardware and memory on EAP's modeling servers and individual staff laptop computers will be sufficient to meet the hardware needs for this project. Software needs for this project are listed below:

- EPA BASINS – developed by EPA (2015) as a multipurpose environmental analysis system that includes several modeling plug-ins, one of which is HSPF, and is available for free download at: https://www.epa.gov/exposure-assessment-models/basins. The installation of BASINS also includes:
  - HSPFParm – HSPF Parameter Database, which is an evolving database of parameter values that users can use as a starting point for developing HSPF parameter values, based on values used in HSPF models that have been calibrated and applied to watersheds in North America. The database was developed by Aqua Terra Consultants under contract to EPA (EPA, 1999).
  - WDMUtil – a utility program for managing Watershed Data Management (WDM) files, which contain input and output time-series data for HSPF.
- HSPFEXP+ - developed by RESPEC to support calibration of watershed models developed using HSPF. This is an open-source project and available for free at: http://www.aquaterra.com/resources/downloads/HSPEXPplus.php.
- SARA Timeseries Utility – supports analysis and management of time-varying environmental data, including listing, graphing, computer statistics, and computing meteorological data used in HSPF. Available for free download at: http://www.aquaterra.com/resources/downloads/saratsutility.php.
- Indicators of Hydrologic Alteration (IHA) – developed by scientists at The Nature Conservancy to facilitate hydrologic analysis in an ecologically-meaningful manner. The program calculates ecologically-relevant statistics from daily streamflow data, and is available for download at: https://www.conservationgateway.org/ConservationPractices/Freshwater/EnvironmentalFlows/MethodsandTools/IndicatorsofHydrologicAlteration/Pages/IHA-Software-Download.aspx

- Microsoft Excel – for data analysis, model calibration comparisons, etc. This is standard software available on all agency computers.
- R-Program – for statistical analysis and generation of plots. This software is already installed and available for free at: https://www.r-project.org/. A number of libraries of R scripts exist and are freely available to perform statistical analysis and plotting functions.
- Matlab – for statistical analysis and generation of plots. This software is already installed with a valid user license.
- ESRI ArcGIS – for GIS analysis and making maps; Ecology already has agency-wide licenses for employee use.

7.3.4 Model setup and data needs

Model setup

The first step in HSPF model development involves watershed and channel segmentation. The purpose of segmentation is to divide the study area into individual land and channel segments that are assumed to represent relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation is the basis of assigning similar or identical parameter values and functions to all portions of a particular land or channel segment.

Watershed segmentation is usually done by delineating individual hydrologic catchments based on uniform precipitation, soils, topography, and land cover. Each delineated catchment is called a hydrologic response unit (HRU). The HSPF model that we plan to use for this study has already been delineated into 60 HRUs, each with a unique identifier (Figure 6). The details of the delineation process, and how flow is routed between reaches, is described in King County (2013). The delineation process identified four precipitation zones, three soil types, four slope categories, and six land uses/vegetation covers. The catchment sizes range from 0.05-4.7 square miles, with a mean of 1.1 square miles.

The model will be run at an hourly interval for the WYs 1998-2015, but WYs 2001-2015 will be the main period of interest. (As noted earlier, the simulation between 1998-2000 is primarily to allow for model spin up time.)

Model input parameters are specified in a User Control Input (UCI) file, which contains most of the information to run the model except time-series data (e.g. precipitation and evaporation). The UCI file is a txt (ASCII) file, and is the main file that the user interacts with to specify model input parameters. The UCI file is divided into several ‘blocks’ that each contain information related to different parts of the model (e.g. global parameters, linkages to time-series data, specific modules in the model and associated parameters, and linkages/connections between, for example, land segments and reaches). Setting up the model involves setting up the UCI file. This can be done via the HSPF GUI or via a text editor.

Table 10 lists the HSPF catchments that have different types of sampling data, including the number of sites in each catchment.

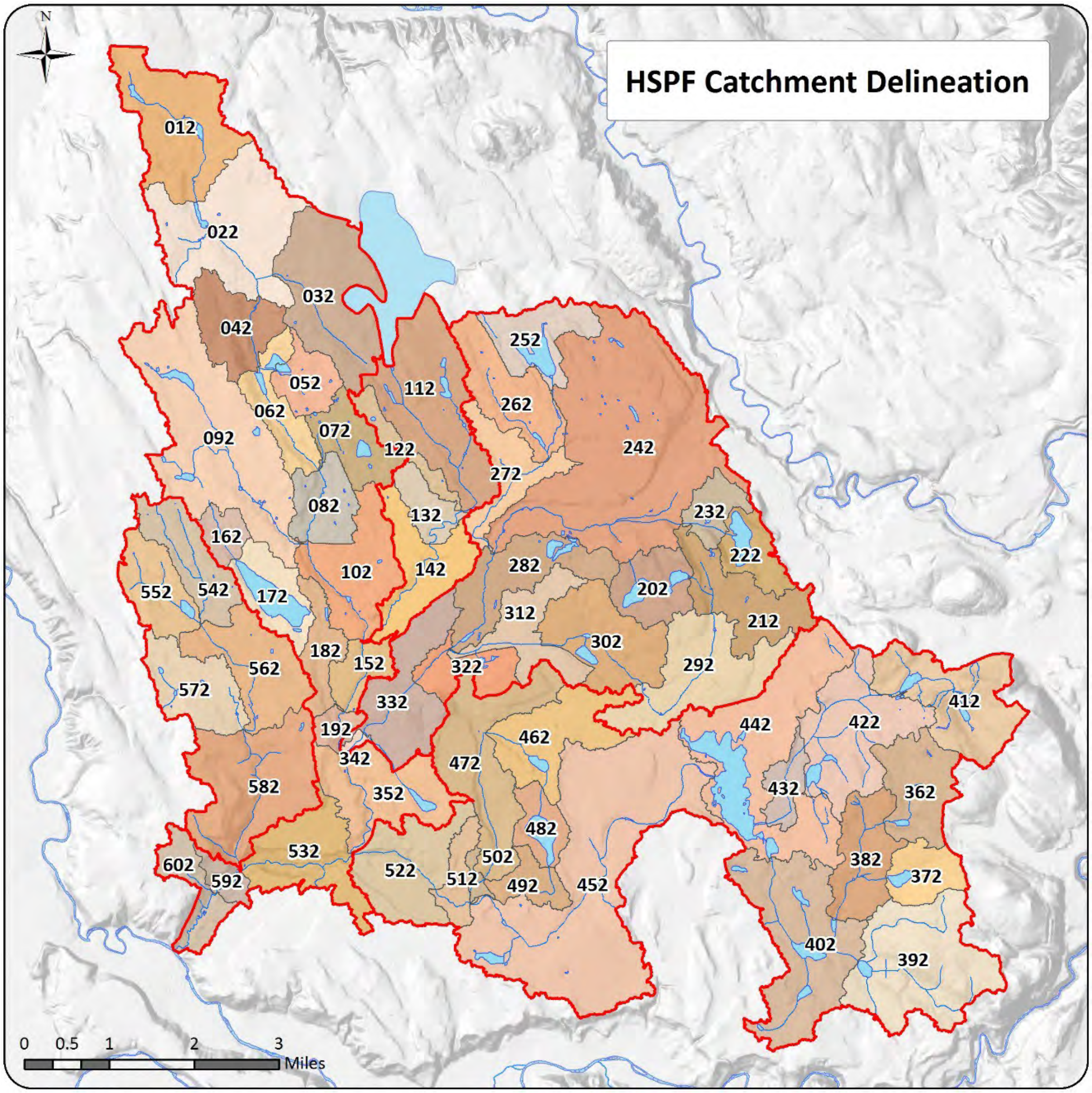

Figure 6. Map identifying the HSPF catchment delineations for this study.

Table 10. List of HSPF catchments that have field sampling sites for flow, TSS, grain size, and B-IBI.

HSPF Catchment ID	Subbasin	% Impervious Cover	Stream Order	Area (sq mi)	Number of sampling sites			
					Flow Gage	TSS	Grain Size	B-IBI
032	Big Soos	6%	1	1.71				1
022		21%	2	2.05			2	1
042		15%	3	0.83			1	
062		5%	3	0.65			1	
072		7%	4	0.68				1
082		12%	4	0.65			1	1
092		27%	4	2.98				1
102		19%	5	1.21		2	2	1
192		8%	6	0.20	1	1	1	
352		7%	6	1.26			1	1
532		13%	6	1.16				2
592		11%	7	0.23	1		1	
602		19%	7	0.55		2	2	1
382	Covington	15%	1	0.91				3
402		8%	2	2.07				1
422		7%	2	1.58			1	1
432		2%	2	0.35	1	1		1
442		11%	2	2.67	1	1		
452		8%	6	4.58		1	4	3
512		7%	6	0.36	1	1	1	1
522		8%	6	1.23			1	2
232	Jenkins	16%	1	0.40			1	
242		9%	1	4.72			1	1
282		20%	1	1.13			2	2
322		11%	2	0.55			1	
332		16%	2	1.20	1	2	1	1
112	Little Soos	7%	5	1.90			1	2
142		25%	5	0.97	1	2	2	2
582	Soosette	13%	1	1.88	1	1		2

Hydrology model inputs and parameters

The hydrology data that will be used to drive the HSPF model are described in Section 4.3. Model inputs for precipitation and evaporation will be developed using the same methods described in King County (2013) to extend the model simulation through WY 2015. Alternatives from this approach (e.g. using gridded precipitation inputs from the WRF (Weather Research & Forecasting: http://www.wrf-model.org/index.php) model will be explored if the established method does not yield reasonable model inputs for the extended simulation period.

The King County approach involved:

- Creating a composite precipitation record based on the weighted average (using the Thiessen Method) of rainfall from the following three King County precipitation gages: 09U, 26U, and 54V (see Table 2).
- Using evaporation data from the Puyallup weather station, and filling in any gaps in the data using the Jensen-Haise equation. These data will then be adjusted to estimate potential evapotranspiration using a pan evaporation coefficient of 0.78.

Modeling of hydrology within HSPF involves a large number of parameters. These are usually determined first by estimating values that fall within typical ranges. We plan to retain the existing hydrology parameter values within the model for the extended simulation through WY 2015. A series of Technical Notes have been published for the BASIN/HSPF framework that provides users with guidance on how to estimate these input parameters. If recalibration is necessary, we will use Technical Note 6 (EPA, 2000b) and the HSPFParm database (EPA, 1999) to guide the initial estimation of these parameters.

HSPF also performs hydraulic calculations to route water within stream channels and reaches (called RCHRES) by combining inflows from the local drainage and upstream reaches, and physical data about that channel. The physical data about each reach is defined within an FTABLE, which defines the flow rate, surface area, and volume of the reach as a function of the water depth. The original HSPF model developed by King County used observed data and estimated values to determine the channel geometric and hydraulic properties and to develop the FTABLEs for streams within the Soos Creek watershed. We do not anticipate the need to change these hydraulic properties or edit the FTABLES during this study.

Sediment model inputs and parameters

Simulating sediment does not require any new times-series input data, but does require several additional model parameters. Setting up the model to simulate sediment involves turning on the following components of the HSPF model:

- SEDMT – production and removal of sediment from pervious surfaces
- SOLIDS – accumulation and removal of solids from impervious surfaces
- ADCALC – advection of fully entrained constituents within reaches
- SEDTRN – behavior of inorganic sediment within reaches

Once the above modules are activated, each of them require a set of parameters to simulate sediment processes in the watershed and sediment transport within stream reaches. King County has a calibrated hydrology and sediment HSPF model for the whole of WRIA 9 (which includes the Soos Creek watershed); the parameters used in that model for the Soos Creek subbasin will be used as a starting point for this study. In addition, we will use Technical Note 8 (EPA, 2006) the HSPFParm database (EPA, 1999), and the guidance outlined in Donigian and Love (2003) to refine parameter estimates during the calibration process and to ensure that values are within typical/expected ranges.

Existing data for sediment grain size will be used to estimate how to fraction the sediment load to the stream into sand, silt, and clay before entering a model reach.

Potential model scenarios

Once the model is calibrated to 2001-2015, this will represent our 'baseline' or 'existing/current condition' scenario. Following is a list of additional model scenarios that we might run. This list does not include all the scenarios we might determine necessary; a final list of model scenarios will be determined with the input of the project team once model calibration is complete.

- **Fully-forested/reference conditions –** simulation of hydrology and sediment under forested/reference conditions to (1) provide a benchmark for comparing to existing conditions and (2) to help us understand how much human land uses have altered the flow regime and the sediment loading to the creeks. The forested/reference condition is a hypothetical replacement of developed and agricultural land with forest cover equivalent to existing forest cover in the basin; this will be consistent with King County's target stormwater flow mitigation condition. This condition does not represent true historical forested conditions since HSPF does not model features that would have been present historically that are absent today (e.g. large woody debris in streams, beaver dams, relatively undisturbed mature coniferous forest). Forested conditions have been modeled and used by King County, as well as MIT, as part of their modeling efforts. We will use this existing information as much as possible.
- **Zero watershed sediment loads –** this model scenario would potentially help us distinguish how much of the TSS load comes from instream channel erosion/scour vs. watershed sediment sources by running the baseline and forested model scenarios, but with zero sediment loads coming in from the watershed. This would allow the sediment deposition/storage processes to be modeled in the absence of watershed sources of sediment. To prevent the model from 'running out' of sediment, we would set the initial bed depth to a very large artificial value to ensure that instream bed sediment does not get depleted over the simulation period. (There is no limit to initial bed depth in the model, and this value does not change the channel geometry or the hydraulic characteristics of model reaches.)
- **TMDL scenarios –** model scenarios can be run in the model to evaluate the downstream improvement of various flow and sediment control BMPs or retrofits. This could include, for example:
  a) A scenario where we explore which BMPs would reduce HPCs or TSS load to an identified target level.
  b) Evaluate potential TSS load reductions resulting from only treatment of flow entering the creeks, for only flow controls, and a combination of the two.

7.3.5 Potential approaches to establishing TMDL targets

The following list includes approaches that we are considering to establish load and wasteload allocations and/or implementation targets. We may explore additional approaches during the analyses that are not listed below.

- **Model simulated forested conditions approach**

  Set targets based on the difference between model-simulated existing and forested conditions as simulated by the model or some benchmark (e.g. 90th percentile of forested conditions). Examples of how TMDL targets would be established under this approach include:

  - A TSS reduction based on the difference between the modeled existing TSS load and forested/reference TSS load.
  - Flow target(s) based on limiting the level of flow alteration (e.g. number of HPCs) to be close to the number of HPCs or other flow-alteration metric simulated under forested conditions.
  - Flow target(s) based on meeting pre-development flow duration curves that are consistent with the minimum requirements in the Stormwater Manual for Western Washington.

- **Reference watershed approach**

  Set reduction targets based on the difference between modeled and/or measured existing conditions and observed reference conditions based on data from Puget Sound lowland reference streams/watersheds. Since there is limited flow data to estimate flow alteration in Puget Sound lowland reference streams, this approach may be limited to sediment targets. Flow targets could still be developed using the model as described in the previous bullet.

- **Statistical analysis approach**

  Use the results of the quantile regression and/or conditional probability (described in section 7.3.1) to determine the flow and/or sediment targets/thresholds that would be necessary to ensure the potential to reduce biological impairment and improve B-IBI scores. This approach would enable us to demonstrate how limiting flow alteration and/or the TSS load is necessary for B-IBI scores to potentially reach compliance with the water quality criteria, if no other limiting factors were present.

- **A combination of the above approaches**

  Synthesize and combine the results of the modeling and statistical analysis, as well as existing flow control requirements, and use a weight-of-evidence approach to develop flow and/or TSS targets. For example, flow alteration thresholds identified from statistical analysis could be compared to flows under forested conditions to see how the two compare. Or, the HSPF model run could be run to (1) find the TSS load associated with a particular flow alteration threshold identified from statistical analysis or (2) determine to what extent meeting the flow control requirements in the Stormwater Manual would limit flow alteration or reduce the TSS load.

The following reports will be used to provide us with additional technical support and a scientific and policy framework to inform the target setting approach and subsequent implementation actions:

- *Protecting Aquatic Life from Effects of Hydrologic Alteration* (Novak et. al., 2016): a joint EPA-USGS report that provides scientific and technical support for efforts by States and Tribes to advance the protection of aquatic life from the adverse effects of hydrologic alteration in streams and rivers, including a non-prescriptive framework to quantify targets for flow-regime components that are protective of aquatic life.
- *Method to support TMDL development using hydrologic alteration as a surrogate to address aquatic life impairment in New Jersey streams* (Kennen et. al., 2013): a USGS report that describes an effort to develop an applicable 'hydro-TMDL' approach to address aquatic-life impairments associated with hydrologic alteration, using a reference/attainment stream approach for developing the TMDL endpoint.
- *Using Stressor-response Relationships to Derive Numeric Nutrient Criteria* (EPA, 2010b): provides technical guidance on developing stressor-response relationships to derive numeric nutrient criteria, and some of the approaches described could analogously be applied to derive appropriate flow alteration and/or sediment targets.
- *Benthic macroinvertebrates as indicators of water quality: The intersection of science and policy* (Kenney et al., 2009): presents science, policy, and management approaches on how to use the role of macroinvertebrates to inform water quality decisions and improve impaired waters.

Clarks Creek TMDL approach

The Clarks Creek TMDL is discussed here as an example of an approach for sediment load allocation that was implemented in our state (James et al., 2014). Soos Creek and Clarks Creek are different waterbodies with different impairments. The Clarks Creek TMDL does not have as an explicit goal to improve bioassessment scores, but the Soos Creek TMDL does. So, there are shortcomings for using the Clarks Creek approach for Soos Creek.

With respect specifically to sediments, the Clarks Creek TMDL requires load reductions based on the "difference between the percentage of sand and fines in Clarks Creek and the 90th percentile of percent of sand and fines in Puget Sound lowland reference systems." Puget Sound lowland streams that have high levels of biological integrity, reflected in their BI-BI scores, are used as reference. The TMDL ended up specifying a sediment reduction target of 66% (James et al., 2014). With this approach, a total sediment load reduction achieved collectively by facilities, or via other actions, within a jurisdiction may or may not correspond with an equivalent reductions in either TSS or percent sand fines at any targeted stream segment. In order for the Soos Creek TMDL to be effective, allocations need to be shown to reduce impacts at targeted stream segments so that B-IBI scores can be improved.

Although the Clarks Creek TMDL references B-IBI data (pg. 80-82), 'physical habitat assessments' (pg. 83-84), and nutrients (pg. 85-87), these data are not incorporated in allocation calculations or implementation planning. The TMDL analysis references modeled conditions when channel degradation occurred (pg. 67), but flow parameters were not explicitly addressed in the TMDL sediment allocation. Thus, in the Clarks Creek TMDL the explicit linkage between

TMDL allocation and degradation of physical habitat was not sought, and this impedes directly addressing hydrologic alteration that negatively impact the biology in the stream. Given that the Clarks Creek TMDL is not a bioassessment TMDL, the course of action chosen was acceptable, but it is not for the Soos Creek TMDL, which *is* a bioassessment TMDL.

7.4 Assumptions in relation to objectives and study area

This study is designed based on the following assumptions:

- Existing information is sufficient to run the HSPF model and meet project goals.
- Sufficient support is available to overcome problems with debugging the program and producing a calibrated model and scenarios.
- The model's representation of hydrologic and sediment processes at the scale of individual catchments and reaches is adequate for its application to this TMDL.
- The model simulates scouring and erosion of the sediment bed but does not separately simulate channel bank scour and erosion. We are assuming that through acceptable TSS calibration, we can adequately capture total scour/erosion, without the need to distinguish between bed vs. channel scour/erosion.

Conservative assumptions will be used in developing this study in order to implicitly build in a margin of safety into the TMDL. For example, since the study is focused on alteration of flow (more specifically, high-flow events) and sediment load due to human activities, an example of a conservative assumption is: using upper confidence limits for setting targets/thresholds, but lower confidence limits for determining what B-IBI scores could be achieved if that target was met.

7.5 Possible challenges and contingencies

7.5.1 Logistical problems

Since this project does not include any field work, we do not anticipate any logistical problems.

7.5.2 Practical constraints

This is a one of the first TMDLs in Washington State that will address biological impairments using sediment and flow relationships to establish load and wasteload allocations. Because this approach is new, technical and policy issues may arise for which we do not have precedence from previous TMDL work done by Ecology.

The following technical challenges/constraints are involved in this study:

- Contractor modeling support is contingent upon funding availability.
- We have limited sediment grain-size data to correlate fine-sediment values to TSS.

- The model does not distinguish between channel-bed erosion vs. side-bank erosion, but the total scour is more important to this TMDL than distinguishing where each sediment particle originated.
- Information on the specific locations, effectiveness, and performance of existing stormwater infrastructure in the watershed is not available and will not be fully represented in the existing/baseline condition model run. This stormwater infrastructure likely offsets some of the effects of recent urbanization in the watershed. The model calibration process will indirectly account for existing stormwater infrastructure (e.g. by adjusting parameters that increase infiltration and/or storage of water) even if this infrastructure is not explicitly included in the model.

If the HSPF model is not able to resolve sediment processes in sufficient detail for the TMDL (based on the evaluation of model performance and quality assessment as described in Sections 6.3 and 13.4), we will evaluate the need for additional data collection and/or modeling tools to complete the TMDL study.

For the above technical issues, as well as policy issues, we plan to work closely with Ecology's Water Quality Program, the EPA, the rest of the project team, and affected stakeholders to anticipate, discuss, and resolve these issues as needed throughout the course of this project. This will help ensure that the technical analysis aligns well with implementation needs and goals, and that the relevant parties are aware of the decisions that might affect them.

7.5.3 Schedule limitations

Technical and scientific work, including modeling, often involves unforeseen analysis. There is always the possibility that during the modeling process, additional analysis is warranted to improve the scientific robustness of the study. Any additional analysis will take more time. Any new policy issues that come up may also take extended discussions and time to resolve.

This project is just one part of the larger Soos Creek multi-parameter TMDL (which includes temperature and DO impairments in addition to biological impairments) and involves multiple partners and organizations who have been involved in the project over the years. Some of the previous technical work done on temperature and DO impairments still needs to be finalized, and the results of this Soos Creek TMDL will need to be synthesized with previous results in a holistic way in order to make this an effective TMDL that addresses all the impairments. This process, and resolution of policy questions that come up, may delay finalizing of the work described in this Soos Creek TMDL QAPP addendum.8.0 Field Procedures
Not applicable. There is no new field work associated with this project.

9.0 Laboratory Procedures

Not applicable. There is no new laboratory work associated with this project.

10.0 Quality Control Procedures

In addition to data and model quality assessments, verification, and usability (described in Sections 6, 13, and 14), quality control procedures will include the following:

- Consulting with HSPF modeling experts in western Washington (e.g. technical staff that work for MIT and King County have extensive HSPF modeling expertise) for advice and resolution of issues related to HSPF modeling.
- Collaborating with the project advisory team to ensure that the stressor ID analysis is being interpreted appropriately in this study.
- Periodically sharing and discussing interim model results and outputs with the project advisory team.
- Peer review of the draft technical memo and discussion of the draft TMDL report with the TMDL Advisory Group before the public comment period and before submitting the TMDL for EPA approval.
- Hiring a consultant to review model setup and calibration as well as model scenarios.[7]

10.1 Table of field and laboratory quality control

Not applicable. There is no new field or laboratory work associated with this project.

10.2 Corrective action processes

Corrective action processes may be needed if the model does not meet quality objectives. Options include:

- Revisiting model calibration and considering refinement of model set-up for improved performance, followed by a model validation phase.
- Seeking expert advice on how model results could be improved.
- Qualifying model results and clearly describing limitations of model applicability in the final TMDL report.
- Making recommendations for additional data collection to improve model quality.

[7]This review by a consultant is contingent on funding.

11.0 Management Procedures

11.1 Data recording and reporting requirements

Not applicable – No new data is being collected, recorded or reported.

11.2 Laboratory data package requirements

Not applicable – There is no new laboratory data analysis associated with this project.

11.3 Electronic transfer requirements

Not applicable – There is no transfer of data expected between the laboratory and staff.

11.4 EIM/STORET data upload procedures

Not applicable – No new data is being collected that would be required to be uploaded into EIM.

11.5 Model information management

Modeling can be a complex process, involving multiple steps and procedures, as well as various iterations. Model information will be managed by meticulous file organization and naming conventions that will identify, track, and date model input/output files associated with each significant model run and each major iteration in model calibration.

This will be done by:

- Creating separate sub-folders to contain the inputs and outputs of each significant model/scenario run with the date of each model run.
- Tracking model runs in an Excel spreadsheet which will include the name for each significant model run/scenario run, as well as the name(s) and location(s) of associated input and output files, and major parameters changed for different model scenarios.
- If the model version is changed during the modeling process, all sub-folders/files associated with each version of the model will be placed within a larger folder that identifies the version of the model used for those model runs.

The approximate size of HSPF model files for a single combined hydrologic and sediment model run are:

Input files: 10 MB
Output files: 300 MB
Post-processing files: 100 MB

It is difficult to predict how many total model runs will be needed for model calibration and model scenarios, so the total size of model-related files generated by this study cannot be estimated. However, we do not anticipate that file storage will be a limiting factor.

Model versions are managed by Aqua Terra Consultants (a division of RESPEC) that occasionally releases new version of the HSPF model. We plan to use WinHSPF Version 3.0 for this study. If a newer version of the model is released while the project is ongoing, and we find the need to update, we will do so. We will document which version(s) of the model were used in the final TMDL report.

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

No audits are planned for this study.

12.2 Responsible personnel

Not applicable.

12.3 Frequency and distribution of report

The results of the sediment analysis and modeling will documented in a technical memo and eventually incorporated into the TMDL report. See Section 5.4 for the schedule. No other reports are expected, though progress will be tracked monthly using EAP’s Activity Tracker.

12.4 Responsibility for reports

A draft TMDL report already exists. It documents some of the modeling and analysis work already done on the temperature and DO parts of this TMDL by TetraTech. MIT, and EPA.

The EAP project manager/principal investigator will be responsible for first authoring the technical memo and then integrating all previous work done and incorporating this technical memo into the relevant sections of the final TMDL report. The TMDL lead will be responsible for authoring the Implementation Section of the TMDL report.

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

Not applicable – No field data are being collected for this study.

13.2 Laboratory data verification

Not applicable – No lab data will be generated by this study.

13.3 Validation requirements, if necessary

Not applicable – No field/lab data need to be validated for this study.

13.4 Model quality assessment

Absolute criteria for model acceptance or rejection are usually not appropriate 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. However, model performance will be evaluated, using quantitative and qualitative methods, to determine the relative quality of model calibration and model results. As stated previously, the quality objectives listed in Section 6.3 will provide a coarse and initial assessment of model quality to help determine if additional model refinements, input parameters, or data are needed. If initial model quality seems satisfactory, we will begin a more extensive model calibration and validation process, as described below.

The HSPF model is already calibrated for hydrology for WYs 2001-2008. For this study, we will extend the model simulation to WYs 2009-2015 and evaluate whether the existing parameters can reasonably represent flow conditions for WYs 2009-2015 as well as it did for WYs 2001-2008 without any changes in model parameters. This extension of the model to a new time-period without a change in model parameters is analogous to model validation. If the model validation does not show acceptable quality metrics (listed in Table 11), this may suggest that recalibration is necessary.

In this study, calibration of sediment modeling results will be done for the whole simulation period, WYs 2001-2015. Sediment data are generally sparser than streamflow data, making it more challenging to have a separate calibration and validation period. This long time-period will strengthen our ability to determine how well the sediment model is performing over a wide-range of conditions. To validate the sediment model, we will randomly select a subset of the available sediment calibration data for validation and remove these data from the calibration dataset. Once the sediment model is calibrated, we will perform model validation (of sediment parameters) against the random subset of data that were not used during calibration, but over the same time-period.

The calibration process will be an iterative process of making parameter changes, running the model, comparing simulated and observed values, interpreting results, and then making more parameter changes to improve model skill. This process will be facilitated by the use of HSPEXP+, which is a software tool designed specifically for use with HSPF. The software gives the user calibration advice based on predetermined rules (e.g. which model parameters to adjust, which inputs to check), and allows the user to interactively modify HSPF model input files, make model runs, examine statistics, and generate a variety of plots.

13.4.1 Hydrologic calibration and validation process

For hydrology calibration and validation, we will first compare simulated and observed values for the following four major characteristics of watershed hydrology:

Characteristic	Parameters to adjust during calibration (if needed)
Annual water balance	Soil moisture storages, infiltration rates, actual evapotranspiration, and losses to deep groundwater recharge.
Seasonal and monthly flow volumes	Infiltration parameters (interflow, upper-zone soil moisture storage, percolation to lower-zone soil moisture, and groundwater storage).
Baseflow	Infiltration parameters and groundwater recession rate.
Storm events	Surface detention and interflow parameters.

If the calibration and validation are satisfactory for the above four characteristics, we will compare simulated and observed values for the following additional hydrology metrics:

- Geometric mean of flows
- Monthly average flows
- Flow percentiles (10th, 25th, 50th, 75th, and to 90th)
- Mean annual maximum flows
- Mean annual 7-day low flows
- Storm, winter, and summer volumes
- Average storm peak
- High pulse count, high pulse range, and ratio of peak-to-baseflow

We will compare the model quality metrics (described in section 13.4.3) for the validation period WYs 2009-2015 with the calibration metrics achieved by the HSPF model developed by King County (2013) and refined by Carlson and Massmann (2015) to identify differences, improvements, and weaknesses and to see whether hydrologic recalibration is necessary.

13.4.2 Sediment calibration and validation process

Sediment calibration is always done after hydrologic calibration has reached a satisfactory level of quality. Sediment calibration is also extremely sensitive to hydrology.

The parameters involved in the simulation of watershed sediment erosion are generally more uncertain than hydrologic calibration (Duda et al., 2012 and King County, 2013). However, the process is analogous in the sense that sediment parameters are modified to improve agreement between simulated and observed annual and monthly sediment loss and storm-event sediment removal.

There are two main components to sediment calibration within HSPF:

- Sediment loading calibration (loading of sediment from the watersheds and individual land uses to the stream).
- Sediment transport calibration (instream sediment transport).

Sediment loading calibration

Since the model predicts sediment loading/delivery to the stream, we need to compare these predictions with observations or other estimates. For this study, we will compare model predicted loading to the range of estimated values of sediment loading and delivery from existing literature data (Horner et al. 1994, Burton 2002, and King County 2007).

The sediment loading calibration mainly involves adjusting the following model parameters until simulated loadings are consistent with estimated loadings from literature:

- KRER – coefficient in soil detachment equation for pervious areas
- KSER – coefficient in sediment washoff equation for pervious areas
- KEIM – coefficient in washoff equation for impervious areas
- ACCSDP – accumulation rate of solids on impervious areas

Though several other parameters are involved, these are the primary ones controlling sediment loading rates.

Sediment transport calibration (instream processes)

After sediment loading rates from the watershed (to the stream) are calibrated to acceptable levels, we will calibrate the transport of sediment within the stream channel. In HSPF, this usually involves the following steps (from Duda et al., 2012):

1. Divide input sediment loads into appropriate size fractions (silt, clay, and sand).
2. Run HSPF to calculate shear stress in each reach to estimate critical scour and deposition values.
3. Estimate initial parameter values and storages for all reaches.
4. Adjust scour, deposition, and transport parameters to impose scour and deposition conditions at appropriate times (e.g. scour at high flows, deposition at low flows).
5. Analyze sediment bed behavior and transport in each channel reach.
6. Compare simulated and observed sediment concentrations, sediment loads, and sediment rating curves (e.g. a log-plot of observed and simulated streamflow vs. TSS concentration).
7. Repeat steps 1 through 5 as needed.

Sediment data are usually sparser than streamflow data, and it is not common to have sediment data for each reach in the model domain. There are rarely sufficient observed local data at adequate spatial detail to accurately calibrate all parameters for all land uses and each reach (EPA, 2006). For this study, sediment transport calibration will be focused on those reaches where observed sediment data are available (Figure 3). Similar to hydrologic calibration, parameter guidance is available for sediment in Technical Note 8 (EPA, 2006).

13.4.3 Calibration and validation assessment

This study will assess the quality of model calibration and validation using a combination of quantitative and qualitative approaches. These are described in more detail below.

Statistical/quantitative assessment

Table 11 describes the quantitative/statistical methods that will be used to assess hydrologic and sediment model calibration and validation for various hydrologic metrics and sediment concentrations and loads. These calculations will be made at the scale of each of the five major subbasins of the Soos Creek watershed: Big Soos, Little Soos, Soosette, Jenkins, and Covington Creeks. These calculations will be averaged over the whole calibration or validation period for the following list of metrics. (Not all metrics may be evaluated for each of the statistical methods listed to evaluate calibration):

- Geometric mean of flows
- Monthly average flows
- Flow percentiles (10^{th} to 90^{th} percentiles, in 10% increments)
- Mean annual maximum flows
- Mean annual 7-day low flows
- Storm, winter, and summer volumes
- Average storm peak
- High pulse count, high pulse range, and ratio of peak-to-baseflow
- TSS concentration
- TSS load

Precision

Precision is a measure of the variability in the model results relative to measured values. This study will evaluate precision and model variability using several different statistics, presented in Table 11.

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, we will evaluate bias in this study through use of mean error and RPD, both described in Table 11.

Table 11. Statistical calculations that we plan to use to assess the quality of HSPF model calibration and validation.

This table is adapted from King County (2013).

Statistical Test	Description/Comment	Used for hydrology?	Used for sediment?	Measure of?
Mean Error	The total error, or the average of all simulation errors, including cancellation of errors when some errors are positive and others are negative.	X	X	Bias
Mean Absolute Error (MAE)	The absolute value of the total error; emphasizes magnitude of model error without regard to direction or sign of the errors.	X	X	Precision
Root Mean Square Error (RMSE)	Calculated as the square root of the mean of the squared difference between observed and simulated values. It is similar to the MAE, but usually emphasizes larger errors.	X	X	Precision
Relative Percent Difference (RPD)	The difference between simulated and observed, relative to observed. It is calculated by taking the average of the simulation error divided by the observed value. It provides a relative estimate of whether a model consistently predicts values higher or lower than the measured value.	X	X	Bias
Pearson Correlation (R)	The correlation coefficient based on least squares regression. Values of R range from $-1 \le R \le 1$, where negative values represent inverse correlations and values close to 1.0 indicated well-correlated predictions.	X	X	Precision
R-squared (r^2)	The coefficient of determination, where r^2 represents how much variance in the data can be explained by the model. The value ranges from $0 \le r^2 \le 1.0$, and the closer to 1.0, the better the model characterizes predicted concentrations.	X	X	Precision
Kruskal-Wallis (KW)	A non-parametric equivalency test that evaluates whether ranked distributions of simulated and observed datasets are significantly different based on an *a priori*-selected *p*-value.	X	X	Precision
Nash-Sutcliffe (NS)	An index measuring the model's ability to accurately simulate observed conditions. The values of NS can theoretically range from $\infty \le NS \le 1.0$, and the closer to 1.0, the more skill a model has in representing observed conditions.	X	X	Precision

Representativeness

Representativeness ensures that the model results are useful for a variety of conditions rather than, for example, only storm events or only low-flow conditions. The existing HSPF model used for this study has already been calibrated for a range of flow conditions and simulates WYs 2001-2008, capturing a range of temporal and spatial conditions, including variations in weather, soil moisture, seasonal changes, and inter-annual variability.

When the model simulation is extended through 2015, we will assess whether the original hydrology calibration is still representative for this newer time period across all the years. Observed and model-simulated flows will be compared for daily, monthly, seasonal, and annual values, in addition to flow duration curves, flow percentiles, HPC, high pulse range, and the ratio of peak-to-baseflow.

Often a model does not calibrate equally well for all parameters, locations, and metrics. Since this TMDL is more concerned with high-flow/stormwater flow events, the calibration process will be focused on improving the accuracy of streamflow and TSS predictions during storm events (as opposed to baseflow conditions).

Graphical/qualitative assessment

HSPF results can be graphically assessed to compare observed and measured values along the length of the modeled stream segment, or over the course of a particular time period. Evaluating these plots and graphs will be part of the model assessment process. Graphical comparisons that will be done for this study include:

- Time-series plots of observed and simulated values for flow, sediment concentration, and sediment load
- Observed and simulated scatter plots, with 45^{o} linear regression line displayed
- Flow duration curves
- Cumulative frequency distributions of observed and simulated sediment loads

In addition, water balance components (input and simulated) will be reviewed for consistency with expected literature values for the Puget Sound region.

13.4.2 Analysis of sensitivity and uncertainty

Model sensitivity

Model sensitivity analysis is used to identify the most influential parameters influencing model predictions and performance. More specifically, it is a measure of the change in output parameters resulting from a unit change in input parameters. When a model is highly sensitive to a particular input dataset or parameter, it highlights the importance of having a high level of confidence in that particular input and can also affirm that the model is responding as we expect it to.

In watershed modeling, flow and sediment loads are probably going to be most sensitive to precipitation inputs. This is because precipitation drives the hydrologic cycle and the delivery of sediment loads to the stream. However, a number of other parameters are involved in hydrologic and sediment simulation, and a formal sensitivity analysis can be valuable in assessing the influence of these parameters.

For this study, we will perform a model sensitivity assessment after model calibration for hydrology and sediment is complete. We will use the following procedure, adapted from Donigian and Love (2007):

1. Identify a finite number of critical model inputs and parameters (between 5-10) based on the calibration experience and the experience of others who have performed modeling in the Soos Creek watershed.
2. Identify reasonable percent increases and decreases relative to calibrated values for these inputs and parameters.
3. Perform model sensitivity runs for the model simulation period, with each run representing a single input/parameter change.
4. Process the model sensitivity run results and calculate the sensitivity factor, defined as the percent change in model output divided by the percent change in input/parameter value (relative to the baseline/calibrated value).
5. Rank the model input and parameters by the sensitivity factor to highlight those that have the greatest to least impact on model results.

The above process will likely be limited to the following output metrics: mean annual streamflow, mean annual runoff, 10% percentile of highest and lowest flows, average storm/peak flow, and mean annual TSS loading.

Model uncertainty

Model uncertainty analysis involves the assessment of how the uncertainty involved in estimating model input parameters contributes to the uncertainty in model results. Dynamic and comprehensive watershed models have high computational demands, and formal uncertainty analysis involving numerous iterations are rare, often unfeasible, and have not historically been done (Donigian and Imhoff, 2009). There are a few examples of using Monte Carlo Simulations to perform model uncertainty analysis in HSPF, but this sort of resource-intensive process is beyond the scope of this study.

However, evaluating model uncertainty is still important in order to build confidence in model results. For this study, the results of the model calibration and performance evaluation, including quantitative statistics such as the RMSE, will be used to represent model uncertainty. This, along with other model skill metrics, and the results of the model sensitivity analysis, will be used to address and describe model uncertainty.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining if project quality objectives were met

14.1.1 Data usability

Any water quality data generated outside of this QAPP that are used in a water quality impairment study must meet the requirements of Ecology's credible data policy (https://www.ecology.wa.gov/DOE/files/3b/3bf2eaab-090b-49d1-8ff4-fd8c82960f7a.pdf). This requirement does not apply to non-water quality data such as flow or meteorological data. Table 12 summarizes the sources of external data that we plan to use in this study. Most of the external data sources listed have their own data assessment processes in place. Data that does not meet established quality criteria are often flagged with appropriate data qualifiers. Qualified data will be used with caution or discarded based on professional judgment.

The usability of data from external sources that do not have readily available information on whether the data were peer reviewed or followed QA/QC procedures or SOPs will be assessed. This assessment will include exploratory data analysis, plotting and visually assessing quality, and comparison/correlation to other data collected at nearby locations.

If not already detailed in an existing QAPP or report, the final report will include:

- An assessment of data quality for external data sources used in the analysis which do not have readily available QA/QC information.
- An assessment that these data meet the requirements of the Washington State regulations and Ecology policy for use in the project.

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

- Reference to a peer-reviewed and published QAPP (or equivalent) or report.
- Documentation that the objectives of the QAPP or equivalent QA 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 any data outliers or other unusual patterns that result in the censoring of data used in this study.
- 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).

Table 12. Information about datasets we plan to use in this study, organizations who collected these data, and relevant data quality information.

Organization	Data Type	Established QA/QC Program?	Used accredited labs, SOPs, & equipment?	Data collected under a QAPP or SAP?	QA/QC information or web link
King County - Hydrology Monitoring Program	streamflow	Yes	Yes	Yes	http://www.kingcounty.gov/services/environment/watersheds/hic/About.aspx
	precipitation	Yes	Yes	Yes	
King County - Streams Monitoring	TSS, turbidity	Yes	Yes	Yes	We have a copy of their Final Draft SAP, which is of being updated this year (King County, 2002).
King County - Green-Duwamish Water Quality Assessment	TSS, turbidity	Yes	Yes	Yes	http://your.kingcounty.gov/dnrp/library/2002/kcr1534.pdf
King County Field Data collection for stormwater retrofit planning WRIA 9	continuous turbidity	Yes	Yes	Yes	http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/green-duwamish/stormwater-retrofit-project/qa-project-plan-data-collection.pdf
King County - Sediment Monitoring Program	particle grain size	Yes	Yes	Yes	http://green2.kingcounty.gov/ScienceLibrary/Document.aspx?ArticleID=135
King County – monitoring in Bear Creek for watershed-scale stormwater plan	particle grain size	Yes	Yes	Yes	We have a copy of the QAPP (King County, 2015).
AgWeatherNet (WA State University)	evaporation	Yes	Yes	Yes	We have a copy of a draft QA Protocol (AgWeatherNet, 2015).
Ecology Regional Stormwater Monitoring (Puget Sound Lowland Ecoregion Streams)	TSS, turbidity	Yes	Yes	Yes	https://fortress.wa.gov/ecy/publications/SummaryPages/1410054.html
Muckleshoot Indian Tribe (data collected by Tetra Tech under contract)	TSS, turbidity	Yes	Yes	Yes	We have a copy of the QAPPs for each year of monitoring (Tetra Tech, 2013b, 2014, and 2015).
Puget Sound Stream Benthos (PSSB) Database (data collected by various entities)	B-IBI scores	Database contains data collected by different jurisdictions (cities, tribes, and counties), agencies, and other collaborative projects, which may have their own QA/QC protocol or program. However, the goal is to store data in a way that allows for consistent comparisons among sites and programs over time, so consistency in the data included in the database is a prerequisite to having the data included in the database.			

QA/QC = Quality Assurance/Quality Control
SOP = Standard Operation Procedure
QAPP = Quality Assurance Project Plan
SAP = Sampling and Analysis Plan

Since data submitted into the PSSB database (last row of Table 12) are collected by multiple entities and may use different sampling protocols, these will be looked into in more detail. We will only use data that were collecting using analogous sampling protocols, unless we have a citable study that demonstrates that differences sampling protocols do not result in significant differences in B-IBI scores. Most of these data have attachments describing the sampling protocols, including field methods and QA/QC information. Data that do not have the relevant information and/or do not meet the RCW 90.48.785 requirements or the state's agency's credible data policy will not be used.

14.2.1 Model usability

The model must meet certain quality objectives in order to be usable and adequate to meet project objectives. Model quality will be assessed using the techniques described in Section 13.4. If the model quality assessment shows that the model is inadequate to fully meet project objectives, the project team will discuss alternatives on how to move forward with the project, such as using the model in a more limited manner appropriate to the level of model quality, and/or implementing the corrective action processes described in Section 10.2. In addition, model limitations, assumptions, and resulting implications will be clearly stated and documented.

14.2 Treatment of non-detects

The existing data that will be used for this study do not contain any non-detects.

14.3 Data analysis and presentation methods

Observed data that are analyzed and are relevant/interesting to the study, as well as comparisons between model output and observations, will be presented using a combination of tables and plots of various kinds, such as time series plots, histograms, and box plots in the technical memo, in the subsequent TMDL report, and in presentations made to the project team and to stakeholders.

14.4 Sampling design evaluation

There is no new data being collected for this study, so a sampling design evaluation will not be necessary. However, the process of model development and calibration will involve the evaluation of available existing data, which we expect to be sufficient to meet project goals and objectives.

14.5 Documentation of assessment

The technical memo and final TMDL report will include a summary of the data used in the study and findings of the model quality evaluation.

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16.0 Appendix. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

Ambient: Background or away from point sources of contamination. Surrounding environmental condition.

Anthropogenic: Human-caused.

Baseflow: The component of total streamflow that originates from direct groundwater discharges to a stream.

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.

Effluent: An outflowing of water from a natural body of water or from a human-made structure. For example, the treated outflow from a wastewater treatment plant.

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

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

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

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

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.

Phase I stormwater permit: The first phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to medium and large municipal separate storm sewer systems (MS4s) and construction sites of five or more acres.

Phase II stormwater permit: The second phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to smaller municipal separate storm sewer systems (MS4s) and construction sites over one acre.

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.

Primary contact recreation: Activities where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and water skiing.

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).

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.

Total suspended solids (TSS): Portion of solids retained by a filter.

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

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

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

303(d) list: Section 303(d) of the federal Clean Water Act, 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.

90th percentile: An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 90th percentile value is a statistically derived estimate of the division between 90% of samples, which should be less than the value, and 10% of samples, which are expected to exceed the value.

Acronyms and Abbreviations

B-IBI	Benthic Index of Biotic Integrity
BMP	Best management practice
DO	Dissolved Oxygen
EAP	Environmental Assessment Program
e.g.	For example
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
GIS	Geographic Information System software
HPC	High Pulse Count
HSPF	Hydrologic Simulation Program - Fortran
i.e.	In other words
MIT	Muckleshoot Indian Tribe
NPDES	National Pollutant Discharge Elimination System
PSSB	Puget Sound Stream Benthos

QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
TMDL	(See Glossary above)
TSS	(See Glossary above)
USGS	United States Geological Survey
WAC	Washington Administrative Code
WQA	Water Quality Assessment
WRIA	Water Resource Inventory Area
WY	Water Year

Units of Measurement

NTU	nephelometric turbidity units

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, datasets 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 dataset 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)

Dataset: 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 dataset. 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 dataset. 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.
- Dataset 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 dataset for errors or omissions, and assessment of the Data Quality Indicators related to that dataset for compliance with acceptance criteria (MQOs). Verification is a detailed quality review of a dataset. (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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