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Puget Sound Watershed Characterization

Development & Testing of Mid-Scale Models &

Updates to Broad Scale Assessment Models

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Quality Assurance Project Plan

Puget Sound Watershed Characterization Development & Testing of Mid-Scale Models & Updates to Broad Scale Assessment Models

April 2017

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Acronyms and Abbreviations

AU	(Watershed) Assessment Unit
e.g.	For example
EAP	Environmental Assessment Program (Ecology)
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database (Ecology)
EPA	U.S. Environmental Protection Agency
et al.	And others
GIS	Geographic Information System software
GPS	Global Positioning System
HCI	Hydrologic Condition Index
HPC	High Pulse Count
HSPF	Hydrological Simulation Program - FORTRAN
i.e.	In other words
LFC	Low Flow Coefficient
LFI	Low Flow Index
MUTT	Maintenance Update Technical Team
NEP	National Estuary Program (EPA)
PLE	Puget Lowland Ecosystem
PSNERP	Puget Sound Nearshore Ecosystem Restoration Project
PSWC	Puget Sound Watershed Characterization
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
RM	River Mile
STATSGO2	U.S. General Soil Map (Nat'l Cooperative Soil Survey, supersedes STATSGO)
SSURGO	Soil Survey Geographic Database (National Resources Conservation Service)
TSS	Total Suspended Solids
USFS	United States Forest Service
USGS	United States Geological Survey
VELMA	Visualizing Ecosystems for Land Management Assessments (Model)
WAC	Washington Administrative Code
WAG	Watershed Assistance Team
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WDOT	Washington Department of Transportation
WRIA	Water Resource Inventory Area

2.0 Abstract

Through testing in pilot watersheds, the Puget Sound Watershed Characterization staff at the Department of Ecology Shorelines Program is proposing to develop a "proof of concept" for mid-scale (10's to 100's of acres) watershed characterization models. The output from these mid-scale models will allow local governments and resource managers to quantify the impact of new development, in terms of location and design, upon the hydrology of affected watersheds throughout Puget Sound by using: 1) an existing index model developed by King County known as the Hydrologic Condition Index (HCI); and 2) a new model and index to measure low flow conditions (Low Flow Index – LFI) and vulnerability of watersheds to climate change.

If the testing of these mid-scale models in pilot watersheds demonstrates that their output is scientifically supportable and that they meet the goals and objectives listed in Sections 4.1 and 4.2 of this document, then they will be applied through Puget Sound after additional calibration is completed. The results of the HCI model tests will also be used to help validate the broad scale results of the existing water flow degradation model. During the development and testing of the mid-scale models, the existing broad-scale models will be updated, including incorporation of latest spatial data (e.g. land cover, hydrography) and any needed improvements to data aggregation and calculation methods.

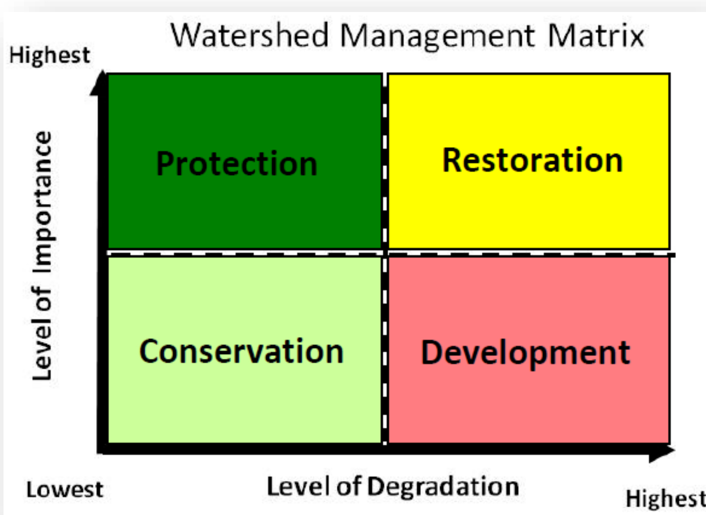
3.0 Background

3.1 Introduction and problem statement

Over the past 5 years, the Puget Sound Watershed Characterization (PSWC) has been successfully used by local governments to help address a variety of land use management issues within a watershed context. This has included decision support tools, using water and habitat assessments, to help inform decisions on where to locate new development, identifying the best locations for protection and restoration actions and prioritizing grants for stormwater retrofit plans.

The decision support tools for water flow use two models, one for assessing importance and the other for assessing degradation. The outputs of these models are combined in a watershed management matrix to identify resource management strategies (Figure 1). The most intensive strategies (broadly denoted “Restoration”) apply to those Assessment Units (AUs) judged most important to restoring water-resource functions but that also have experienced the greatest degradation. Conversely, areas of low importance but also low degradation should require a much lower level of management attention (i.e. “Conservation”). Those with high importance and low existing degradation may need little to or no active intervention to maintain their high function conditions (i.e. “Protection”) while those with low importance and significant existing human impact are broadly the most appropriate areas for “Development.”

At best, these broad scale models provide a decision support tool that is useful at a relatively broad scale (100’s of acres) for planning applications (e.g. comprehensive and shoreline plan updates), but provides little assistance for addressing issues occurring at the stream reach to site scale. (https://fortress.wa.gov/ecy/coastalatlas/wc/landingpage.html)



Hydrologic conditions directly affect structure and function of aquatic systems, and quantify-cation of those conditions provides a better understanding of the overall health of aquatic ecosystems. Mid-scale tools provide a multi-scale approach that evaluates conditions within the larger contributing watershed, including impact of proposed developments and provides a quantified assessment of hydro-logic condition at a reach scale.

Figure 1. Watershed Management Matrix for combining the output of the Importance and Degradation models for water flow.

Modeling and predicting these impacts, in terms of location, type and intensity, would greatly assist planners since it would better inform: 1) environmental review of projects, especially cumulative impact analysis; 2) both long range and current planning by linking land use activities in the greater watershed with reach to site scale impacts; 3) the development of land use regulations, development standards, and best management practices that more effectively mitigate development impacts; and 4) restoration and protection actions. Most importantly, the addition of mid-scale models should provide for an alternative futures scenario capability that would allow users to compare the impacts of different future development scenarios upon watershed processes.

3.2 Study area and surroundings

The study area covers the developing, low-lying western portion of King and Snohomish County, an area of common geologic history, flora, fauna, and human uses. The study watersheds are located in central Puget Sound and distributed across rural King County. Eight study watersheds are located in the Puget Lowland Ecoregion (PLE), which is predominantly less than 150 m (500 feet) in elevation. The ninth study watershed is in the Cascades Ecoregion at the eastern edge of the Puget Lowland Ecoregion. The project proposes to use nine existing "data rich" watersheds in King County (Figure 2) to determine the best water flow routing method and resolution of analysis. The HCI model and gage data for these watersheds has been developed and collected by King County. For testing the alternative futures tool (Task 4.0), a tenth test watershed would be selected in either Snohomish or King County.

3.2.1 History of study area

The project will occur in King and Snohomish Counties, an area that has been subject to intense logging, agricultural and land development from the mid 1880's to mid-1990. Despite the intensity of land use change over the past 100 years, the rural areas of these two counties still have moderate to high ecological value (King County 2007; Stanley et al 2016). Due to state and local planning laws and regulations, the majority of the area in the eastern part of these counties is still rural. However, population pressures are now threating to accelerate the conversion of these rural lands to urban uses, resulting in the loss of ecological processes and biological diversity within these watersheds.

Watershed assessments and modeling have been developed in both counties in an effort to better protect watershed ecosystems and help locate new development in areas that have the least effect on important watersheds. This study is designed to build upon this previous assessment and modeling work and develop a mid-scale decision support tool that will allow planners and citizens to better predict the impacts of future development and climate change and to understand the existing level of impacts.

3.2.2 Summary of previous studies and existing data

In 2008, the EPA and King County partnered in a multiyear, comprehensive scientific study to better understand the County's new regulations and assess whether they would be effective at preventing environmental degradation from ongoing and future development (Lucchetti 2014). A separate QAPP (Lucchetti 2008) was produced for this project, which can be accessed at the following King County website: http://your.kingcounty.gov/dnrp/library/water-and-land/data-and-trends/monitoring/critical-areas/081119-epa-cao-qapp.pdf

Using a quantitative index that measured the effect of land cover change on flows in lowland streams and rivers, the report suggested that County environmental regulations had been effective in protecting the water flow processes relative to urban streams such as Juanita Creek.

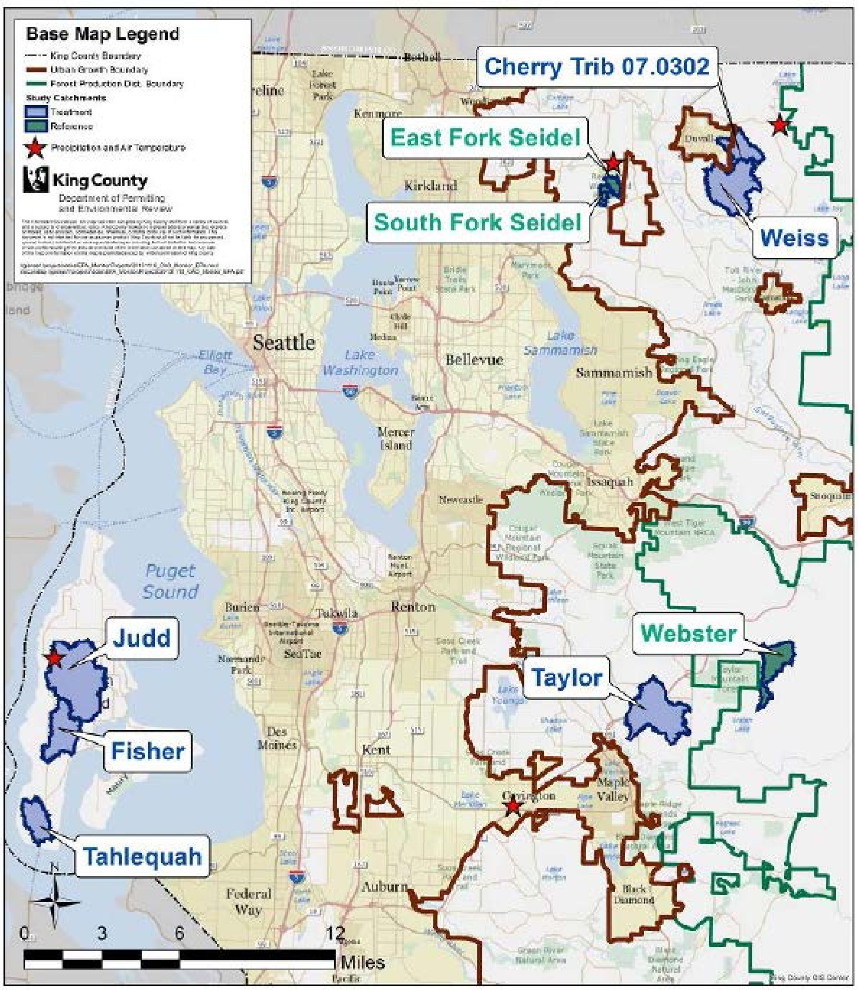


Figure 2. Nine data-rich test watersheds used by King County in developing HCI. These watersheds have land cover patterns similar to many developing suburban watersheds in Puget Sound.

King County based their quantitative index, Hydrologic Condition Index (HCI), on High Pulse Counts (HPC)[1]. DeGasperi et al. (2009) found that HPC and high pulse range met all four criteria for identifying a "useful hydrologic indicator": 1) sensitivity to urbanization consistent with expected hydrologic response; 2) statistically significant trends in urbanizing watersheds and not in undeveloped watersheds; 3) correlation with biological response to urbanization as measured by the Benthic Index of Biotic Integrity (B-IBI); and (4) relative insensitivity to confounding factors like watershed area. Statistical analysis conducted by the County (Table 1) demonstrated that HPC have a significant correlation with the HCI ($r = 0.88$; $p = 0.01$).

Table 1. Correlations between HCI values for average watershed or regulatory stream buffer and average land use (e.g., % impervious surface, forest land cover) and project Environmental Response Values for six watersheds. Correlation of HCI with reach thalweg length is not shown as the length was artificially imposed.

	Average Watershed HCI		Average Regulatory Stream Buffer HCI	
	r	p-value	r	p-value
Watershed Percent Impervious	0.94	<0.01	0.68	0.07
Watershed Percent Forest	-0.91	<0.01	-0.58	0.12
Average Watershed HCI	-	-	0.71	0.06
Average Regulatory Stream Buffer HCI	0.71	0.06	-	-
Ratio of watershed and buffer HCIs	0.05	0.46	-0.66	0.08
High Pulse Count	0.88	0.01	0.96	<0.01
Average Annual Temp at Baseflow	0.20	0.36	0.6	0.10
Conductivity at Baseflow	0.08	0.44	-0.24	0.33
Percent Pool Length of Thalweg	0.44	0.19	-0.03	0.96
CV of Thalweg Depth	-0.44	0.19	-0.55	0.13
Average Velocity at MAD	0.36	0.24	0.85	0.02
Average Residual Pool Depth	0.08	0.44	0.68	0.07
Large Wood per 100m	0.64	0.09	0.55	0.13
Percent Silt and Sand	-0.36	0.24	-0.78	0.03
BIBI	0.42	0.21	0.56	0.12
X7DADMax	0.94	<0.01	0.68	0.07

Taken from King County, Lucchetti et al 2014.

King County then developed coefficients that represented the HPC for combinations of different types of land cover on till and outwash (Table 2). This was accomplished by using calibrated hydrologic models in five WRIA 9 watersheds that used precipitation inputs average over 61 years. The resulting HPC values were averaged and used as coefficients in the nine test watersheds in WRIA 7, 8 and 15.

The County's Science and Technical Support Section (2013) ranked the calibrated hydrologic models used to develop the HPC coefficients as fair ($r^2 \geq 0.6$) to excellent ($r^2 \geq 0.9$) for accuracy

[1] High Pulse Counts are defined as 2 Times Mean Annual Flow

in simulating hourly flow rates and HPC. Therefore, we believe these coefficients are suitable in terms of testing the application of HCI in the nine test watersheds.

Table 2. Model coefficients for yearly high pulse count (HPC).

Results for five watersheds are based on precipitation averaged over 61 years and are arranged from lowest to highest for different land cover type on till and outwash geology. The average values for each geology and land cover type will be used as the HPC coefficient in the HCI model.

Geology	Land Cover	Hamm Creek (set 1)	Miller Creek (set 2)	Des Moines Creek (Set 3)	Newaukum Creek (set 4)	Duwamish LCL1 (set 5)
Till	forest	2.393443	2.672131	3.655738	4.606557	7.049180
	shrub	2.639344	3.311475	4.475410	6.016393	7.081967
	pasture	2.803279	4.032787	4.622951	6.590164	7.606557
	wetland	2.901639	4.868852	4.540984	7.524590	8.245902
	clear cut	3.819672	5.032787	5.360656	8.606557	8.803279
	grass	5.672131	5.213115	6.032787	9.983607	8.475410
	bare	5.114754	8.524590	7.901639	10.508197	11.459016
	building	30.508197	34.803279	33.491803	29.622951	31.836066
	pavement	26.540984	36.885246	36.508197	34.032787	35.737705
	open water	27.934426	38.163934	38.131148	36.655738	37.786885
	unpaved road	33.983607	37.180328	36.901639	34.754098	36.672131
	paved road	34.360656	37.655738	37.344262	35.180328	37.213115
Outwash	forest	2.213115	2.065574	3.360656	3.688525	5.426230
	shrub	2.229508	2.131148	3.393443	4.540984	5.573770
	pasture	2.295082	2.213115	3.262295	6.081967	5.524590
	clear cut	2.295082	2.213115	3.262295	6.081967	5.524590
	grass	2.606557	2.032787	3.409836	5.655738	5.704918
	bare	3.245902	3.311475	4.557377	7.639344	7.852459
	wetland	2.901639	4.868852	4.540984	7.524590	8.245902
	building	31.409836	35.459016	33.245902	31.737705	31.983607
	pavement	26.573770	37.114754	36.475410	35.049180	35.622951
	open water	27.639344	38.081967	37.934426	36.606557	37.819672
	unpaved road	34.016393	37.524590	37.049180	35.491803	36.819672
	paved road	34.196721	37.672131	37.229508	35.868852	37.098361

*For reference only - not used for scoring.

** Because HPC are whole numbers, decimal places were carried to millions when computing averages to reflect fine-scale (1:1200) resolution of land cover mapping and high density (millions) of 1.8 m grid cells per watershed.

From King County, Lucchetti et al 2014.

Other data collected by the County for the purpose of calculating the HCI included:

- Surficial geology (type, location and area): source Ecology. Source data is the 1:100,000 statewide geology produced by the Washington Department of Natural Resources (WDNR). The data set, which was peer reviewed by Ecology geologist Patricia Olson and Derek Booth, geologists at the University of Washington (UW), was amended to provide identification of high and low permeability geologic deposits

- Weather (precipitation and air temperature): source King County
- Land cover (location, area and condition of hand-digitized, mapped land cover polygons): source King County

King County's data represents higher resolution information than for either state or national data sets. For example, the County used air photos to digitize land cover data at a 1.8 meter resolution. The National Atmospheric and Oceanic Administration (NOAA) land cover data for Puget Sound have a 30 meter resolution (i.e. Coastal Change Analysis Program). Similarly, the County's precipitation and air temperature data is for individual watersheds while WDNR precipitation data is often extrapolated from weather stations located to cover an entire county.

This project will also use the previous work completed to establish the spatial and analytical framework and decision support tools for the Puget Sound Characterization. The documentation for these existing decision support tools for the Puget Sound Characterization is set forth in three volumes: Volume 1, The Water Resource Assessments (Ecology Publication #11-06-016); Volume 2, Fish and Wildlife Assessments and; Volume 3, Users Guide (Ecology Publication #13-06-008). All three volumes, including model outputs are available at: http://www.ecy.wa.gov/services/gis/data/inlandWaters/pugetsound/characterization.htm)

Updates of the existing broad scale models, as part of this study, will use existing digital data sets developed from state and national land cover data sources. These data sources met the criteria of the PSWC of having coverage across Puget Sound at the same degree of resolution. These data sources are presented in Table 3. As part of this study, these data sources and data aggregation and calculation methods for broad scale models will be updated.

Table 3. Sources of digital data.

Data/Database	Scale	Agency	Web Site
Precipitation	1:2,000,000	WDNR Forest Practices Division.	http://www.dnr.wa.gov/forestpractices/data/
Rain-on-Snow & Snow-dominated	1:250,000	WDNR	http://www3.wadnr.gov/dnrapp6/dataweb/dmmatrix.html#Climatology
Surficial Geology	1:100,000		http://www.dnr.wa.gov/geology/dig100k.htm
Soils (SSURGO)	1:12,000 – 1:63,000	Natural Resources Conservation Service (NRCS)	http://soildatamart.nrcs.usda.gov/County.aspx?State=WA
Soils (STATSGO)	1:250,000		http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/
Topography Digital Model Elevation	10 Meter	University of Washington	http://duff.geology.washington.edu/data/raster/index.html
Hydrography (streams, lakes)	1:24,000	WDNR	http://www3.wadnr.gov/dnrapp6/dataweb/dmmatrix.html#Hydrography
Wetlands (NWI) (see SSURGO)	1:24,000	US Fish & Wildlife Service	http://www.fws.gov/nwi/downloads.htm

Data/Database	Scale	Agency	Web Site
Channel confinement & gradient	1:24,000	WA Depart of Fish & Wildlife; North West Indian Fisheries Com	http://www.wdfw.wa.gov/hab/sshiap/index.htm
Mass wasting (Shaw Johnson landslide risk)	10 Meter (Western WA)	WDNR, Forest Practices Division	http://www.dnr.wa.gov/forestpractices/data/
Land cover	30 m Grid	US Geological Survey	http://www.csc.noaa.gov/crs/lca/pacificcoast.html

3.2.3 Parameters of interest and potential sources

The project does not involve monitoring or evaluating environmental pollutants or contaminants of interest. It is designed to identify the level of impact that land use actions may have upon water flow processes which in turn affect the biological functions of aquatic areas. Measuring this impact will be accomplished using both the existing Hydrologic Condition Index (HCI) developed by King County staff in 2014 and a new Low Flow Index (LFI) employing a calibrated model known as VELMA[2]. The HCI index is based on High Pulse Counts (HPC) in stream flow generated by different types of land cover. The HPCs were developed using HSPF models calibrated for lowland streams in King County[3].

The sources of data for calibrating these hydrologic models include stream gage data which is available from both King County and the USGS for the nine watersheds used as test sites for developing the mid-scale models.

3.2.4 Regulatory criteria or standards

Because the proposed model updates are part of a "decision support tool" designed to assist local governments making planning decisions (i.e. location, type and density of development) there are no regulatory criteria or standards directly associated with this project.

4.0 Project Description

We propose to test King County's HCI method (Lucchetti 2014) and new LFI (based on VELMA data) in pilot watersheds in King and Snohomish Counties for eventual application as the mid-scale assessment model framework for Puget Sound. More information on the HCI and VELMA model is included in Appendix A and B. The testing will identify the best scale and type of flow network to apply the methods and the degree of correlation with observed hydrologic data.

While the HCI will be used primarily to assess existing overall hydrologic condition of streams, the LFI will assess the vulnerability of watersheds and their streams to climate change as measured by the relative future change in low flows. VELMA has the capability to predict the future change in low flows when both calibrated to the hydrograph of individual watersheds and using precipitation values based on climate change models. We propose to develop and test the LFI in two of the nine test watersheds in King County, using the VELMA model.

[2] More information on the VELMA model is presented in Appendix B.
[3] High Pulse Counts are defined as 2 Times Mean Annual Flow

Additionally, the study will identify any needed updates and changes to existing data sets for the existing broad scale models, including changes to data aggregation and calculation methods. The results of the HCI model tests will also be used to help validate the broad scale results of the water flow degradation model.

The HCI was originally tested in 9 watersheds in King County (Judd, Fisher, Tahlequah, East and South Fork of Seidel, Webster and Taylor Creeks), which included collection of detailed data on stream condition as well as delineation of land cover within a 1.8 meter grid. As an indicator of stream hydrologic condition, the number of HPCs was selected by King County. The HPCs for different land use types (i.e. forest, rural, urban) were developed using a hydrologic model (HSPF) applied in several other representative basins in King County. The HCI routing framework will also be used for the LFI.

There are several key questions to answer regarding application of the HCI and LFI method:

1) Do HCI values vary significantly at different spatial scales[4] (extent and grain)? Test at 2 grain sizes, 1.8 meter and 30 meter grid resolution, and at several different watershed extents.
2) Do HCI values vary significantly using either a simulated natural flow or Euclidean based flow network?
3) Can a metric such as percent impervious cover[5] be used to achieve results similar to those obtained using HPCs?
4) Is the HCI a useful method for evaluating future development scenarios including the type, location and density of development?
5) Additional key questions – Land cover layer effect on HCI calculation and ability to perform alternative futures scenarios:
    a. Will the land cover categories used in other counties in Puget Sound allow for the calculation of HPC values that can be compared between WRIAs?
    b. If land cover categories are not similar, what will be the estimated time and cost required to run HSPF models to generate HPC coefficients for the unique combination of geology and land use found throughout Puget Sound?
    c. What should be the rules for “transferring” or scaling the land cover class attributes up or down in resolution (i.e. 30 meter land cover data should not be scaled down to a 10 or 1 meter grid)?
6) Do existing broad scale results for the water flow degradation model in the 9 test watersheds correlate with the HCI values for those watersheds?
7) Is the LFI useful for evaluating the vulnerability of watersheds to climate change?

[4] Patterns within an ecological system or mosaic is a function of scale which is comprised of extent and grain (Forman and Gordon 1986)

[5] Watershed Percent Impervious cover was included in this work program since King County found that it had the highest correlation with stream HCI (Table 2). Using impervious surface in a routed network would greatly simplify the hydrologic index calculation since individual land uses types would not have to be assigned a calibrated high pulse count value. A consistent method for establishing which land cover classes equate to impervious cover will be needed.

The initial Tasks 1.0 through 2.0 (Section 4.4) will address questions 1 and 2, Task 3.0 will address question 3, and Task 4.0 will address questions 4 and 5. For Tasks 4 and 5 the HPC values in Snohomish and King County should be available since they are required under their current NPDES permit to calculate HPCs for a range of land use types using a HSPF model. Task 6.0 will address question 6; Task 5.0 will address question 7.

4.1 Project goals

The overall goal of the Puget Sound Watershed Characterization (PSWC) 2.0 project is to develop a multi-scale decision support framework that integrates information from abiotic and biotic assessments allowing users to:

- Identify root cause of environmental problems in a watershed at multiple scales
- Identify solutions at a scale that matches local government management tools (zoning, permitting, development standards)

This framework is designed to help users make "watershed-based" land use decisions supporting the protection and restoration of ecologically important lands and allowing the location of development in areas least likely to impact watershed processes and functions. At present the PSWC is a decision support tool that assists with planning level decisions made at a broad or broad scale (1,000s of acres). To attain the overall goal of the PSWC of an integrated, multi-scale decision support network, the development of mid-scale tools (i.e. 10's to 100's of acres) is necessary.

4.2 Project objectives

Mid-Scale Model Objectives:

- Provide quantitative measures of watershed condition at the mid- or reach-scale, within a flexible but uniform assessment framework, using but not limited to:
    - High Pulse Counts
    - Impervious Cover
    - Low Flows
    - Other parameters, such as nutrients, may be considered as budget and time allow.
- Capable of representing conditions in the nine ecosystem units of Puget Sound
- Identify root cause of environmental problems in a watershed at multiple scales
- Identify solutions at a scale that matches local government management tools (zoning, permitting, development standards)
- Allow users to assess future development patterns through alternative futures scenarios

Broad-Scale Objectives:

- Identify any needed updates to existing data layers
- Identify any needed changes to data aggregation and calculation methods for model
- Develop method (e.g. LFI) to help identify watersheds vulnerable to climate change.

4.3 Information needed and sources

For the testing of flow routing methods and analysis scale (resolution) the project will be using existing data collected by King County as part of their April 2014 study "Assessing Land Use Effects and Regulatory Effectiveness on Streams in Rural Watersheds of King County, Washington" (Lucchetti 2014).

For the testing of alternative futures methods using the Hydrologic Conditions Index, the project will be using existing hydrologic data collected by either Snohomish County Surface Water Management for watersheds in WRIA 7 or by King County in WRIA 8 (test watershed will be selected in Task 1).

The existing data to be used will be of following types:

1) Land cover data
2) Surficial geology data
3) Precipitation data
4) High Pulse Counts (gage)
5) Coefficients for High Pulse Counts for different land cover and geology combinations
6) Hydrologic Condition Index scores
7) Low Flow data (gage)
8) Coefficients for Low Flow for different land cover and geology combinations from VELMA model
9) Data sets for the PSWC broad scale assessment models (see Section 6.3)

These data will be used to run the HCI and LFI models; the HCI model will use data types 1 to 2 and 4 to 6. For the LFI model, data from types 1 to 3 and 7 to 9 will be used to develop an index to assess vulnerability of water flow processes in watersheds at the broad scale to climate change. Additionally, the study will update data sources in item 9 and review and identify any needed changes to data aggregation and calculation methods.

The project will not collect any new data in developing the HCI model and index. For testing of the alternative futures tool, existing HSPF data will obtained from Snohomish County for the test basin. For testing of the LFI model, low flow data from existing gages in a test watershed will be used; the VELMA model will be used to develop low flows[6] coefficients.

4.4 Tasks required

The following is a list the tasks required to complete this project:

1.0 Acquire data, select test watersheds in Snohomish or King County and form the Watershed Assistance Group (WAG). For Task 2.0, the nine existing test watersheds in King County (Figure 2) will be used. The HCI model and gage data for these watersheds has been

[6] In conversations with the EPA staff at Region 6, it is their belief that VELMA model is already properly calibrated for application within any Puget Sound watershed.

developed and collected by King County. For Task 4.0, the "alternative futures" test watershed would have to be identified in either Snohomish or King County.

1.1 Meet with King County staff to acquire data and identify initial "alternative futures" test watershed in Snohomish or King County. County staff will work with Ecology GIS staff to transfer test watershed data and setting up the HCI model.
1.2 Form Watershed Assistance Group (WAG). The purpose of this team is to bring together both watershed scientists familiar with the development of watershed assessment methods and local planners who have experience with the interpretation and application of watershed assessment results to local planning and permitting issues. Solicit participation from local government planners and watershed scientists (Ecology, WDFW, EPA and consultants) familiar with use and application of the PSWC and watershed assessment methods to local and regional planning issues.

2.0 Select the best method of routing and resolution (grid size). Compare HCI results and existing stream gauge HPC data using nine test watersheds in King County.

2.1 Develop Euclidian flow network at 1.8, and 30 meters
2.2 Simulate natural flow path. Create a natural flow network grid at 1.8 and 30 meters using a Digital Elevation Model (DEM) tool.
2.3 From existing King County gage data for the nine test watersheds (Figure 2) identify the average HPC.[7]
2.4 Ecology GIS staff acquires and runs HCI Model in four suggested test runs (Figure 5) in order to compare flow path results at existing 1.8 meter resolution flow network with HCI results at 30 meters resolution. Using the decision matrix, or similar, presented in Table 7 evaluate results statistically (Ott 1995) for the test runs (Figure 5) and select the best method for routing and resolution. Present results to WAG for their review and comment.
2.5 Ecology GIS staff makes any needed changes to incorporate selected routing and resolution method into PSWC methods.

3.0 Evaluate if impervious coverage provides similar results to using HPCs

3.1 Compare HCI values using HPCs and impervious surface. Using impervious cover data, apply HCI in a minimum of one test watershed
3.2 Similar to Task 2.0, use regression analysis to compare HCI results for percent watershed impervious relative to using HPCs coefficients. Create test graphs similar to those produced in Figure 5 plotting impervious (based on land cover class) vs HPCs (gage data) and comparing results for regression analysis in task 2.
3.3 Evaluate and determine if impervious cover could be used as indicator. Present results to WAG for their review and comment.

4.0 Apply HCI in Snohomish or King County Watershed and Test Alternative futures.

[7] According to the King County Study (Lucchetti 2014) average annual HCIs varied little during the project (2007-2012), ranging between a low (best condition) of 0.149 for Tahlequah in 2007 to a high (worst) of 0.208 in Taylor Creek in 2012. Among the treatment watersheds, Tahlequah and Cherry Creek were very similar and had the best (lowest HCI) condition while Taylor was the worst (highest HCIs). This is due to the fact that there was very little land cover change in the test watersheds (47.82 ha). Therefore, we suggest that an average of the HPC's be used for the 4 years of gage data.

4.1 Meet with Snohomish and King County staff to finalize selection of watersheds to apply HCI.
4.2 Obtain HPC data from the County, evaluate and develop final HPC values for land cover and surficial geology types shown in Tables 2.
4.3 Apply grid network at resolution and flow path type identified in Task 2.5.
4.4 Select development scenarios, in consultation with WAG, that incorporate several levels of development, size and location (see Table 8). For development density, the scenarios could include: low (rural), medium (suburban), and high (urban) density. For determining the threshold at which HCI is able to detect the effect of development, consider four development sizes such as 1, 5, 20 and 100 acres. For location sensitivity, test the development scenarios at the furthest distance from the stream, half the distance and then directly adjacent to the stream. Initially, the different density types would each be assigned one unique density and HPC value for the area tested. Upon completion of the first set of tests, the unique density types or scenarios (i.e. low, medium and high) would be converted to actual development plans and the HPC values calculated for the mix of land cover within the plan. The purpose of this approach would be to determine at what level of detail do the LFI results change relative to the use of a single HPC for one density type.
4.5 Apply development scenarios within HCI framework as refined by Tasks 2.0 and 3.0.
4.6 Determine if HCI results can identify differences between development scenarios, including different locations within watershed. Identify size, density and location thresholds for which HCI is able to detect development impacts on stream hydrology. In addition, determine if the scenarios should be presented as actual plans or a single area of development with an HPC that corresponds to combination of land use types representative of that scenario. Present results to WAG for review and comment; based on correlation data WAG will determine if output of models is useful.
4.7 Working with WAG and Ecology GIS staff, use a survey of previous and potential users of the alternative futures tool to identify the best way to format and present the tool on the PSWC website. Investigate whether actual development site plans can be incorporated into the alternative futures tool. Estimate time for Ecology GIS staff to incorporate final format for alternative futures tool into PSWC model methods and website. Information from this task will be used to develop the Phase 2 SOW in Task 8.0.

5.0 Develop a Low Flow Index (LFI) for identifying the vulnerability of Puget Sound watersheds to climate change. This will involve exploration and testing of a rapid method such as the LFI that can use sound-wide indicators to reliably predict impacts to critical processes. A calibrated climate change model such as VELMA or similar will be used to develop the low flow coefficients for use in the LFI calculations (Table 9) to test and validate the proposed LFI method (Figures 6 & 7).

5.1 Based on literature review and discussions with watershed hydrologists (e.g. EPA Corvallis, UW Climate Impact Group), refine the draft LFI as presented in Figure 6, for assessing climate change impacts within Puget Sound Watersheds.
5.2 Incorporate data from Climate Impact Group at the UW into Vulnerability Model.
5.3 Run draft method on Snohomish or King County test watershed. Validate results using regression method (or similar) presented in Figure 7.

5.4 Evaluate results and make recommendations on LFI. Present to WAG for review and comment; based on correlation data WAG will determine if output of models is useful. Recommendation should outline of proposed Phase 2 work program to further test and implement method sound-wide and best way to incorporate results into PSWC website; this information will be used to complete Task 8.

6.0 Maintenance update of current PSWC models and indices. The Maintenance Update Technical Team (MUTT), comprised of agency staff and consultants with expertise in the mechanics of data aggregation, binning and calculation methods, model scripting, and display of data, will participate in a series of 3 to 4 meetings to review the existing coarse scale models and indices to recommend any needed updates.

6.1 Review of all base GIS Layers as listed below in Table 3 to determine if updated data sets are available. Assess each new data layer for accuracy and determine if it should replace existing data layers.

6.1.1 For precipitation layer, determine if there are other sources of existing GIS data that would provide a better depiction of actual precipitation across existing assessment units. Presently, the DNR precipitation layer may provide only one precipitation band or value across a single AU of 3 to 5 square miles.

6.1.2 For hydrography layer, review new NHD+ hydrography and assess the required time to correct AU boundaries to include/exclude new hydrography.

6.1.3 For SHIAPP channel confinement data layer, review floodplain mapping completed by Chris Konrad (USGS) for large river valleys and evaluate if it its application to the channel confinement assessments would improve the accuracy of the water flow models.

6.1.4 For land cover data layer, review both the latest land cover data sets from CCAP (i.e. 2011 Coastal Change Analysis Program) and Ken Pierce (change analysis) for accuracy and application to the PSWC.

6.1.5 Review SSURGO data layers for cation exchange capacity (CEC_SSURGO) and clay (CLAY_SSURGO), Hydric soils, “K” and “R” factor. Determine if updates are available and if the SSURGO “R” factor would be a better than the DNR data set for precipitation.

6.1.6 Review Department of Health well data layer. Determine if there is an alternative data layer or analysis method that more accurately captures the impact of wells upon groundwater resources.

6.1.7 Review DNR and WSDOT road data.

6.1.8 Review wetlands layer and determine if there is an alternative data layer or analysis method that better captures historic wetland extent and degradation/loss of wetlands.

6.2 Review of Assessment Unit (AU) boundaries

6.2.1 Correct AU boundaries that do not conform to: 1) existing topography; 2) updated hydrography; 3) AU landscape unit average sizes (e.g. coastal, 1 square mile; lowland 3 to 5 square miles, mountainous 7 to 15 square miles); or 4) configuration (e.g. AUs should incorporate sub-watersheds that extend from confluence to headwaters).

6.2.2 Revise boundaries between Landscape Units in order to better reflect the different ecological processes operating within each. For example, existing AU boundaries in large river valleys are based on SHIAPP boundaries that extend outside of the floodplain upslope to top of valley ridge. As a result, they "mix" the processes of two distinct sub landscape units, floodplains and lowlands. This makes assessment and ranking of the processes in large floodplains difficult. In reviewing and adjusting landscape unit boundaries, refer to Cereghino study (2016) on integrating assessment units in the Puget Sound.

6.2.3 Floodplain and Lowland "sub-landscape units. Review floodplain work conducted by Chris Konrad and use to guide revision of floodplain boundaries in large river valleys.

6.2.4 Review any other boundary issues between other landscape units. This includes PSWC and PSNERP landscape units (e.g. coastal units with nearshore PSNERP). Make revisions as necessary.

6.3 Data aggregation and index binning**.** Review and identify improved data aggregation methods and binning methods. For each index, a numeric value is generated with those values are being "binned" into 4 quartiles or categories of importance and degradation in order to provide a readily interpreted representation of the results. While this approach works well for the majority of assessment units, there are cases where binning into categories does not make sense due to either identical values or "zeros" present in two categories or when there is very little difference between values.

6.3.1 Review binning problems associated with repeated values of "0". Repeated values of "0" create a larger quartile then would be created if all values in the data set were discrete values. Determine, if this type of "uneven" binning creates significant issues with the model output and if so what type of alternative should be used

6.3.2 Review binning problems associated with identical values. A large number of identical values can create uneven quartiles. Determine, if this type of binning problem creates significant issues with the model output and if so what type of alternative should be used.

6.3.3 Test any new data aggregation methods, including binning, identified in Tasks 5.3.1 and 5.3.2.

6.3.4 Incorporate any new data aggregation methods into water flow and water quality models.

6.4 Evaluate, in conjunction with MUTT and consultant, if changing computation methods for the existing broad scale models will improve the output of the model (e.g. reducing uncertainty, improving accuracy). This could include consideration of using "geo mean" and weighted formulas with the current methods[8].

[8] In an effort to combine different environmental indicators for water flow and water quality processes (e.g. area of wetlands for surface water storage and denitrification; area of pavement for degradation of delivery processes) the PSWC used a "ratio-scale" approach. With a "ratio-scale approach the PSWC uses the raw data for a specific parameter in the numerator and the total acres in an AU as the denominator. For the indicators used, this generated a non-dimensional value that was normalized by acres and removed any other measurement units such as quantities of

6.5 Based on MUTTs direction, test new computational methods they recommend.
6.6 Explore use of HCI to validate water flow degradation model outputs for Puget Sound. This may include an initial test in the nine test watersheds that compare the degree of correlation between HCI results and degradation model results. For example, if a test watershed has a "high degradation" score then this should correspond to HCI score of approximately 0.7 or higher; conversely, a watershed with a low "degradation" broad scale model score should correspond to approximately a 0.25 HCI score.
6.7 Update all models to Python script and incorporate any changes made in Tasks 6.0. GIS work may include attending MUTT meetings, revision of existing python script to incorporate any needed changes to index formulas and binning methods, running of the characterization models for all AUs within Puget Sound and incorporation of revised model results into characterization website

7.0. Final Report. During the development of the new models indices, the Ecology PSWC staff will meet with the WAG team a minimum of 4 times to report on the progress of the project. At each of these meetings, staff will provide technical memos that document both the progress on Tasks 1 through 6 including the results of new model runs. The final report will follow the format found in the existing Puget Sound Characterization document (publication #11-06-016) and will be added as Appendix E, "Mid-Scale Models for Assessing Hydrologic Condition in Puget Sound Watersheds."

8.0. Phase 2 Scope of Work. Based on the results of testing for the HCI and LFI indices and alternative futures tool, develop a draft scope of work for implementing application of these indices and tools sound-wide. This should include identification of which regional geomorphic types (e.g. Whatcom County marine-lacustrine drift, Thurston County glacial outwash) require calibrated low flow and high pulse coefficients and the time/expertise required to do so. Scoping for implementation of the alternative futures tool, should include estimation of required steps and associated time to upgrade the PSWC website. Required expertise for completing all of the tasks should also be identified.

precipitation in inches or storage in acre-feet. These values for AUs were then added to other values for each indicator of delivery, movement, and loss and further normalized by the highest value and then ranked. However, when a method choses to use a ratio scale method, the final unweighted ranking result may not accurately represent environmental conditions (Ebert and Welsch 2004). Ebert and Welsch recommend use of a geometric mean, instead of simple addition and normalization of index parameters; this avoids the inclusion of data extremes and introduces a lesser degree of ambiguity into the results.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 4 presents a list of the individuals involved in this project, including their responsibilities, and timeline for completing project tasks.

Table 4. Organization of project staff and responsibilities.

Staff (All EAP except client)	**Title**	**Responsibilities**
Tom Gries Ecology EAP Phone: 360 407 6327	National Estuary Program (NEP) Quality Coordinator	Reviews draft QAPP for compliance with requirements. Recommends approval or approves QAPP (in absence of QA Officer). Comments on draft of final project report.
Bill Kammin Ecology EAP Phone: 360-407-6964	Quality Assurance Officer (QAO)	Reviews and approves QAPP.
Stephen Stanley Ecology NWRO Shorelines Section Phone: 425 649 7007	Project Manager & Principle Investigator	Writes the QAPP. Oversees model development and model runs. Conducts QA review of data, analyzes and interprets data. Writes the draft report and final report.
Colin Hume Ecology NWRO Shorelines Section Phone: 425 649 7139	Manager for Puget Sound Characterization Project	Provides internal review of the QAPP, approves the budget, and approves the final QAPP.
Lauren Driscoll Ecology Wetlands & Watersheds Section Phone: 360 407 7045	Section Manager for the Project Manager	Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP.
King County	HCI Modelers	Assists Ecology project team in setting up and applying HCI model
Bob McKane EPA Corvallis Lab	VELMA Modelers	Assists Ecology project team in setting up and applying VELMA model
WAG	Watershed Assistance Team	Assists Ecology project team in reviewing and interpreting model outputs for HCI and LFI
MUTT	Maintenance Update Technical Team	Assists Ecology project team in identifying necessary changes to existing broad scale models.

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

5.2 Special training and certifications

The project will require expertise using spatial data and modeling within a Geographic Information System (GIS) to address ecosystem questions about the functioning of watersheds.

Susan Grigsby and Christina Kellum will be performing the GIS tasks (1 through 6) for this project. Ms. Grigsby has been the lead GIS analyst on the Puget Sound Characterization since 2005, and has performed the spatial analysis necessary to produce the model outputs.

Stephen Stanley and Colin Hume will provide the analysis and interpretation of test results resulting from Tasks 2 through 3, selecting the best methods for water flow routing and grid size, testing application of an alternative futures tool (Task 4), updating existing broad scale methods (Task 5), and developing a broad scale climate vulnerability tool (Task 6). Mr. Stanley and Mr. Hume are trained as ecologists, with Mr. Stanley specializing in aquatic systems and Mr. Hume in wildlife biology. Both individuals have managed the Puget Sound Watershed Characterization project and are experienced in developing large-scale watershed modeling programs.

5.3 Organization chart

Work Assignment Management Authority

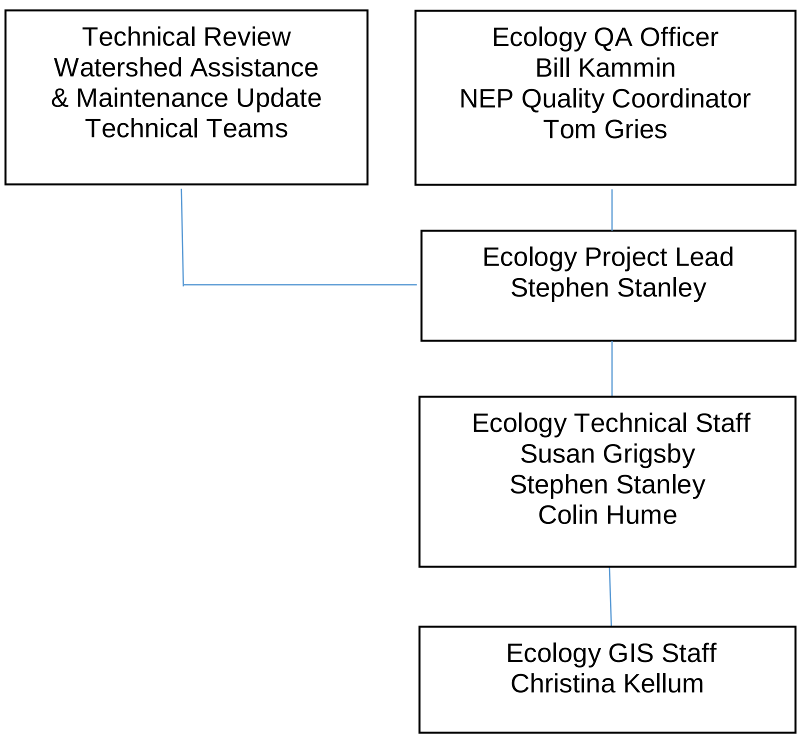


Figure 3. Organization chart for 2017-2018 Puget Sound Watershed Characterization Project 2.0

5.4 Proposed project schedule

The proposed schedule for completing Tasks 1 through 6 for development of the PSWC mid-scale models is set forth in Table 5.

Table 5. Proposed project tasks and schedule.

Data Analysis – Task 1 to 5 Schedule	Due date	Lead staff
QAPP Approval	4/17	Tom Gries, Bill Kammin
Task 1 – Acquire Data	4/17	Stanley, Grigsby, Hume
Task 2 – Test & Select Best Routing	6/17	Stanley, Grigsby, Kellum, Hume
Task 3 – Test Impervious Method	8/17	Stanley, Grigsby, Kellum, Hume
Task 4 – Test Alter Futures Method	12/17	Stanley, Grigsby, Kellum, Hume
Task 5 – Update Broad Scale Models	2/18	Stanley, Grigsby, Kellum, Hume
Task 6 – Develop Climate Vulnerability Method	4/18	Stanley, Grigsby, Kellum, Hume,
Environmental Information System (EIM) database – Not Applicable		
Final report Schedule		
Author lead / Support staff	Stanley, Hume, Grigsby	
Draft due to supervisor	3/18	
Draft due to external & peer reviewer(s)	4/18	
Final (all reviews done) due to publications	6/18	
Final report due on web	7/18	

5.5 Budget and funding

The project is being funded through a grant from the NEP run by the EPA. The two year $228,000 grant was awarded to the Ecology to implement specific stormwater recovery actions listed in the implementation plan for the Puget Sound Partnership Action Agenda (Table 6). This grant was for implementing Near Term Action 2016-0399 which was ranked 9th overall out of 119 actions in the 2016 implementation plan: https://pspwa.box.com/shared/static/mb0f4hcd4p2lrrkmvo21969zmdf504sm.pdf

Near Term Action 2016-0399 states: "Review and update of Puget Sound watershed characterization indices to develop a climate change module. Incorporate new data to keep assessments accurate and current in how they inform land use decisions by local governments."

Table 6. Project budget and funding.

Budget Item	Budget Amount
Salary, benefits, and indirect/overhead	$178,000
Equipment	0
Travel and other	0
Contracts	$50,000
Budget Total	$228,000

6.0 Quality Objectives

6.1 Data quality objectives [9]

NA. No new environmental data will be collected by this project.

6.2 Measurement quality objectives

NA. No new environmental data will be collected for this project.

6.3 Acceptance criteria for quality of existing data

All model input data are either obtained from reputable federal/state sources and are widely used, or have been collected by King/Snohomish Counties according to approved QAPPs[10]. All these environmental data are *assumed* to be representative and comparable.

For example, the development of the HCI mid-scale indices for this project relies upon data and modeling conducted by King County in their study of the effectiveness of land use regulations protecting stream and watershed processes (Lucchetti, 2014 and 2008). The County study sought to identify environmental response variables that had a high correlation between environmental conditions in a stream relative to conditions in the contributing watershed.

For more information on data sources see section 3.2.2.

6.4 Model quality objectives

The primary project objective, as stated in section 4.2, is to develop a mid-scale indices that provide a quantitative measure of the hydrological condition (HCI and LFI) of streams within an individual watershed. Because the HCI and LFI model outputs are a representation of stream hydrological condition, its relative accuracy can be tested against actual measurements of stream hydrological condition, known as "High Pulse Counts" and low flow data. Gage data for the test watersheds are available and can be used to identify the number of High Pulse Counts and low flow values during the four year study period from 2008 to 2012. As a stream's HCI and LFI value increases, the number of observed high pulse counts should increase and the size of low flows should decrease. Furthermore, the HCI index value should also increase for watersheds that have increasingly higher levels of development; thus, there should be a significant correlation between the actual HPC values measured at a stream gage and the calculated HCI value. This is described in section 7.3.2.

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[9] 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.

[10] A separate QAPP (Lucchetti 2008) was produced for this project, which can be accessed at the following King County website: http://your.kingcounty.gov/dnrp/library/water-and-land/data-and-trends/monitoring/critical-areas/081119-epa-cao-qapp.pdf

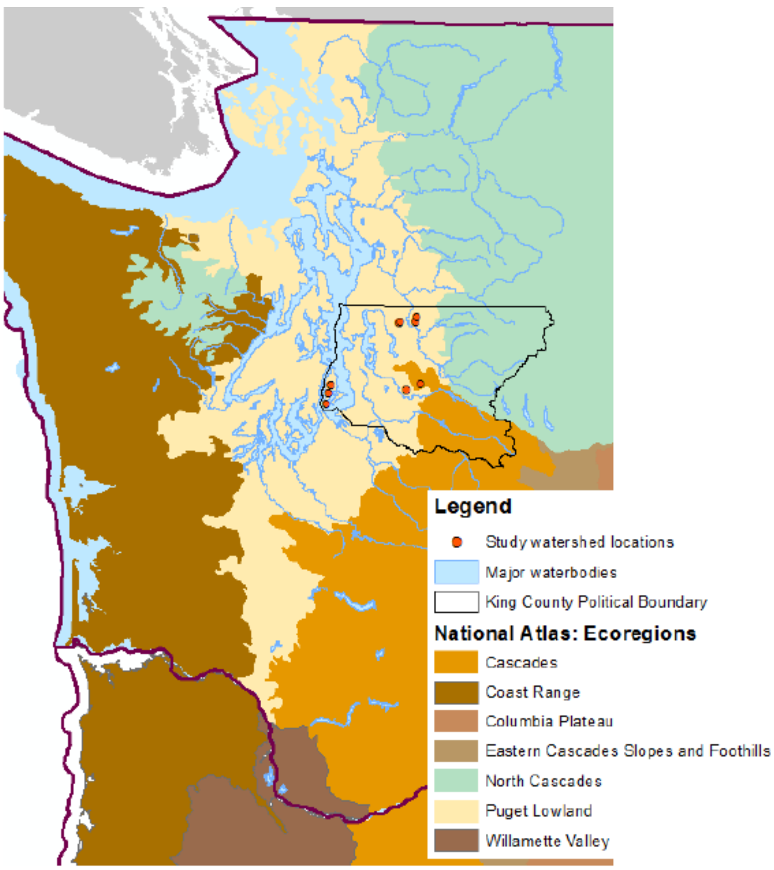
Therefore, the quality of the HCI model in predicting hydrologic condition will be tested in a series of scenarios employing different land cover resolution and flow routing methods. The LFI model will be tested by comparing the LFI output against observed low flows in the test watersheds. This is described in section 7.3.2. Furthermore, the WAG will evaluate the degree of correlation (r^2) between the HCI and LFI outputs with available gage data and determine if they are useful models.

Additionally, because the results of the mid-scale model runs in the test watershed are based on a calibrated HSPF model, they can be used to help validate the results of the existing broad scale degradation models for water flow. For example, if a test watershed has a "high degradation" score then this should correspond to HCI score of approximately 0.7 or higher; conversely, a watershed with a "low degradation" broad scale model score should correspond to approximately a 0.25 or lower HCI score.

7.0 Study Design

7.1 Study boundaries

The study area includes watersheds within WRIA 7, 8, and 15 (Figures 2 and 4). The study area covers the developing, lowland terraces of WRIA 8, located in central Puget Sound beneath the west slopes of the Cascade Mountains. The nine test watersheds to be used in Tasks 1 through 3 are located in these terraces within the rural eastern and western edges of King County. Eight of the study watersheds are located in the Puget Lowland Ecoregion (PLE; Figure 4), which is primarily less than 150 m (500 feet) in elevation, with the ninth study watershed located in the Cascades Ecoregion at the eastern edge of the PLE.



Graphic courtesy of King County.

Figure 4. Boundary of main study area (King County, WRIA 7, 8 and 15) for testing the HCI and LFI Indices. One additional watershed will be added in either Snohomish County to the north or in King County for testing of the Alternative futures tool.

7.2 Field data collection

NA. No field data will be collected.

7.2.1 Sampling locations and frequency

NA. There are no sampling locations.

7.2.2 Field parameters and laboratory analytes to be measured

NA. There are no field parameters or lab analysis required.

7.3 Modeling and analysis design

7.3.1 Analytical framework

This study will use an existing the HCI model developed by King County, (Lucchetti 2014) and an existing hydrological Mode, VELMA, developed by the EPA. These models have been tested and peer reviewed and their design and output was judged to be based on best available science and useful as a tool in representing an "indexed" condition of watershed processes. The HCI model is a mechanistic model that simulates water flow routing and response to land cover and surficial geology condition; it does not estimate rates, quantities, or patterns of hydrologic flow as other more complex hydrologic models. VELMA is a recently developed "eco-hydrologic" model that simulates the movement of water, nutrients, and heat within a watershed based on the interaction of these components with vegetation and soil and in response to changes in land cover and climate (Abdelnour 2011).

The models were selected because they:

1) Provide a quantitative measure of the effect of land cover change upon stream hydrological processes;
2) Are calibrated for lowland watersheds of Puget Sound where the testing will occur;
3) Can be incorporated into the PSWC framework and used throughout Puget Sound watersheds
4) King County and EPA staff are available to provide some level of technical assistance in running the model

Ecology staff will acquire the model from King County and run it within the existing modeling framework for the PSWC. This will not require any major changes to the existing watershed assessment unit boundaries or existing broad scale models.

7.3.2 Model setup and data needs

The primary project objective, as stated in section 4.2, is to develop mid-scale indices that provide quantitative measures of the hydrological condition based on high flow pulses and low flows (HCI and LFI) of streams within an individual watershed. In order to develop indices that provide the most accurate measure of hydrologic health, the project proposes to first test the HCI model and variables under different conditions of resolution and routing of flow; this will establish the best type of flow routing network and resolution. There are four hypothesis behind the testing: 1) that a higher correlation between HCI values and HPC will be occur when the best model methods are identified (e.g. resolution, routing); 2) that HCI will be able to detect changes in development in terms of location and size (alternative futures); 3) that HCI results will generally correspond to the existing broad scale "degradation" model results for water flow; and 4) low flow results (i.e. LFI) using VELMA coefficients will exhibit a high correlation with observed low flow gage data for the test watersheds.

This would include addressing the following questions:

1) Do HCI values vary significantly at different spatial scales[11] (extent and grain size)? Test at 2 grain sizes, 1.8 meter 30 meter grid resolution and at several different watershed extents.
2) Do HCI values vary significantly using either a simulated natural flow or Euclidean based flow network?
3) Can a metric such as percent impervious cover[12] be used to achieve results similar to those obtained using HPCs?
4) Is the HCI a useful method for evaluating future development scenarios including the type, location and density of development?
5) Do the existing degradation model results for water flow correspond to HCI values in the nine test watersheds?
6) Is LFI a useful method for evaluating the vulnerability of watersheds to climate change?

The results of these tests for questions 1 and 2 would be evaluated using regression analysis of HCI values and HPC, as shown in Figure 5; a decision matrix (Table 7) would be used to assist in the evaluation of these tests for questions 1 and 2. The results of the test for question 3 would be evaluated by comparing HCI values using impervious cover relative to using HCI results based on the full range of land cover and associated HPCs coefficients. This would involve generating test graphs similar to those produced in Figure 5 plotting impervious (based on land cover class) vs HPCs (gage data) and comparing to the regression graphs produced in Task 2 for HCIs based on HPC coefficients for the full range of land cover. The results for question 4 should demonstrate whether the HCI index can detect land cover changes that affect hydrologic processes and at what size of development that change can be detected (see Table 8). For question 5, HCI values for the test watersheds would be used to assess the validity of the broad scale model results for degradation of water flow processes. For question 6, the LFI results would be compared to observed gage data for the 9 test watersheds and evaluated for its usefulness as a climate vulnerability tool by the WAG (see Table 9, Figures 7 and 8).

HCI Model inputs requires the following data inputs, all of which are available:

1) Land cover data

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[11] Patterns within an ecological system or mosaic is a function of scale which is comprised of extent and grain (Forman and Gordon 1986)

[12] Watershed Percent Impervious cover was included in this work because King County found that it had the highest correlation with stream HCI (Table 4). Using impervious surface in a routed network would greatly simplify the hydrologic index calculation because individual land uses types would not have to be assigned a calibrated HPC value. A consistent method for establishing which land cover classes equate to impervious cover will be needed.

2) Surficial geology
3) HPCs for test watersheds
4) HPC coefficients
5) Existing data sets for the broad-scale water flow models

The HPC coefficients have already been developed by King County and are presented in Table 2.

The DOE staff will develop a LFI model using the same flow network developed for the HCI and using a similar algorithm to apply the model (Figure 7). Low Flow Coefficients, similar to Table 9, will be developed using the VELMA hydrologic model within the 9 test watersheds. Model inputs for VELMA include land cover, surficial geology, and precipitation data, all of which are existing and available.

Figure 5 presents the method for validating the LFI, using observed low flow gage data and the output from the LFI model for the nine test watersheds.

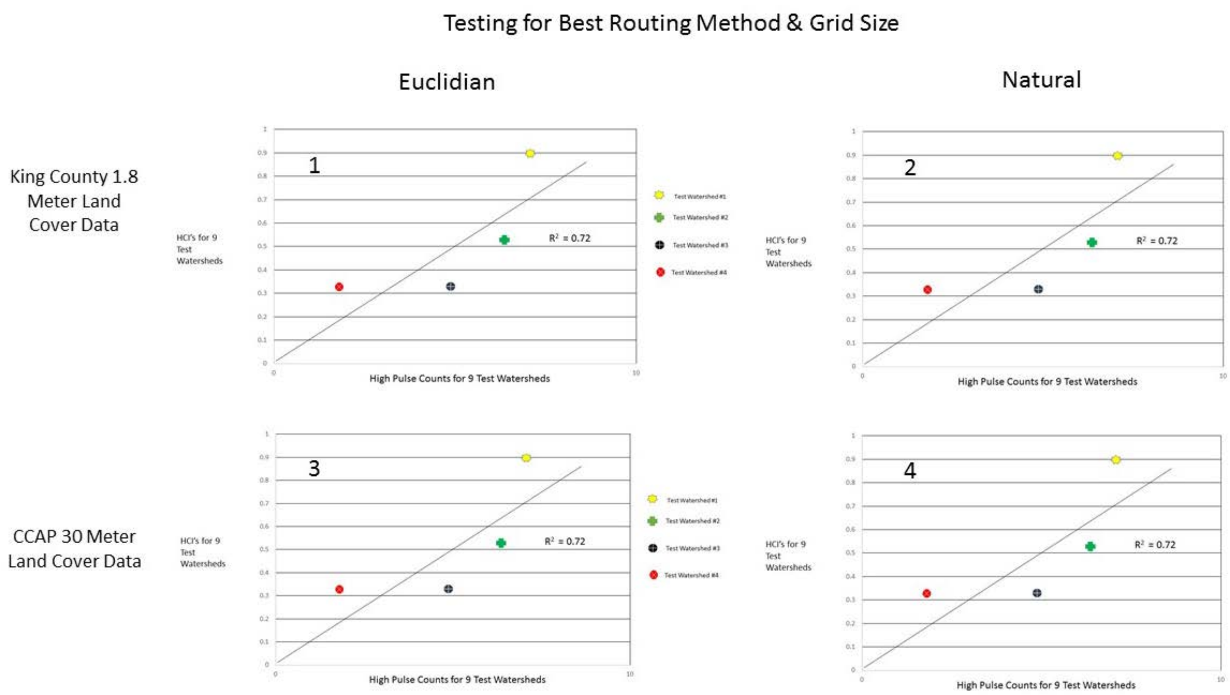


Figure 5. Suggested statistical approach for determining best model grid size and routing method.

Regression analysis will be used to evaluate which combination of model resolution (grid size) and routing method (Natural vs Euclidian flow path) provides best results for a given area of interest. A total of 4 test or regression graphs will be used with the decision matrix presented in Table 7. High pulse counts for each of the nine test watersheds shown in Figure 2 will be obtained from existing gage data. HCI data will be generated by running the HCI model with different resolutions and routing methods.

Table 7. Decision Matrix for evaluating the results of regression tests proposed in Figure 5.

Decision Matrix for Comparing and Evaluating Routing and Grid Size (Resolution) Tests

Test Comparison	Regression Result (R^2)	Suggested Conclusion
1 & 2	1>2	Euclidian Routing is Best
1 & 2	2>1	Natural Routing is Best
3 & 4	3>4	Euclidian Routing is Best
3 & 4	4>3	Natural Routing is Best
1 & 3	1>3 3>1	1.8 meter grid and Euclidian Routing is Best 30 meter grid and Euclidian Routing is Best
1 & 4	1>4 4>1	1.8 meter grid and Euclidian Routing is Best 30 meter grid and Natural Routing is Best
2 & 3	2>3 3>2	1.8 meter grid and Natural Routing is Best 30 meter grid and Euclidian Routing is Best
2 & 4	2>4 4>2	1.8 meter grid and Natural Routing is Best 30 meter grid and Natural Routing is Best

Table 8. Matrix for testing the combination of factors (development size, density, and location) used to determine thresholds for detecting change using the HCI tool.

Development Density:	1 Acre	5 Acres	20 Acres	100 Acres	Distance From Stream:
High Density	1 Acre High Density Furthest,1/2, & Adjacent	5 Acre High Density Furthest,1/2,& Adjacent	20 Acre High Density Furthest,1/2,& Adjacent	100 Acre High Density Furthest,1/2, & Adjacent	Furthest, ½ & Adjacent
Medium Density	1 Acre Med. Density Furthest,1/2, & Adjacent	5 Acres Med Density Furthest,1/2,& Adjacent	20 Acres Med Density Furthest,1/2,& Adjacent	100 Acres Med Density Furthest,1/2, & Adjacent	Furthest, ½ & Adjacent
Low Density	1 Acre Low Density Furthest,1/2, & Adjacent	5 Acres Low Density Furthest,1/2,& Adjacent	20 Acres Low Density Furthest,1/2,& Adjacent	100 Acres Low Density Furthest,1/2, & Adjacent	Furthest, ½ & Adjacent

Table 9. Example of low flow coefficients, developed using VELMA or another calibrated hydrologic model, to predict future climate conditions.

Develop Low Flow Coefficients

Use VELMA in watershed representative of geology, topography and precipitation type to develop low flow coefficients (LFC) for 3 climate periods

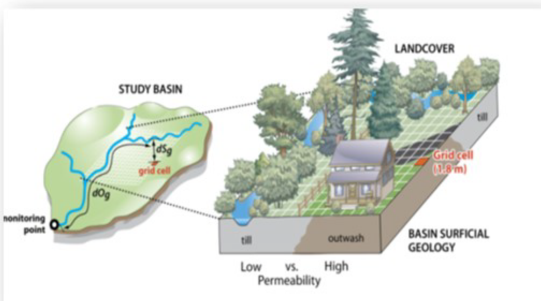
2070 to 2089

Geology	Land Cover	Low Flow Coefficient
Till	Forest	0.25
Outwash	Forest	0.20
Till	Shrub, grassland	0.40
Outwash	Shrub, grassland	0.35
Till	Impervious	0.65
Outwash	Impervious	0.75

Coefficients would be developed for different time periods and applied in the LFI model, shown in Figure 6, using the same flow network developed for the HCI index.

Develop and Test Low Flow Index

Apply Low Flow Coefficients (LFC) to individual grid cells and calculate normalized Low Flow Index (LFI)



$$LFVs = \sum_{g=1}^{n} LFCg\left(\frac{1}{dOg + dSg}\right)$$

$$LFIs = \frac{LFVs}{LFV\_highest}$$

Where:
LFC = Low flow coefficients developed from VELMA model for specific combinations of land cover, geology, topography and climate
LFVs = Low flow values for land cover pattern
g = index 1 to n for all grid cells in watershed
dOg = distance along stream course from stream discharge point, upstream to intersection point with dSg flow line
dSg = distance from grid cell "g" to stream course along natural or Euclidian flow path
s = watershed location for which LFI is calculated

Figure 6. Algorithm and method for applying and testing the Low Flow Index (LFI).

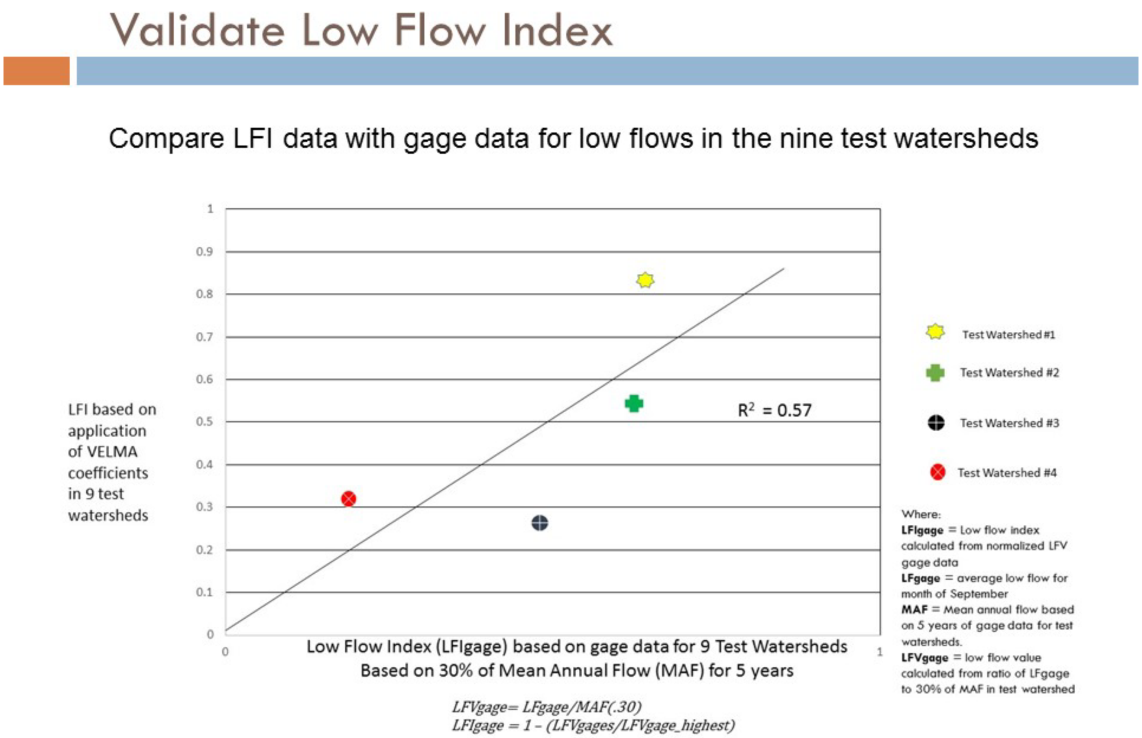


Figure 7. Proposed method for validating the LFI.

7.4 Assumptions in relation to objectives and study area

The study design assumes that:

- The HPC coefficients are representative of the land cover type and surficial geology present in the nine test watersheds (lowland glacial terrace)
- The HCI will be sensitive enough to help identify changes to land use development patterns at the mid-scale that will protect water flow processes
- The Low Flow Index will demonstrate a strong correlation with observed low flow gage data.

The HPC coefficients were developed using a calibrated HSPF model within a lowland glacial terrace landform similar to that of the nine test watersheds. By statistically comparing the calculated HCI of a watershed relative to actual HPCs, the study will be able to demonstrate, in part, whether the coefficients developed are representative of land cover type and surficial geology in the study area. If not, then adjustments may have to be made to the HCI method and if that is not successful then the accuracy of the calibrated HPC coefficients may be of concern. This is not expected, since the HCI results of the previous County study showed comparable HCI values for watersheds with similar land cover and geologic conditions (Table 2 and Figure 8).

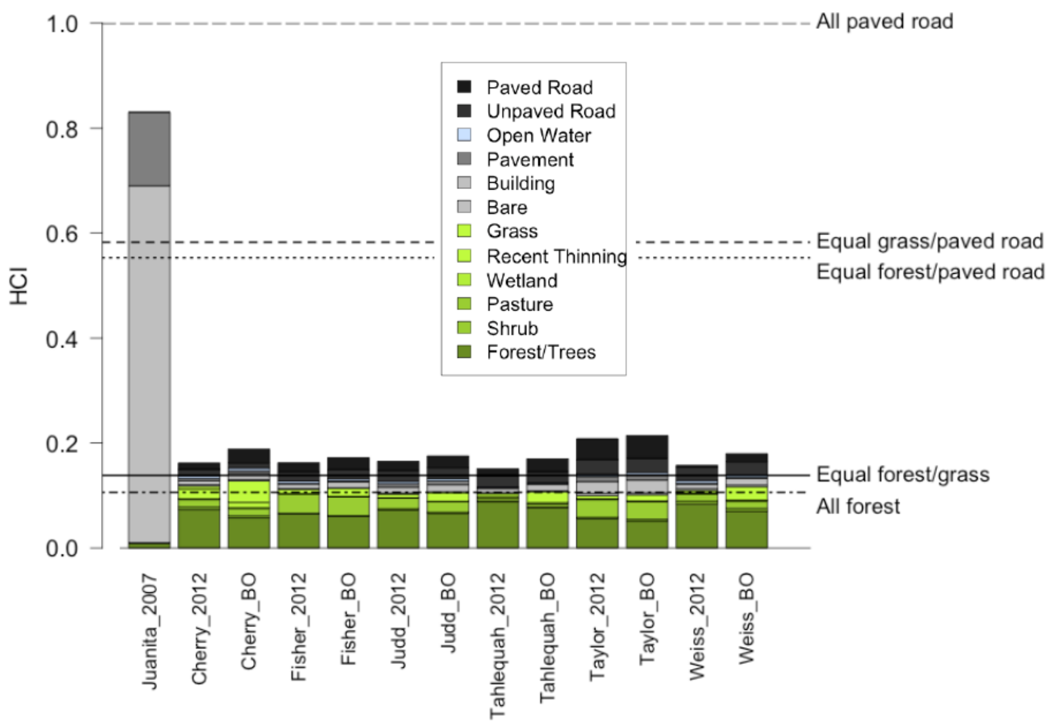


Figure 8. HCI values for the King County test watersheds for 2012 land cover and at predicted "build out."

Source: King County (Lucchetti 2014)

Existing results from the King County HCI Study indicates that HCI is relatively sensitive to small changes land cover. For example, Table 10 shows that for five of the test watersheds, impervious surfaces are very low (around 3%) with Taylor Creek showing an increase to just above 6%. Excluding Taylor, the HCI is around 0.15 for five watersheds (Figure 10) which show a similar mix of forest, scrub wetland, grass and pasture. For Taylor Creek watershed with a 3% greater cover of impervious surfaces, the HCI increased to approximately 0.2 showing that the model is able to detect the effect of relatively small increases in land cover change. In order to further test the sensitivity of the model, the alternative futures scenarios will evaluate a wider range of impervious cover (e.g. low, medium and high density urban cover).

Table 10. Percentage of 2012 land cover for six test watersheds at the watershed (WS) and regulatory buffer scales (BF).

Note that all of the watersheds have similar low levels of impervious surfaces, with Taylor having the highest.

	Cherry Cr. Tributary		Fisher		Judd		Tahlequah		Taylor		Weiss		Average	
	WS	BF	WS	BF	WS	BF	WS	BF	WS	BF	WS	BF	WS	BF
Forest	64.9	81.5	61.9	94.3	70.1	82.8	82.8	95.6	53.3	70.0	75.4	82.9	68.1	84.5
Shrub	3.7	4.6	0.8	0.3	1.8	0.7	1.4	0.3	2.5	1.1	4.1	4.2	2.4	1.9
Pasture	9.7	4.6	27.0	0.6	16.1	10.8	4.0	0.0	27.2	15.9	10.7	2.8	15.8	5.8
Wetland	1.0	1.8	0.3	0.0	0.4	0.0	0.0	0.0	1.0	3.9	0.6	3.3	0.5	1.5
Recent clear-cut	12.7	5.2	0.1	0.0	0.1	0.0	3.4	0.5	0.1	0.0	0.7	0.7	2.8	1.1
Grass	2.7	0.4	4.4	2.4	4.2	1.4	2.8	1.4	3.6	1.8	2.4	1.5	3.3	1.5
Building	0.9	0.0	1.0	0.3	1.3	0.4	0.8	0.4	2.5	0.7	1.0	0.4	1.2	0.4
Bare	1.1	0.2	0.6	0.1	0.9	0.3	0.9	0.2	1.9	0.8	1.3	0.6	1.1	0.4
Pavement	0.5	0.2	0.2	0.0	0.8	0.1	0.2	0.3	1.0	0.2	0.3	0.1	0.5	0.1
Open water	0.5	1.0	0.4	0.7	0.5	0.8	0.1	0.0	0.4	0.2	0.5	1.9	0.4	0.8
Unpaved road	1.2	0.2	1.8	0.5	2.1	1.0	2.2	0.7	2.8	1.8	2.6	1.5	2.1	0.9
Paved road	1.2	0.3	1.7	0.9	1.8	1.7	1.3	0.7	3.8	3.7	0.4	0.2	1.7	1.2

From King County (Lucchetti et al 2014)

The VELMA model has been applied in both the Tolt and Mashel Watersheds in Washington and has demonstrated a high degree of correlation between model values of low flow with actual observed gage values for low flow. Therefore, we anticipate that the LFI results, based on the VELMA model will also exhibit a high degree of correlation with observed gage data for the nine test watersheds.

7.5 Possible challenges and contingencies

Because the study does not rely on the collection of field data, there will be no challenges in terms of access to the nine test watershed sites. The primary challenges will involve availability of GIS staff time to work on this project. Contingency measures include "set aside" of available funds to hire GIS consultants. Similarly, funds are also set aside for assistance from consultants on reviewing the existing broad scale models in Task 6.0 and recommending any needed changes to data aggregation and calculation methods.

7.5.1 Logistical problems

NA. No anticipated logistic problems since field data will not be collected and therefore problems with access to sampling sites will not occur.

7.5.2 Practical constraints

As stated above in section 7.5, practical constraints may involve scheduling of sufficient time from GIS staff. This is being addressed with the creation of "contingency funds" to hire a GIS consultant (i.e. $50K in budget).

7.5.3 Schedule limitations

Scheduling problems could delay progress on Tasks 2 through 4 (HCI testing). It is anticipated, based on conversations with the GIS staff that this delay could be until June of this year. During this time, we plan to work on Task 1 (forming WAG, acquiring HCI model). As a result, the delay should not affect the completion of the work outlined since we incorporated a 6-month buffer into the overall schedule (18 months of work within a 2-year schedule).

8.0 Field Procedures

NA. There will be no field activities or data collection for this project.

9.0 Laboratory Procedures

NA. There will not be any laboratory procedures associated with this project since it does not involve the collection of water or biological samples.

10.0 Quality Control Procedures

This project will use the Watershed Technical Advisory Team (WAG) to track task progress, as well as review and comment on products produced. The team was established in 2012 to assist in the application of the broad scale models to land use decisions at the local government level. Representatives on the team included Ecology staff experts from the Water Quality and Environmental Assessment Programs as well as a Wildlife Biologist from WDFW. In addition, meetings of the team, which will occur on a quarterly basis, will be facilitated by a consultant familiar with the development of watershed models.

10.1 Table of field and laboratory quality control

NA. There will be no water or biological samples collected with this project.

10.2 Corrective action processes

The WAG will discuss progress at quarterly meetings and review all interim and final products produced for Tasks 1 through 6. The WAG will identify corrective actions when progress or a deliverable does not meet the goals and objectives set forth in sections 4.1 and 4.2.

The corrective action process at the staff level will involve: 1) reviewing output maps to see if they fit expected outcomes (e.g. higher HCI values for more urbanized watersheds); 2) identifying any problems (e.g., if output shows anomalies, then the Python script will be reviewed to determine if it matches the model algorithms and data aggregation and binning methods); 3) identifying solutions (based on findings in Step 2, staff will identify any needed corrective actions); and 4) implementing solutions or corrections and reviewing revised output. If revised output does not address original problem, Steps 2 through 4 will be repeated.

11.0 Data Management Procedures

11.1 Data recording and reporting requirements

There will be no data collection involved with this project so no data transfer to Ecology's EIM database. However, Ecology has established standards for GIS work, which will be followed by this project: http://www.ecy.wa.gov/services/gis/data/standards/standards.htm)

The project will use GIS software from Environmental Systems Research Institute (ESRI):

- ArcGIS Version 10.x
- ArcGIS Server 10.x
- ArcSDE 10.x.

All data incorporated into the project will be in ESRI ArcExport (E00), shapefile, ESRI Personal Database or File Geodatabase format and will comply with the following data storage and import standards:

Horizontal Datum	NAD 83 HARN
Vertical Datum	NAVD-88
Projection System	Lambert Conic Conformal
Coordinate System	Washington State Plane Coordinates
Coordinate Zone	South (or zone-appropriate if not statewide)
Coordinate Units	U.S. Survey Feet
Accuracy Standard	+/-40 feet or better
Vector Import Format	ArcExport E00 file, Shapefile, File Geodatabase, Personal Geodatabase
Raster Import Format	TIFF, BIL/BIP/BSQ, ESRI Grid, ERDAS Imagine
Metadata	Federal Geographic Data Committee (FGDC), Metadata Content Standards*

11.2 Laboratory data package requirements

NA. No analytical lab will be involved with this project.

11.3 Electronic transfer requirements

NA. There will be no lab data generated.

11.4 EIM/STORET data upload procedures

NA. There will be no EIM/STORET data generated.

11.5 Model information management

Modeling results will be described in a technical addendum to be incorporated either as an appendix to a chapter in Ecology Publication #11-06-016 or a separate publication. This will include a description of the file structure and file metadata (i.e. version control number etc.) for storing the model runs in the Ecology GIS program. All model documentation, scripts, and results will be stored on a designated Ecology GIS server and maintained for the mandatory seven-year retention period. All results will include agency standard metadata documentation that transfers with the data. The project web site will provide links to all data results. These will be downloadable by the public in the form of zip files of the geodatabase, including all final data layers as well as intermediate analyses and maps.

12.0 Audits and Reports

12.1 Field, laboratory, and other audits

The Ecology GIS staff, in conjunction with the PSWC staff, will review all new model run outputs to ensure that Python scripting has been entered correctly. It is anticipated that this will occur at least twice with the HCI model test (Tasks 2 and 3) in King County and twice with the test of the alternative futures model run (Task 4) and twice with the climate vulnerability index (Task 5). King County will also review and monitor the transfer and initial application of the HCI model and data from them (Task 1) in order to assure that it is being applied correctly. In addition, the results of audits will be shared with the Watershed Assistance Group (WAG).

12.2 Responsible personnel

Stephen Stanley, Susan Grigsby, Colin Hume and Christina Kellum will conduct the review of new model runs.

12.3 Frequency and distribution of reports

During the development of the new models indices, the Ecology PSWC staff will meet with the WAG team a minimum of 4 times to report on the progress of the project. At each of these meetings, staff will provide technical memos that document both the progress on Tasks 1 through 6, including the results of new model runs. The final report will follow the format found in the existing Puget Sound Watershed Characterization document (publication #11-06-016) and will be added as Appendix E, "Mid-Scale Models for Assessing Hydrologic Condition in Puget Sound Watersheds." This appendix will address each of the sections (3 to 14) of this QAPP that pertain to results meeting the project objectives including study design, data quality, verification and usability.

12.4 Responsibility for reports

Authors on the final report will be Stephen Stanley, Colin Hume, and Susan Grigsby.

13.0 Data Verification

EPA defines data verification as "the process of evaluating the completeness, correctness, and Conformance/compliance of a specific data set against the method, procedural, or contractual requirements."

13.1 Field data verification, requirements, and responsibilities

NA. There will be no field data collected for this project.

13.2 Laboratory data verification

NA. There will be no laboratory analysis or data generated by this project.

13.3 Validation requirements, if necessary

NA. There will be no new field or lab data generated needing to be validated.

13.4 Model quality assessment

The final report for the new models will assess the overall quality of the new assessment indices by evaluating the indices output against the project goals and objectives listed in Sections 4.1 and 4.2, as well as meeting the data quality objectives listed in section 6.4 of this QAPP.

13.4.1 Calibration and validation

The HPC coefficients used in the HCI model were developed by King County using a calibrated HSPF model. This process is outlined in their study of 9 test watersheds in King County (Lucchetti 2014). Section 7.3 describes validation of the HCI model using existing hydrologic data from stream gages, including the annual number of high pulses. Calibration and validation of the VELMA (or similar) model, and LFI method, will be documented and published in Appendix E, "Mid-Scale Models for Assessing Hydrologic Condition in Puget Sound Watersheds," of Volume 1 of the PSWC (publication #11-06-016).

13.4.1.1 Precision

Model precision will be measured using regression analysis as set forth in section 7.3 of this QAPP. Precision will be based on testing the following hypothesis: The correlation (coefficient of determination) between observed high pulse counts (independent variable) and HCI values (dependent variable) for test watersheds will exceed 0.6 (explaining 60% of the variance between the dependent and independent variables of the test).

13.4.1.2 Bias

Bias will be assessed for the HCI model by calculating the percent error (average of paired observed-modeled values divided by observed value). This will require normalizing the observed high pulse counts and obtaining a 0 to 1 value.

13.4.1.3 Representativeness

The HCI and LFI model will be representative of the conditions present in the test watersheds since the coefficients for the model were developed in watersheds, using a calibrated HSPF and VELMA model, with similar geologic, landform, cover and precipitation characteristics.

13.4.1.4 Qualitative assessment

Regression graphs, as presented in section 7.3, Figure 5, will be used to graphically display the degree of variation between the HCI values and observed high pulse counts for the 9 test watersheds as well as for the LFI values and observed low flows.

13.4.2 Analysis of sensitivity and uncertainty

There is essentially one dependent variable, the high pulse count coefficient, associated with the HCI model and one dependent variable, the low flow coefficient associated with the LFI model. Therefore, sensitivity cannot be easily measured by eliminating these single input values for the HCI and LFI models. We propose, however, to test the sensitivity of the model by 1) placing confidence intervals on the regression test plots for testing the HCI and LFI models (section 7.3.2) and; 2) identifying the threshold size of land cover change that results in no change in the HCI and LFI values during the application of the alternative futures tool.

In the future, as funds become available the project will collect field data (e.g. high pulse counts, low flows) in different watersheds and conduct additional analysis on the correlation between HCI and LFI output and field data.

14.0 Data Quality (Usability) Assessment

14.1 Process for determining project objectives were met

WAG and the PSWC staff will evaluate the output of testing the HCI in the nine test watersheds (Tasks 1 through 4) and in the alternative futures watershed (Task 5) and determine if the goals and objectives in section 4.1 and 4.2 were met and if results are deemed usable after verification (e.g., quality objectives detailed in the QAPP have been met). If WAG and PSWC determine that the project goals and objectives are not met and/or the results are not deemed usable then recommendations will be made for modifying the approach for developing mid-scale models.

14.2 Treatment of non-detects

NA. There are no water quality samples involved with this project so no "non-detects" will be present.

14.3 Data analysis and presentation methods

See section 7.3.2. There are four hypothesis behind the testing: 1) that the correlation between HCI values and High Pulse Counts will be similar at different grid resolution and flow networks; 2) that HCI will be able to detect changes in development or land use in terms of location and size (alternative futures); 3) that HCI results will correspond to the existing broad scale "degradation" model results for water flow; and 4) low flow results (i.e. LFI) based on VELMA coefficients will exhibit a high correlation with observed low flow gage data for the test watersheds.

This would include addressing the following questions:

1) Do HCI values vary significantly at different spatial scales[13] (extent and grain)? This will be tested using 2 grain sizes, 1.8 meter and 30 meter grid resolution and, if needed, several different watershed extents.
2) Do HCI values vary significantly using either a simulated natural flow or Euclidean-based flow network?
3) Can a metric such as percent impervious cover[14] be used to achieve results similar to those obtained using HPCs?
4) Is the HCI a useful method for evaluating future development scenarios including the type, location and density of development?
5) Do the existing degradation model results correspond to HCI values in the nine test watersheds?

[13] Patterns within an ecological system or mosaic is a function of scale which is comprised of extent and grain sizes (Forman and Gordon 1986)

[14] Watershed Percent Impervious cover was included in this work program since King County found that it had the highest correlation with stream HCI (Table 4). Using impervious surface in a routed network would greatly simplify the hydrologic index calculation since individual land uses types would not have to be assigned a calibrated high pulse count value. A consistent method for establishing which land cover classes equate to impervious cover will be needed.

6) Is the LFI a useful method for evaluating the vulnerability of watersheds to climate change?

The results of these tests for questions 1 and 2 would be evaluated using regression analysis of HCI and HPC values, as shown in Figure 5; a decision matrix (Table 7) would be used to assist in the evaluation of these tests for question 1 and 2. The results of the test for question 3 would be evaluated by comparing HCI values using impervious cover relative to using HPCs coefficients. This would involve generating test graphs similar to those produced in Figure 5 plotting impervious (based on land cover class) vs HPCs (gage data) and comparing to the regression graphs produced in Task 2 for HCIs based on HPC coefficients. For question 4, different extents of development scenarios would be run to determine the size threshold at which the HCI model will be able to detect change in hydrologic conditions (Table 8). For question 5, the degradation model results for water flow processes would be compared to the HCI results in the 9 test watersheds. For question 6, the LFI results would be compared to observed gage data for the 9 test watersheds (Figure 7) and evaluated for its usefulness by the WAG.

14.4 Sampling design evaluation

NA. There will be no sampling associated with this project.

14.5 Documentation of assessment

Documentation of the data usability assessment will be included in the final report on the project; the report will follow the format found in the existing Puget Sound Characterization document (publication #11-06-016).

15.0 References

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16.0 Appendices

Appendix A. Description of HCI Index

http://your.kingcounty.gov/dnrp/library/water-and-land/critical-areas/CAO-Report-Final-for-Web.pdf

The Hydrologic Condition Index predicts the cumulative downstream impacts of land cover alteration upon the movement of water across the landscape. The Hydrologic Condition Index (HCI), has been developed by King County (Lucchetti et al 2014) and is designed to evaluate watershed condition in terms of the number of "high pulse counts" that occur within a stream system . High pulse counts capture a level of high flows (typically 2X mean annual flow) that is particularly damaging to stream structure (Figure A-1). Research has demonstrated that the frequency and duration of higher flows in streams and rivers is responsible for simplifying stream structure to a point where it can no longer maintain the stream's aquatic food web that supports salmonid populations (Booth et al 2002). DeGasperi (2009) determined out of fifteen hydrologic metrics that high pulse count (HPR) and high pulse range were the best in predicting the effect of land cover change upon stream flow.

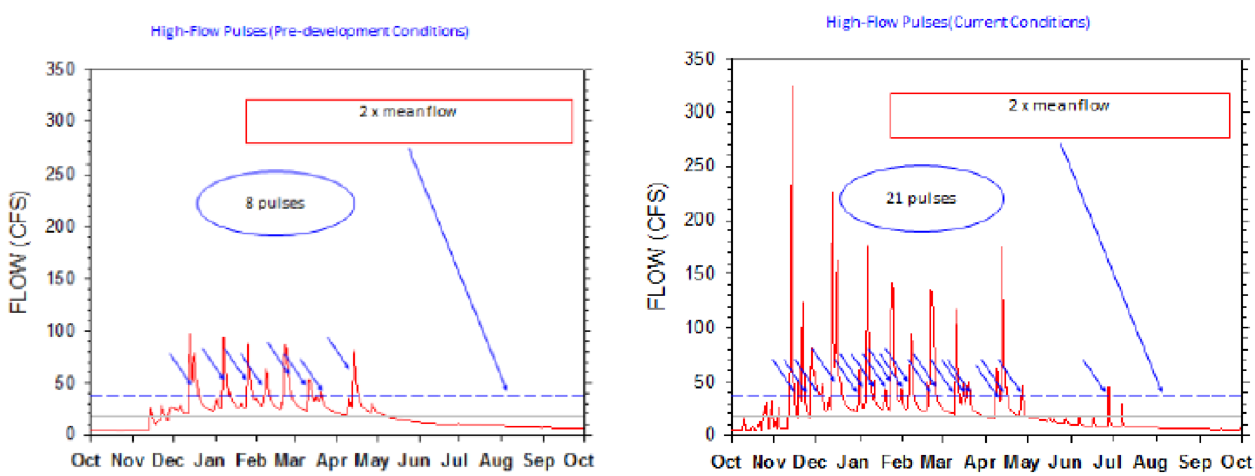

Figure A-1. High-flow pulses (High Pulse Counts) under pre-development (left) and developed (right) conditions for a King County watershed (from Horner 2013).

Because the HCI method does not simulate water movement based on a water balance model (quantification of water input and output) it simplifies the calculations that are typically required in a traditional hydrologic model. Instead it uses the known high pulse count for each land cover type (Table 2) and by adding those values along a path that water would flow to the outlet of the watershed, accounting for a greater influence of land cover closer to a stream, the relative hydrologic condition of the watershed can be obtained (Figure A-2). The HCI values can be compared between watersheds, because they are based on high pulse counts observed in representative watersheds for the full suite of land cover types, using calibrated hydrologic models. In essence, the HCI becomes a calibrated measure of expected impacts to stream flow that can be applied to any glacially formed watersheds within the Puget Sound Basin.

The primary advantage of HCI, is that it would allow local governments to understand not only the impacts of existing land cover patterns within a watershed but also of future land use patterns in an alternative futures scenario building exercise. An equally important advantage is its ability to be adapted to other watershed indicators such as nutrient loading in order to create other useful watershed condition indices. These indicators, such as nutrient transport would also need to be calibrated to land cover type using a hydrologic model such as VELMA.

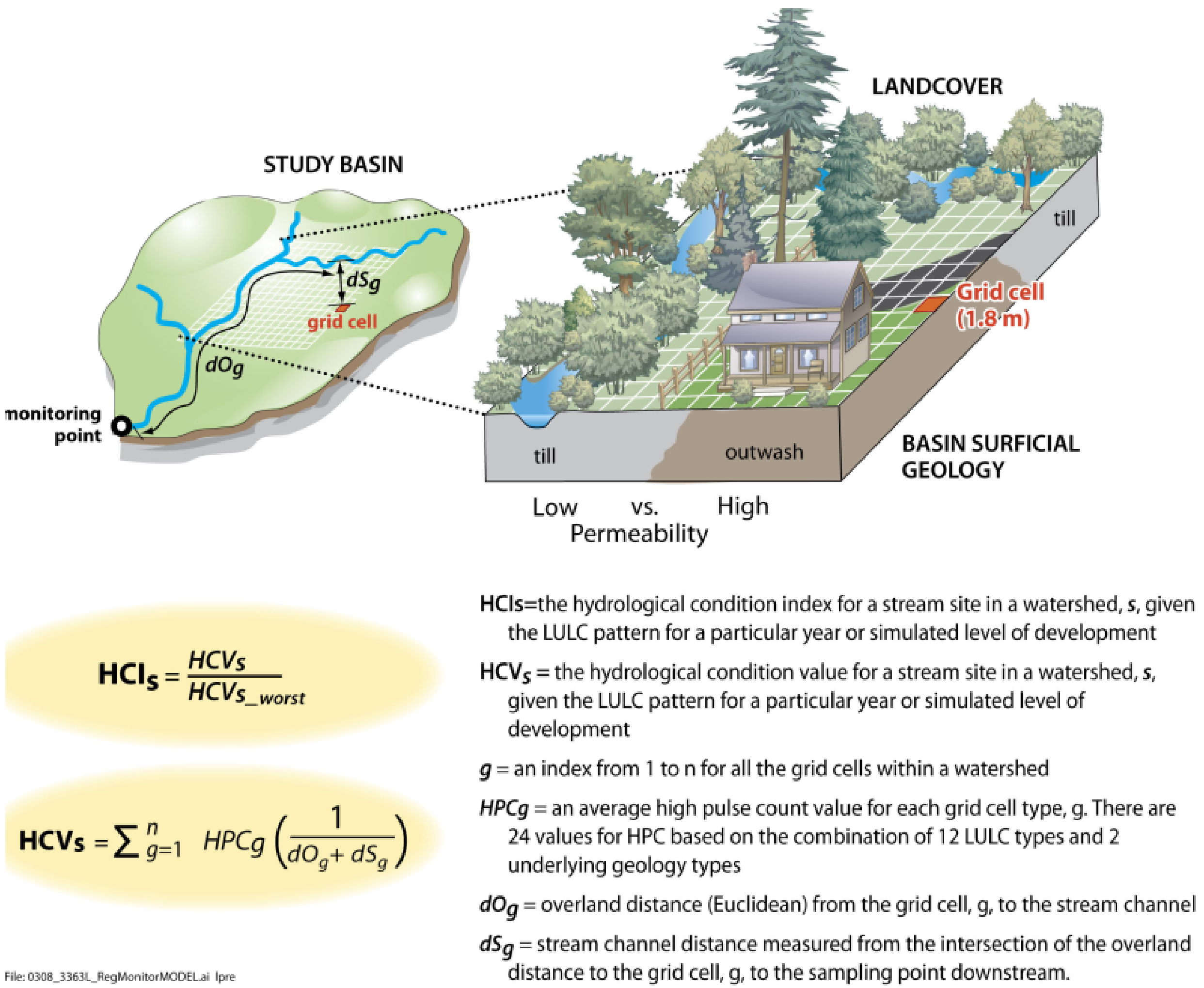

Figure A-2. Illustration of how King County calculated the HCI within a single watershed.

Appendix B. Description of VELMA Model

The Visualizing Ecosystems for Land Management Assessments model (VELMA) is a recently-developed "eco-hydrologic" model that simulates the movement of water, nutrients, and heat within a watershed based on the interaction of these components with vegetation and soil and in response to changes in land cover and climate (Abdelnour 2011).   This model can be used to develop the coefficients for the movement of water, sediment, nutrients, and pollutants that can then be used in the HCI model.

For hydrology, the basic framework consists of a multi-layer soil column model (Figure B-4) that simulates the infiltration and percolation of surface waters and its lateral movement downstream. This is achieved by solving the water balance for each soil layer including input from the upper layer, soil water storage and lateral flow out and input to the next layer.   This also includes calculating standing surface water pool and snow melt. All of the layers are not only connected to one another but also to adjoining soil columns. In addition two other sub-models for soil temperature and plant soil, model the movement of heat and nutrients.

The model was initially developed and applied in the H.J Andrews Experimental Forest, a 10-hectare forested catchment in the Willamette Nation Forest located east of Eugene, Oregon. Results of the model runs demonstrated that clearing forest closer to the stream affected annual flows more significantly (almost a 2X increase) relative to clearing further away, along the ridgetop of the watershed. Additionally, there was found to be a linear relationship between the percent of cleared forest and annual stream flow. These findings help confirm the approach taken by King County in developing the HCI, which increases the weighing for the high pulse value when the land cover change is located closer to the stream.

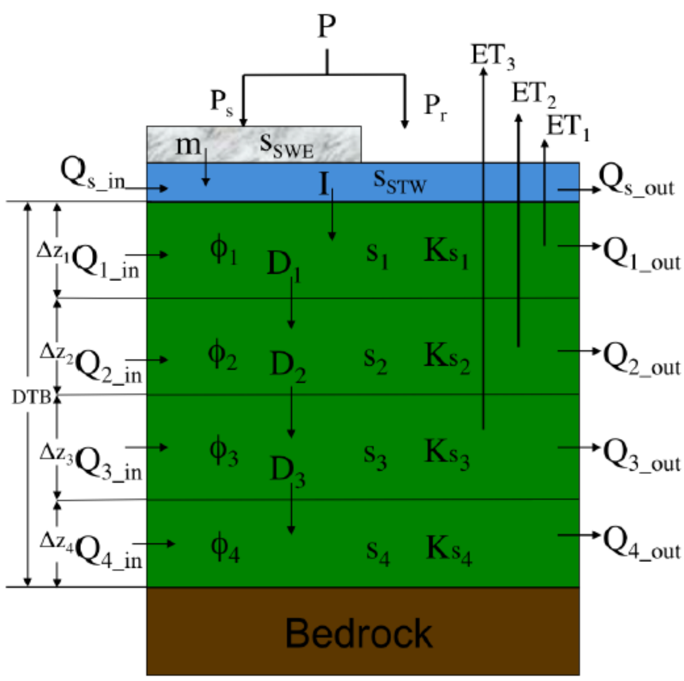

Figure B-4. Schematic of the basic model framework for VELMA, consisting of a surface layer and four coupled soil layers. DTB is the soil column depth to bedrock. zi, Ksi, ϕi, and si, are the thickness, the saturated hydraulic

conductivity, the soil porosity, and the soil water storage of layer i, respectively. S_{swe} is the snow water equivalent, "m" is the snow melt that enters the standing water pool and S_{stw} is the standing water pool.

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Appendix C. Quality Assurance Glossary

Glossary

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)

Bankfull stage: Formally defined as the stream level that "corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels (Dunne and Leopold, 1978).

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

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)

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

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.

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

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

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

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

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

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

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

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

Examples of data types commonly validated would be:

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

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

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

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

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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.

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)

Existing uses: Those uses actually attained in fresh and marine waters on or after November 28, 1975, whether or not they are designated uses. Introduced species that are not native to Washington, and put-and-take fisheries comprised of non-self-replicating introduced native species, do not need to receive full support as an existing use.

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.

High Pulse Count (HPC): A level of stream flow, as measured on a hydrograph, that is 2 times average annual flow.

Hydrologic Condition Index (HCI): a quantitative measure of the hydrologic condition of streams that uses the number of high pulse counts from different combinations of surficial geology and land cover to calculate the index.

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

Low Flow Index (LFI): A quantitative measure of the relative condition of a stream that uses low flows derived from a modeled low values for different combinations of surficial geology and land cover to calculate the index.

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

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)

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)

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)

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.

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)

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 snowmelt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

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

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

Thalweg: The deepest and fastest moving portion of a stream.

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

VELMA: - Visualizing Ecosystems for Land Management Assessments. A recently developed "eco-hydrologic" model that simulates the movement of water, nutrients, and heat within a watershed based on the interaction of these components with vegetation and soil and in response to changes in land cover and climate (Abdelnour 2011). This model can be used to develop the coefficients for the movement of water, sediment, nutrients, and pollutants that can then be used in the HCI model.

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.

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).

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

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)

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)

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