Appendix D: Geospatial Methods for the Water Resource Assessments

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Introduction

This appendix explains the steps taken to develop the geographic information systems (GIS) geospatial database created for the **water flow and water quality assessments** as part of the Puget Sound Characterization project. It provides detail on the geo-processing steps used in support of the methods described in Appendix B and C of this document. The purpose of this appendix is to provide an understanding of the data development and analysis steps for those with some understanding of GIS capabilities and applications. The Watershed Technical Advisory Group reviewed and guided many of the decisions concerning data development and spatial scale. Specifics regarding methods to develop the automated modeling scripts were completed by Ecology's GIS group.

Database Structure

The main requirements for the database structure are to support analysis at multiple spatial scales, and to provide repeatability through an automated modeling program. We use the geodatabase format provided by ESRI™ (Environmental Systems Research Institute, Inc.) and have a toolbox of models in ArcGIS 10.2, supported by Python scripts.

Scale of Assessment Units

The geographic extent of this effort is the area draining into the Puget Sound basin, from the Cascade crest to the Strait of Juan de Fuca, and up to the Canadian border. It includes 19 major watersheds or island groupings called Watershed Resource Inventory Areas (**WRIA**) used by Washington State. Covering over 13,000 square miles, these range in size from hundreds to thousands of square miles.

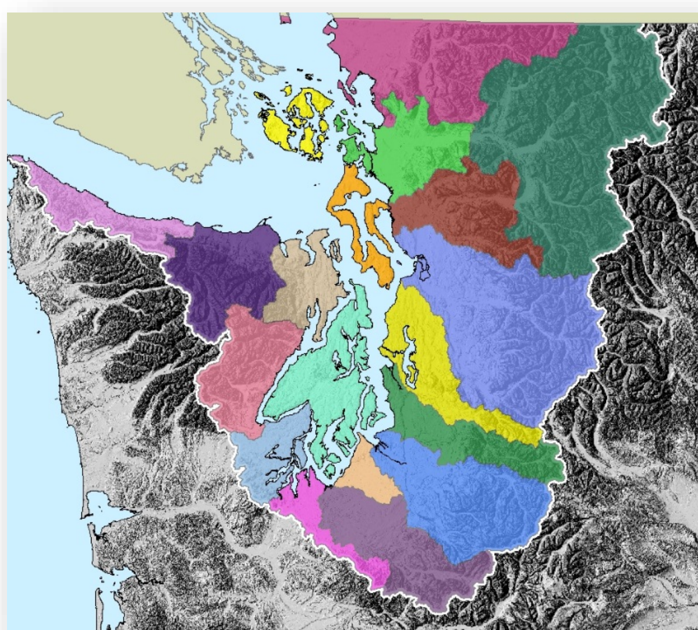


Figure D-1. Nineteen WRIA's of Puget Sound.

Each of these 19 WRIA were subdivided into smaller units for analysis, called '*assessment units*' (**AU**). There are 2977 AU's within the Puget Sound basin, ranging in size from approximately one square mile up to 15 square miles. The size variation depends on the topographic location within the watershed. Small coastal drainages are in the minimum size range, lowland plateaus are the mid-size, and upper watershed areas are the largest AUs.

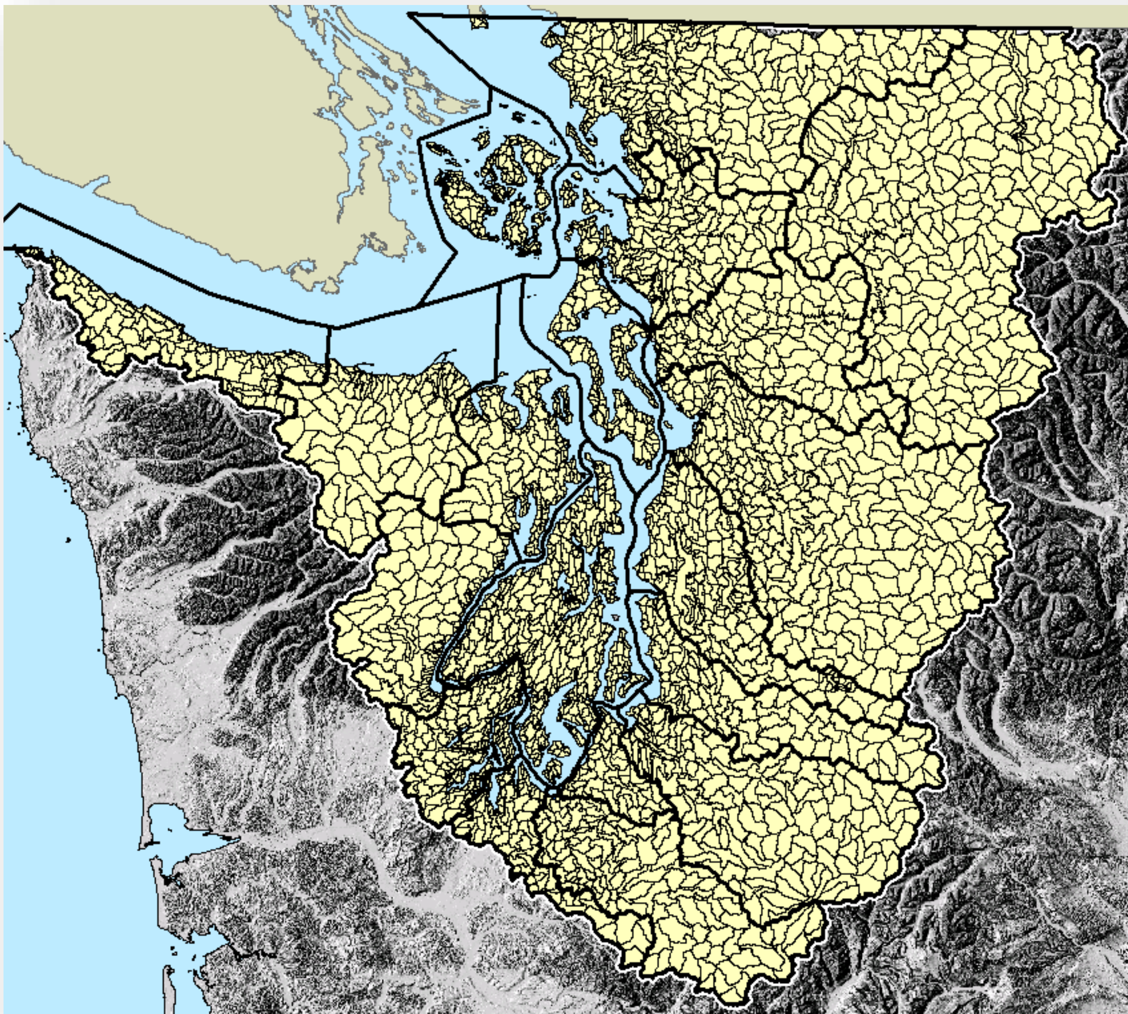


Figure D-2. Assessment Units across Puget Sound.

The Data Development section discusses these units in more detail. The important point is that **the AU is the unit of assessment across all spatial extents** of interest, whether it is WRIA 1 or the entire Puget Sound basin.

The central concept of our method is a '***relative***' comparison across a geographic area. The water flow and water quality models provide numerical values for each analysis unit, which are **compared to all other values** in the analysis extent to get an overall **ranking of the AU**. The final results, however, do not provide actual values on the amount of water stored or sediment transported. They are numeric representations of the relative importance and degradation of physical processes within a watershed. Details of methods for ranking and grouping results are explained in 'Attachment D5: Quartile Grouping Methods'.

Landscape Groups

To address the inherent physical differences across Puget Sound watersheds, we added another nested unit, the '*landscape group*' (**LG**). This allows for comparison of AUs that have similar, natural landscape conditions (e.g. geology, topography, precipitation type) and therefore similar watershed processes. This avoids comparison of dissimilar landscape types such as snow dominated mountainous units with small coastal drainages. The landscape groups are applied only to the Model 1 analyses (importance for water flow, and export potential for water quality) when analyses are comparing natural, unaltered landscape condition.

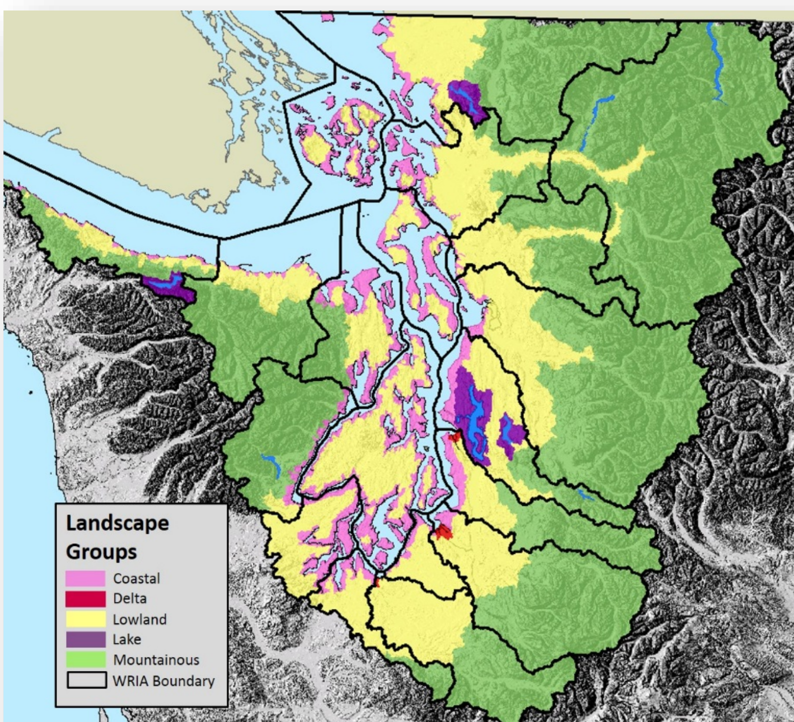


Figure D-3. Landscape groups across Puget Sound.

This landscape group unit nests between the WRIA and AU level. There are five types of landscape groups: 1) coastal, 2) lowland, 3) mountainous, 4) lake, and 5) delta. Details on development of these units are in Attachment D1. For any WRIA, many assessment units are coded as one of these landscape types. Therefore, coastal AU's are compared and ranked relative to other coastal AU's, etc.

Not every WRIA has every landscape group. There are only five "lake" groups for lakes Washington, Sammamish, Whatcom, Cushman, and Crescent. Only three delta areas were large enough to code separately, in WRIA's 9, 10, and 11. Four WRIA's, 2, 6, 14, & 15, have only coastal and lowland groups. The "nesting" of these three units of spatial scale is shown in Figure D-4.

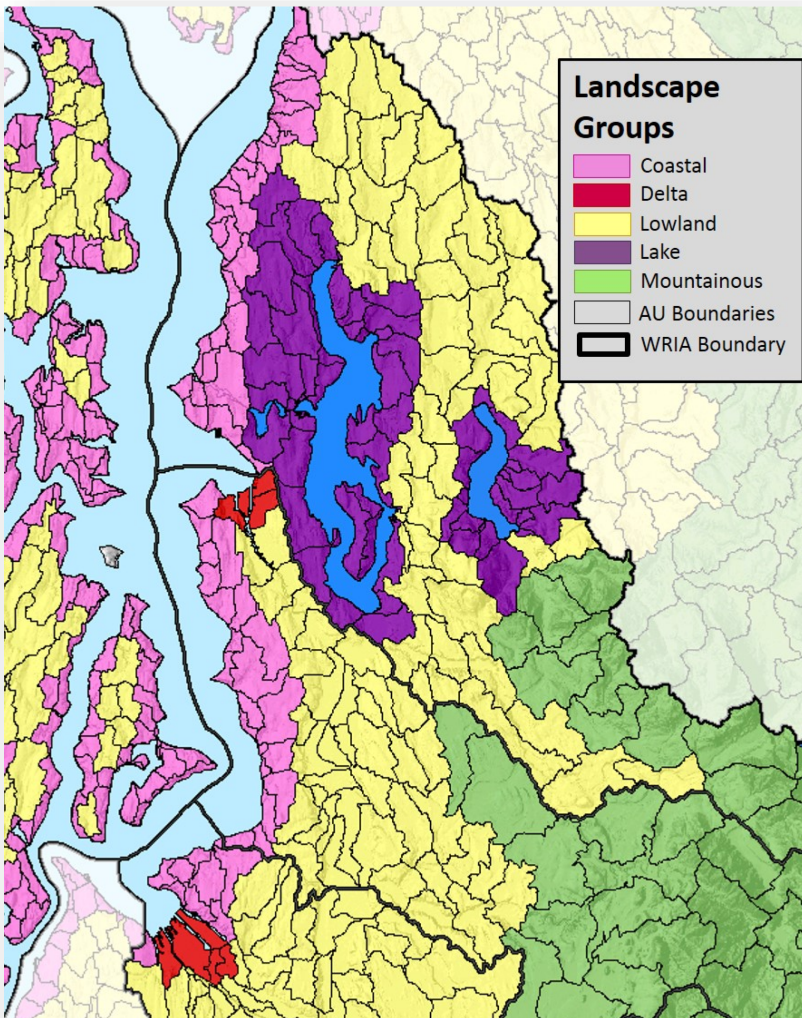


Figure D-4. Landscape groups with AU boundaries.

Types of Analysis

The nature of the planning question being addressed determines the spatial scale, extent of the analysis area, and level of detail. Table D-1 below demonstrates these relationships. Characterization assessments address planning questions outlined in columns two and three of the table. This includes a spatial extent of basins and sub-basins, or tens to hundreds of square miles. The level of detail of input data for both these assessments is coarse, so characterization results should not be applied directly to site scale decisions.

Spatial Scale *– describes the range in size of assessment units (AU). For the Puget Sound characterization this ranges from an average of 1 to 10 square miles.*

Spatial extent *– the area across a landscape that is included in the analysis. The AUs within this area are organized by WRIA and sub-basins. The size depends on the type of planning question being addressed.*

Table D-1. Relationships between scale, extent, and level of information of analysis types.

Level of Information and Analysis	Coarse/General			Fine/Detailed
Unit of Organization	Basin (WRIA)/Sub-basin	Sub-basin / Valley segment/drift cell	Reaches / Waterbodies	Segments / Sites
Typical spatial extent (area)	> 100 mi^2	1-100 mi^2	1– acres – 1 mi^2	<100 acres
Type of Data Acquisition	Existing GIS data layers from Puget Sound Characterization	Existing GIS layers from Puget Sound Characterization	Using existing data or field collection of new data on biological, physical and chemical conditions at these scales.	Usually requires field collection of new data on biological, physical and chemical conditions at these scales.
Type of Application at Each Level	Land-use planning and zoning, such as the location, type, and/or intensity of new development to avoid and to buffer mapped watershed features.	Refinements of coarse-level assessment for application to land-use planning and zoning to protect existing, mapped watershed features serving important watershed processes and functions.	Reach- and watershed-scale strategies for land and water protection & restoration. Reach-specific actions & BMP's to protect and restore conditions.	Adaptive management; (bio) feedback and site- and reach-scale project designs for the specific SMP's to remediate stressors to restore and protect healthy water bodies.
How the Puget Sound Characterization results could be applied	Water-flow and water-quality assessments are most applicable at this scale, integrating sub-basin information on conditions of importance to each of these processes.	Water-flow and water quality assessments provide information at a sub-basin scale	**The Characterization does not provide results at these scales.** However, characterization results should be used to confirm whether actions at these scales are appropriate. For example, installation of wood at the site or reach scale should not be undertaken if upper water delivery and storage processes are highly degraded.	

When possible, a complete “multi-scale” analysis should always incorporate finer scale data and assessments which are outlined in the last two columns of Table D-1, reaches and segments.

The assessment units (AUs) for the characterization are “sized” to meet the spatial scales in the first two columns in Table D-1. We always recommend that AUs be grouped by at least sub-basins so that any assessment considers results within a watershed unit. The sub-basins should be aggregated according to the planning question or issue being addressed. A resource management agency or NGO, might look at all sub-basins across Puget Sound for the best restoration or protection opportunities. A county conducting an update of a comprehensive plan may group sub-basins at the WRIA level. A city developing a sub-area plan could consider several sub-basins, which may extend outside of city jurisdictional boundaries.

Therefore, our methods are flexible enough to allow for the selection of various sizes of analysis area depending on the type of planning question or issue, ranging from several watersheds draining into a city to all the watersheds of Puget Sound. Further detail on the steps required to apply assessments and data at multiple scales is presented in the section “Using the Characterization Results” in Volume 1 (publication #11-06-016).

We begin by providing analysis results at the Sound wide, next at the WRIA, and then at sub-basin scales.

Sound Wide Extent

The Sound wide results of the characterization would be applicable for any entity involved in sound-wide planning efforts, where comparing areas across the Sound would be helpful. In this case, the water flow and water quality models are run once, with the extent of analysis being all 2977 AU's. They are ranked by their landscape group, so a mountainous AU in the Olympics can be compared to a mountainous AU in the Cascades, and so on with the other landscape groups.

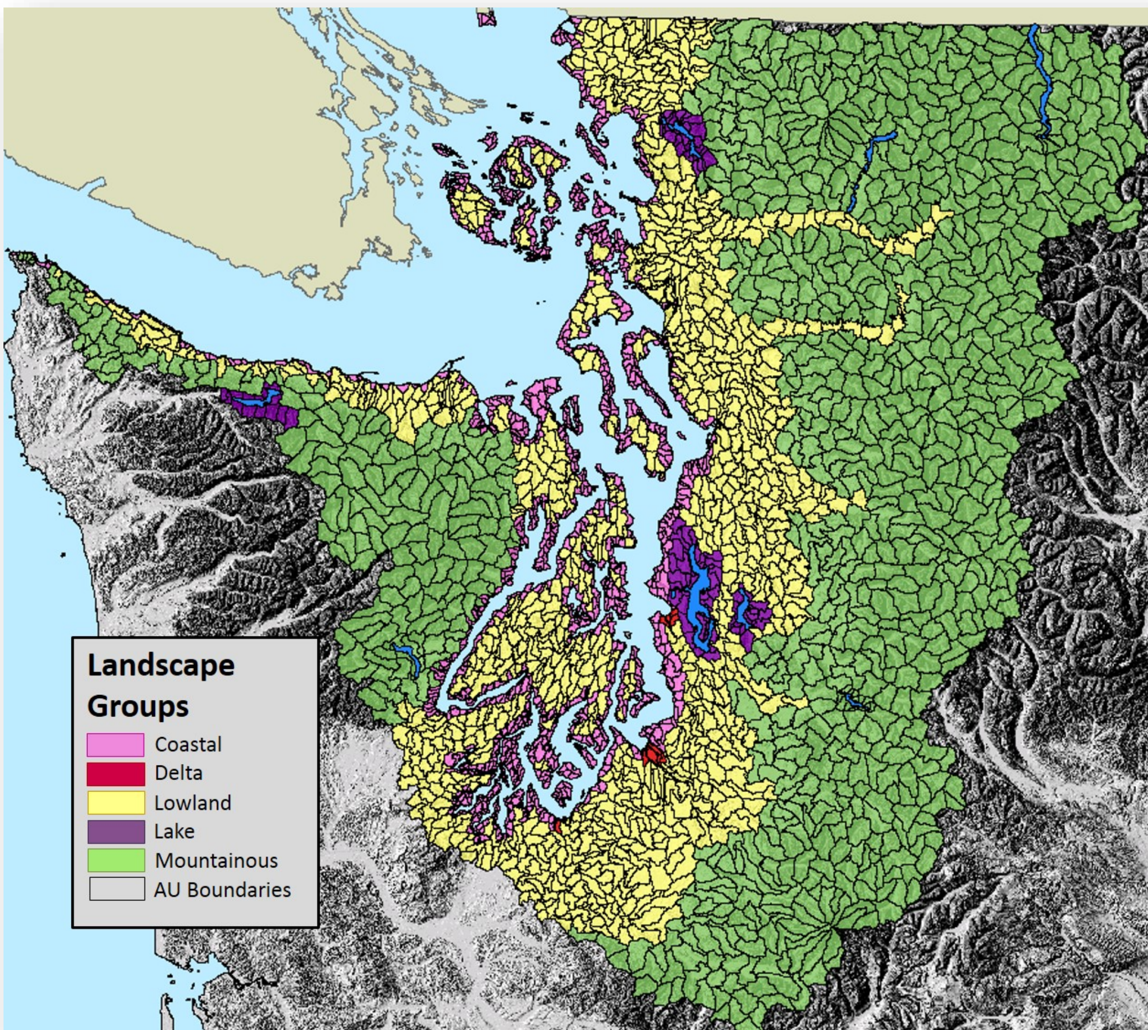


Figure D-5. Sound-wide analysis.

WRIA Extent

The widest array of planning issues occurs at the **WRIA extent**. The WRIA 8 boundaries for the Seattle area are shown in the heavy black line in Figure D-6. Each WRIA is modeled separately, ranking the AU's within that WRIA by their landscape group. Thus, in WRIA 8, the Cedar/Sammamish watershed, the green mountainous AU's are ranked relative to each other, the yellow lowland AU's are ranked relative to each other, the purple lake AU's are ranked relative to each other, and the pink coastal AU's are ranked relative to each other. The WRIA 8 watershed does not have any delta AU's.

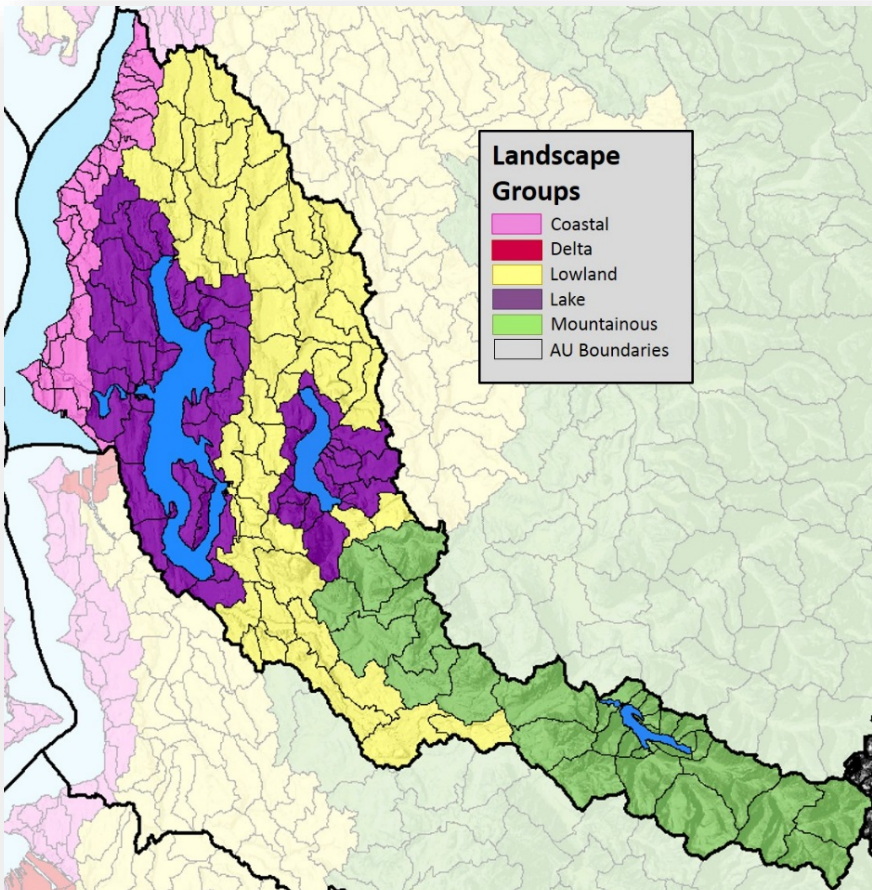


Figure D-6. WRIA scale analysis – within one WRIA.

The models for water flow and water quality are run for each WRIA, producing WRIA level results. AU's within a WRIA cannot be directly compared to AU's in any other WRIA. These results are intended to be the starting point for most jurisdictional planning work.

However, our methods can accommodate the planning needs of an organization to allow for comparisons at different extents.

A common type of regional planning issue involves protection of an important aquatic resource that crosses into more than one WRIA. An example of this is the analysis for Hood Canal to inform an effort to prioritize across the area draining to the Canal. All of WRIA 16 and parts of WRIA's 14, 15, & 17 drain into Hood Canal, so the extent of the analysis included all of this area, while maintaining the original AU boundaries. In this case, a lowland AU in WRIA 17 can be compared to a lowland AU in WRIA 15.

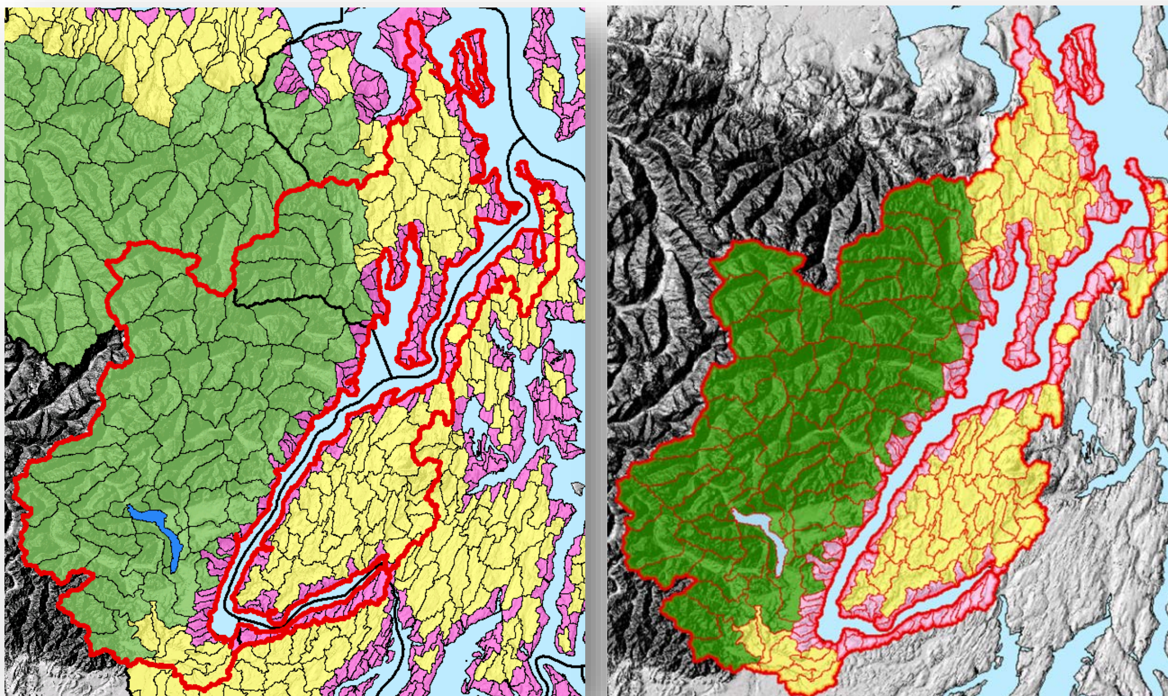


Figure D-7. WRIA-scale analysis – crossing WRIA boundaries.

Sub-basin Extent

Frequently jurisdictions are in need of results for a part of a WRIA since they may have planning questions regarding individual stream systems or sub-basins. There are two variations of how this can be applied.

The first is to take a **subset of the AU's** from within a WRIA, maintaining the same AU boundaries. An example of this approach was done for the Snoqualmie Valley.

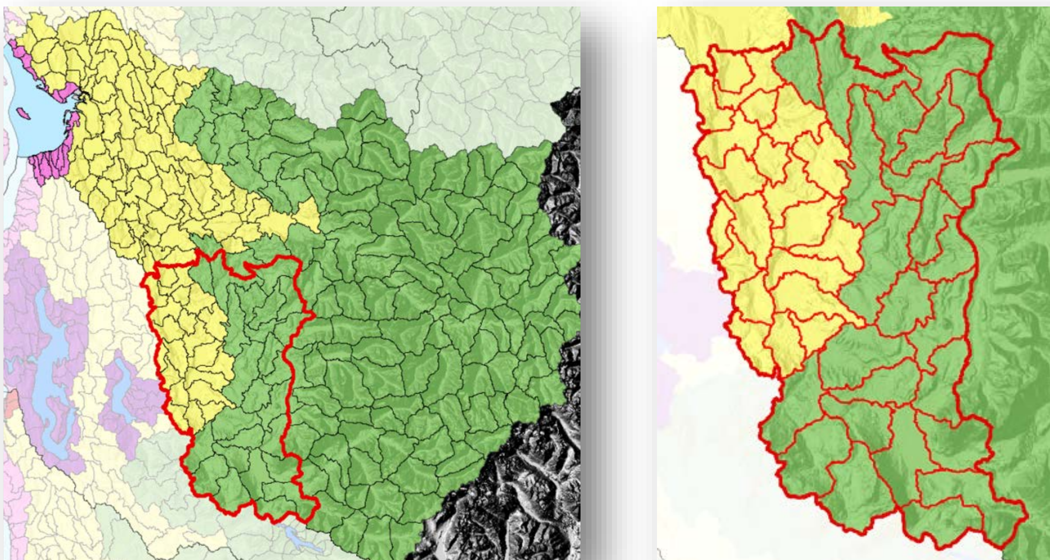


Figure D-8. Subset of AUs from a WRIA.

In this case, though the values for each attribute will be the same as the WRIA-wide analysis, the ranking of the AU's will change since the number and range of values to compare to is different.

The second approach is to **create new AU boundaries** at a smaller scale than originally developed for the characterization. This can be done when a jurisdiction needs to focus on a much smaller geographic area, such as a single sub-basin or stream system and requires results that help identify the best areas for protection, restoration, and development. This typically occurs for small cities that have watersheds encompassed by only a few AUs from the WIRA scale analysis.

The caveat for this scale is that the ***AU size should match the scale of the data and the processes being analyzed***. Keep in mind that the models were developed for coarse scale, sound-wide, available data layers, which limit the scale at which the models can be applied and still provide meaningful results. Using this kind of data, we suggest that the smallest size for an AU should be about half a square mile. This still depends on the topography and location of the AU. Small coastal drainages will be smaller by necessity. Units should be as uniform in size as possible, and not so small that they emphasize one feature on the landscape. The intent is to analyze units where the processes are functioning together and not being fragmented.

An example of this kind of analysis is the Gorst Creek watershed. This 9½ square mile watershed has four AU's in the WRIA scale analysis (WRIA 15-Kitsap). For the analysis of just the Gorst Creek watershed, these four AU's are subdivided into 21 AU's, all nesting within the original Au boundaries. The purpose of this analysis was to support a sub-area plan.

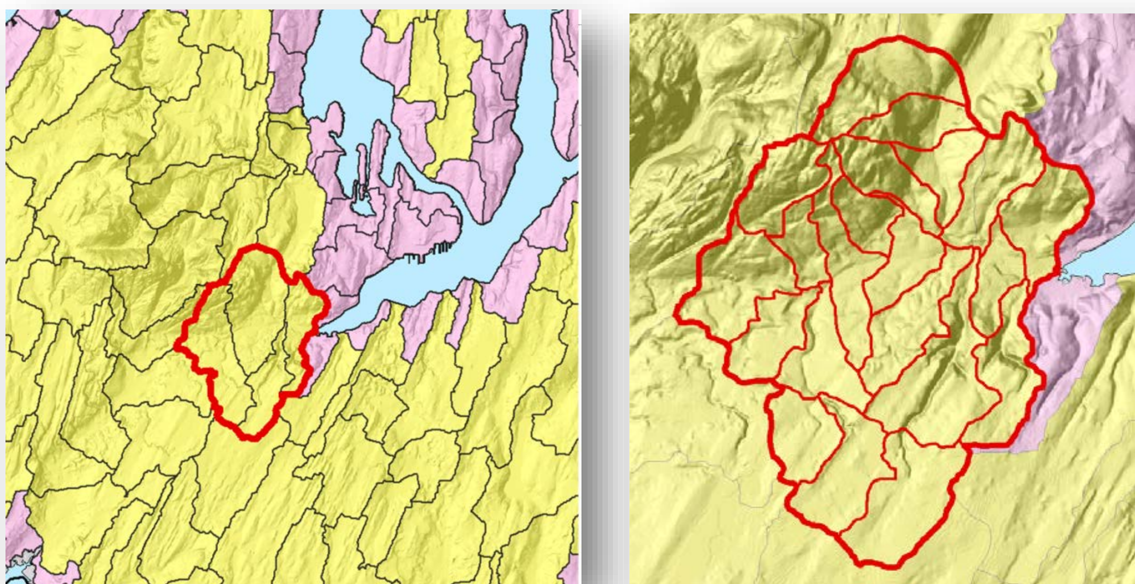


Figure D-9. Gorst Creek – creating smaller AUs**.** The left panel shows the original 4 AUs used at the WRIA scale. The right panel shows the 21 smaller AU's delineated for the sub-basin scale.

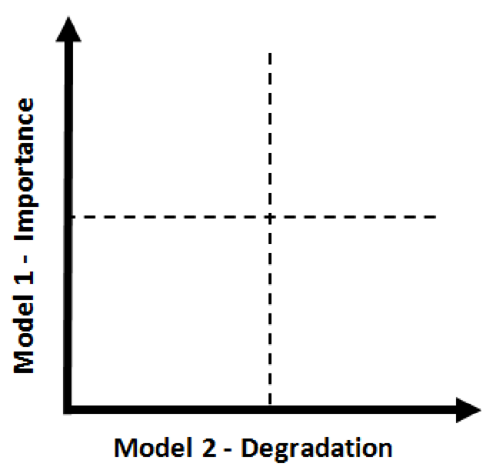
Model Structure

Overview

Major Principles;

- Results are relative
- 2 separate sub-models
- Results from each sub-model are ranked, then grouped into 4 categories – High, Moderate High, Moderate, Low (H,MH,M,L)
- The categories from the 2 sub-models produce the management matrix
- The matrix suggests the most appropriate land management

The water resource assessment models, including water flow and water quality, each have two fundamental sub-models**: importance and degradation**. The importance sub-model is Model 1 in the GIS scripts, and the degradation sub-model is Model 2.



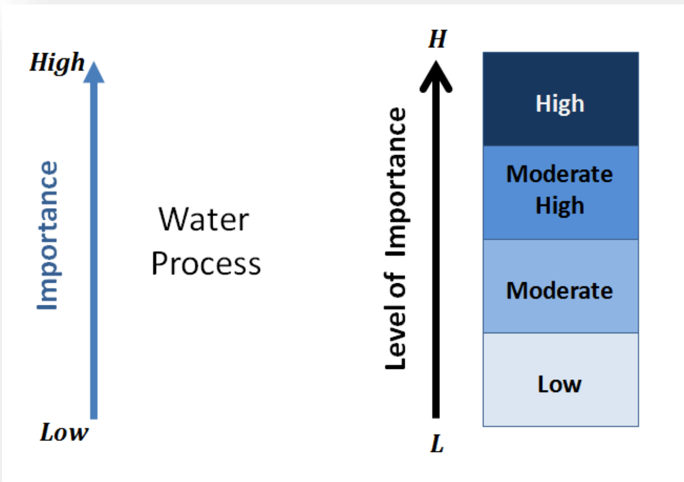
Combining the results of these two sub-models produces a matrix of management options. The relationship between these two sub-models and the resulting matrix is shown in Figure D-10.

Figure D-10. Relationship between sub-models for Importance and Degradation**.**

The importance sub-model includes several assessments that combine to provide a **relative value** of each assessment unit compared to the other units, for the importance that assessment unit provides in supporting the water processes. **The importance sub-model assumes an un-altered condition** to the landscape, and only analyzes features of the landscape that we can measure from existing data, as indicators for the water processes we are assessing.

The degradation sub-model also provides a relative value of an assessment unit compared to other units, for the degradation to the water processes within that unit. The **degradation sub-model accounts for alterations** to the natural landscape from human activity, and analyzes changes from land use to features that can be measured from existing data, as indicators for the processes we are assessing.

Ecological models can only provide an approximate representation of the complex interactions within a natural system. Likewise this model is providing a representation of the inner workings of the freshwater hydrologic cycle. The model is designed to use **existing data that is uniformly available** across Puget Sound. The resolution makes it most useful for planning level decisions and not site scale decisions. Therefore, it is a decision support tool and not a decision making model.

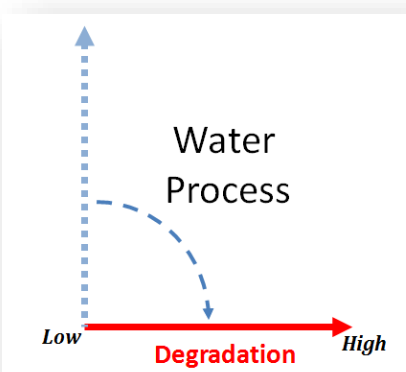


The importance sub-model compares the final assessment values for each AU relative to all other AUs in the analysis extent. The values are ranked from highest value to lowest value, and then normalized from zero to one. These normalized values are then put into four quartiles or categories: High (H), Moderate High (MH), Moderate (M), and Low (L).

Figure D-11. Ranking and grouping of values for Importance.

Methods for developing the quartiles are described in Attachment D5: Quartile Grouping Methods.

The degradation sub-model follows the same procedure for ranking normalized values and then grouping them into quartiles of H, MH, M, and L. The only difference is that the degradation values become the x-axis in the final results matrix discussed below, so the quartiles here are displayed horizontally.



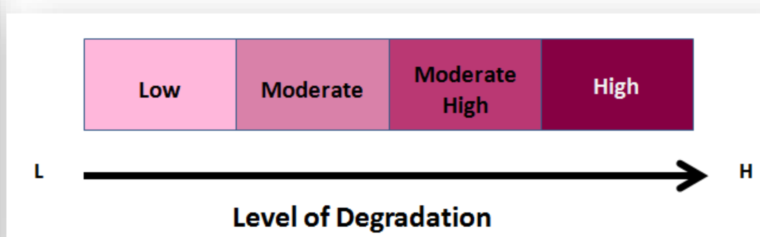


Figure D-12. Ranking and grouping of values for Degradation.

We use a matrix approach to assess an AU's relative condition resulting from the combination of importance **and** degradation quartiles. The importance categories become the vertical y-axis, and the degradation categories become the horizontal x-axis. The relationship between these two models is the **foundation for the management results, their display, and interpretation**. With four quartiles for both model results, the resulting management matrix has 16 possible combinations of AU condition.

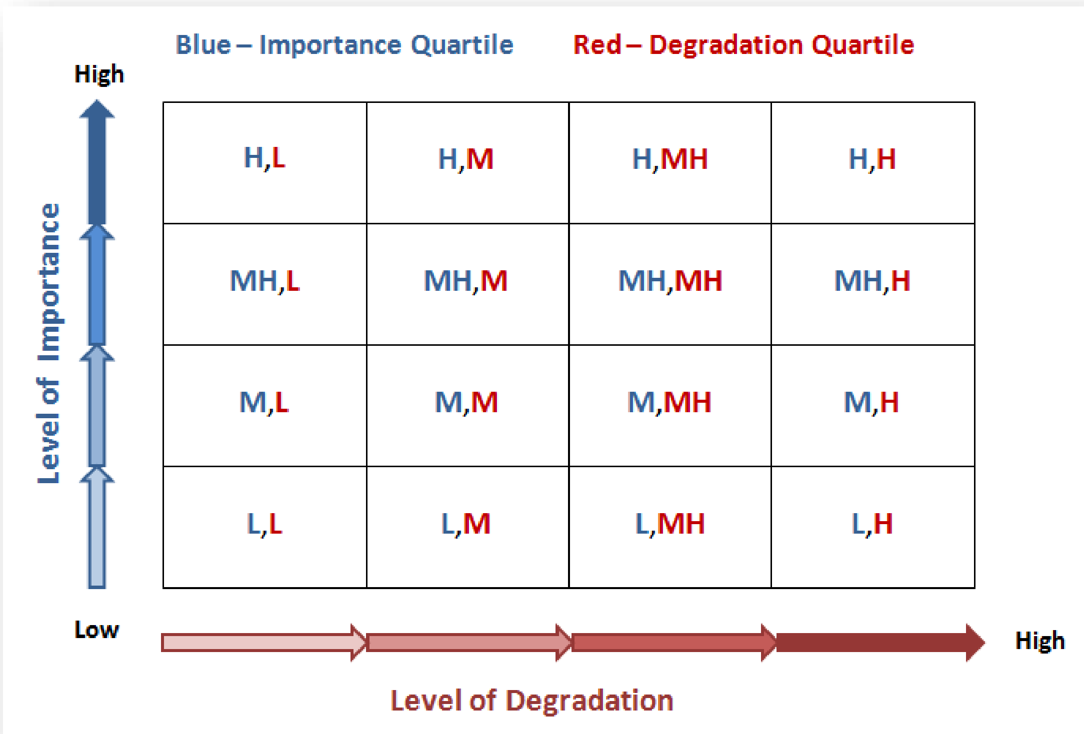


Figure D-13. Management matrix showing sixteen possible AU conditions.

The model results retain a unique GIS code for each of the sixteen combinations.

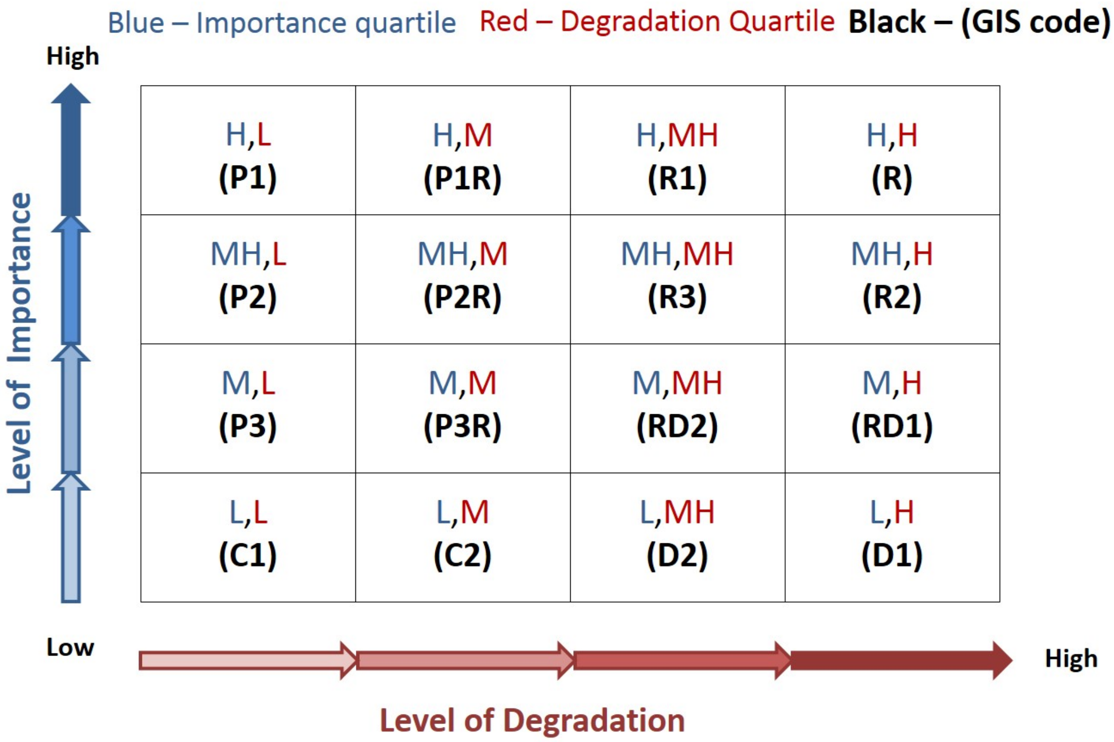


Figure D-14. GIS codes for sixteen matrix combinations.

Depending on the application, the scale, and the questions being asked, these results can provide management guidance at several levels of detail. The most general is four management categories of Protection (P), Restoration (R), Conservation (C), and Development (D). However the results can be displayed as 8 categories or even 16, given the appropriate circumstances (Figure D-13).

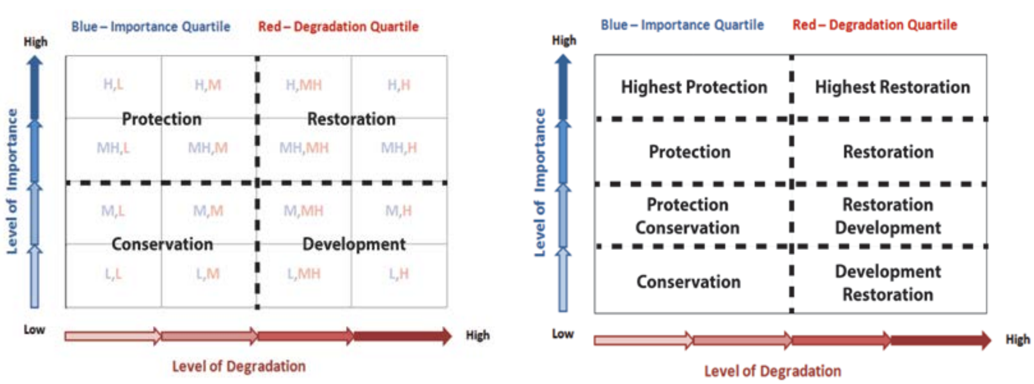


Figure D-15. Management matrix showing four and eight possible categories.

For the map displays we currently produce, we use the eight categories and apply the color scheme below. This level of detail still provides sufficient information for local governments making planning level decisions.

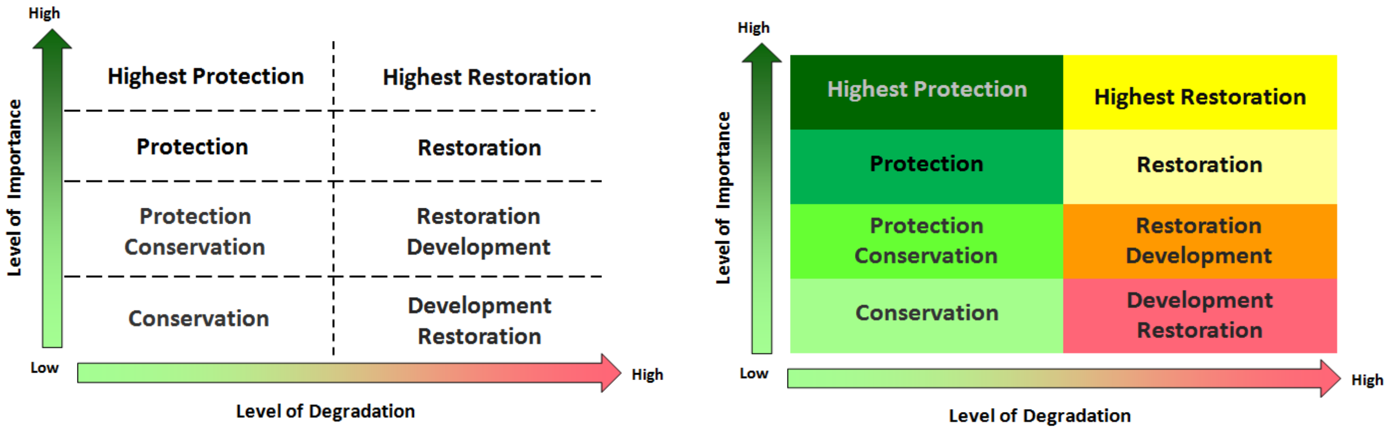


Figure D-16. Management matrix for water flow with eight categories used in display maps.

The **water quality model** follows this same framework, but because of the nature of water quality parameters, we use slightly different terminology. The 'importance' sub-model for water quality is called ***export potential***, or Model 1. It measures features of the landscape that naturally contribute to the delivery and movement of each water quality parameter. These features are substitutes or indicators for the parameter, in **an unaltered condition,** and results are a **relative value** of each assessment unit compared to all the assessment units in the analysis extent. Final values are ranked and grouped into the same four categories, low to high.

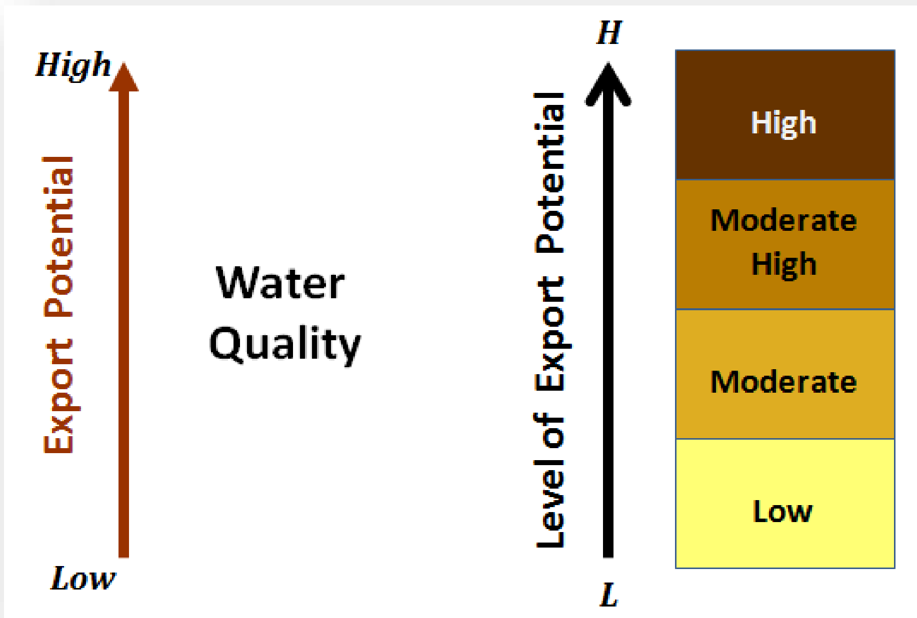


Figure D-17. Groups of water quality values for Export Potential

The degradation sub-model for water quality, Model 2, runs calculations on results of the Nonpoint Source Pollution and Erosion Comparison Tool (**N-SPECT**) developed by NOAA Coastal Services Center. N-SPECT characterizes the degree of existing degradation to water quality processes based on existing land use type, details of which are in section 'Degradation of Water Quality Parameters – NSPECT'. The calculation portion of the degradation sub-model summarizes the N-SPECT results by assessment unit, ranks the results, and groups them into the four categories (H, MH, M, L) of **level of degradation**, again resulting in a **relative ranking** of assessment units throughout the analysis extent.

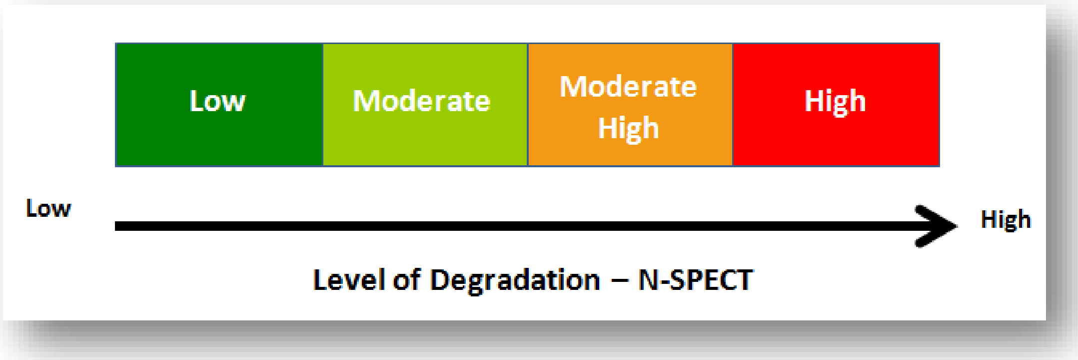


Figure D-18. Groups of water quality values for Degradation – N-SPECT.

We use a matrix analogous to the water flow matrix to assess an AU's relative condition of export potential **and** degradation to water quality processes. The results from both the export potential and degradation sub-models, provide the y-axis and x-axis information to create a management matrix for water quality. The results can produce 16 possible combinations of AU condition.

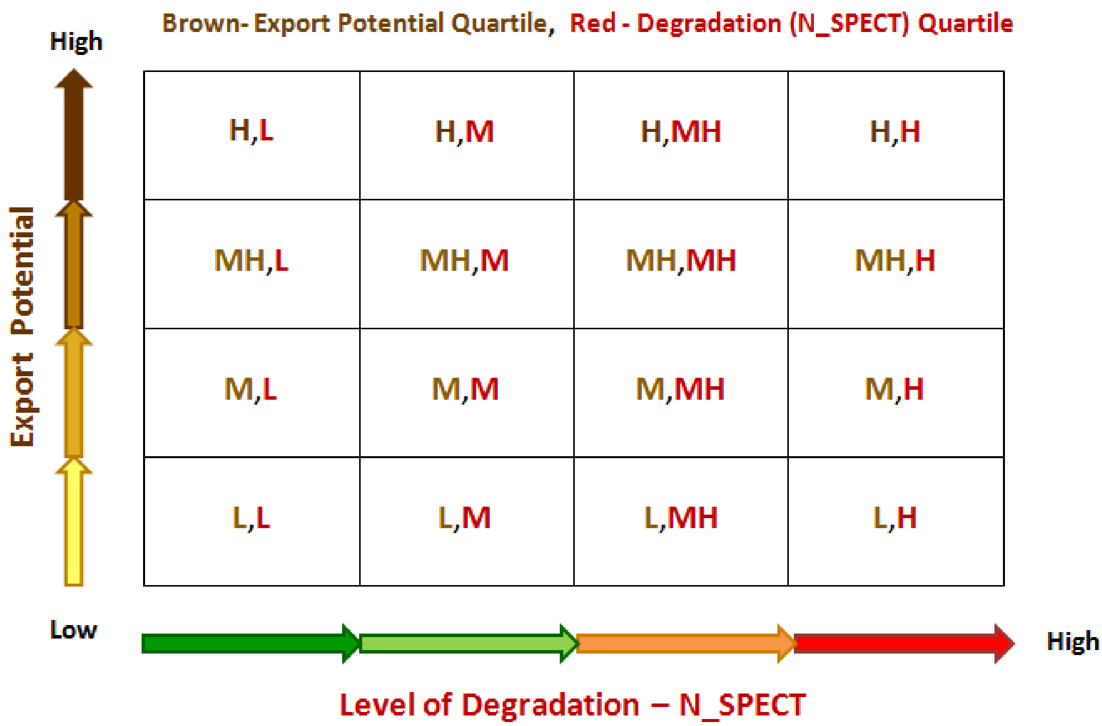


Figure D-19. Water Quality management matrix of 16 possible AU conditions.

Because water quality parameters are fundamentally different from the 'importance' for water flow, we describe water quality export potential in terms of '**sources**' and '**sinks**'. A 'source' for a water quality parameter is a natural feature on the landscape, such as erodible soils or stream density that supports the delivery or movement of that parameter. Those areas that rank 'high' in export potential for sediment are more likely to transport sediment downstream if disturbed by large-scale impacts such as forest clearing. A 'sink' is a natural feature that retains or transforms that parameter, such as a wetland by storing sediment. An area that ranks lower in its export potential is more influential as a sink area. In the case of sediment, the AU would likely have a relatively greater area of wetlands.

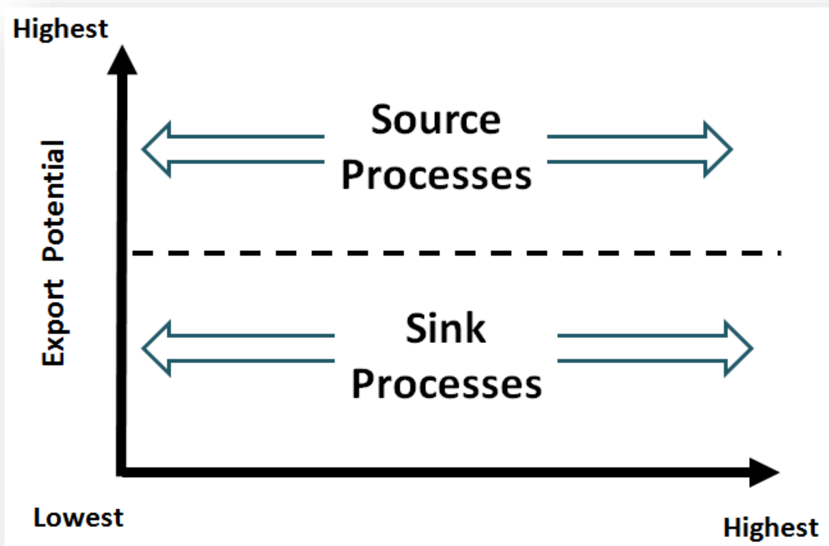


Figure D-20. Export Potential of water quality processes relative to sources and sinks.

The relative level of degradation of an AU influences whether management practices should focus on protection of the process or restoration of the process. Areas that are less degraded have more potential for protecting the processes already functioning. Areas that are more degraded have more potential for improvement from restoration.

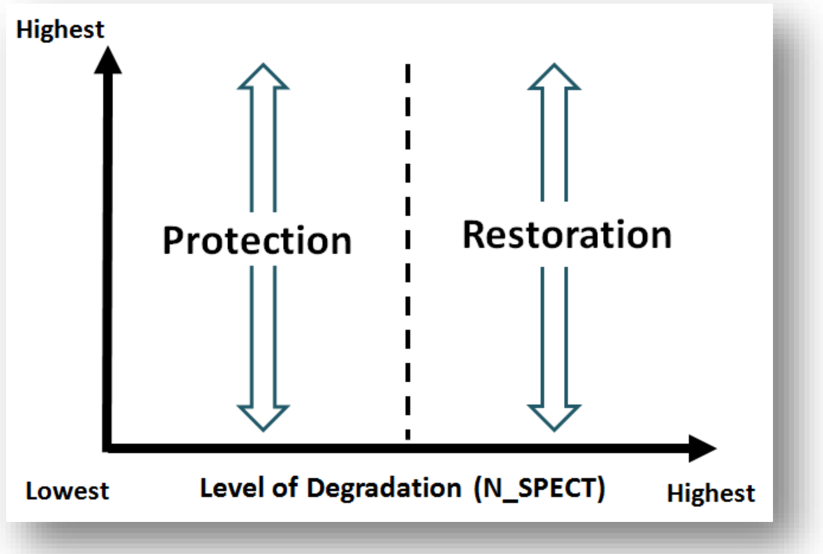
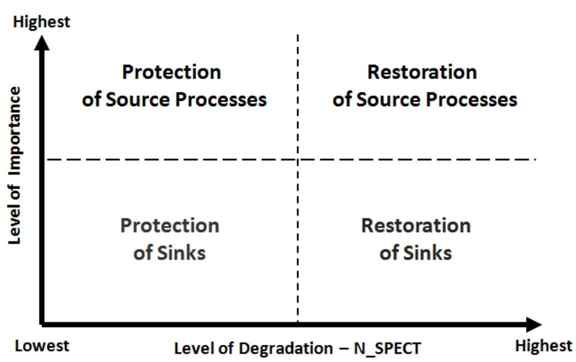


Figure D-21. Level of Degradation of water quality processes relative to protection and restoration.

Taken together, these concepts result in a management matrix for water quality (Figure D-19). Though 16 different AU conditions are possible, we only display up to the eight management groups.



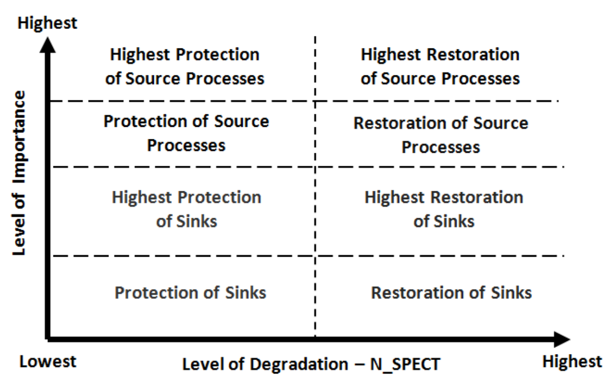


Figure D-22. Management matrix for water quality processes–four and eight categories.

For our map displays, we use the eight category color scheme in Figure D-23. This level of detail still provides sufficient information for local governments making planning level decisions.

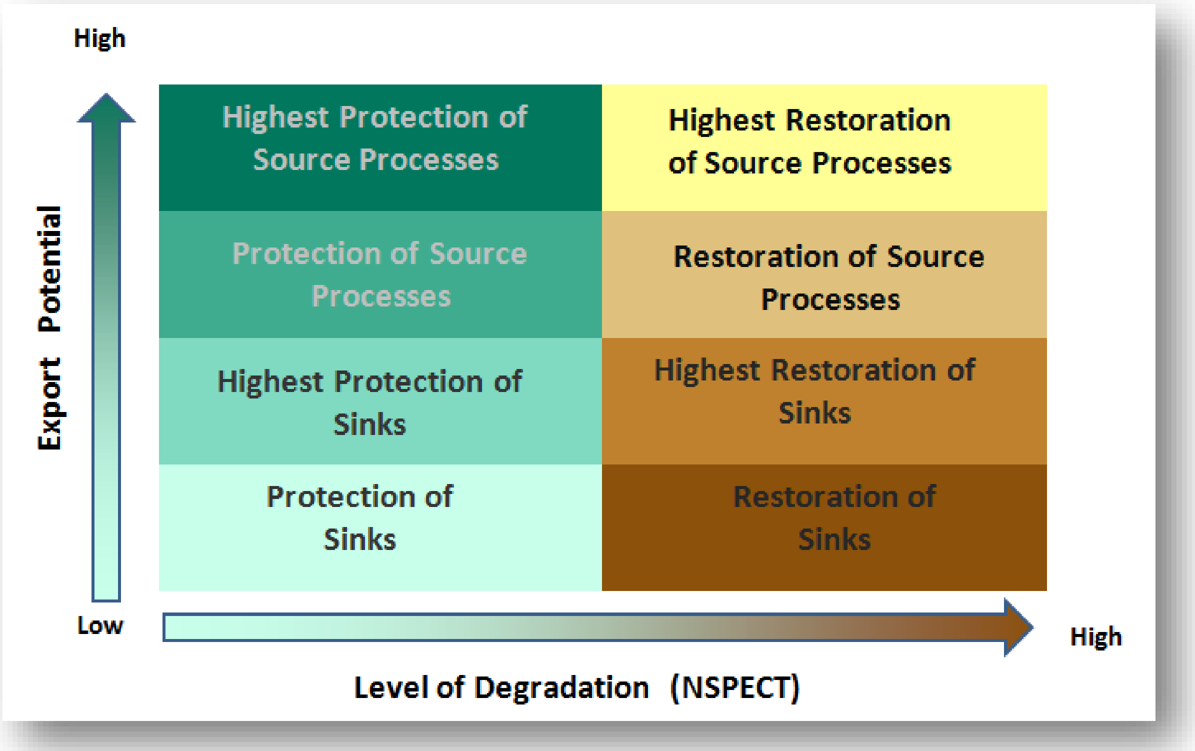
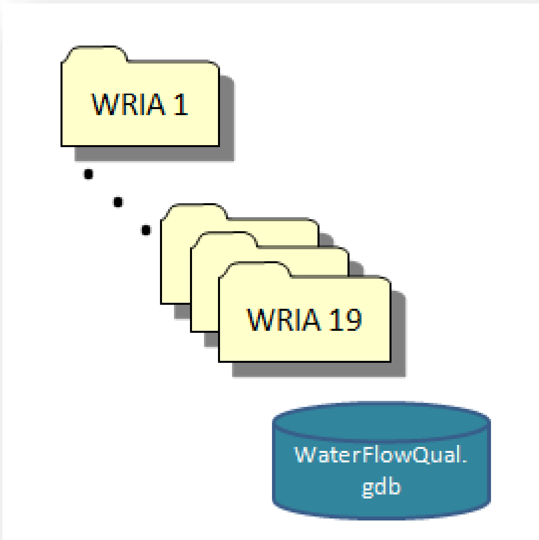


Figure D-23. Management matrix for water quality processes for display maps.

GIS Format

The GIS database reflects the model structure described in the previous section. We use the geodatabase (gdb) format provided by ESRI™ (Environmental Systems Research Institute, Inc.) and a toolbox of models for use in ArcGIS 10.2.



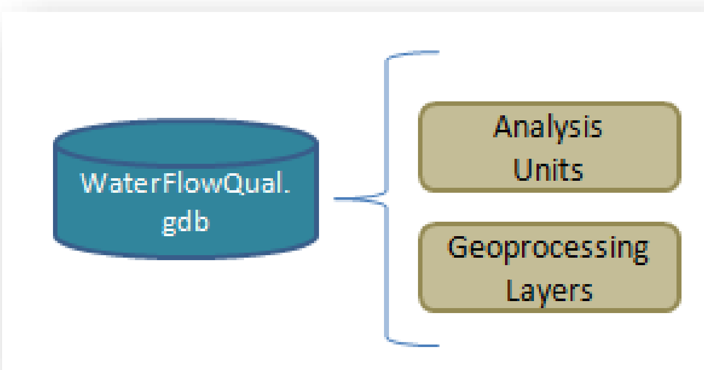
For any analysis, the output is the '*water flow-water quality geodatabase*', **WaterFlowQual.gdb**, which includes intermediate feature classes, summary tables, as well as the final results for both the water flow and water quality assessments.

Our initial analyses include assessments for each of the 19 WRIA of Puget Sound. These results are posted on the Characterization web page for download:

Figure D-24. Results geodatabase – WaterFlowQual.gdb.

(http://www.ecy.wa.gov/services/gis/data/pugetsound/characterization.htm).

The WaterFlowQual.gdb contains two feature data sets. The *Analysis Units* feature data set includes nine feature classes: one for the AU boundaries, five for model results for water flow, and three for water quality.



The *Geoprocessing Layers* feature data set contains all the intermediate layers. These are useful for reviewing the results of any individual assessment.

Figure D-25. Feature data sets within WaterFlowQual.gdb.

Each of the nine feature classes in the Analysis Units data set contains the spatial boundaries of the assessment units with numerous attribute fields for different parts of the sub-models.

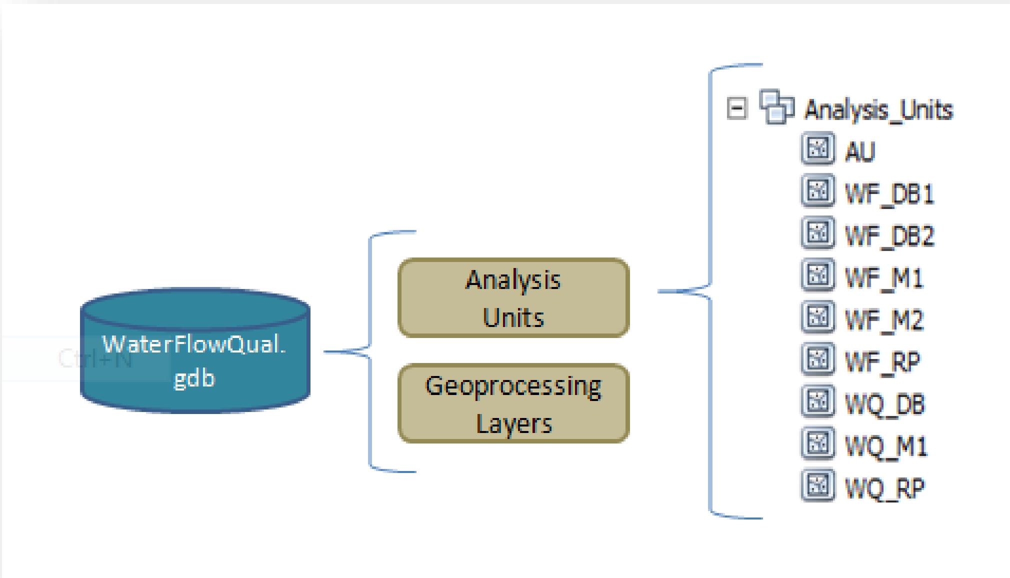


Figure D-26. Feature classes in the Analysis Units feature data set.

Brief descriptions of the contents of the Analysis Units feature data set are here:

AU – (Assessment Unit). This feature class is the polygon boundaries of the assessment units used in analysis. It contains the identification number (AU_ID) for each unit, which is unique across Puget Sound. A detailed description on development of these units is in Attachment D-1.

WF_DB1 – (Water Flow DataBase 1). This feature class contains the raw values from geo-processing of various data layers for model one, importance to water flow, for each assessment unit.

WF_DB2 – (Water Flow DataBase 2). This feature class contains the raw values from geo-processing of various data layers for model two, degradation to water flow, for each assessment unit.

WF_M1 – (Water Flow Model 1). This feature class contains the calculations used in the importance model (model 1). Inputs are from the WF_DB1 feature class.

WF_M2 – (Water Flow Model 2). This feature class contains the calculations used in the degradation model (model 2). Inputs are from the WF_DB2 feature class.

WF_RP – (Water Flow Restoration Protection). This feature class combines the importance and degradation results for water flow and is used to display model results. It contains the normalized assessment values, the quartile ranking (H, MH, M, L) of those values, and the management code that results from the combination of the importance rank and degradation rank. The *management matrix* displays the 16 combinations of quartile pairs in Figure D-13, and the corresponding management code in Figure D-16.

WQ_DB – (Water Quality DataBase). This feature class contains the raw values from geo-processing of various data layers for the importance/export potential models for all five water quality parameters (sediment, nitrogen, phosphorous, pathogens, and metals).

WQ_M1 – (Water Quality Model 1). This feature class contains the calculations for the importance/export potential, (model1) for all five water quality parameters.

WQ_RP – (Water Quality Restoration Protection). This feature class combines the importance/export potential and degradation/NSPECT results for the five water quality parameters, and is used to display model results. It contains the normalized assessment values, the quartile ranking (H, MH, M, L) of those values, and the management code that results from the combination of the importance rank and degradation rank. The management matrix for water quality displays the 16 combinations of quartile pairs in Figure D-19, and the corresponding management code in Figure D-23.

The Geoprocessing Layers feature data set contains the feature classes resulting from combining source layers with the assessment units for both the importance and degradation sub-models for water flow. The degradation feature classes are indicated with a red box.

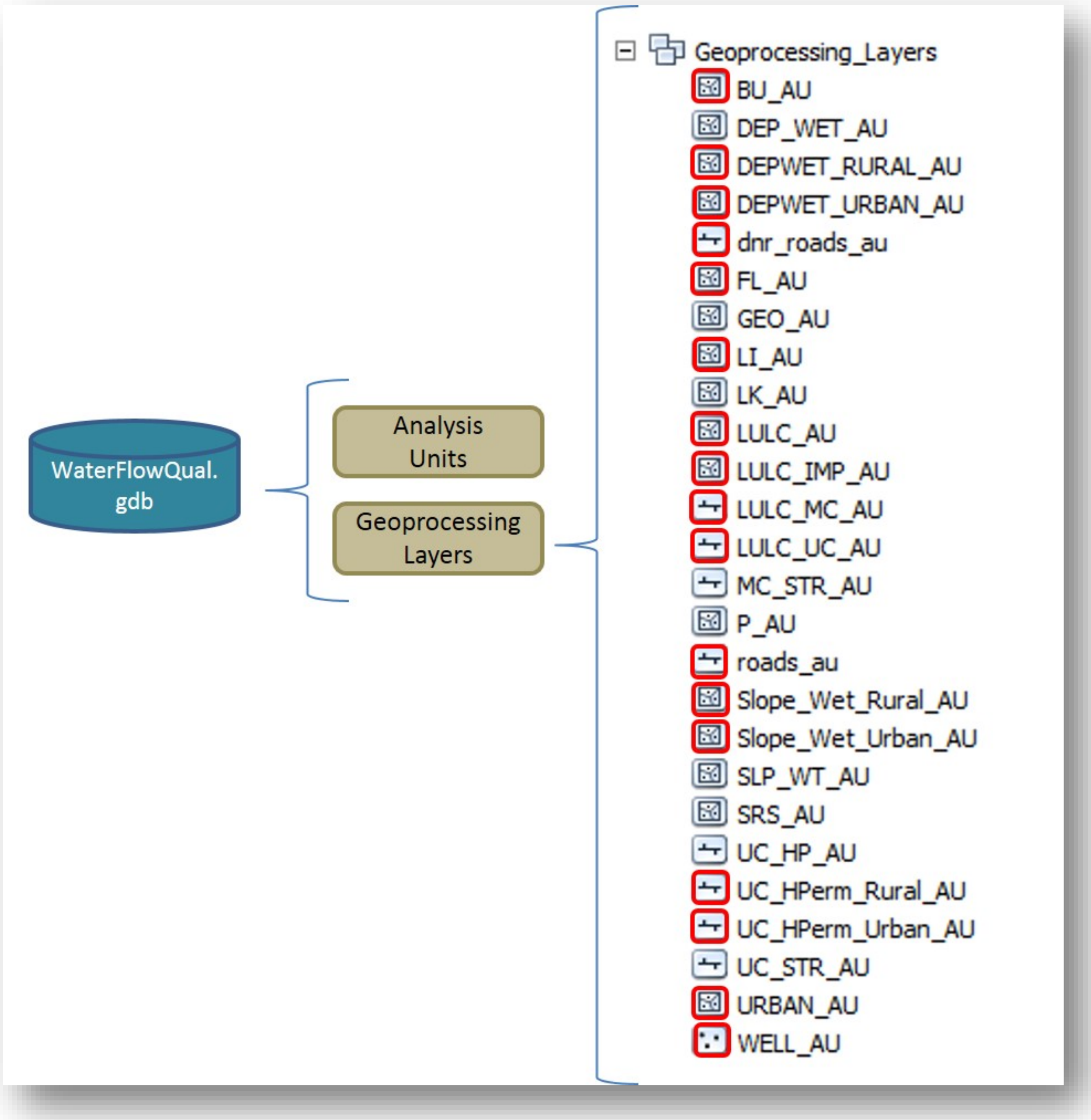


Figure D-27. Feature classes for the water flow analyses.

ArcGIS displays the feature classes alphabetically as shown in Figure D-27. The brief descriptions below are listed alphabetically, but separated in two groups, the first including analyses for the importance to water flow:

DEP_WET_AU – (depressional wetlands). This feature class is the area of the AU with depressional wetlands.

GEO_AU – (permeability). This feature class is the area of higher and lower permeable surficial geology in the AU. (See Attachment D-2: Geology Data)

LK_AU – (lake area). This feature class is the area of lakes within the AU.

MC_STR_AU – (moderately confined streams). This feature class is the miles on moderately confined streams in the AU. (SSHIAP streams where valley width is 2-4 times channel width)

P_AU – (precipitation). This feature class is the average precipitation value for the AU.

SLP_WT_AU – (slope wetlands). This feature class is the area of slope wetlands in the AU.

SRS_AU – (rain-on-snow). This feature class is the area of the AU that has rain-on-snow or snow dominated zones.

UC_HP_AU – (unconfined streams in higher permeable deposits). This feature class is the stream miles for unconfined streams that intersect the higher permeable deposits in the AU.

UC_STR_AU – (unconfined streams). This feature class is the miles of unconfined streams in the AU. (SSHIAP streams where valley width is > 4 times channel width)

This second group includes the analyses for the degradation to water flow (red boxes in Figure D-27):

BU_AU – (built-up area). This feature class is the area of build-up land use type in the AU. (LU_CODE = 2, High intensity developed with 80-100% impervious area; LU_CODE = 3, Medium intensity developed with 50-79% impervious area).

DEPWET_RURAL_AU – (rural depressional wetlands). This feature class is the area of depressional wetlands that intersect rural land use types.

DEPWET_URBAN_AU – (urban depressional wetlands). This feature class is the area of depressional wetlands that intersect urban land use types.

DNR_RDS_AU – (roads from DNR). This feature class is the miles of roads, including forest roads, within the AU.

FL_AU – (forest loss). This feature class is the area of the AU that has been changed from forest to another land cover type. (LU_CODE = 2-7)

LI_AU – (low intensity area). This feature class is the area of low intensity land use type in the AU. (LU_CODE = 4, Low intensity developed with 21-49% impervious area).

LULC_AU – (land cover). This feature class is the area of the AU that includes land cover types that could be altered by land use changes. It excludes areas that are naturally 'bare' including: snow/ice, tundra, bare land, and water.

LULC_IMP_AU – (impervious surface). This feature class is the area of the AU that contains impervious surfaces from land use, including land cover values of 2-5.

LULC_MC_AU – (moderately confined streams in urban areas). This feature class is the miles of moderately confined streams that intersect urban land use types.

LULC_UC_AC – (unconfined streams in urban areas). This feature class is the miles of unconfined streams that intersect urban land use types.

ROADS_AU – (roads). This feature class is the miles of roads within the AU.

SLOPE_WET_RURAL_AU – (slope wetlands in rural). This feature class is the area of slope wetlands intersecting rural land use types.

SLOPE_WET_URBAN_AU – (slope wetlands in urban). This feature class is the area of slope wetlands intersecting urban land use types.

UC_HPERM_RURAL_AU – (unconfined streams, high permeability, rural). This feature class is the miles of unconfined streams that intersect both higher permeable soils and rural land use types.

UC_HPERM_URBAN_AU – (unconfined streams, high permeability, urban). This feature class is the miles of unconfined streams that intersect both higher permeable soils and urban land use types.

URBAN_AU – (urban area). This feature class is the area of urban land use type in the AU. (LU_CODE = 2, High intensity developed with 80-100% impervious area)

WELL_AU – (wells). This feature class is the wells from Department of Health that are in the AU.

The water quality models add several more feature classes to the geodatabase. They are included in the list below and are highlighted with red arrows. Here is a brief description of each feature class for the water quality analyses for *export potential*:

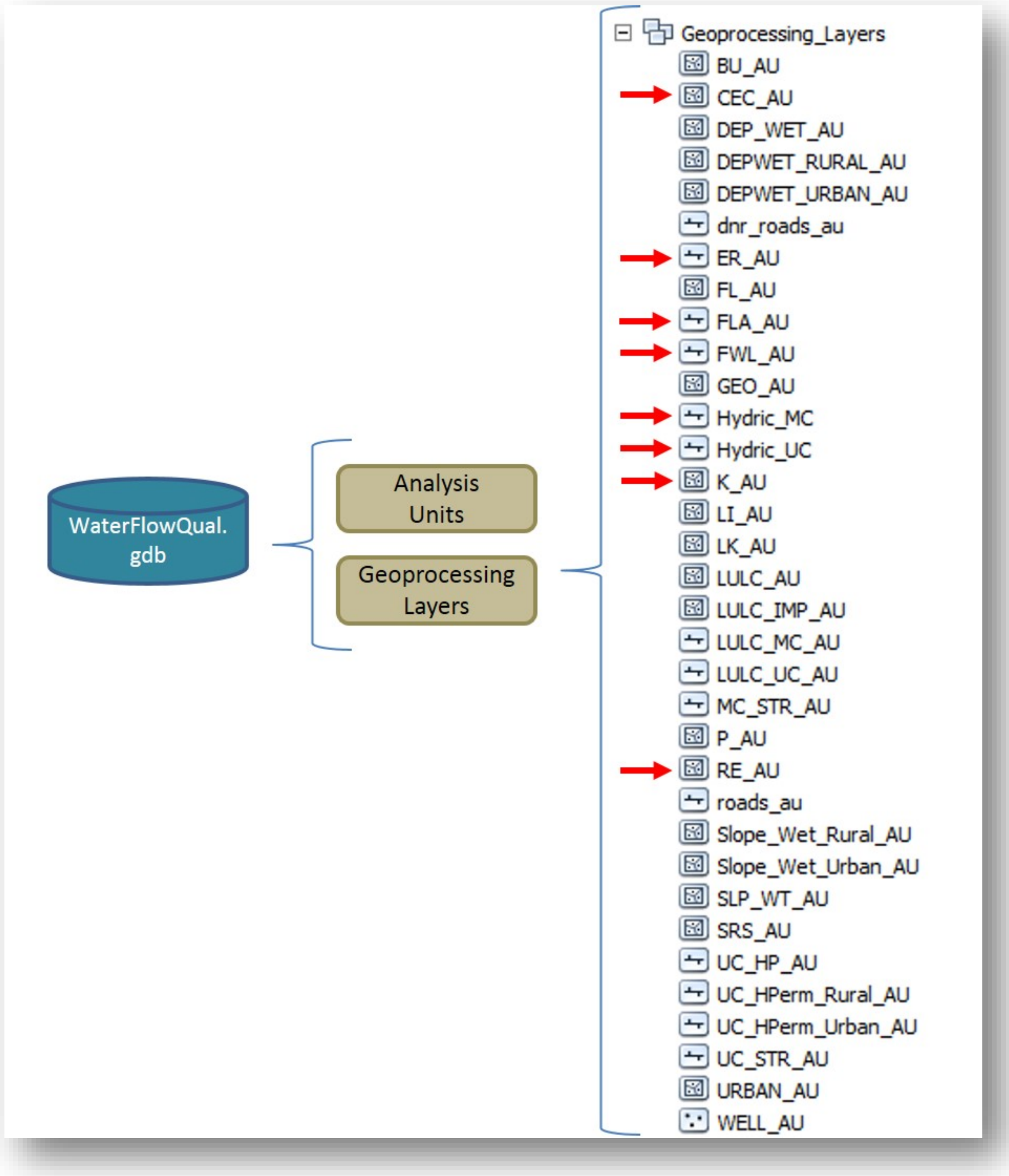


Figure D-28. Feature classes for the export potential of the water quality analyses (red arrows).

CEC_AU – (cation exchange capacity). This feature class is the areas within an AU where the soil types have different cation exchange capacities that affect retention of metals.

ER_AU – (channel erosion). This feature class is the streams that intersect areas of erodible soils within the AU.

FLA_AU – (flowline/aquatic). This feature class includes streams and centerlines for the entire aquatic network, including wetlands and lakes.

FWL_AU – (flowline/water). This feature class is the streams coded as a stream or river only.

Hydric_MC – (hydric soils & moderately confined streams). This feature class is the moderately confined streams that intersect hydric soils in the riparian denitrification tool in the nitrogen model.

Hydric_UC – (hydric soils & unconfined streams). This feature class is the unconfined streams that intersect hydric soils in the riparian denitrification tool in the nitrogen model.

K_AU – (soil erodibility). This feature class is the areas within an AU with different K-factors which control a soil type's susceptibility to erosion.

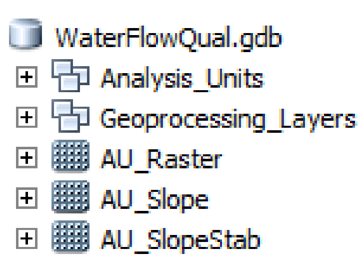
RE_AU – (rainfall erosivity). This feature class is the area within the AU of different *R-factors* which control a soil type's susceptibility to erosion from precipitation.

The water quality models also produce three raster layers for the sediment model:

AU_RASTER – (raster version of the AU layer). This feature class is a raster interpolation of the AU boundaries. It is used in averaging N-SPECT results to the AU.

AU_Slope – (slope). This feature class is a raster layer of the slope.

AU_SlopeStab – (slope stability). This feature class is a raster layer of the results of a slope stability model developed by Shaw & Johnson, giving a landslide hazard rating.



Limitations of Model Results

These methods are the result of significant peer review and ongoing comment from an advisory team. We believe the methods provide a useful, and scientifically credible relative comparison across the landscape. Even so, these methods are the product of subjective judgments and data limitations, both of which display varying levels of uncertainty.

The water resource assessments are part of a coarse scale, decision support tool, intended to support regional, county, and watershed planning. The methods are adaptable to a range of planning questions and issues that require different spatial extents. These spatial extents may involve single or multiple watersheds and may cross between one or more WRIAs. In some cases the AUs may have to be reduced in size to match smaller watersheds and to address planning issues within smaller jurisdictions. We suggest a strong understanding of these methods to ensure appropriate application of the results.

As in any GIS analysis, the scale and accuracy of the source data dictates the confidence level in the output. If finer scale data is available, it can replace the source layers currently referenced. The only requirement is that any data used is geographically complete for the area of interest. In any case, care is necessary to ensure application of the methods is within the bounds of the intended uses and data limitations. Though the results can provide a landscape context for locating protection or restoration actions, they cannot be used to inform specific site locations or project design. In all cases the methods represent a decision support tool and not a decision making tool and should not be used in lieu of finer scale data or other methods designed for assessing processes and functions at finer scales.

Data Development

A requirement of these methods is to use **existing data that is uniform across Puget Sound**. Our data sources require a minimum of data editing or formatting. All layers are in Washington State Plane South, NAD 83, Zone 4602. All models call up data from the source layers geodatabase called PS_Layers.gdb.

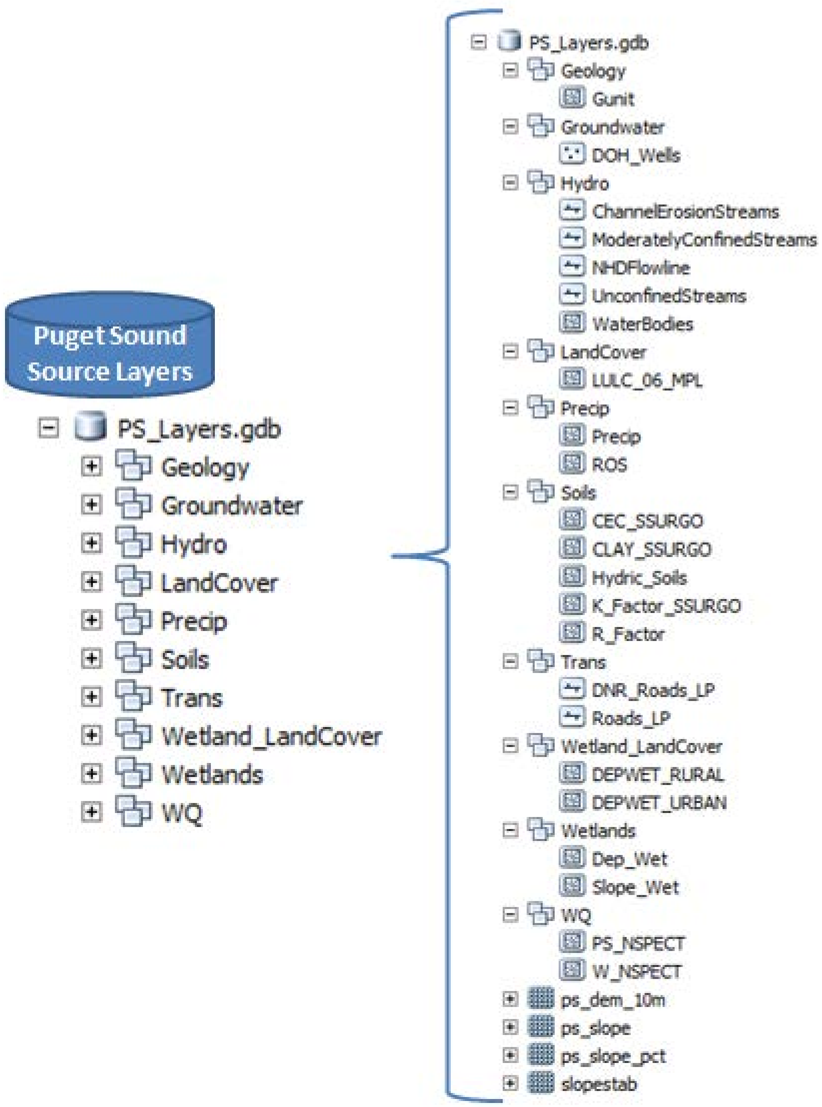


Figure D-29. Feature classes for source layers for water resource assessments.

Each feature class is described below in the order listed in Figure D-29, which is the ArcCatalog (ESRI) format. All original data is clipped to the boundary of the Puget Sound basin, and we describe any additional geoprocessing steps, editing, formatting, or coding additions. All layers have metadata attached for viewing in the ArcGIS (ESRI) environment.

Gunit – geologic layer with unit name [GUNIT_TXT, LITHOLOGY1); we added two attributes, "**geo_hp**" and "**chnl_ersn**"; "geo_hp" is coded for those units with higher permeability (Hperm) such as alluvium and recessional outwash, and the rest with lower permeability (Lperm); reviewed by Patricia Olson and Derek Booth; "chnl_ersn" has a code for those units within the mountainous landscape groups with higher permeability and with higher susceptibility to channel incision, such as alluvium and Fraser-age glacial outwash; for the complete list of both of these values see Attachment D2: Geology Data.

DOH_wells – Department of Health drinking water wells for larger public well systems (group A, for 15 or more connections, and group B, for 3-14 connections).

ChannelErosionStreams – selected stream arcs from NHD data that intersect the higher permeable deposits (Gunit, Hperm) with higher susceptibility to erosion (chnl_ersn).

ModeratelyConfinedStreams – moderately confined streams from the SSHIAP (Salmon and Steelhead Habitat Inventory and Assessment Program) data, defined as streams with a valley width two to four times the width of the channel.

NHDFlowline – stream lines from the National Hydrography Data; centerline and single line streams are used for stream density analysis; centerlines of lakes and wetlands are included for aquatic system density analysis.

UnconfinedStreams – unconfined streams from the SSHIAP (Salmon and Steelhead Habitat Inventory and Assessment Program) data, defined as streams with a valley width greater than four times the width of the channel.

WaterBodies – water bodies coded as lake or pond from the NHD.

LULC_06_MPL - 2006 land cover data from NOAA, combined with the Major Public Lands layer from DNR; NOAA land cover had 22 categories, which we combined into several groups for various assessments. The major public lands layer is used to screen out areas where land cover is assumed to not result from alteration by human activities. See Attachment D-4: Land Cover Classes.

Precip – average yearly precipitation isohyets, in inches, for Washington State from the Department of Natural Resources.

ROS – rain-on-snow and snow dominated areas from the Department of Natural Resources.

CEC_SSURGO – cation exchange capacity average (cecl, cech, cec7_rnk) value from SSURGO data.

Hydric_Soils – soil types coded as 'hydricrat' from the SSURGO data.

K_Factor_SSURGO – soil erodibility factor (kfact) for the susceptibility of soil particles to be moved by water, from SSURGO data; data gaps filled by NW Hydraulics.

R_Factor – rainfall erosivity factor from Richard Horner/NW Hydraulics.

DNR_Roads_LP – roads layer from DNR; has more complete coverage of forest roads in mountainous areas.

Roads_LP – roads layer from Department of Transportation (DOT); has more complete roads for the lowland and developed areas.

DEPWET_RURAL – depressional wetland layer of potential wetlands; from combined layers including hydric soils, NWI (National Wetland Inventory) wetlands, wetlands from NHD hydrography layer, and wetland pixels from 2006 CCAP land cover; selected areas are on slopes of 2% or less and intersect 'urban' pixels from 2006 CCAP land cover.

DEPWET_URBAN – depressional wetland layer of potential wetlands; from combined layers including hydric soils, NWI (National Wetland Inventory) wetlands, wetlands from NHD hydrography layer, and wetland pixels from 2006 CCAP land cover; selected areas are on slopes of2% or less and intersect 'rural' pixels from 2006 CCAP land cover.

Dep_Wet – depressional wetland layer of potential wetlands; from combined layers including hydric soils, NWI (National Wetland Inventory) wetlands, wetlands from NHD hydrography layer, and wetland pixels from 2006 CCAP land cover; selected areas are on slopes of 2% or less.

Slope_Wet – slope wetland layer of potential wetlands; from combined layers including hydric soils, NWI (National Wetland Inventory) wetlands, wetlands from NHD hydrography layer, and wetland pixels from 2006 CCAP land cover; selected areas are on slopes >2%.

PS_NSPECT – N-SPECT water quality results for Puget Sound wide analysis; results are in three forms: 1) average value for AU for load per unit area, 2) rank order of AU across Puget Sound, 3) quartile grouping of the rank order; includes eight analyses: runoff, phosphorous, nitrogen, suspended solids, zinc, copper, pathogens, and MUSLE (Modified Universal Soil Loss Equation). Runoff and suspended solids analyses are not used. Zink and copper are averaged together for a combined 'metals' rank and quartile. See Degradation of Water Quality Parameters – N-SPECT

W_NSPECT – N-SPECT water quality results for each of the 19 WRIAs; results are in three forms: 1) average value for AU for load per unit area, 2) rank order of all AU's across the WRIA, 3) quartile grouping of the rank order; includes eight analyses for: runoff, phosphorous, nitrogen, suspended solids, zinc, copper, pathogens, and MUSLE (Modified Universal Soil Loss Equation). Runoff and suspended solids analyses are not used. Zink and copper are averaged together for a combined 'metals' rank and quartile. See Degradation of Water Quality Parameters – N-SPECT.

ps_dem_10m – 10 meter digital elevation data (DEM) for entire Puget Sound.

ps_slope – slope grid from the 10 meter DEM for Puget Sound.

ps_slope_pct – percent slope grid from the 10 meter DEM for Puget Sound.

slopestab – predictive layer of shallow-rapid slope stability from the Shaw-Johnson model. Also called the Shaw Johnson Hazard Index, it is calculated using a combination of slope and slope curvature (concave vs. convex), with values range from 1, low potential for mass wasting, 2, moderate potential, and 3, high potential.

Table D-2. Shaw-Johnson slope stability classes.

Slope Class					
Curvature	**0 - 15%**	**15 - 25%**	**25 - 47%**	**47 - 70%**	**> 70%**
Concave	Low	Low	Low	Low	Moderate
Planar	Low	Low	Low	Moderate	High
Convex	Low	Moderate	High	High	High

SMORPH: Shaw, S.C. and Johnson, D.A., 1995, Slope Morphology Model Derived from Digital Elevation Data, in Proceedings,1995 Northwest Arc/Info Users Conference, Coeur d'Alene, Idaho, Oct. 23-25, 13p.

Data Synthesis

The tables below summarize the suite of analyses used in both the water flow and water quality models. Some of the analyses in model 1 apply to more than one variable. For example, the percentage of depressional wetland area (WLS) is a factor in the water flow and all of the water quality models. The parameters for each analysis are described in the tables that follow.

Table D-3. Summary of Attributes Produced From Model 1 Assessments.

MODEL 1	Water Resource Assessments											
GIS Analyses for Importance (WF)	Water Flow Importance		Water Quality - Export Potential									
			Sediment		Phosphorous		Metals		Nitrogen		Pathogens	
	Del	Mvt	Source	Sink	Source	Sink	Source	Sink	Source	Sink	Source	Sink
Precipitation patterns	P						Not Significant		Not Significant		Not Significant	
Rain-on snow and snow dominated zones	RS											
Depressional wetlands		WLS		WLS		WLS		WLS		WLS		dpwt
Channel confinement (stream storage)		STS		STS		STS		STS		STS		
Permeability of surficial geology (recharge areas)		IR										
Channel confinement and permeability (discharge)		SD										
Slope wetlands		SWD										
GIS Analyses for Export Potential (WQ)												
Surface erosion			SE		SE							
Mass wasting areas intersected by aquatic ecosystems			MW		MW							
Channel erosion			CE		CE							
Soil Retention of Ph						SRP						
Soil Retention of Metals								SRM				
Riparian denitrification										RDN		

Table D-4. Summary of Attributes Produced From Model 2 Assessments.

Model 2	Water Resource Assessments							
GIS Analysis for Degradation (WF)	**Water Flow Degradation**			**Water Quality - Degradation**				
	Del	**Mvt**	**Loss**					
Land use with impervious cove	IMP		TR					
Loss of forests	FL							
Loss of depressional wetlands								
○ Urban land use		UW						
○ Rural/ag land use		RW						
Loss of stream/storage								
○ Unconfined		UDS						
○ Moderately confined		MDS						
Reduction in recharge from Land use		DR						
Road density		D_RD						
Well density		D_WEL						
Stream discharge		STD						
Wetland discharge		WD						
NSPECT - Degradation				**Sediment**	**Phosphorus**	**Metals (Zinc, Copper)**	**Nitrogen**	**Pathogens**
Relative Degradation 1 = maximum level of degradation, 0 = no increase in load due to degradation to LU				WRIA_nmusl PS_nmusle	WRIA_ntpco PS_ntpconc	W_mecon PS_Mecon	WRIA_ntnco PS_ntnconc	WRIA_npath PS_npath
Rank - Relative rank among compairson area(PS/WRIA), 1 = AU with lowest change				WRIA_MUSLE PS_MUSLE_R	WRIA_TP_Rn PS_TP_Rnk	W_Me_Rnk PS_Me_Rnk	WRIA_TN_Rn PS_TN_Rnk	WRIA_Path_ PS_Path_Rn
Qrtl - Ranked values group in quartiles (1= lowest values)				WRIA_MUS_1 PS_MUSLE_Q	WRIA_TP_Qr PS_TP_Qrtl	W_Me_Q S_Me_Q	WRIA_TN_Qr PS_TN_Qrtl	WRIA_Path_1 PS_Path_Qr

Water Flow Analyses

Methods for mapping important areas for water flow and export potential for water quality are based upon the relationships described in Appendices B and C. You can map these areas using a suite of GIS analyses with regionally available datasets. We provide details for conducting the analyses in the subsequent discussion.

Important Areas to Water Flow

The "Importance" sub-model is based on an assessment of the physical characteristics that control the natural performance of each watershed process in its unaltered state without any consideration of land-use changes or human modifications. Thus, "*important areas*" for water flow have characteristics that maintain one (or more) of the key watershed processes (delivery, surface storage, recharge, discharge). Figure D-30 shows the mathematical relationship between the sub-models of the watershed process and the overall scoring for the model. There is no weighting assigned to any one sub-model, so each has a value of one with a final calculation of three for the entire model.

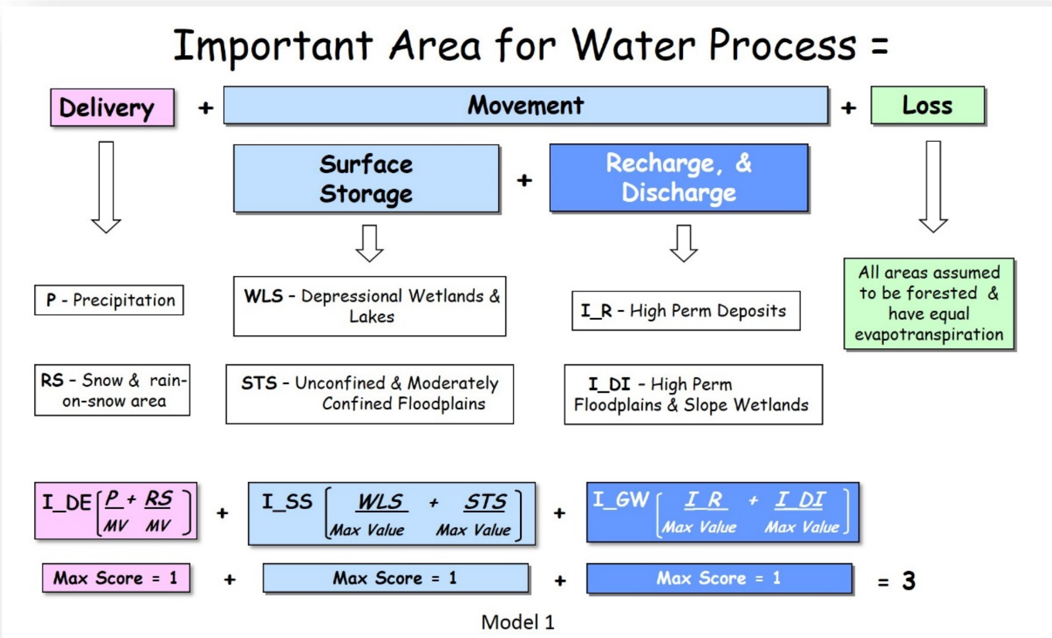


Figure D-30. Equation for calculating the importance for water flow.

The details of the model are explained in Appendix B. This appendix will focus on the GIS methods for this calculation. As described in the section on *'Landscape Groups'*, importance models are comparing natural landscape conditions, so we keep the comparison among AUs within a particular landscape group (LG_M1).

Table D-5: GIS analyses for variables for important areas for the water flow**.** These variables are appropriate for use in Western Washington. The column to the right lists the feature class where the field is located. Yellow fields are raw data, blue are summary calculations, and orange are final quantile groups.

MODEL 1 Important Areas for Water Flow by LG (Landscape Group)		Field	Calculation	Values	Max	Description	Model/ Feature Class
		AU_ID	ID number			Analysis Unit ID number	AU
		LG_M1	landscape groups for Model 1			Landscape Group (C-Coastal, L-Lowland, M-Mountainous, D- Delta, LK- Lake)	AU
		LG_M2	no groups for Model 2 except Urban			**X - All, U - urban AU's (>90% area in urban LC (2-5)**	AU
		acres	sum area in AU	acres		acres in AU	AU
		sqmi	acres / 640	miles		sq mi in AU	AU
Delivery	Precipitation	av_prec	sum [precip x (p_ac/Au acres)]	inches		average precipitation in inches for AU (per year)	WF_DB1
		P	av_prec / max value BY LG_M1	%	1	value for **Precipitation**	WF_M1
	Timing of Precip	SRS_ac	sum area	acres		acres of AU in snow dominated (SD, 'highlands' HL) & rain-on-snow (ROS)	WF_DB1
		SRS_pct	SRS_ac / acres	%		% cover for rain-on-snow & snow dominated zone	WF_DB1
		RS	SRS_pct / max value BY LG_M1	%	1	value for PRECIP TIMING from **Rain on Snow**	WF_M1
		IDE	**P + RS**	0-2	0-2	sum of DElivery	WF_M1
	DELIVERY	***I_DE***	**IDE** / max value BY LG_M1, ***AND D = 1***	0-1	**1**	**NORMALIZE DELIVERY BY LG_M1 - Delta (LG_M1) = 1**	WF_M1
		I_DE_Q	*quantile ranking* ***AND D = H***			**Delta (LG_M1) = High; always overrides actual model results**	WF_RP
Movement	Surface Storage	dpwt_ac	sum area	acres		**all depressional wetlands (hydric, NWI, LC_wet, marsh on ≤2% slop**	WF_DB1
		dpwt_pct	dpwt_ac / acres (in AU)	%		percent of **all depressional** wetlands	WF_DB1
		lk_ac	sum area	acres		lake acres in AU (WB_CART_FT = 421 - ps_waterbodies layer)	WF_DB1
		lk_pct	lk_ac / acres	%		% of lake acres in AU	WF_DB1
		wt_lk	dpwt_pct + lk_pct	%		sum of storage percent from wetlands and lakes	WF_M1
		WLS	wt_**lk** / max value BY LG_M1	%	1	value for **Wetland/Lake Storage**	WF_M1
		uc_mi	sum length	miles		**mi**les of **UN** confined floodplain/streams	WF_DB1
		mc_mi	sum length	miles		**mi**les of **M**oderately **C**onfined floodplain/streams	WF_DB1
		UNSS	(uc_mi / sqmi) x 3	%		area value for **UN**confined floodplain/**S**tream **S**torage	WF_M1
		MCSS	(mc_mi / sqmi) x 2	%		area value for **M**oderately **C**onfined floodplain/**S**tream **S**torage	WF_M1
		UN_MC	UNSS + MCSS	%		sum of **UN**confined & **M**oderately **C**onfined stream storage	WF_M1
		STS	UN_MC / max value BY LG_M1	0-1	1	value for **ST**ream **S**torage	WF_M1
		ISS	**WLS + STS**	0-2	2	sum of **S**urface **S**torage	WF_M1
	STORAGE	***I_SS***	**ISS** / max value BY LG_M1, ***AND D=1***	0-1	**1**	**NORMALIZE SURFACE STORAGE BY LG_M1, Delta = 1**	WF_M1
		I_SS_Q	*quantile ranking* ***AND D = H***			**Delta (LG_M1) = High**	WF_RP

Table D-5 (cont.): GIS analyses for variables for important areas for the water flow.

	MODEL 1	Field	Calculation	Values	Max	Description	Model/ Feature Class
Movement	Recharge	PermH	sum area	acres		acres of AU in high/moderate permeable deposits (geology - coarse grain: alluvial, outwash) (gunit - geo_hp = 'Hperm')	WF_DB1
		PermL	acres - PermH	acres		acres for low perm - geology- fine grained (bedrock, till, etc)	WF_DB1
		rechH	[(aver_prec x .838) - 9.77] x PermH	in/ac/yr		estimated recharge value in high perm deposits (inches/acre/yr)	WF_M1
		rechL	[(aver_prec x .497) - 5.03) x PermL	in/ac		recharge value in low perm deposits	WF_M1
		IR	(rechH + rechL) / acres	inches		value for total **recharge in inches** (per year)	WF_M1
		I_R	IR / max value BY LG _M1, ***AND D = 1***	0-1	1	**NORMALIZE RECHARGE BY LG_M1, Delta = 1**	WF_M1
		I_R_Q	*quantile ranking* ***AND D = H***			**Delta (LG_M1) = High**	WF_RP
	Discharge	ucHp_mi	sum length	miles		miles of Unconfined streams in High perm deposits	WF_DB1
		ucHp_area	ucHp_mi / sqmi	%		area value within AU for Unconfined streams in High perm deposits	WF_DB1
		SD	ucHp_area / max value BY LG_M1	0-1	1	value for UNconfined floodplain/**Stream Discharge**	WF_M1
		slpwt_ac	sum area	acres		acres of slope wetlands >2% (compliment to depressinal wetlands ≤2% slope)	WF_DB1
		slpwt_pct	slpwt_ac / acres	%		% of AU with slope (.2%) wetland	WF_DB1
		SWD	slpwt_pct / max value BY LG_M1	0-1	1	value for **slope wetland discharge** areas	WF_M1
		IDI	**SD + SWD**	0-2	2	sum of **DI**scharge	WF_M1
		I_DI	IDI /max value BY LG_M1	0-1	1	**NORMALIZE DISCHARGE BY LG_M1, Delta = 1**	WF_M1
		I_DI_Q	*quantile ranking*			**Delta (LG_M1) = High**	WF_RP
	GROUNDWATER	*IGW*	**I_R + I_DI**	0-2	2	sum of **G**round**W**ater model 1	WF_M1
		I_GW	**IGW** / max value BY LG_M1	0-1	**1**	**NORMALIZE GROUNDWATER BY LG_M1**	WF_M1
		I_GW_Q	*quantile ranking*			**Delta (LG_M1) = High**	WF_RP
Model 1		*WF_M1*	I_DE + I_SS + I_GW	0-3	**3**	**SUM OF NORMALIZED SCORES FOR MODEL 1 ACROSS ALL AU's**	WF_M1
Model 1 by LG		*WF_M1_LG*	**WF_M1 / max value BY LG_M1**	0-1	**1**	**NORMALIZE SCORES FOR MODEL 1 BY EACH LG_M1**	WF_M1
		WF_M1_CAL	**WF_M1_LG shifting all values to zero to one scale**	0-1	**1**	**CALIBRATE DATA RANGE TO ZERO TO ONE (1) FOR MANAGEMENT UNITS - for each LG, subtract lowest value from highest, then divide all values by highest remaining value**	WF_M1
Overall Importance Quantile		**WF_M1_Q**	**Model 1 - Importance for Water Flow BY LG_M1** ***AND D = H***		**H, MH M,L**	**WF_MI_CAL - BY QUANTILES**	WF_RP

Model 1 = (P + RS) N + (WLS + STS) N + (I_R + I_DI) N --> CALIBRATE VALUES FROM ZERO TO ONE

WF_M1 = I_DE + I_SS + I_GW = 3

Details of analyses for important areas

This section describes the GIS methods for the main indicator included in Table D-5 in the order listed. The transformation steps of the model to return all values to a standard scale for ranking and grouping are self-explanatory and not additionally described here.

- Average precipitation (av_prec):
  Precipitation isohyets are overlain with the AU boundaries to determine the average precipitation value for the AU measured in inches per year.

- Rain-on-snow and snow dominated zones (SRS_pct):
  This layer represents the areas where the timing to the delivery of precipitation is most prominent – those prone to rain-on-snow events, and areas important for providing base flow in late summer to streams in lower elevations. Areas of rain-on-snow and snow dominated zones are overlain with the AU boundaries to determine the percent cover of the AU.

- Depressional Wetlands (dpwt_pct):
  This layer is an estimate for potential wetland areas, including both existing and potential historic wetland extent, by using hydric soils from NRCS soil surveys. There is good correlation between areas with 2% slope or less that have hydric soils, according to the NRCS soil survey, and known potential depressional wetlands. Overlay of area results in the percent wetland coverage for the AU.

- Lakes (lk_pct):
  The National Hydro Data was used to estimate the percent of lake area within an AU.

- Unconfined channels (UNSS):
  In most watersheds of the Puget Sound region, the SSHIAP (Salmon and Steelhead Habitat Inventory and Assessment Program) has developed data layers describing the confinement of stream segments. Stream segments classified as 'unconfined' are summed by length, divided by the square miles of the AU, and multiplied by three to represent a greater storage effect than the moderately confined streams. This indicator identifies AUs likely to have floodplains that provide more surface water storage.

- Moderately confined channels (MCSS):
  Stream segments classified as 'moderately unconfined' (SSHIAP) are summed by length, divided by the square miles of the AU, and multiplied by two to represent a smaller storage effect than the unconfined streams.

- Permeability and recharge (rechH, rechL):
  Permeability is used as an indicator of relative recharge capability. We assign low or high permeability classes to each of the deposits in the surficial geology layer (Table D-19) to get acres of each within the AU. We use the relationships from Vaccaro et al. 1998 to estimate the recharge value for the high and low permeability areas in inches per acre per year.

  [(aver_prec x .838) – 9.77] x PermH ….and... [(aver_prec x .497) – 5.03] x PermL

  Some general guidance on interpreting geologic maps is outlined in Table B-2, but there are inconsistencies and nuances of these maps that are clarified below. Furthermore, the relationships between a geologic type and its permeability should be reviewed by a geologist with local knowledge.

  Typically the geologic types need to be grouped into a more simplified classification scheme. Below are some assumptions or points of clarification that may be useful for initially classifying the type and then the permeability of surficial geologic deposits:
  - Alluvium and recessional outwash are generally of high permeability.
  - Till, moraines, organic deposits, lacustrine, glacial marine drift, mudflows, fine alluvium, and bedrock are generally of low permeability.
  - Advanced outwash can be of moderate permeability, but it may be locally overridden with glacial till (advanced outwash was deposited in front of the glacier and was often subsequently covered with glacial ice). In this instance, permeability should be low since the till layer intercepts percolating water first.
  - Areas of glacial marine drift are sometimes included within areas mapped as glacial outwash. Given its extremely low permeability, you should map glacial marine drift areas separately and assign them to the low permeability class.
  - Sometimes the geologic mapping is quite coarse. Because soils are derived from the underlying surficial deposit, soil data can be used to subdivide geologic classes that are quite broad. However, a geologist should review this information since the accuracy of soil data can vary greatly across the Puget lowlands.

- Stream discharge (ucHp_area):
  A combination of unconfined streams in areas of higher permeability are used as an indicator of stream discharge potential.

- Slope wetland discharge (slpwt_pct):
  The relative amount of slope wetlands, measured as the percent of an AU with wetlands on greater than 2% slope, is another indicator of discharge potential.

Degradation to Water Flow

The "degradation" sub-model is based on an assessment of the indicators of human activity that alter the natural performance of each watershed process. Figure D-31 shows the mathematical relationship between the sub-models of the watershed process and the overall scoring for the model. There is no weighting assigned to any one sub-model, so each has a value of one with a final calculation of four for the entire model.

Methods for mapping degradation to the important areas for each watershed process are based upon the relationships described in Appendices B and C. You can map the indicators of these impairments using a suite of regionally available datasets. We provide details for conducting the analysis in the subsequent discussion and describe each analysis in the order seen in Table D-6.

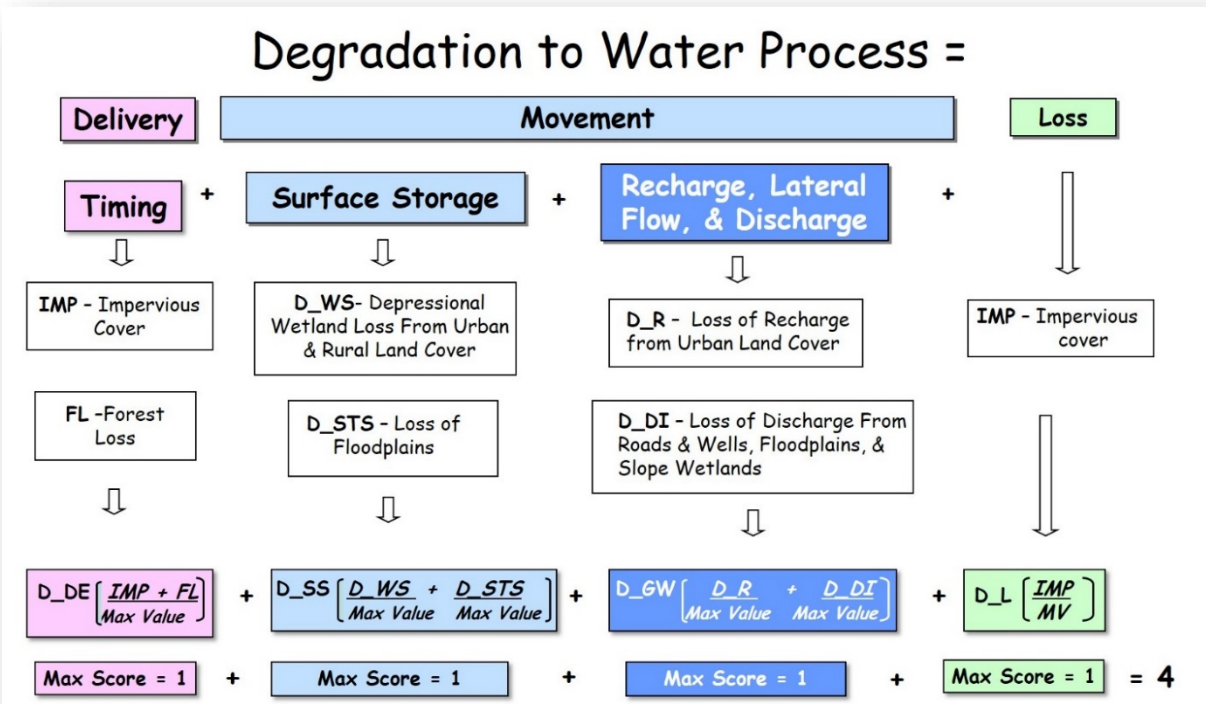


Figure D-31. Equation for calculating the degradation to water flow.

The details of the model are explained in Appendix B. This appendix will focus on the GIS methods for this calculation. Because degradation is a comparison of the amount of change from human activity, and is not determined by the natural character of the landscape, we do not use landscape groups in these analyses (LG_M2).

Table D-6: GIS analyses for variables for degradation to the water process. These variables are appropriate for use in Western Washington. The far right column lists the Feature Class where the field is located. Yellow fields are raw data, green are summary calculations, and orange are final quantile groups.

MODEL 2 Degradation to Water Flow (Not by LG, but by LG_M2, which is Urban or Not Urban)	LG_M2 - all AU's are 'X', except those with >90% area in 'urban' landcover [LC = (2-4) high, medium, & low intensity developed, and (5) developed open space], (imp_pct >.90), then LG_M2 = "U"; they all get calc'd to 1 or High for degradation					
	Field	**Calculation**	**Values**	**Max**	**Description**	**Model/ Feature Class**
	LC_ac	sum area	acres		**acres in AU for Forest Loss calculation [minus areas in snow/ice(25) & water(21); AND minus bare land(20), grassland(8), and scrub shrub(12) that are WITHIN EXCLUDED federal lands (02-National Park, 03-FS Wilderness, 07-FS Recreation) ("EXCLUDE" = 'X')**	WF_DB2
	LC_sqmi	sq miles	miles		from 'sqmi' in WF_DB1	WF_DB2
DELIVERY	imp_ac	sum area	acres		acres of urban area in AU (>20% impervious per pixel: LC value = **2-5**)	WF_DB2
DELIVERY	imp_pct	imp_ac / LC_ac	%		% of urban (indicator of impervious) area in AU	WF_DB2
DELIVERY	***IMP***	imp_pct / max value BY LG_M2	0-1	**1**	normalize value for urban (indicator of impervious) surface	WF_M2
DELIVERY	**for_ac**	sum area	acres		current forest land (LU_CD = **9**-deciduous, **10** - evergreen, **11** - mixed, **13** - forested wetland)	WF_DB2
DELIVERY	fl_pct	**1** - (for_ac / **LC_ac**)	%		percent of loss of forest within AU	WF_DB2
DELIVERY	***FL***	fl_pct / max value by LG_M2	0-1	**1**	normalize value for forest loss	WF_M2
DELIVERY	***DDE***	**IMP + FL**	0-2	**2**	sum of DElivery	WF_M2
DELIVERY	***D_DE***	DDE / max value by LG_M2, *AND U = 1*	0-1	**1**	**NORMALIZE DELIVERY BY LG_M2 (Urban = High)**	WF_M2
DELIVERY	*D_DE_Q*	*quantile ranking AND U = H*			**Urban (LG_M2) = High; always overrides actual model results**	WF_RP
DELIVERY	***DE_RP***	*I_DE_Q & D_DE_Q*			*Restoration_Protection for Delivery*	WF_RP
Movement – Surface Storage	w_ur_ac	sum area	acres		acres of depressional Wetlands degraded by URban (value = **2-5**) land cover	WF_DB2
Movement – Surface Storage	***UW***	(w_ur_ac / **acres**) x 3	0-3		value for depressional Wetlands degraded by Urban land cover	WF_M2
Movement – Surface Storage	w_ru_ac	sum area	acres		acres of depressional Wetlands degraded by RUral / ag (value = **6,7,8**) land cover (outside of protected areas)	WF_DB2
Movement – Surface Storage	***RW***	(w_ru_ac / **acres**) x 2	0-2		value for depressional WETlands degraded by RUral / ag	WF_M2
Movement – Surface Storage	*DW*	**UW + RW**			sum for Degraded Wetlands (urban & rural)	WF_M2
Movement – Surface Storage	***D_WS***	DW / max value BY LG_M2	0-1	**1**	normalize value for DEGRADATION TO WETLAND STORAGE	WF_M2
Movement – Surface Storage	uc_alt_mi	sum length	miles		miles of degraded (altered LU value = **2-5 [urban]; AND LU value = 6-8 [rural]** outside of protected areas) UNconfined streams	WF_DB2
Movement – Surface Storage	mc_alt_mi	sum length	miles		miles of degraded (altered LU value = **2-8**) Moderately Confined streams, (outside of protected areas)	WF_DB2
Movement – Surface Storage	***UDS***	(uc_alt_mi / sqmi) x 3	0-3		value for Unconfined Degraded Streams	WF_M2
Movement – Surface Storage	***MDS***	(mc_alt_mi / sqmi) x 2	0-2		value for Moderately confined Degraded Streams	WF_M2
Movement – Surface Storage	***DST***	**UDS + MDS**			sum for Degraded Streams	WF_M2
Movement – Surface Storage	***D_STS***	DST / max value BY LG_M2	0-1	**1**	value FOR DEGRADATION TO STREAM STORAGE	WF_M2

Table D-6 (cont.) GIS analyses for variables for degradation to the water process.

		Field	Calculation	Values	Max	Description	Model/ Feature Class
Movement		DSS	D_WS + D_STS	0-2	2	sum of Degradation to Surface Storage	WF_M2
	STORAGE	D_SS	DSS / max value BY LG_M2, AND U = 1	0-1	1	NORMALIZE DEGRADATION TO SURFACE STORAGE	WF_M2
		D_SS_Q	quantile ranking AND U = H			Urban (LG_M2) = High; always overrides actual model results	WF_RP
		SS_RP	I_SW_Q & D_SW_Q			Restoration_Protection for Surface Water	WF_RP
	Recharge	u_ac	sum acres x .9	ac		urban acres (LC value = 2)	WF_DB2
		bu_ac	sum acres x .7	ac		built up acres (LC value = 3)	WF_DB2
		li_ac	sum acres x .35	ac		low intensity acres (LC value = 4)	WF_DB2
		RRC	(u_ac + bu_ac + LI_ac) / acres	%		reduction recharge coefficient	WF_M2
		DR	RRC x IR (% x inches)	inches		score for Degraded Recharge - amount of precip reduced in inches across the unit	WF_M2
		D_R	DR / max value by LG_M2, AND U = 1	0-1	1	value for DEGRADATION TO RECHARGE	WF_M2
		D_R_Q	quantile ranking AND U = H			Urban (LG_M2) = High; always overrides actual model results	WF_RP
		R_RP	I_R_Q & D_R_Q			Restoration_Protection for Recharge	WF_RP
Movement	Discharge & Lateral Sub-surface Flow	rd_mi	sum road length	miles		total road miles per AU	WF_DB2
		rd_den	rd_mi / sqmi	%		density of road miles per AU	WF_DB2
		D_RD	rd_den / max value BY LG_M2	0-1	1	value for Degradation from RoaDs	WF_M2
		well_cnt	sum number of well connections	number		number of A & B type well connections (Dept. of Health well data base)	WF_DB2
		well_den	well_cnt / sqmi	density		number of well connections per unit area	WF_DB2
		D_WEL	well_den / max value BY LG_M2	0-1	1	value for DEGRADATION from WELL density in AU	WF_M2
		ucHp_u	sum stream length	miles		Unconfined stream miles in High perm areas in Urban land cover (LC value = 2-5)	WF_DB2
		UUS	(ucHp_u / sqmi) x 3	0-3		value for degradation to Unconfined Urban Streams	WF_M2
		ucHp_r	sum stream length	miles		Unconfined stream miles in High perm in Rural land cover (LC value = 6-8) (outside of protected areas)	WF_DB2
		URS	(ucHp_r / sqmi) x 2	0-2		value for degradation to Unconfined Rural Streams	WF_M2
		STD	UUS + URS			sum of STream Discharge	WF_M2
		D_STD	STD / max value BY LG_M2	0-1	1	value for Degradation to STream Discharge by land cover	WF_M2
		slpw_u	sum area of slpwet_ac intersect with urban	acres		urban LC on slope wetlands (>2%) (LC value = 2-5)	WF_DB2
		SWU	(slpw_u / acres) x 3	%	0-3	value for Slope Wetlands in Urban LC	WF_M2
		slpw_r	sum area of slpwet_ac intersect with rural	acres		rural LC on slope wetlands (>2%) (LC value = 6-8) (outside of protected areas)	WF_DB2
		SWR	(slpw_r / acres) x 2	%	0-2	value for Slope Wetlands in Rural LC	WF_M2
		WD	SWU + SWR			sum for Wetland Discharge	WF_M2
		D_WD	WD / max value BY LG_M2	0-1	1	value for Degradation to Wetland Discharge (hydric slopes)	WF_M2

Table D-6 (cont.) GIS analyses for variables for degradation to the water process.

		Field	Calculation	Values	Max	Description	Model/ Feature Class
		DDI	D_RD + D_WEL + D_STD + D_WD	0-4	4	sum for DIscharge	WF_M2
		D_DI	DDI / max value BY LG_M2, AND U = 1	0-1	1	Degradation to DIscharge from loss of wetland, streams, and wells to LC	WF_M2
		D_DI_Q	quantile ranking AND U = H				WF_RP
		DI_RP	L_DI_Q & D_DI_Q			Restoration_Protection for Discharge	WF_RP
		DGW	D_R + D_DI	0-2	2	sum of GroundWater model 2	WF_M2
	GROUNDWATER	D_GW	DGW /max value BY LG_M2, AND U = 1	0-3	1	NORMALIZE DEGRADATION TO GROUNDWATER	WF_M2
		D_GW_Q	quantile ranking AND U = H				WF_RP
		GW_RP	L_GW_Q & D_GW_Q			Restoration_Protection for Groundwater	WF_RP
Loss	Transpiration	TR	imp_pcnt	%		loss of transpiration from loss of forest	WF_M2
		D_L	imp_pcnt / max value BY LG_M2, AND U = 1	0-1	1	NORMALIZE LOSS OF ET	WF_M2
Model 2		WF_M2	D_DE + D_SS + D_GW + D_L	0-4	4	SUM OF NORMALIZED SCORES FOR MODEL 2 ACROSS ALL AUs	WF_M2
Model 2 by LG		WF_M2_LG	WF_M2/ max value BY LG_M2	0-1	1	SCORES FOR MODEL 2	WF_M2
		WF_M2_CAL	WF_M2_LG shifting all values to zero to one scale	0-1	1	CALIBRATE DATA RANGE TO ZERO TO ONE (1) FOR MANAGEMENT UNITS – for each LG, subtract lowest value from highest, then divide all values by highest remaining value	WF_M2
Overall Degradation Quantile		WF_M2_Q	Model 2 - DEGRADATION to Water AND U = H		H, MH, M, L	D_CAL - BY QUANTILES	WF_RP
		Model 2 (WF_M2) = (IMP + FL) N + [(D_WS + D_STS) N] + [(D_R + D_DI) N] + (D_L)					
		WF_M2 = D_DE + D_SS + D_GW + D_L = 4					
Management Matrix		WF_RP	Synthesis - Protection/ Restoration Matrix			COMBINATION OF WF_M1_Q (by LG's) & WF_M2_Q (no LG's) Using Management Matrix	WF_RP

Details of analyses for degradation

The transformation steps of the model to return all values to a standard scale for ranking and grouping are self-explanatory and not additionally described here.

- Land use with impervious cover (imp_pct):
  Table D-7 shows the common land use categories and associated estimates of percent effective imperviousness. CCAP categories of 2-5 were used to indicate the relative area of urban land within the AU with at least an imperviousness of 20% per pixel. These categories are high, medium, and low intensity developed, and developed open space respectively.

Table D-7: Land use category and corresponding % effective impervious area (from Booth and Jackson 1997)

Land use Category	% Effective Impervious Area (EIA)
Low density residential (1 unit / 2-5 acres)	4
Medium density residential (1 unit / acre)	10
Suburban density (4 units / acre)	24
High density (multi-family or 8 units / acre)	48
Commercial and industrial	86

- Non-forest vegetation or land cover (fl_pct):
  Current forest loss is represented by the inverse of current forest land cover relative to the area of the AU. Forest types used include CCAP categories 9-13, representing deciduous, evergreen, mixed, and forested wetlands.

- Loss of area in depressional wetland (UW, RW):
  To obtain a relative estimate of the amount of wetland area lost, we use a current/potential wetland layer overlaid with urban (CCAP categories 2-5) and rural (CCAP categories 6-8) land cover. An estimate of the potential wetland area can be achieved by using a combination of hydric soils on slopes of less than 2%, along with any current wetland identified through the NWI or land cover data. Then intersect with current urban and rural land cover pixels. Depressional wetlands have likely been lost anywhere these two layers intersect. Multipliers of 3 and 2 are used to represent the higher level of degradation assumed to occur between the urban and rural wetlands respectively.

- Degraded stream storage (UDS, MDS):

Streams with unconfined and moderately confined floodplains and adjacent to urban or rural/agricultural land will have a greater relative degree of degradation than streams with natural land cover. Unconfined and moderately confined streams from the SSHIAP data layer are intersected with CCAP urban and rural land cover. Multipliers of 3 and 2 are used to represent the higher level of degradation assumed to occur between the urban and rural streams respectively.

- Degradation to recharge (DR):
  Various levels of development intensity reduce the quantity of recharge. In Western Washington these reductions were found to be the following: high intensity urban, 90%, built up areas, 75%, low intensity urban, 50% (Vaccaro et al. 1998). We use CCAP land cover classes 2, 3, & 4 respectively to develop a ‘reduction recharge coefficient’ that is then applied to the recharge value (IR) developed in the importance model. The results is an estimate of the reduction in precipitation in inches available for recharge across the unit.

- Road density degradation to discharge (rd_den):
  Road density is an indicator of greater degradation to discharge through alteration of surface and sub-surface flow.

- Well density (wel_den):
  The density of wells can decrease the quantity of water available for discharge through groundwater pumping. The density of wells was determined using Group A and B (greater than and less than 15 connections respectively) wells from the Department of Health well data.

- Degradation to discharge of streams (UUS, URS):
  Unconfined streams in deposits of higher permeability provide a discharge function. Urban and rural land cover near these streams reduces this function. Multipliers of 3 and 2 are used to represent the higher level of degradation assumed to occur between the urban and rural streams respectively.

- Loss of area of slope wetlands (SWU, SWR):
  Relative degradation to slope wetlands is an indicator for degradation to discharge. Potential wetland area on >2% slope is intersected with both urban and rural land cover. CCAP land cover codes are 2-5 for urban and 6-8 for rural. Degradation factors of 3 and 2 are applied to differentiate between the severity of land cover change between urban and rural respectively.

- Loss from transpiration (imp_pct):

The loss of forest is an indicator of loss of transpiration capability. The relative amount of impervious area represented by urban land cover is an indicator for this change.

- <u>Dams:</u>
  The storage capacity of a dam can greatly influence the severity of degradation to timing of surface flow. A separate model was used to determine the relative degradation from a dam to the downstream segments. The degradation is represented by the storage volume of the dam relative to the drainage area of the dam. As the analysis moves downstream the area of additional unregulated runoff downstream of the dam is added to the analysis, which results in a decrease in effect with distance from the dam. See Attachment D-6 for details of this analysis.

Water Flow Synthesis and Map Display

Results from each analysis are displayed in three maps, one for the relative importance to water flow, one for relative degradation to water flow, and the third is a combination of the two showing the management matrix. The blue importance maps and pink degradation maps both show the four buckets of low to high AUs, lighter to darker respectively.

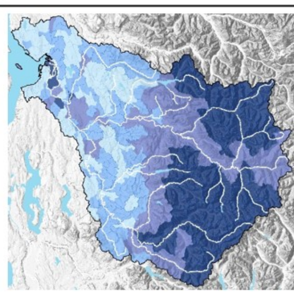
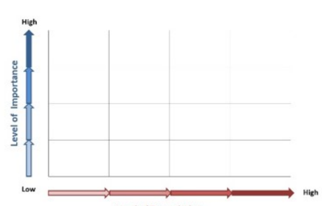
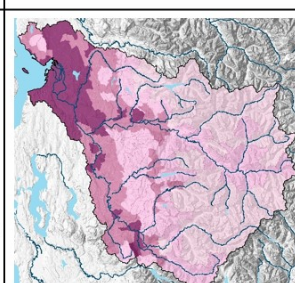
WRIA 7	Importance (WF_M1_Q)		Degradation (WF_M2_Q)
Legend	Highest Importance Moderate High Importance Moderate Importance Low Importance		Highest Degradation Moderate High Degradation Moderate Degradation Low Degradation
Overall Water Flow Results			

Figure D-32. Importance and degradation map display.

As described earlier, the results of both model 1 and model 2, importance and degradation respectively, produce a management matrix with sixteen possible combinations (Figure D-33) that can be used to prioritize management actions. Generally we group these sixteen possibilities into eight management groups for effective display and meaningful understandable appropriate interpretation.

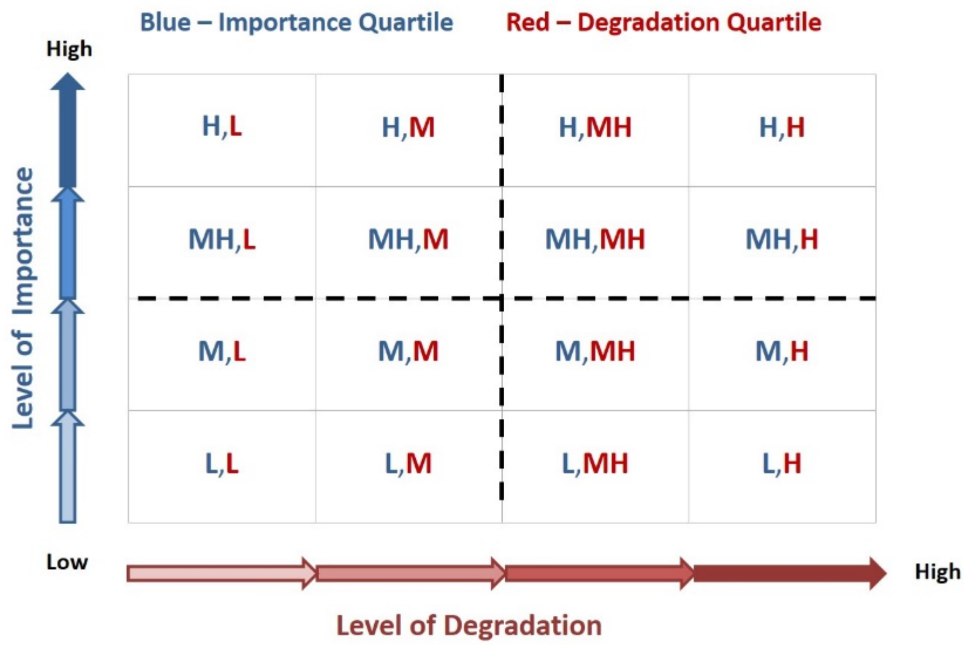


Figure D-33. Sixteen combinations of management results.

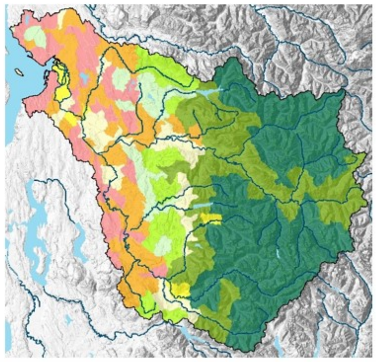
<table>
<tr><th>WRIA 7</th><th>Protection & Restoration</th><th>Management Matrix</th></tr>
<tr><td>Legend</td><td>
</td><td>Sixteen possible combinations grouped into eight for display maps.</td></tr>
<tr><td>Overall Water Flow Results (WF_RP)</td><td></td><td>
</td></tr>
</table>

Figure D-34. Management Matrix using 8 groups**.**

Water Quality Analyses

The water quality analyses follow the same structure as the water flow, with two components that result in a management matrix. For water quality, the export potential model is analogous to the importance model for water flow. The degradation model is the N-SPECT analysis discussed in Appendix C. Five constituents are modeled: sediment, phosphorous, nitrogen, pathogens, and metals (copper & zinc).

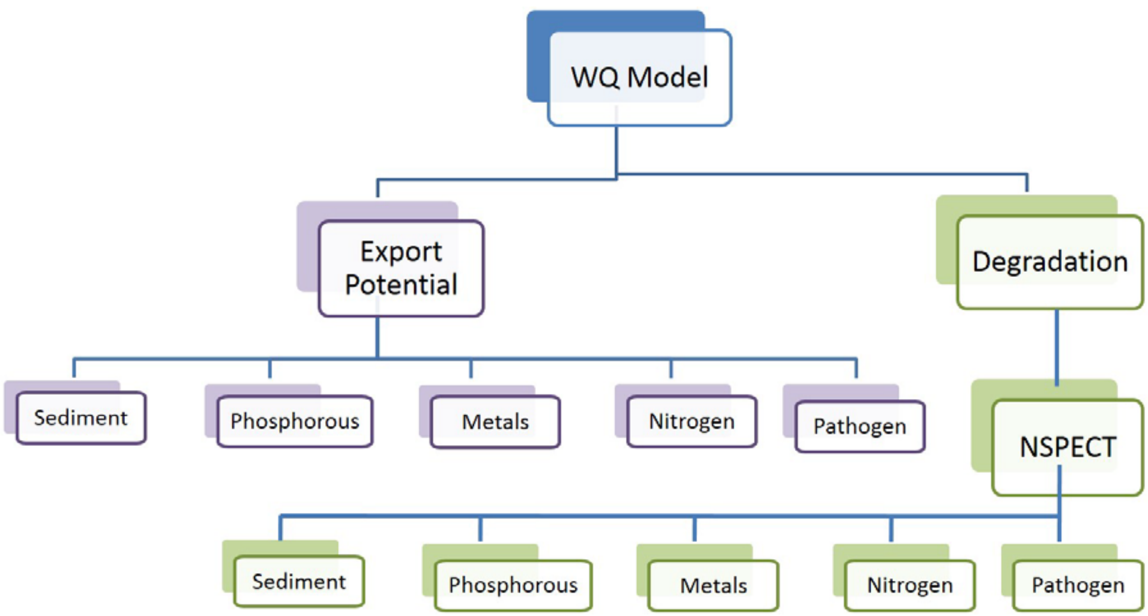


Figure D-35. Water Quality models.

Export Potential of Water Quality Parameters

The export potential models comprise both a 'source' and 'sink' component. The source component represents the delivery and movement of the water quality parameter to the system. The sink component represents the interruption of the pollutant transport, so the difference between the 'source' and 'sink' components is the export potential. These are still a comparison of natural characteristics of the landscape, so the landscape groups are used to compare like areas to each other (LG_M1).

Sediment

The sediment model includes indicators for the three major mechanisms for delivery of sediment to aquatic systems: surface erosion, mass wasting, and channel erosion. Areas that rank higher in indicators of these processes can be expected to have higher export of sediment than others. A sink is an area that temporarily or permanently stores sediment due to low transport capacity.

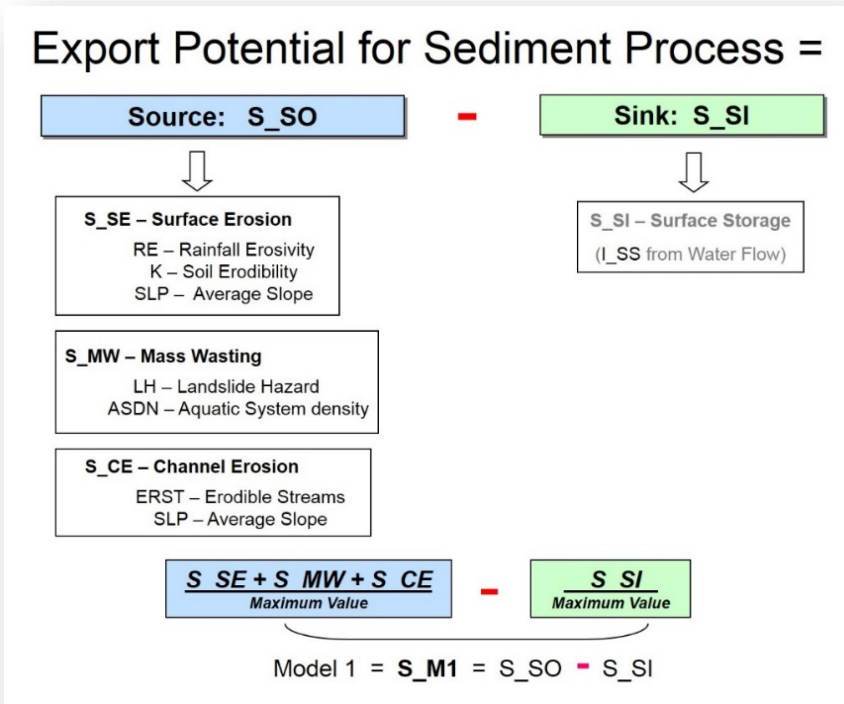


Figure D-36. Export potential for sediment.

Table D-8. GIS analyses for variables for the export potential of sediment.

		Field	Calculation	Values	Max	Description	Model
Analysis of Sediment Export Potential by LG (Landscape Group)		AU_ID	ID number			Analysis Unit ID number	AU
		LG_M1	landscape groups for Model 1			Landscape Group (C-Coastal, L-Lowland, M-Mountainous, D- Delta, LK- Lake)	AU
		LG_M2	**no groups for Model 2**			**X - All, U- urban AU's (>90% urban)**	AU
		acres	acres in AU	acres		acres in AU	AU
		sqmi	acres / 640	sqmiles		sq mi in AU	AU
		strm_mi	miles	miles		ONLY	WQ_DB
		SDN	strm_mi / sqmi	ratio	1	stream density	WQ_M1
		AS_mi	miles	miles		'Centerline_TYP' = StreamRiver, Artificial Path, Ditch, LakePond)	WQ_DB
		ASDN	AS_mi / sqmi	ratio	1	**Aquatic System Density** for AU	WQ_M1
Sources	Surface Erosion	RE	∑ (R x acres) / AU acres	ratio	1	rainfall erosivity ('R' from SSURGO); average of AU	WQ_DB
		K	∑ (K x acres) / AU acres	ratio	1	soil erodibility (average of AU)	WQ_DB
		SLP	average slope of AU from 10M DEM	0-1	1	topography - mean hillslope gradient of AU	WQ_DB
		SE	RE x K x SLP	0-3	3	rainfall erosion value	WQ_M1
		S_SE	**SE / max value by LG_M1**	ratio	1	Surface Erosion	WQ_M1
	Mass wasting	LH	landslide hazard rating; average LH for AU	1,2,3	3	aver slope stability value from Shaw Johnson model 1-3, low to high	WQ_DB
		MW	LH x ASDN	ratio		landslide hazard rating	WQ_M1
		S_MW	MW / max value BY LG_M1	ratio		value for Mass Wasting	WQ_M1
	Channel Erosion	ERST_mi	geology value = 1 for analysis	miles		miles of stream intersecting erodible geology type	WQ_DB
		ERST	ERST_mi / strm_mi	ratio		miles of stream intersecting erodible geology type	WQ_M1
		CE	SLP x ERST			Channel Erosion	WQ_M1
		S_CE	CE / max value by LG_M1	ratio	1	normalized Channel Erosion	WQ_M1
	Source	*SSO*	S_SE + S_MW + S_CE	ratio	3	sum of Sediment SOurce	WQ_M1
		S_SO	**SSO / max value BY LG_M1**	0-2	0-1	**NORMALIZE SOURCE BY LG_M1**	WQ_M1
		S_SO_Q	*quantile ranking*				WQ_RP
Sink		*S_SI*	I_SS from Water Flow		0-1	**Normalized value for Sediment Sink**	AU_M1
		S_SI_Q	*quantile ranking (from Water Flow)*				WQ_RP
Model 1 Export Potential		*S_M1*	S_SO **-** S_SI		(-1) - 1	**EXPORT POTENTIAL = SOURCE minus SINK**	WQ_M1
Model 1 by LG		*S_M1_LG*	S_M1 / max value BY LG_M1		0-1	NORMALIZE SCORES FOR MODEL 1 BY EACH LG_M1	WQ_M1
		S_M1_CAL	**(S_M1 -/+ lowest value) / max value BY LG_M1**		0-1	**CALIBRATE DATA RANGE TO ZERO TO ONE (1) FOR MANAGEMENT UNITS - for each LG, subtract lowest value from highest (+/- accounts for negative values), then divide all values by highest remaining value**	WQ_M1
Management Units		**S_M1_Q**	**Model 1 - Sediment Sources Minus Sinks BY LG_M1**	**Delta = M**	**H,M H M,L**	**S_M1_CAL - BY QUANTILES**	WQ_RP
		Model 1 = (S_SE + S_MW + S_CE) - (I_SS) --> CALIBRATE VALUES FROM ZERO TO ONE					
		S_M1 =	S_SO **-**	S_SI			

Details of analyses for sediment:

- <u>Potential for surface erosion and delivery to aquatic ecosystems (SE):</u>
  To locate areas that are prone to surface erosion, we used the SSURGO soils data, slope (calculated from a DEM), and 'rainfall erosivity' factor (R) to map areas with the combination of slope and K factor shown in Table D-9.

Table D-9. Slope and K factor combinations as indicators of potential for soil erosion. (WFPB, 1997a)

Slope	K Factor		
	<0.25	0.26-0.4	>0.4
<30%			
30-65%			
>65%			

- Mass wasting risk areas (MW):
  The output of the Shaw Johnson model for the Puget Sound region shows areas with low, moderate, or high risk of mass wasting events. This model was developed from a combination of slope gradient and form (convex, concave, or planar). This slope stability value and the aquatic system density together predict AUs with a relatively higher probability for mass wasting events and increased soil erosion.

- Channel erosion (CE):
  Slope and erosivity of underlying lithology directly influence the erosive capacity of a channel. The surficial geology layer was coded either a 1 for those units more susceptible to erosion, or a zero for those units more resistant to erosion. The stream layer was overlaid with the surficial geology to calculate the stream miles of these 'erodible streams'. This is converted to a proportion by dividing by the total stream miles, and then multiplied by slope.

- Sediment sink (S_SI):
  Sediment transport is impeded or stopped in lakes, depressional wetlands, and floodplains outside stream channels. Thus, the sink component for sediment is taken as the surface storage component of the water flow process (I_SS).

Phosphorous

Since phosphorus is present in some amount in soil and geological material, it enters water along with sediments through the same sources, surface erosion, mass wasting and in-channel erosion. Therefore, these mechanisms are identical in the Sediment and Phosphorus Processes. A phosphorus enrichment indicator, PE, could be added to the model to distinguish sediments with higher phosphorous content if local data or knowledge is available.

The model indicator for the sink component, is a combination of surface storage from the water flow component (I_SS), and phosphorus retention by soils, SRP, or soil clay content.

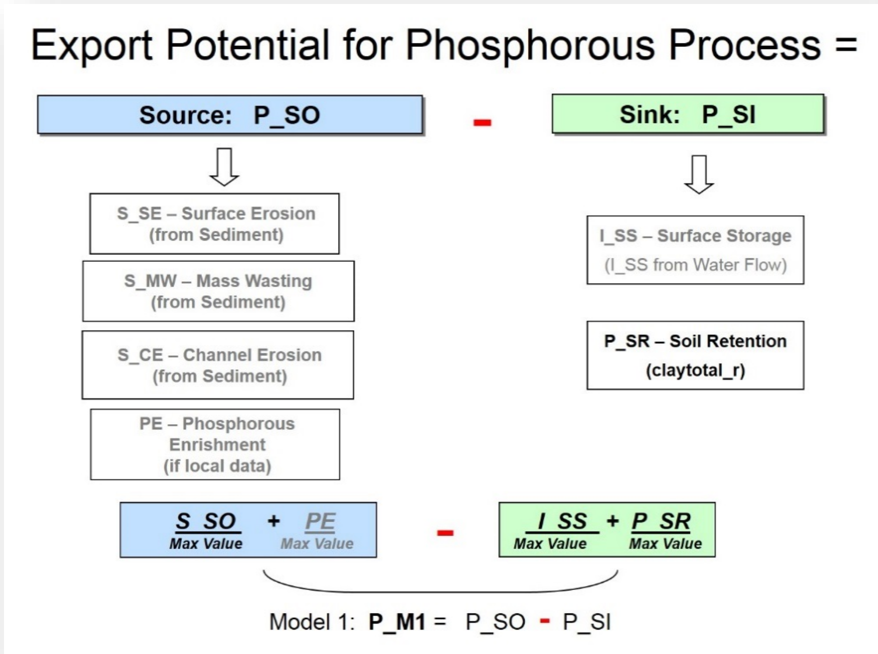


Figure D-37. Model for the Export Potential for Phosphorous**.**

Table D-10. GIS analyses for variables for the export potential of phosphorous.

Analysis of Export Potential of Phosphorus by LG (Landscape Group)		Field	Calculation	values	Max	Description	Data	Model
		AU_ID	ID number			Analysis Unit ID number		AU
		LG_M1	landscape groups for Model 1			Landscape Group (C-Coastal, L-Lowland, M-Mountainous, D- Delta, LK- Lake)		AU
		LG_M2	**no groups for Model 2**			**X - All, U - urban AU's (>90% urban)**		AU
		acres	acres in AU	acres		acres in AU		AU
		sqmi	acres / 640	miles		sq mi in AU		AU
Source	Surface Erosion	RE				rainfall erosivity (from WF Model?); average precip of AU	Rfactor.shp from NW Hydraulics	WQ_DB
		K				soil erodibility	from NW Hydraulics	WQ_DB
		SLP	average slope from 10M dem			topography - mean hillslope gradient	10M DEM	WQ_DB
		SE	RE x K x SLP			rainfall erosion value		WQ_M1
		S_SE	***SE / max value by LG_M1***			Rainfall Erosion		WQ_M1
	Mass wasting	LH	landslide hazard rating			aver slope stability value from Shaw Johnson model 1-3, low to high		WQ_DB
		MW	LH x ASDN			landslide hazard rating		WQ_M1
		S_MW	MW / max value BY LG_M1			value for Mass Wasting		WQ_M1
	Channel Erosion	ERST_mi	geology value = 1 for analysis			miles of stream intersecting erodible geology type		WQ_DB
		ERST	ERST_mi / strm_mi			miles of stream intersecting erodible geology type		WQ_M1
		CE	SLP x ERST			Channel Erosion		WQ_M1
		S_CE	CE / max value by LG_M1			normalized Channel Erosion		WQ_M1
	Phosphorous Enrichment	*CC*	clay content			if local data	local knowledge	WQ_DB
		PC	CC x ASDN			Phosphorus content		WQ_DB
		PE	PC / max value by LG_M1			phosphorous enrichment normalized		WQ_M1
	Total P Source	*PSO*	SSO + PE			**Sediment Source** (+ Phosphorpous Enrichment)		WQ_M1
		P_SO	PSO / max value BY LG_M1	0-2	0-1	NORMALIZE SOURCES BY LG_M1		WQ_M1
		P_SO_Q	*quantile ranking*					WQ_RP

Table D-10 (cont.). GIS analyses for variables for the export potential of phosphorous.

Sink		I_SS	SS / max value BY LG_M1 (from Water Flow)	0-2	0-1	NORMALIZE SURFACE STORAGE/WATER BY LG_M1		WF_M1
		SRP	∑(clay_rnk x area) / AU area			Soil Retention-Phosphorus CLAY_SSURGO - 'clay_rnk' (claytotal_R, SSURGO) clay content >28% = 3 (include peat,muck), 10-28% = 2, <10% = 1	claytotal_r from SSURGO; for data gaps - use soil texture as surrogate (rock outcrop=0, sandy=0-10(1), silt loam or gravel loam =10-28(2), organic soils = >28 or 3)	WQ_DB
		P_SR	SRP / max value by LG_M1					WQ_M1
	Total P Sink	PSI	I_SS + P_SR			Phosphorous Sink		WQ_M1
		P_SI	PSI / max value for LG_M1		0-1	Normalized Importance of Phosphprous Sink		WQ_M1
		P_SI_Q	quantile ranking					WQ_RP
Model 1 EXPORT POTENTIAL		P_M1	P_SO − P_SI		0-1	EXPORT POTENTIAL = SOURCE minus SINK		WQ_M1
Model 1 by LG		P_M1_LG	P_M1 / max value BY LG_M1		0-1	NORMALIZE SCORES FOR MODEL 1 BY EACH LG_M1		WQ_M1
		P_M1_CAL	(P_M1 -/+ lowest value) / max value BY LG_M1		0-1	CALIBRATE DATA RANGE TO ZERO TO ONE (1) FOR MANAGEMENT UNITS – for each LG, subtract lowest value from highest (+/– accounts for negative values), then divide all values by highest remaining value		WQ_M1
Management Units		P_M1_Q	Model 1 - Importance for Sediment Process BY LG_M1	Delta = M	H,M H M,L	P_M1_CAL - BY QUANTILES		WQ_RP
Model 1 = (SSO + PE) − (I_SS + P_SR) --> CALIBRATE VALUES FROM ZERO TO ONE								
			P_M1 = P_SO − P_SI					

Details of analyses for phosphorous:

- Soil Retention of Phosphorous (SRP): From the SSURGO soil data layer, the 'clay_rnk' value indicates the clay content. For clay content > 28%, clay_rnk = 3, for 10-25, clay_rnk = 2, and for <10% clay content, clay_rnk = 1. Peat and muck soils are included in clay_rnk = 3. For areas without data, soil texture is used as a surrogate: rock outcrop = 0, sandy soil of 0-10 = clay_rnk of 1, silt loam or gravel loam of 10-28 = clay_rnk of 2, and organic soils where clay content is > 28% are clay_rnk of 3.

Metals

Overall, natural processes are not considered to be a significant mechanism, relative to human inputs, for delivery of toxic metals to western Washington aquatic ecosystems. Accordingly, metal sources are considered in the degradation model but not the export potential model. However, natural processes do mediate the transport and fate of metals introduced by other sources, thus sink processes are addressed.

The model indicators used to represent the metals sink mechanisms are surface storage and soil retention of metals. Surface storage is the same indicator as for the water flow component, represented by I_SS. For the metals retention by soils (M_SRM), the indicator is the cation exchange capacity of the soil. The attribute field used is 'CEC-7' from the SSURGO database.

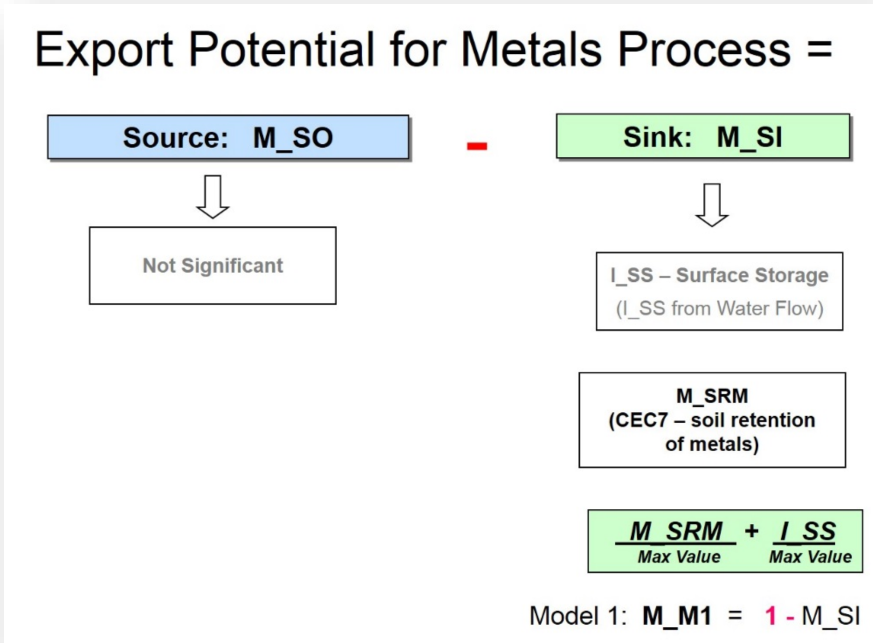


Figure D-38. Model for the Export Potential for Metals.

Table D-11: GIS analyses for variables for the export potential of metals.

Analysis of Export Potential for Metals by LG (Landscape Group)		Field	Calculation	values	Max	Description	Model
		AU_ID	ID number			Analysis Unit ID number	
		LG_M1	landscape groups for Model 1			Landscape Group (C-Coastal, L-Lowland, M-Mountainous, D-Delta, LK- Lake)	
		acres	acres in AU	acres		acres in AU	
		sqmi	acres / 640	miles		sq mi in AU	
Sink	Channel transport	CT	SD			stream density	
		I_CT	SD / max value by LG_M1		0-1	normalized value for terrestrial erosivity	
	Stream storage	STS	from WF model		1-5		
	Lake/ Wetland storage	WLS	from WF model			from WF_Model; sum of Surface Storage (wetlands, lakes, streams)	
		I_SS	SS / max value BY LG_M1	0-2	0-1	NORMALIZE SURFACE STORAGE/WATER BY LG_M1	WF_M1
	Soil Storage	SRM	∑ (CEC7_rnk x area) / AU area			Soil Retention-Metals ; CEC7_SSURGO; 'cec_rnk' ; cation exchange capacity	WQ_DB
		M_SRM	SRM/ max value by LG_M1			NORMALIZE Soil Retention of Metlas	WQ_M1
Sink Value		MSI	M_SRM + I_SS		0-2	SUM OF NORMALIZED SCORES FOR MODEL 1 ACROSS ALL AU's	WQ_M1
		M_SI	MSI / max value BY LG_M1		0-1	NORMALIZE SCORES FOR SINK VALUE BY EACH LG_M1	WQ_M1
Model 1 Export Potential		M_M1	1 - M_SI		0-1	EXPORT POTENTIAL --> REVERSE ORDER - High Sink value = Low Export Potential	WQ_M1
		M_M1_CAL	(M_M1 -/+ lowest value) / max value by LG_M1		0-1	CALIBRATE DATA RANGE TO ZERO TO ONE (1) FOR MANAGEMENT UNITS - for each LG, subtract lowest value from highest (+/- accounts for negative values), then divide all values by highest remaining value	WQ_M1
Management Units		M_M1_Q	Model 1 - Metals Process BY LG_M1		H,MH M,L	M_M1_CAL - BY QUANTILES	WQ_RP
		Model 1 = (M_SRM + I_SS) --> CALIBRATE VALUES FROM ZERO TO ONE					
			M_M1 = 1 - M_SI				

Details of analyses for metals:

- Soil Retention of Metals (SRM):
  The attribute field 'CEC-7' from the SSURGO database provides the cation exchange capacity by soil type at a pH of 7. These values are then grouped into ranks 1-3 according to the table below. The acres for each type within an AU are summed to determine the average value for the AU. This is then normalized by dividing by the maximum value for all the AU's within the landscape group.

Table D-12: CEC rank values.

CEC-7* Values	CEC_rnk
Urban land, beach/dune, rock outcrop, river wash, water	0
> 0 - 10	1
>10 - 28	2
>28 - 175	3

* Cation exchange capacity at pH of 7.

Nitrogen

Overall, natural processes are not considered to be a significant mechanism, relative to human inputs, for production of nitrogen in western Washington aquatic ecosystems. Accordingly, N sources are not considered in the export potential model, but are addressed in the degradation model (N-SPECT). However, natural processes do mediate the transport and fate of nitrogen introduced by other sources, thus sink processes are addressed here.

The principal nitrogen sinks are wetlands, lakes, and riparian areas. Therefore, the modeling is based on the complete complement of wetlands and lakes in an AU, as represented by the Wetland/Lake Storage (WLS) indicator from the Water Flow Process. Riparian area denitrification (N_RDN) is characterized by intersecting the GIS layers for unconfined floodplains and hydric soils. This formulation identifies riparian areas with the highest potential to offer all essential denitrification conditions.

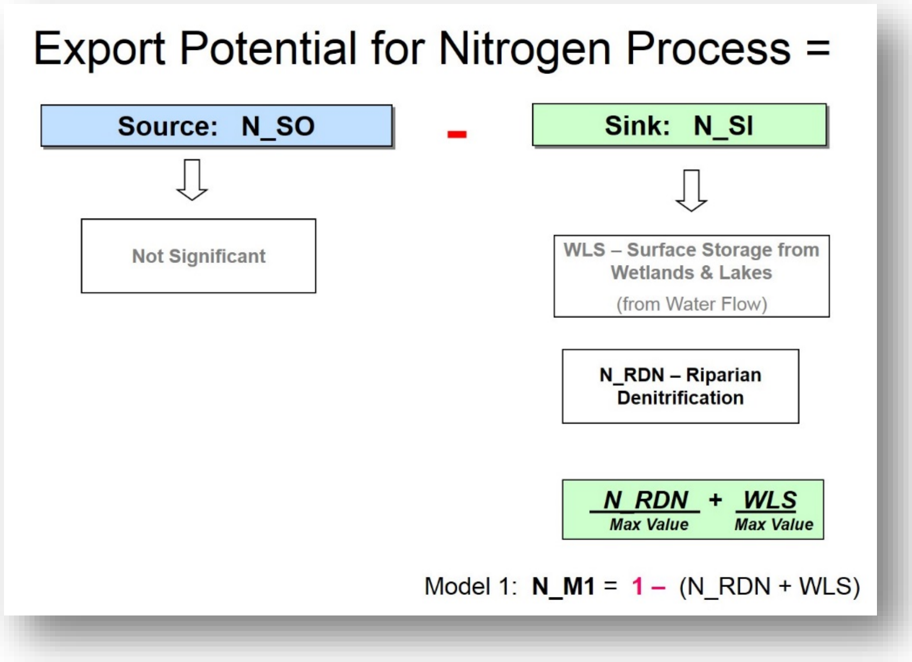


Figure D-39. Model for the Export Potential for Nitrogen.

Table D-13: GIS analyses for variables for the export potential of nitrogen.

Analysis of Sinks for Nitrogen by LG (Landscape Group)		Field	Calculation	Values	Max	Description	Model
		AU_ID	ID number			Analysis Unit ID number	AU
		LG_M1	landscape groups for Model 1			Landscape Group (C-Coastal, L-Lowland, M-Mountainous, D- Delta, LK- Lake)	AU
		acres	acres in AU	acres		acres in AU	AU
		sqmi	acres / 640	miles		sq mi in AU	AU
	Lake/ Wetland storage	*WLS*	from WF model			from WF_Model; sum of Surface Storage (wetlands, lakes, streams)	WF_M1
	Riparian DeNitrification	*RDN_mi*	un_mi & mc_mi in hydric soil_miles			Riparian DeNitrification - floodplains in hydric soils	WQ_DB
		RDN	RDN_mi/ AU sqmi			NORMALIZE Riparian DeNitirification	WQ_M1
		N_RDN	RDN / Max value by LG_M1			NORMALIZE Riparian DeNitirification	WQ_M1
		NSI	N_RDN + WLS		0-2	SUM OF NORMALIZED SCORES FOR MODEL 1 ACROSS ALL AU's	WQ_M1
Sink Value by LG		*N_SI*	NSI / max value BY LG_M1		0-1	NORMALIZE SCORES FOR SINK VALUE BY EACH LG_M1	WQ_M1
Model 1 Export Potential		*N_M1*	1 - N_SI		(-1)-1	EXPORT POTENTIAL --> REVERSE ORDER - High Sink value = Low Export Potential	WQ_M1
		N_M1_CAL	(N_M1 -/+ lowest value) / max value BY LG_M1		0-1	CALIBRATE DATA RANGE TO ZERO TO ONE (1) FOR MANAGEMENT UNITS - for each LG, subtract lowest value from highest (+/- accounts for negative values), then divide all values by highest remaining value	WQ_M1
Management Units		N_M1_Q	Model 1 - Sink for Nitrogen Process BY LG_M1	Delta = M	H,MH M,L	N_M1_CAL - BY QUANTILES	WQ_RP
		Model 1 = (N_RDN + WLS) --> CALIBRATE VALUES FROM ZERO TO ONE					
			(NSI)				
	Export Potential		N_M1 = 1 - N_SI				

Details of analysis for nitrogen:

- Riparian denitrification (RDN):
  Total stream miles categorized as unconfined or moderately confined from the SSHIAP stream layer were intersected with the hydric soils layer from SSURGO. The result is converted to an area based value by dividing by the square miles of the AU. Then the value is normalized by dividing by the maximum value of all AUs.

Pathogens

Overall, natural processes are not considered to be a significant mechanism, relative to human inputs, for production of pathogens in western Washington aquatic ecosystems. Accordingly, pathogen sources are not considered in the export potential model, but are addressed in the degradation (N-SPECT) model. However, natural processes do mediate the transport and fate of pathogens introduced by other sources, thus sink processes are addressed here.

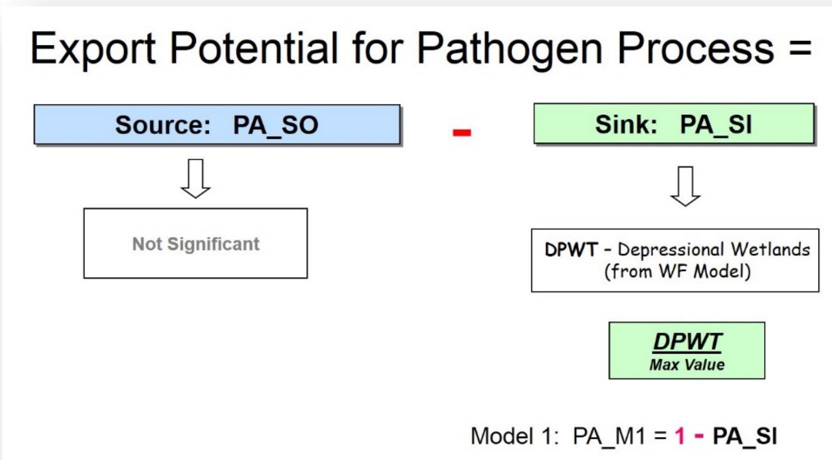


Figure D-40. Model for the Export Potential for Pathogens.

Aquatic ecosystems that allow predation of pathogens to occur over a longer period of time play an important role in eliminating pathogens. Due to their ability to hold water back, depressional wetlands provide longer residence time for surface waters than streams and rivers. Thus, they are unique in furnishing all of the essential conditions and control an AU's role in pathogen mortality to a much greater degree than any other feature.

Table D-14: GIS analyses for variables for important areas for the pathogen process.

		Field	Calculation	values	Max	Description	Model
Analysis of Sinks for Pathogen by LG (Landscape Group)		AU_ID	ID number			Analysis Unit ID number	AU
		LG_M1	landscape groups for Model 1			Landscape Group (C-Coastal, L-Lowland, M-Mountainous, D- Delta, LK- Lake)	AU
		acres	acres in AU	acres		acres in AU	AU
		sqmi	acres / 640	miles		sq mi in AU	AU
Sink	Depressional Wetlands	dpwt_ac	acres (from WF Model)	acres		all depressional wetlands (hydric, NWI, LC_wet, marsh on ≤2% slope)	WF_DB1
		dpwt_pct	dpwt_ac / acres (from WF_Model)	%		percent of all depressional wetlands	WF_DB1
Sink		*PA_SI*	**dpwt_pct / max value by LG_M1**		**0-1**	NORMALIZE SCORES FOR MODEL 1 BY EACH LG_M1	WQ_M1
Model 1 Export Potential		*PA_M1*	**1 - PA_SI**		**(-1) - 1**	EXPORT POTENTIAL --> REVERSE ORDER - High Sink value = Low Export Potential	WQ_M1
		PA_M1_CAL	**(PA_SI -/+ lowest value) / max value BY LG_M1**		**0-1**	CALIBRATE DATA RANGE TO ZERO TO ONE (1) FOR MANAGEMENT UNITS - for each LG, subtract lowest value from highest (+/- accounts for negative values), then divide all values by highest remaining value	WQ_M1
Management Units		**PA_M1_Q**	**Model 1 - Export Potential for Pathogen Process BY LG_M1**	**Delta = M**	**H,MH M,L**	PA_M1_CAL - BY QUANTILES	WQ_RP
		Model 1 = (DPWT) --> CALIBRATE VALUES FROM ZERO TO ONE					
		Export Potential --> PA_M1 = 1 - PA_SI					

Details for analysis for pathogens:

- <u>Depressional wetlands (DPWT_PCT):</u>
  The model indicator is the relative presence of depressional wetlands as quantified in the Water Flow model 1 as dpwt_pct. Acres of depressional wetlands are represented as a percent of the area of the AU.

Degradation of Water Quality Parameters – (N-SPECT)

The Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) examines the relationship between land cover, nonpoint source pollution, and erosion. It uses spatial elevation data to calculate flow direction and flow accumulation throughout a watershed (Puget Sound). Coefficients representing the contribution of each land cover class to the expected pollutant load are also applied to the land cover data sets to approximate total pollutant loads. The output layers display estimations of runoff, pollutant loads, pollutant concentration, and total sediment loads. N-SPECT provided the functionality to compare current land cover conditions with pre-development conditions.

Since degradation is a function of the degree of human alteration to the landscape, these models do not use landscape groups in the calculations (LG_M2). All AUs within the analysis extent can be compared to each other.

Pre-Processing

In order to run N-SPECT, it was necessary to collect input datasets and do some pre-processing of the data.

The first step was to create a new mountain classification within the land cover layer (CCAP- Coastal Change Analysis Program) to allow mountainous bare earth to have different runoff and pollutant export coefficients than lowland bare earth. A conditional statement was used to convert ONLY bare earth ABOVE 2000 feet to the new Mountain Class (26).

Conditional Statement:

$$Con(\mathrm{CCAP} == 20, Con(\mathrm{dem} < 2000, 20, 26), \mathrm{CCAP})$$

The statement reads, "Pixel values that equal 20 at an elevation of less than 2000 feet stay at pixel value 20, above 2000 feet they change to pixel value 26, all other values stay the same".

The second step was to create a pre-development landuse layer that will represent Puget Sound prior to human influences. A conditional statement was used to convert some of CCAP's values to Evergreen Forest (10).

Conditional Statement:

$$Con([CCAP] > 12, Con([CCAP] <> 20, [CCAP], 10), 10)$$

The statement reads, "Pixel values that are greater than 12 stay the same except pixel value 20 which changes to 10. All other values (less than or equal to 12) change to 10".

Table D-15: CCAP land cover reclassification for pre-development land cover.

CCAP	CCAP Pixel value	Pre-Development	Predev pixel value
High Intensity Developed	2	Evergreen Forest	10
Medium Intensity Developed	3	Evergreen Forest	10
Low Intensity Developed	4	Evergreen Forest	10
Developed Open Space	5	Evergreen Forest	10
Cultivated	6	Evergreen Forest	10
Pasture/Hay	7	Evergreen Forest	10
Grassland	8	Evergreen Forest	10
Deciduous Forest	9	Evergreen Forest	10
Evergreen Forest	10	Evergreen Forest	10
Mixed Forest	11	Evergreen Forest	10
Scrub/Shrub	12	Evergreen Forest	10
Palustrine Forested Wetland	13	Palustrine Forested Wetland	13
Palustrine Scrub/Shrub Wetland	14	Palustrine Scrub/Shrub Wetland	14
Palustrine Emergent Wetland	15	Palustrine Emergent Wetland	15
Estuarine Emergent Wetland	18	Estuarine Emergent Wetland	18
Unconsolidated Shore	19	Unconsolidated Shore	19
Non-Mountainous Bare Land	20	Evergreen Forest	10
Water	21	Water	21
Palustrine Aquatic Bed	22	Palustrine Aquatic Bed	22
Estuarine Aquatic Bed	23	Estuarine Aquatic Bed	23
Snow/Ice	25	Snow/Ice	25
Mountainous Bare Land	26	Mountainous Bare Land	26

The third step was to modify the precipitation data to address runoff reduction and pollutant export reduction associated with snowfall or snow cover. A conditional statement was used to reduce runoff (by reducing rainfall) in snow zones by 80%, 60%, and 40% in the rain-on-snow (1), snow-dominated (3), and highland (2) zones.

Conditional Statement: Where ROS is the Rain on Snow dataset and prism24hr2yr is the precipitation dataset for a 24 hour 2 year event.

$$Con([ROS] == 1, 0.8 * [prism24hr2yr], Con([ROS] == 3, 0.6 * [prism24hr2yr], Con([ROS] == 2, 0.4 * [prism24hr2yr], [prism24hr2yr])))$$

The statement reads, “Where pixel values in the Rain on Snow dataset equal 1, multiply Precipitation dataset by 0.8. Where pixel values in the Rain on Snow dataset equal 3, multiply Precipitation dataset by 0.6. Where pixel values in the Rain on Snow dataset equal 2, multiply Precipitation dataset by 0.4. All other values stay the same.”

N-SPECT model run

The N-SPECT model characterizes the degree of degradation to water quality processes based on existing land use type. The following eight water quality processes were examined using N-SPECT:

1. Total Phosphorous
2. Total Nitrogen
3. Total Suspended Solids
4. Zinc
5. Copper
6. Pathogens
7. Sediment
8. Runoff

The N_SEPCT model was run twice to produce two sets of data, one set for current land use conditions (CCAP) and one set for pre-development conditions.

Post Processing

To find the differences between pre-development landuse conditions and current conditions, the Pre-development values were subtracted from the current land use conditions to get an Absolute Change Calculation raster grid.

$$CCAP - PreDevelopment = Absolute\ Change$$

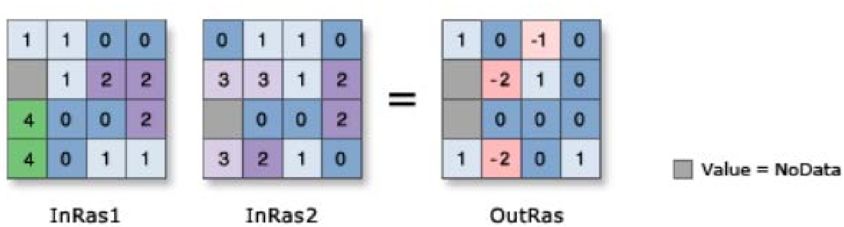


Figure D-41. Absolute change calculation from N-SPECT output grids.

Table D-16: Grid names for each N-SPECT parameter.

Pollutant	CCAP Current Land Cover	Pre-Development Land Cover	Change Grid	Normalized Grid	AU Average to WF_RP
Sediment	clocmusle1	plocmucle1	ca1mpa1	nmusle	nmusl
Total Phosphorous	clocconc1	plocconc1	c1mp1	ntp	ntPco
Total Nitrogen	clocconc2	plocconc2	c2mp2	ntn	ntPco
Zinc	clocconc4	plocconc4	c4mp4	nzn	nznco
Copper	clocconc5	plocconc5	c5mp5	ncu	ncuco
Pathogens	clocconc6	plocconc6	c6mp6	npath	npath

To calculate the relative degradation of pollutants within a certain area, it is necessary to normalize the outputs so that all values range from zero to one within the study area (WRIA). The maximum pixel value for each pollutant within each WRIA was found and saved as a raster grid with one value (maximum value) for each WRIA.

A special correction for the sediment output is used to recalculate the maximum pixel value to exclude dam faces with erroneous values.

- The Alder Lake pixel value in Pierce County (WRIA 11) was ignored. Used value of 200088.453125 instead.
- The Lake Cushman pixel value in Mason County (WRIA 16) was ignored. Used value of 490556.718750 instead.
- The Spada Lake pixel value in Snohomish County (WRIA 7) was ignored. Used value of 741985.25 instead
- The Ross Lake pixel value in Whatcom County (WRIA 3) was ignored. Used value of 1519670.5 instead.

Then each pollutants Absolute Change values are divided by the maximum pixel value for each WRIA. Now all Absolute change values range from zero to one within the WRIA.

$$Absolute\ Change\ \div\ Max\ value\ per\ WRIA$$
$$= Normalized\ Absolute\ Change\ by\ WRIA$$

Another special correction for the sediment N_SEPCT output is used to force dam faces to equal 1.0 and change null values to zeroes. Two conditional statements were used to modify the sediment output (nmuslewria).

First Conditional Statement: used to force values higher than 1 (i.e. dam spillways) to 1

$$Con([nmuslewria] > 1, 1, [nmuslewria])$$

The statement reads, “If a pixel value in nmuslewria is greater than 1, replace it with the value 1. All other values stay the same.”

Second Conditional Statement: used to change null values to be zero rather than null…

$$Con(IsNull([nmuslewria]), Con(IsNull([clocaccum1]), [nmuslewria], 0), [nmuslewria])$$

The statement reads, "If a pixel value in nmuslewria is NULL, look at clocaccum1. If clocaccum1 is NULL keep nmuslewria value, otherwise change it to 0. All other values stay the same."

The Absolute Change Calculations, for each water quality process, were then averaged within each Analysis Unit (AU) by using the "Zonal Statistics As Table" tool to output DBF tables for each process. Again, we wanted values to range from zero to one within Puget Sound, so it was necessary to re-normalize the values. The maximum mean value for each process was found, and all values were divided by this maximum value causing there to be one AU within the Puget Sound to have a value of 1.

The following numbers are the maximum values for all of Puget Sound. Therefore, one AU within Puget Sound will have a value of 1.0.

Table D-17: Maximum mean values for each water quality constituent.

Pollutant	Max Value	WRIA #
Sediment	0.003	17
Total Phosphorous	0.317	1
Total Nitrogen	0.452	9
Zinc	0.495	13
Copper	0.499	13
Pathogens	0.576	13

Water Quality Synthesis and Map Display

Again, the synthesis of water quality results and the map displays mirror those for water flow. Results from analyses for each of the five components are displayed in three maps, one for the relative export potential of the component, one for the relative degradation to the components natural process through N-SPECT, and the third is a combination of the two showing the management matrix. The export potential maps each have a unique color scheme to distinguish that component, and N-SPECT degradation maps all use the same four color scheme as shown below.

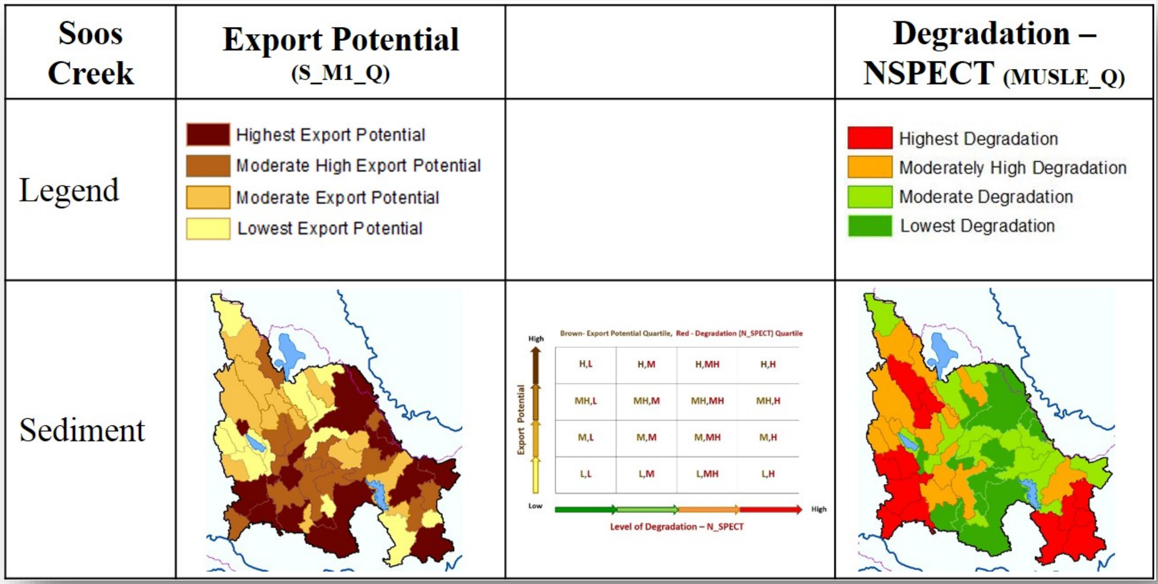


Figure D-42. Map display used for sediment export potential and degradation.

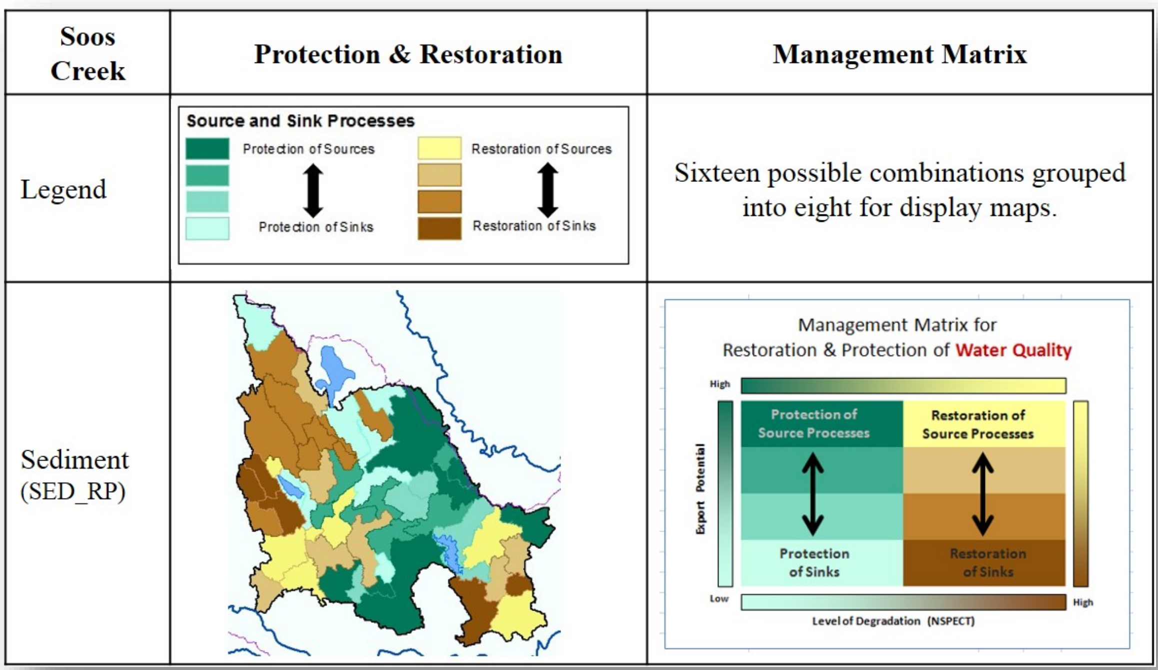


Figure D-43. Map display for the water quality management matrix.

Sources of Regional Data

Geographic information systems (GIS) have increased in use in the last decade primarily because they provide an efficient method of managing complex data and information. GIS also provides the framework for making this information usable for planners and decision makers with powerful analysis and display capabilities. With new technologies continually developing, this role will expand rapidly in the years to come.

One result of this increasing use of GIS is that digital data is becoming more readily accessible. Cooperative agreements between neighboring jurisdictions also make acquiring new data more affordable. Additionally, many agencies provide access to the data they maintain through web sites at minimal or no cost.

You can complete the methods described in this guidance using available digital data. It is efficient, provides more flexibility, and allows for clearer display of the results. Smaller jurisdictions should seek out cooperation with their associated county and consider including GIS as a requirement when hiring a consultant.

The use of any data requires an understanding of the accuracy and appropriate application for the scale of the data. This information should be clearly described in the analysis. Since the results of any of the analyses described here are for planning purposes over larger land areas, statements on its usefulness are all that is necessary. As with any analysis, greater confidence in the accuracy of the data results in a higher degree of certainty in the conclusions. Whenever more accurate data is available, it should be used.

The following table lists major sources for the digital data layers that are used in this guidance.

Table D-18: Sources of digital data.

Data	Scale	Agency	Web Site
Precipitation	1:2,000,000	WA Department of Natural Resources, Forest Practices Division	http://www.dnr.wa.gov/forestpractices/data/
Rain-on-Snow & Snow dominated zones	1:250,000	WA Department of Natural Resources	http://www3.wadnr.gov/dnrapp6/dataweb/dmmatrix.html#Climatology
Surficial Geology	1:100,000	WA Department of Natural Resources	http://www.dnr.wa.gov/geology/dig100k.htm
Soils (SSURGO)	1:12,000 – 1:63,000	Natural Resources Conservation Service	http://soildatamart.nrcs.usda.gov/County.aspx?State=WA
Soils (STATSGO)	1:250,000	Natural Resources Conservation Service	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	WA Department of Natural Resources	http://www3.wadnr.gov/dnrapp6/dataweb/dmmatrix.html#Hydrography
Wetlands (NWI) (also SSURGO – see above)	1:24,000	US Fish & Wildlife Service	http://www.fws.gov/nwi/downloads.htm
Channel confinement & gradient (SSHIAP)	1:24,000	WA Department of Fish & Wildlife; North West Indian Fisheries Commission	http://www.wdfw.wa.gov/hab/sshiap/index.htm
Mass wasting (Shaw Johnson landslide risk model)	10 Meter (Western WA)	WA Department of Natural Resources, Forest Practices Division	http://www.dnr.wa.gov/forestpractices/data/
Land cover	30 Meter Grid	US Geological Survey	http://www.csc.noaa.gov/crs/lca/pacificcoast.html

Definition of Terms and Acronyms

AU – Assessment Unit

C-CAP – Coastal Change Analysis Program; a regional land cover and change data layer produced by NOAA.

DEM – Digital Elevation Model

ESRI – Environmental Systems Research Institute

GIS – Geographic Information Systems

GDB – Geodatabase

LG – Landscape Group

N-SPECT – Nonpoint Source Pollution and Erosion Comparison Tool; developed by NOAA Coastal Services Center it is a GIS tool using ESRI's ArcMap software package and requiring the Spatial Analyst extension. It uses topography, land cover, soils, and precipitation data to assess spatial patterns of surface water runoff, nonpoint source pollution, and erosion. See Section XXXX for a more detailed discussion. Also see: http://www.csc.noaa.gov/digitalcoast/_/pdf/Tutorial.pdf

NWIFC – Northwest Indian Fisheries Commission; supplied SSHIAP data

NOAA – National Oceanic and Atmospheric Administration

SCALE – The relationship between the size of the geographic area covered and the level of detail. A large scale means more detail for a smaller area. A small scale means less detail for a large area.

SPATIAL EXTENT – Size of the land area covered by the analysis.

SSHIAP – Salmon and Steelhead Habitat Inventory and Assessment Program. This is a spatial data system that characterizes salmonid habitat conditions and distribution of salmonid stocks in Washington at the scale of 1:24,000. It is co-managed by the Washington Department of Fish and Wildlife (WDFW) and the Northwest Indian Fisheries Commission (NWIFC).
http://wdfw.wa.gov/mapping/salmonscape/sshiap/
http://nwifc.org/about-us/habitat/sshiap/

WDFW – Washington Department of Fish and Wildlife

WDNR – Washington Department of Natural Resources

WDOE – Washington Department of Ecology

WRIA – Watershed Resource Inventory Area. Administrative and planning boundaries that underpin Department of Ecology business. Formalized under the Water Resources Act of 1971, they were agreed upon by Washington's natural resource agencies (Ecology, Natural Resources, Fish and Wildlife) in 1970.

GIS Models for Characterization

All analyses were developed within the Model Builder application of ArcGIS 10, a commercial GIS software product of Environmental Systems Research Institute, Inc. (ESRI^{TM}). The purpose of creating the models was to provide an efficient way to provide:

- Repeatability of the analyses,
- Saleable applications,
- Standardized methods, and
- Transparent documentation

The result of this is a collection of models and scripts organized as a 'toolbox'. The guidance document detailing description of these tools is available at: https://fortress.wa.gov/ecy/publications/SummaryPages/1106016.html

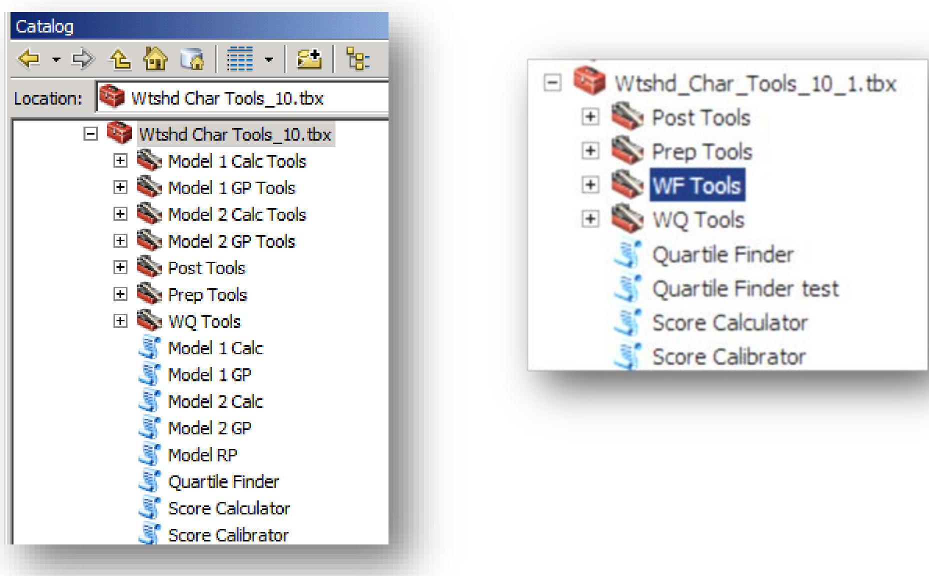


Figure D-44. Watershed Characterization toolbox of models and scripts.

Attachment D-1: Development of Analysis Unit (AU) Boundaries

Significant effort was spent determining the most appropriate size for the analysis units. They are the foundation unit for summarizing and displaying all the analyses, so choosing a scale that provided meaningful and useful results was critical. Equally important well as to develop a unit size that would be suitable for the source data available for analysis. Additionally, we did not want to reinvent units that already existed across the Sound if they could be adapted to our scale requirements. The *AquaScape* catchments provided the most robust and comprehensive data coverage, as well as the possibility of linking to other data sources. For these reasons they became the foundation of our analysis units, with minor adjustments described below.

The source data for creating the analysis units (AU) came from two existing data sets.

- SSHIAP *AquaScape* Segment Catchments – these were the basis for all AUs except those in WRIA 2 & 6 where this data did not exist. The *AquaScape* catchments were developed by the Northwest Indian Fisheries Commission and represent drainage areas based on Habitat Segments and DNR Shorezone segments. The habitat segments were defined by gradient and confinement, and then habitat type.
- PSNERP Drainage Units (DUs) – these were the basis for AUs within WRIA 2 and 6, the island WRIAs. They were developed by the Puget Sound Nearshore Restoration Project and represent drainage units based on drift cells.

The catchments in both these layers were not consistently appropriate in scale to be used directly as analysis units for our assessments across Puget Sound. To create more consistency, we used the following criteria in making adjustments to the source layers for development of our analysis units.

- SSHIAP catchments were not further divided, but were aggregated where needed to achieve a more consistent size. This aggregation follows hydrologic principles as much as possible. (See Federal Guidelines, Requirements, and Procedures for the National Watershed Boundary Dataset: U.S. Geological Survey Techniques and Methods 11-A3; http://pubs.usgs.gov/tm/tm11a3/
- PSNERP catchments (for WRIAs 2 and 6) will be grouped or divided to more consistently mirror SSHIAP catchments.

All analysis units are coded into one of five landscape groups, defined by the geomorphic criteria below:

- Mountainous unit (M) – generally above 500 feet elevation (with more than half of the catchment above); this commonly captures areas dominated by bedrock, rain-on-snow or snow dominated areas, high precipitation, and high slope. Generally they have less diverse land cover, lower development pressure, and often include federal land. They average ~10-15 square miles in size.

- Lowland unit (L) – generally below 500 feet elevation (with more than half of the catchment below); this generally captures geology dominated by glacial deposits, rain dominated precipitation, land forms of terraces and large river valleys with predominately floodplain hydrology (overbank flooding and groundwater discharge). These areas have more diverse land cover and higher development pressure. They average ~3-5 square miles in size.
- Coastal unit (C) – generally captures small drainages to the marine shoreline of 1st or 2nd order streams, and groups of remnant, wedge-shaped areas creating a contiguous *composite* unit. It does not include larger, complex river systems. They average ~ 1 square mile in size.
- Delta unit (D) – this captures three of the large delta systems that have important water flow or habitat value (Nisqually, Puyallup, and Duwamish).
- Lake unit (LK) – this captures the small drainages of 1st or 2nd order streams, and remnant areas between them, that drain to one of the four largest lakes: Washington (LKW), Sammamish (LKS), Whatcom (LKWH), and Lake Crescent (LKC).

See Figure D-5 for a map showing the AUs for Puget Sound, and Figure D-4 for the relationship between the AUs, the landscape groups, and the WRIAs.

Several issues in developing the AU layer were resolved as follows:
- Very small islands were eliminated from the analysis since they are smaller than the appropriate size for the data and combining them didn't make sense.
- There were some small pockets of 'mountainous' AUs surrounded by lowland area that were recoded to 'lowland'.
- We did not treat the large reservoirs the same as the large lakes by making the AUs draining to them a separate landscape group. They are left as mountainous units.

Attachment D-2: Geology Data

The source data for our geology layer is the 1:100,000 statewide geology layer produced by the Department of Natural Resources. We use the polygon shape file (gunit.shp) of geologic units primarily for recharge, discharge, and erosion analyses.

For recharge and discharge analyses, we added the field 'geo_hp' to group all lithology categories into either a higher permeable ('Hperm') type or a lower permeable type ('Lperm'). The scale of the data requires a somewhat simplified classification scheme. These assumptions framed our initial grouping of surficial geologic deposits:

  - Alluvium and recessional outwash are generally of higher permeability.
  - Till, moraines, organic deposits, lacustrine, glacial marine drift, mudflows, fine alluvium, and bedrock are generally of lower permeability.

– Advanced outwash can be of moderate permeability, but it may be locally overridden with glacial till (advanced outwash was deposited in front of the glacier and was often subsequently covered with glacial ice). In this instance, permeability should be low since the till layer intercepts percolating water first.
– Areas of glacial marine drift are sometimes included within areas mapped as glacial outwash. Given its extremely low permeability, you should map glacial marine drift areas separately and assign them to the low permeability class.
– Sometimes the geologic mapping is quite coarse. Because soils are derived from the underlying surficial deposit, soil data can be used to subdivide geologic classes that are quite broad. However, a geologist should review this information since the accuracy of soil data can vary greatly across the Puget lowlands.

Our initial coding was subsequently reviewed by Patricia Olson and again by Derek Booth, producing the following list of deposits coded as higher permeable deposits:

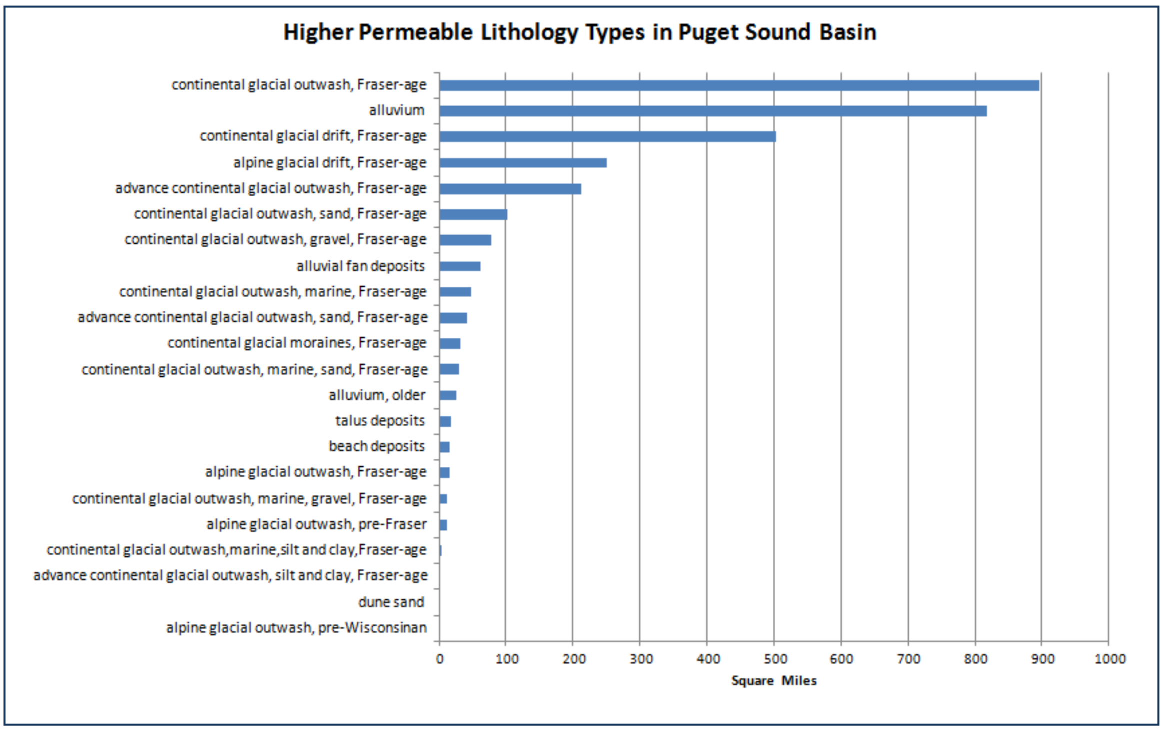


Figure D-45. Higher permeable geologic units.

The following list includes the remaining geologic units, within Puget Sound, coded as lower permeability.

Table D-19. Lower permeable geologic units.

acidic intrusive rocks	intrusive andesite and dacite
acidic intrusive rocks	intrusive breccia
alpine glacial drift, pre-Fraser	intrusive dacite
alpine glacial till, Fraser-age	intrusive rhyolite
alpine glacial till, pre-Fraser	intrusive rocks, undivided
amphibolite	intrusive-volcanic complex
andesite flows	lahars
argillite	marble
artificial fill, including modified land	marine metasedimentary rocks
banded gneiss	marine sedimentary rocks
basalt flows	mass-wasting deposits
basalt flows and flow breccia, Crescent Formation	mass-wasting deposits, mostly landslides
basaltic andesite flows	mass-wasting deposits, other than landslides
basic intrusive rocks	metasedimentary and metavolcanic rocks
chert-rich marine sedimentary rocks	metasedimentary rocks
continental glacial drift, pre-Fraser	metasedimentary rocks, cherty
continental glacial drift, pre-Fraser, and nonglacial deposits	metavolcanic rocks
continental glacial outwash, silt and clay, Fraser-age	monzonite
continental glacial till, Fraser-age	nearshore sedimentary rocks
continental sedimentary deposits or rocks	orthogneiss
continental sedimentary deposits or rocks, conglomerate	paragneiss
dacite and andesite flows, breccia	peat deposits
dacite flows	phyllite, low grade
diorite	pyroclastic flows
gabbro	quartz diorite
gabbro and diorite	quartz monzonite
glacial and non-glacial deposits, undivided	rhyolite flows
glacial drift, undivided	schist, high grade
glaciolacustrine deposits, Fraser-age	schist, low grade
glaciomarine drift, Fraser-age	sedimentary deposits or rocks
gneiss	tectonic breccia
granite	tectonic zone
granodiorite	tonalite
heterogeneous metamorphic rocks	tuffs and tuff breccia
heterogeneous metamorphic rocks, chert bearing	ultrabasic rocks
heterogeneous metamorphic rocks, chert-bearing	volcanic and sedimentary rocks
ice	volcanic breccia
intermediate intrusive rocks	volcanic rocks
intrusive andesite	volcaniclastic deposits or rocks

There is an additional field for severity of channel erosion by different lithology types. The types coded with a higher degree of erosive geology are the following:

- Advance continental glacial outwash, Fraser-age
- Advance continental glacial outwash, sand, Fraser-age
- Alluvium
- Alluvium, older
- Beach deposits
- Continental glacial outwash, Fraser-age
- Continental glacial outwash, sand, Fraser-age
- Continental glacial outwash, marine, sand, Fraser-age
- Dune sand
- Terraced deposits

Attachment D-3: Wetland Data

Our wetland layer was developed from four sources of wetland data: the National Wetland Inventory (NWI), SSURGO hydric soils, hydrography water bodies, and C-CAP land cover. Wetland classifications from NWI where 'cover_type' was any wetland category were included. From the SSURGO soils layer, any polygon where 'hydricrati' = 'Yes' was included. From the hydrography water bodies layer, we included any polygon identified as 'marsh/wetland' within the 'wb_cart_ftr_cd' field. From the C-CAP land cover layer, any grid code that had a wetland description for 'Class_name' (lulc_cd = 13, 14, 15, 18, 22, & 23) was included as wetland.

The NWI, C-CAP, and water body layers indicate current presence of a wetland. However, the hydric soils layer may not represent a current wetland area, but likely an area that would naturally be wetland without human alteration. We included this layer to provide the maximum extent of probable wetland coverage. For the degradation analyses, the overlay of current land cover on this composite wetland layer would better indicate areas that likely were wetlands but are not wetlands now. For example, this could be represented by a hydric soil polygon that intersects a 'cultivated' land cover polygon.

To create the depressional and slope wetland categories, we intersected the composite wetland layer with a slope grid developed from a 30-meter DEM. Any wetland on a slope that was 'equal to or less than 2%' was a depressional wetland. Any wetland on a slope 'greater than 2%' was coded a slope wetland.

Attachment D-4: Land Cover Classes

Land cover data was developed from NOAA's Coastal Change Analysis Program (C-CAP) from the 2006 30-meter land cover raster. This data had 22 categories for the Puget Sound region which we combined into several groups for various assessments. Table D-20 shows the land cover groups.

Table D-20. C_CAP land cover classes and groups for analysis.

Grid Value	Description	LU_Code	Impervious %	Forest/ Non-Forest	Urban/ Rural
2	**High intensity developed**	High	80-100%	Altered Forest	Urban
3	**Medium intensity developed**	Medium	50-79%		
4	**Low intensity developed**	Low	21-49%		
5	**Developed open space**	Open space	<20%		
6	Cultivated	Cultivated			Rural
7	Pasture/hay	Pasture			
8	Grassland	Grassland		Excluded	
9	Deciduous forest	Forest		Forest	
10	Evergreen forest				
11	Mixed forest				
12	Scrub/shrub	Shrub		Excluded	
13	Palustrine Forested Wetland	Wetland		Forest	LC wetlands
14	Palustrine Scrub/Shrub Wetland				
15	Palustrine Emergent Wetland				
18	Estuarine Emergent Wetland				
19	Unconsolidated Shore	Bare Land		NA	
20	Bare Land			Excluded	
21	Water	Water		NA	
22	Palustrine Aquatic Bed	Wetland		NA - open water	LC wetlands
23	Estuarine Aquatic Bed			NA - open water	
24	Tundra	Tundra/Snow/Ice		NA	
25	Snow/Ice			NA	

Additionally, we used the major public lands layer to screen out areas where land cover is assumed to be natural and not the result of alteration by human activities. For example, bare land in a wilderness area is assumed to be natural land cover and not the result of forest clearing. Table D-21 shows the list of public land areas where grassland, scrub/shrub, and bare land cover types are excluded from the analysis for forest loss.

Table D-21. Major public lands excluded from land cover alteration analyses.

NAME	MANAGER	MANAGEMENT	MPL_TYP
Mount Rainier National Park	National Park Service	Park/Non Wilderness	02
North Cascades National Park	National Park Service	Park/Non Wilderness	02
Olympic National Park	National Park Service	Park/Non Wilderness	02
Ross Lake National Recreation Area	National Park Service	Park/Non Wilderness	02
Alpine Lakes Wilderness	US Forest Service	Wilderness	03
Boulder River Wilderness	US Forest Service	Wilderness	03
Buckhorn Wilderness	US Forest Service	Wilderness	03
Clearwater Wilderness	US Forest Service	Wilderness	03
Glacier Peak Wilderness	US Forest Service	Wilderness	03
Glacier View Wilderness	US Forest Service	Wilderness	03
Henry M Jackson Wilderness	US Forest Service	Wilderness	03
Mount Baker Wilderness	US Forest Service	Wilderness	03
Mount Skokomish Wilderness	US Forest Service	Wilderness	03
Noisy-Diobsud Wilderness	US Forest Service	Wilderness	03
Norse Peak Wilderness	US Forest Service	Wilderness	03
Pasayten Wilderness	US Forest Service	Wilderness	03
Tatoosh Wilderness	US Forest Service	Wilderness	03
The Brothers Wilderness	US Forest Service	Wilderness	03
Wild Sky Wilderness	US Forest Service	Wilderness	03
Wonder Mountain Wilderness	US Forest Service	Wilderness	03
Mount Baker National Recreation Area	US Forest Service	Recreation	07

Attachment D-5: Quartile Grouping Methods

The results of these models produce relative comparisons between an AU and other AUs. Instead of representing the numerical results of the models, we chose to use a method of classifying the data. The rationale for this approach is that the coarse level of source data and lower confidence level in numerical values does not support direct comparison of model results. A more appropriate representation of results is to group them for a relative comparison.

To achieve a standard, repeatable, transparent method, we developed a 'Quartile Finder' tool using Python scripting. In this way, quartile breaks are done consistently throughout the model.

The basics of this approach are to order all results for each analysis from highest to lowest value, then divide the total number of records into four roughly equal quartiles: low, moderate, moderate high, and high [qtrBreaks = totRows/numBreaks]. Repeat values are kept in the same quartile, even if the number of records per quartile is exceeded. The following groups are then adjusted. Grouping begins with the low bucket, which receives the lower number of records if they are not even, then counts records for each subsequent bucket, finishing with the high group. An uneven number of records will give the last one or more buckets an additional record.

For example, if the number of AUs is 20, four buckets would place 5 records per bucket. However, adjustments are made in several scenarios shown in Figure D-46.

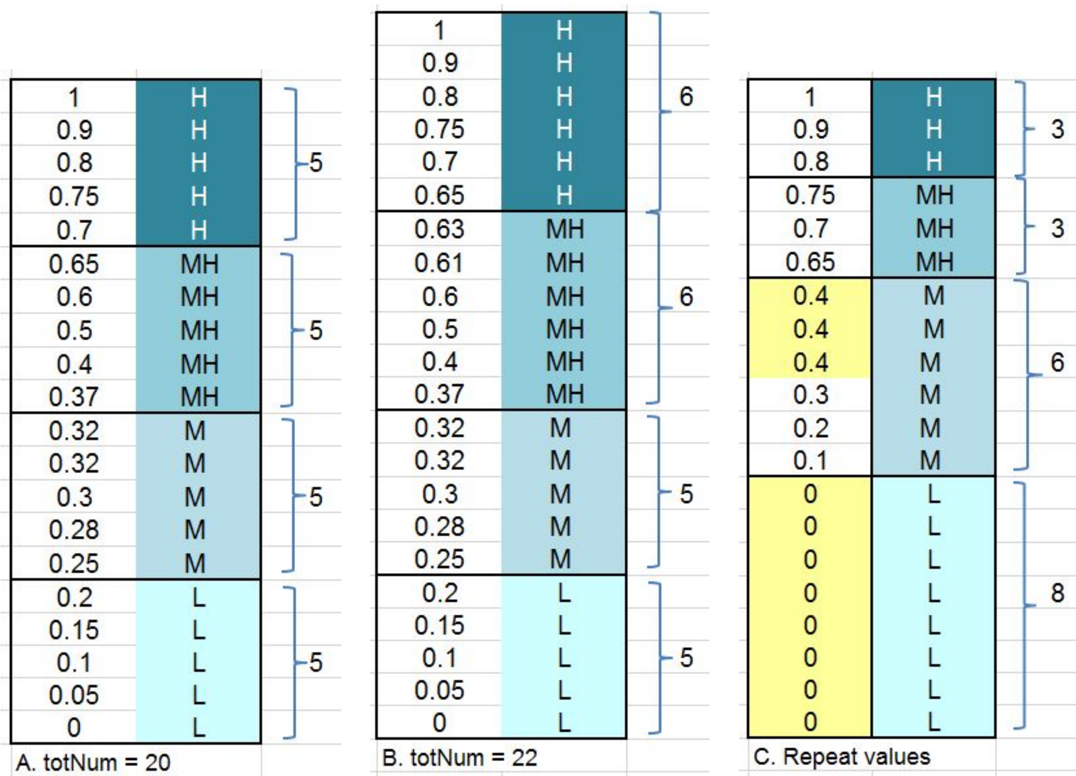


Figure D-46. Examples of quartile grouping.

Quartile buckets in the left panel show 20 records resulting in four evenly divided quartiles with 5 records each. Quartile buckets in the middle panel show adjustments from an uneven record number. Quartile buckets in the right panel show adjustments to accommodate 8 zero values, and repeat values requiring adjustment to all quartiles.

This process is applied to the records for each landscape group for the analyses where they are used. The water flow importance models and the water quality export potential models (Model 1) use the landscape groups. The water flow degradation models and the water quality N-SPECT models (Model 2) don't use landscape groups, but may adjust for highly urban areas.

LG_M1 for WF & WQ Importance/Export Potential Includes:	
L	Lowland
M	Mountainous
C	Coastal
D	Delta
LKW	Lake Washington
LKS	Lake Sammamish
LKWH	Lake Whatcom
LKC	Lake Cushman

LG_M2 for WF Degradation Includes:		
X	No topographic landscape group	
U	AU with >.9 area in 'urban' land use (LC = 2-5)	
	2	High intensity developed
	3	Medium Inensity developed
	4	Low Intensity developed
	5	Developed Open Space
LG_M2 for WQ/NSPECT Includes:		
X	No topographic landscape groups **or U's**	

Figure D-47 Landscape groups used for models 1 and 2.

There are pros and cons to this method. Pros, mentioned above, are that it is: consistent, repeatable, and transparent. The cons are several. First, this method does not evaluate the variance within classes or between classes. Thus, the difference in value from one bucket to the next is sometimes negligible given that the difference in value is not considered, only the number of values put into any one quartile. Second, all four quartiles are forced to exist, again creating differences where they may be slight. Third, zero's and repeat values are included in one bucket, even if they represent more than the number of records that would normally be included.

It is important to remember that the tool forces all four groups to be represented, even when the difference in values is small. This is a particular issue when looking at a smaller geographic area. An example of this is the Delivery analysis where the precipitation can be fairly uniform across a landscape, like the island WRIAs. Thus, it is always advisable for the values to be reviewed by the user to make sure they represent the geography in a meaningful way. Depending on the analysis area and the purpose for the analyses, these groupings can be adjusted if users determine it is warranted.

Attachment D-6: Analysis for Effects of Dams

A dam that captures greater than 4 feet of runoff, which is roughly equivalent to 100% of annual precipitation for most parts of the Puget Sound region, has the potential to significantly change downstream hydrologic regimes (Booth, personal communication). A dam that captures between 1 to 4 feet of runoff (equivalent to about 20-100% of annual precipitation in most parts of the Puget Sound) is represented to have a moderate potential impact. Less than 1 foot of runoff represents a low potential impact.

The severity of degradation to water flow processes by dams is modeled as 1) the storage capacity of the dam relative to annual runoff generated by the watershed above the dam; and 2) the amount of unregulated runoff contributed to the stream system downstream of the dam.

$$AU\ Dam\ Score_n = SD \div \left(A_{\text{dam}} + \sum_n A_{\text{AU}} \right)$$

SD = the storage volume of the dam in acre feet.

A_{dam} = the watershed area impounded above the dam in acres.

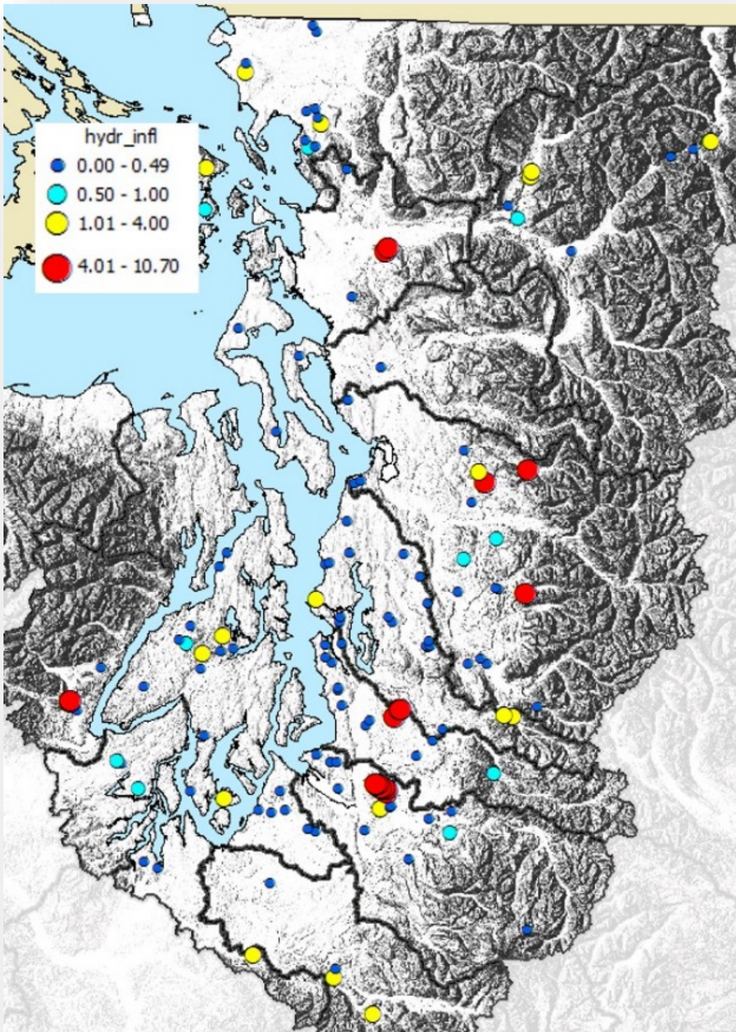
A_{AU} = the unregulated watershed area in acres for an AU(s) below the dam that drains to the regulated stream. Depending on point downstream that the dam score is calculated, all upstream AUs would be included in this term, except the AUs above the dam.

The dam data layer was downloaded from Ecology's Dam Safety Office database. It included 614 dams in the Puget Sound region. Two attribute fields from this data were used in the analysis: MAX_STOR_Q in feet per acre, and DRN_AREA in square miles. We added the field 'drng_ac' and converted the square miles to acres. A dam with a drainage area of less than 1 square mile was deemed not significant for the purpose of our analysis. That left 148 dams with a drainage area of greater than or equal to 1 square mile.

The 'hydrologic influence' score (hydr_infl) was calculated as:

Hydr_infl = MAX_STOR_Q / drng_ac

MAX_STOR_Q = maximum storage of the dam in acre feet
Drng_ac = drainage area of the dam in acres
Hydr_infl = hydrologic influence score in feet



A dam with the potential to capture less than .5 foot was deemed not significant for our analysis (96 dams). The remaining 52 dams had a 'hydrologic influence' score from .5 – 10.7 feet.

A score of .5 – 1 foot was categorized as low impact. Moderate impact was 1-4 feet, and potential for high impact was > 4 feet.

Figure D-48. Hydrologic influence of dams in Puget Sound. (With <1 sqmi of drainage area).

Note that *actual* downstream consequences depend largely on the applied operation schedule of the dam, which is not considered in this analysis.

The effects of the dams were also displayed relative to propagation of the downstream changes. This analysis converted the point data from the dam to the downstream arc, while accounting for the additional drainage area as we move downstream. Since the display was for the stream segment, we used the 100K waters layer, and split the mainstem arcs at the intersection of assessment unit boundaries. We recalculated a 'dam_scor' by summing the MAX_STOR_Q for any dam in the upper watershed, and dividing by the area of all assessment units above that confluence. The result was applied to the downstream segment until the next confluence.

The following figures display how this was done in WRIA 8. The upper watershed has two dams associated with Chester Morse Lake with a total maximum storage of 250,000 ac/ft. The total watershed area, highlighted in yellow, is 50,198 acres.

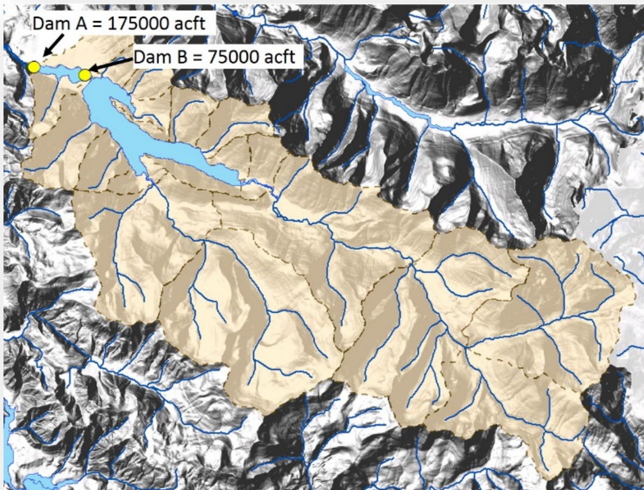
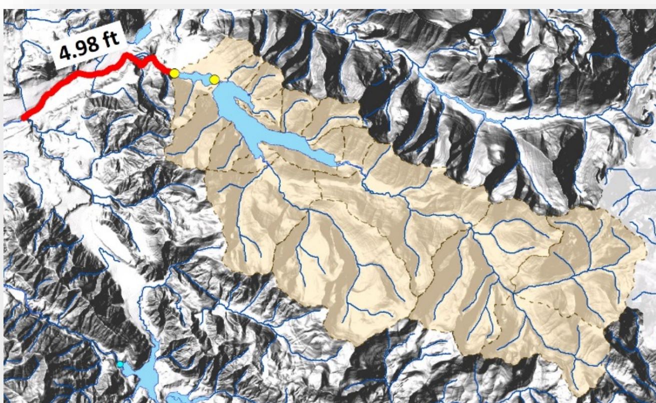
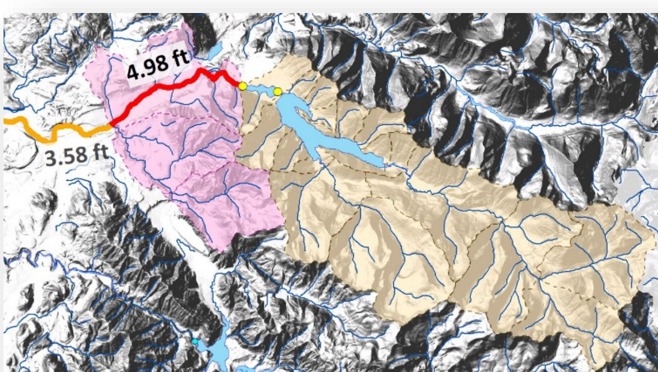


Figure D-49. Total maximum storage for watershed area.



The total 'dam_scor' at the lowest point in the watershed at Dam A is 4.98 ft. That value is attached to the downstream segment until the next assessment unit boundary.

Figure D- 50. Downstream influence.



At the next downstream confluence, an additional 19,702 acres are added by the area in pink. Thus the downstream value drops to 3.58 ft.

Figure D-51. Downstream influence at next confluence.

Attachment D-7. Lists of Field Names

Table D-22. List of field names in the order they appear in the model:

Current Name	Description	Model Order
	Water Flow Importance	
P	precipitation	1
RS	rai-on-snow	2
IDE	importance of delivery	3
I_DE	importance to delivery	4
I_DE_Q	importance to delivery quantile	5
WT_LK	wetlands & lake area	6
WLS	wetland lake storage	7
UNSS	unconfined stream storage	8
MCSS	moderately confined stream storage	9
UN_MC	stream storage total	10
STS	stream storage	11
ISS	surface storage	12
I_SS	importance to surface storage	13
I_SS_Q	importance to storage quantile	14
IR	recharge	15
I_R	importance to recharge	16
I_R_Q	importance to recharge quantile	17
SD	stream discharge importance	18
SWD	slope wetland discharge	19
IDI	importance discharge total	20
I_DI	importance of discharge	21
I_DI_Q	importance of discharge quantile	22
IGW	groundwater	23
I_GW	importance of groundwater	24
I_GW_Q	importance of groundwater quantile	25
WF_M1	sum of normalized scores for model 1	26
WF_M1_LG	normalized scores for model 1 by LG	27
WF_M1_CAL	calibrated score for model 1 importance	28
WF_M1_Q	quantiles for model 1	29
	Water Flow Degradation	
IMP	impervious surface indicator (urban)	30
FL	forest loss	31
DDE	degradation of delivery	32
D_DE	degradation to delivery	33
D_DE_Q	degradation to delivery quantile	34
DE_RP	**Delivery Restoration Protection**	35
UW	urban wetlands	36
RW	rural wetlands	37
DW	degraded wetlands	38
D_WS	degradation to wetland storage	39
UDS	unconfined degraded streams	40
MDS	moderately confined degraded streams	41

DST	degraded streams	42
D_STS	degradation to stream storage	43
DSS	degradation to surface storage	44
D_SS	degradation to surface storage	45
D_SS_Q	degradation to surface storage quantile	46
SS_RP	**Surface Storage Restoration Protection**	47
RRC	reduction recharge coefficient	48
DR	degraded recharge	49
D_R	degradation to recharge	50
D_R_Q	degradation to recharge quantile	51
R_RP	**Recharge Restoration Protection**	52
D_RD	degradation by roads	53
D_WEL	degradation by wells	54
UUS	unconfined urban streams	55
URS	unconfined rural streams	56
STD	stream discharge degradation	57
D_STD	degradation to stream discharge	58
SWU	slope wetlands urban	59
SWR	slope wetlands rural	60
WD	wetland discharge	61
D_WD	degradation wetland discharge	62
DDI	degradation discharge total	63
D_DI	degradation to discharge	64
D_DI_Q	degradation to discharge quantile	65
DI_RP	**Discharge Restoration Protection**	66
DGW	degradation to groundwater	67
D_GW	degradation to groundwater	68
D_GW_Q	quantiles for groundwater	69
GW_RP	**Groundwater Restoration Protection**	70
D_L	degradation to loss	71
WF_M2	normalized scores for model 2	72
WF_M2_LG	normalized scores for model 2 (with adjustments,U/D)	73
WF_M2_CAL	calibrated scores for model 2	74
WF_M2_Q	quantiles for model 2	75
WF_RP	**Water Flow Restoration Protection**	76
	Water Quality - Sediment	
SDN	stream density	77
ASDN	aquatic system density	78
RE	rainfall erosivity	79
K	soil erodibility	80
SLP	slope	81
SE	soil erosion	82
S_SE	sediment_ soil erosion	83
LH	landslide hazard	84
MW	mass wasting	85
S_MW	sediment_mass wasting	86
ERST	erodible stream	87
CE	channel erosion	88

S_CE	sediment_channel erosion	89
SSO	sediment source	90
S_SO	sediment source normalized	91
S_SO_Q	sediment source quantile	92
S_SI	sediment sink normalized	93
S_SI_Q	sediment sink quantile	94
S_M1	export potential for sediment	95
S_M1_LG	export potential for sediment normalized	96
S_M1_CAL	export potential for sediment calibrated	97
S_M1_Q	sediment model 1 quantiles	98
MUSL_Q	N-SPECT Sediment Degradation	99
SED_RP	**Sediment Restoration Protection**	100
	Water Quality - Phosphorous	
CC	clay content	101
PC	phoshporous content	102
PE	phosphorous enrichment value	103
PSO	phosphorous sources	104
P_SO	phosphorous sources normalized	105
P_SO_Q	phosphorous sources quantiles	106
SRP	soil retention for phosphorous	107
P_SR	phosphorous soil retention	108
PSI	phosphorous sink	109
P_SI	phosphprous sink normalized	110
P_SI_Q	phosphorous sink quantile	111
P_M1	export potential for phosphorous	112
P_M1_LG	export potential for phosphorous by LG	113
P_M1_CAL	export potential for phosphorous calibrated	114
P_M1_Q	phosphorous model 1 quantiles	115
P_Q	N-SPECT Phosphorus Degradation	116
P_RP	**Phosphorus Restoration Protection**	117
	Water Quality - Metals	
SRM	soil retention for metals	118
M_SRM	soil retention for metals normalized	119
MSI	metals sink model	120
M_SI	metals sink model normalized	121
M_M1	export potential for metals	122
M_M1_CAL	export potential for metals calibrated	123
M_M1_Q	metals model 1 quantiles	124
ME_Q	N-SPECT Metals Degradation	125
ME_RP	**Metals Restoration Protection**	126
	Water Quality - Nitrogen	
RDN	nitrogen riparian denitrification	127
N_RDN	nitrogen riparian denitrification normalized	128
NSI	nitrogen sink	129
N_M1	export potential for nitrogen normalized	130
N_M1_CAL	export potential for nitrogen calibrated	131
N_M1_Q	nitrogen model 1 quantiles	132
N_Q	N-SPECT Nitrogen Degradation	133

N_RP	**Nitrogen Restoration Protection**	134
	Water Quality - Pathogens	
PA_SI	pathogen sink	135
PA_M1	export potential for pathogens	136
PA_M1_CAL	export potential for pathogens calibrated	137
PA_M1_Q	pathogen model 1 quantile	138
PA_Q	N-SPECT Pathogen Degradation	139
PA_RP	**Pathogen Restoration Protection**	140

Table D-23. List of field names in alphabetical order:

Field Name	Description	Model Order
ASDN	aquatic system density	78
CC	clay content	101
CE	channel erosion	88
D_DE	degradation to delivery normalized	33
D_DE_Q	degradation to delivery quantile	34
D_DI	degradation to discharge normalized	64
D_DI_Q	degradation to discharge quantile	65
D_GW	degradation to groundwater normalized	68
D_GW_Q	quantiles for groundwater	69
D_L	degradation to loss	71
D_R	degradation to recharge normalized	50
D_R_Q	degradation to recharge quantile	51
D_RD	degradation by roads	53
D_SS	degradation to surface storage normalized	45
D_SS_Q	degradation to surface storage quantile	46
D_STD	degradation to stream discharge	58
D_STS	degradation to stream storage	43
D_WD	degradation to wetland discharge	62
D_WEL	degradation by wells	54
D_WS	degradation to wetland storage	39
DDE	degradation to delivery	32
DDI	degradation discharge total	63
DE_RP	**Delivery Restoration Protection**	35
DGW	degradation to groundwater	67
DI_RP	**Discharge Restoration Protection**	66
DR	degradation to recharge	49
DSS	degradation to surface storage	44
DST	degraded streams	42
DW	degraded wetlands	38
ERST	erodible stream	87
FL	forest loss	31
GW_RP	**Groundwater Restoration Protection**	70
I_DE	importance to delivery normalized	4
I_DE_Q	importance to delivery quantile	5

I_DI	importance of discharge normalized	21
I_DI_Q	importance of discharge quantile	22
I_GW	importance to groundwater normalized	24
I_GW_Q	importance to groundwater quantile	25
I_R	importance to recharge normalized	16
I_R_Q	importance to recharge quantile	17
I_SS	importance to surface storage normalized	13
I_SS_Q	importance to storage quantile	14
IDE	importance to delivery	3
IDI	importance discharge total	20
IGW	importance to groundwater	23
IMP	impervious surface indicator (urban)	30
IR	importance to recharge	15
ISS	importance to surface storage	12
K	soil erodibility	80
LH	landslide hazard	84
M_M1	export potential for metals	122
M_M1_CAL	export potential for metals calibrated	123
M_M1_Q	metals model 1 quantiles	124
M_SI	metals sink model normalized	121
M_SRM	soil retention for metals normalized	119
MCSS	moderately confined stream storage	9
MDS	moderately confined degraded streams	41
ME_Q	N-SPECT Metals Degradation	125
ME_RP	**Metals Restoration Protection**	126
MSI	metals sink model	120
MUSL_Q	N-SPECT Sediment Degradation	99
MW	mass wasting	85
N_M1	export potential for nitrogen normalized	130
N_M1_CAL	export potential for nitrogen calibrated	131
N_M1_Q	nitrogen model 1 quantiles	132
N_Q	N-SPECT Nitrogen Degradation	133
N_RDN	nitrogen riparian denitrification normalized	128
N_RP	**Nitrogen Restoration Protection**	134
NSI	nitrogen sink	129
P	precipitation	1
P_M1	export potential for phosphorous	112
P_M1_CAL	export potential for phosphorous calibrated	114
P_M1_LG	export potential for phosphorous by LG	113
P_M1_Q	phosphorous model 1 quantiles	115
P_Q	N-SPECT Phosphorus Degradation	116
P_RP	**Phosphorus Restoration Protection**	117
P_SI	phosphorous sink normalized	110
P_SI_Q	phosphorous sink quantile	111
P_SO	phosphorous sources normalized	105
P_SO_Q	phosphorous sources quantiles	106
P_SR	phosphorous soil retention	108
PA_M1	export potential for pathogens	136
PA_M1_CAL	export potential for pathogens calibrated	137

PA_M1_Q	pathogen model 1 quantile	138
PA_Q	N-SPECT Pathogen Degradation	139
PA_RP	**Pathogen Restoration Protection**	140
PA_SI	pathogen sink	135
PC	phosphorous content	102
PE	phosphorous enrichment value	103
PSI	phosphorous sink	109
PSO	phosphorous sources	104
R_RP	**Recharge Restoration Protection**	52
RDN	nitrogen riparian denitrification	127
RE	rainfall erosivity	79
RRC	reduction recharge coefficient	48
RS	rain-on-snow	2
RW	rural wetlands	37
S_CE	sediment channel erosion	89
S_M1	export potential for sediment	95
S_M1_CAL	export potential for sediment calibrated	97
S_M1_LG	export potential for sediment normalized	96
S_M1_Q	sediment model 1 quantiles	98
S_MW	sediment mass wasting	86
S_SE	sediment_ soil erosion	83
S_SI	sediment sink normalized	93
S_SI_Q	sediment sink quantile	94
S_SO	sediment source normalized	91
S_SO_Q	sediment source quantile	92
SD	stream discharge importance	18
SDN	stream density	77
SE	soil erosion	82
SED_RP	**Sediment Restoration Protection**	100
SLP	slope	81
SRM	soil retention for metals	118
SRP	soil retention for phosphorous	107
SS_RP	**Surface Storage Restoration Protection**	47
SSO	sediment source	90
STD	stream discharge degradation	57
STS	stream storage	11
SWD	slope wetland discharge	19
SWR	slope wetlands rural	60
SWU	slope wetlands urban	59
UDS	unconfined degraded streams	40
UN_MC	stream storage total	10
UNSS	unconfined stream storage	8
URS	unconfined rural streams	56
UUS	unconfined urban streams	55
UW	urban wetlands	36
WD	wetland discharge	61
WF_M1	sum of normalized scores for model 1	26
WF_M1_CAL	calibrated score for model 1 importance	28
WF_M1_LG	normalized scores for model 1 by LG	27

WF_M1_Q	quantiles for model 1	29
WF_M2	normalized scores for model 2	72
WF_M2_CAL	calibrated scores for model 2	74
WF_M2_LG	normalized scores for model 2 (with adjustments,U/D)	73
WF_M2_Q	quantiles for model 2	75
WF_RP	**Water Flow Restoration Protection**	76
WLS	wetland lake storage	7
WT_LK	wetlands & lake	6

Table D-24. List of field names for N-SPECT, Puget Sound-wide Analysis

	Field Name	**Description**
Puget Sound Wide Analysis	PS_nrunoff	Puget Sound - runoff **load per area**
	PS_ntpconc	Puget Sound - total phosphprous load per area
	PS_ntnconc	Puget Sound - total nitrogen load per area
	PS_ntsscon	Puget Sound - total suspended solids load per area
	PS_nznconc	Puget Sound - zink load per area
	PS_nncuconc	Puget Sound - copper load per area
	PS_npath	Puget Sound - pathogen load per area
	PS_nmusle	Puget Sound - sediment load per area
	PS_TP_Rnk	Puget Sound - total phosphorous **rank**
	PS_TN_Rnk	Puget Sound - total nitrogen rank
	PS_TSS_Rnk	Pugst Sound - total suspended solids rank
	PS_Zn_Rnk	Puget Sound - zink rank
	PS_Cu_Rnk	Puget Sound - copper rank
	PS_Metals_Rnk	Puget Sound - metals rank (Ecology added)
	PS_Path_Rn	Puget Sound - pathogen rank
	PS_MUSLE_R	Puget Sound - sediment rank
	PS_TP_Qrtl	Puget Sound - total phosphorous **quartile**
	PS_TN_Qrtl	Puget Sound - total nitrogen quartile
	PS_TSS_Qrtl	Pugst Sound - total suspended solids quartile
	PS_Zn_Qrtl	Puget Sound - zink quartile
	PS_Cu_Qrtl	Puget Sound - copper quartile
	PS_Metals_Qrtl	Puget Sound - metals quartile (Ecology added)
	PS_Path_Qrtl	Puget Sound - pathogen quartile
	PS_MUSLE_Q	Puget Sound - sediment quartile

Table D-25. List of field names for N-SPECT, WRIA-wide Analysis

	Field Name	Description
WRIA Wide Analysis	WRIA_nrunoff	WRIA - runoff **load per area**
	WRIA_ntpconc	WRIA - total phosphprous load per area
	WRIA_ntnconc	WRIA - total nitrogen load per area
	WRIA_ntsscon	WRIA - total suspended solids load per area
	WRIA_nznconc	WRIA - zink load per area
	WRIA_nncuconc	WRIA - copper load per area
	WRIA_npath	WRIA - pathogen load per area
	WRIA_nmusle	WRIA - sediment load per area
	WRIA_TP_Rnk	WRIA - total phosphorous **rank**
	WRIA_TN_Rnk	WRIA - total nitrogen rank
	WRIA_TSS_Rnk	WRIA - total suspended solids rank
	WRIA_Zn_Rnk	WRIA - zink rank
	WRIA_Cu_Rnk	WRIA - copper rank
	WRIA_Metals_Rnk	WRIA - metals rank (Ecology added)
	WRIA_Path_Rn	WRIA - pathogen rank
	WRIA_MUSLE_R	WRIA - sediment rank
	WRIA_TP_Qrtl	WRIA - total phosphorous **quartile**
	WRIA_TN_Qrtl	WRIA - total nitrogen quartile
	WRIA_TSS_Qrtl	WRIA - total suspended solids quartile
	WRIA_Zn_Qrtl	WRIA - zink quartile
	WRIA_Cu_Qrtl	WRIA - copper quartile
	WRIA_Metals_Qrtl	WRIA - metals quartile (Ecology added)
	WRIA_Path_Qrtl	WRIA - pathogen quartile
	WRIA_MUSLE_Q	WRIA - sediment quartile