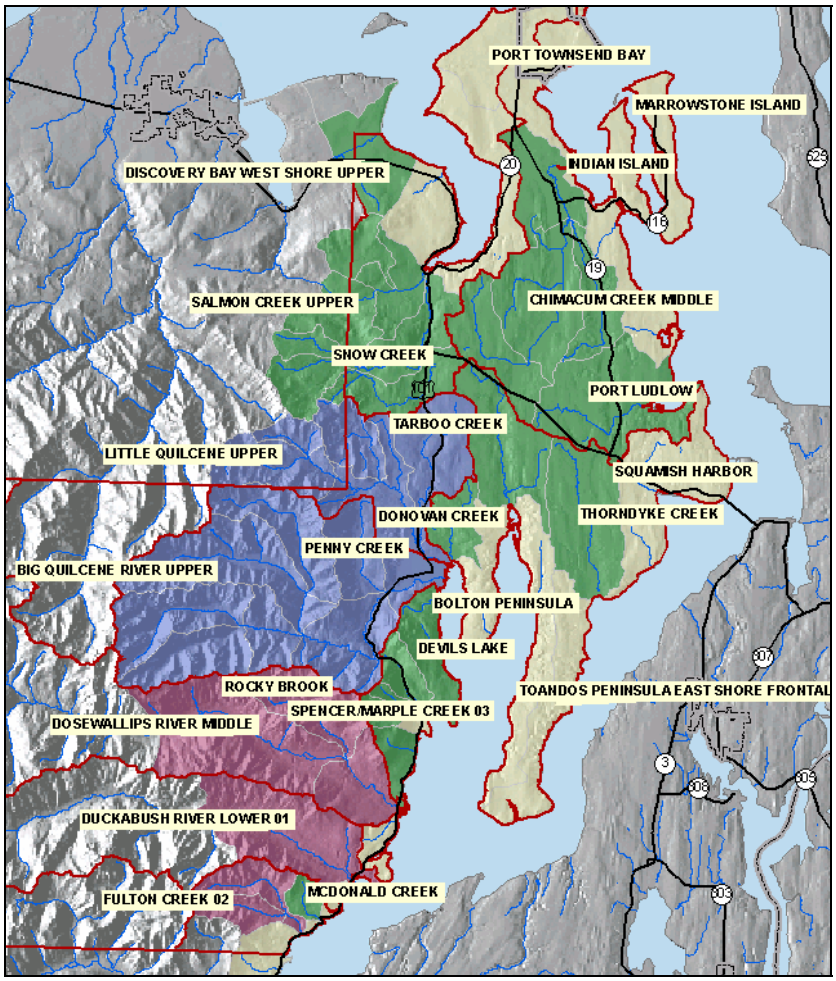
Draft Watershed Characterization of Jefferson County

May 16, 2007
Version 3



Department of Ecology
Shorelands & Environmental Assistance Program

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1.0 Introduction

1.1 Background

This characterization is a technical supplement to the County's Shoreline Master Program update. It includes application of the DOE draft scoring methods for characterizing freshwater watersheds and is intended to assist the County in determining appropriate land use designations, development standards, and restoration and protection priorities for shoreline areas.

1.2 Approach

Characterizing processes within the watersheds of the study area is central to developing a successful watershed based mitigation plan. An adequate characterization will provide local jurisdictions with information on the best areas for mitigation, protection of watershed processes, and development.

For example, this watershed characterization and analysis will help us identify areas that are important or key for maintaining watershed processes and how much these areas have been altered (Figures 3 and 4). A matrix (Figure 5) is then applied that evaluates the degree of importance and alteration for each basin, which in turn can produce a final map showing priorities for protection and restoration (Figure 6).

The central assumption to this characterization approach is that the health of aquatic resources is dependent upon intact upgradient watershed processes. Research has demonstrated that we must consider the watershed processes that occur outside of aquatic ecosystems if we are to protect and restore our lakes, rivers, wetlands, and estuaries, (National Research Council 2001, Dale et al. 2000, Bedford and Preston 1988, Roni et al. 2002, Poiani et al. 1996, Gersib 2001, Gove et al. 2001).

Watershed Processes: In this document, *watershed processes* refers to the dynamic physical and chemical interactions that form and maintain the landscape at the geographic scales of watersheds to basins (hundreds to thousands of square miles). These processes include the movement of water, sediment, nutrients, pathogens, toxins, and wood as they enter into, pass through, and eventually leave the watershed.

Our management and regulation of these aquatic ecosystems have typically concentrated on the biological, physical, and chemical character of the individual lake, wetland, stream reach or estuary, and not on the larger watershed that controls these characteristics.

Scientific studies have shown that watershed processes interact with landscape features, climate, and each other to produce the structure and functions of aquatic ecosystems that society is interested in protecting (Beechie and Bolton 1999).

For example, flooding by streams can create off-channel habitat that is important for fish. Much of the research concludes that protection, management, and regulatory activities could be more successful if they incorporated an understanding of watershed processes:

1.3 Potential Uses

This final map could be used by the County to develop an initial suite of potential mitigation sites based on the sub basin priority for protection and restoration. These mitigation sites can include aquatic resources such as wetlands and riparian areas and upland areas that are key to maintaining processes for these aquatic resources. Jefferson County planners and managers can use this information in updating their Shoreland Master Program and Comprehensive Plan. For example, section 173-26-201.3.d.i.A requires local governments to prepare a characterization of ecosystem-wide processes and ecological functions and identify measures to protect and/or restore the ecological functions and ecosystem-wide processes. The characterization can also be used to development comprehensive mitigation programs for CAO updates (e.g. offsite mitigation, in lieu fees, transfer of development rights).

2.0 Methods

For this project, the tools proposed for application are: 1) DOE publication #05-06-027, "Protecting Aquatic Ecosystems: Volume 1, A Guide for Puget Sound Planners to Understand Watershed Processes." This document provides guidance on how to conduct a coarse scale characterization for multiple processes; 2) "Protecting Aquatic Ecosystems: Volume 2 Models for Understanding Watershed Processes." This is a draft document that presents numeric models for implementing the guidance presented in Volume 1 and is attached to this document in Appendix B.

The hydrologic process was characterized for Jefferson County. The qualitative description for analyzing watershed processes is presented in appendices B through G of publication 05-06-027 (Volume 1). These appendices provide a tabular description of how to analyze the individual components of those processes. Volume 2 provides examples of numeric models that can be constructed to identify the geographic locations in a watershed that are key to the delivery, movement and loss of water (Tables B-1 and B-3 in Appendix B). The equations in these models use the environmental characteristics described in the tables as variables in equations that establish importance.

In general, variables are assigned maximum values of 1, 2 and 3; representing respectively, low, medium and high "importance" of a characteristic or "alteration" of a characteristic. The models are constructed so that higher total scores represent sub-basins or basins of greater importance for supporting a process in a watershed, or one with a higher degree of alteration to that process. The scoring is normalized to conditions specific in a watershed or basin. Thus the models provide a *comparison* of the *relative level of importance and alteration* of process components (see Step 3 and 4 of DOE publication 05-06-027). The scores do not represent a specific rate (e.g. rate of removal

of sediment or nitrogen) or specific level of alteration of a process that can be compared to scores outside of an analysis area. We do not have enough information at this time to calibrate models to conditions throughout the state and establish relative importance of processes and alterations among different watersheds.

Appendix B of this document presents the scoring methods in detail and a series of maps that display the results of the numeric models applied to the freshwater watersheds of Jefferson County. These maps and how they were analyzed for Jefferson County is the same analytical process used for Clark County that is presented in this document.

3.0 Hydrogeologic Units

This characterization uses a hydrogeologic classification approach based on the "hydrologic-landscapes" work of Winter (2001) and the hydrogeologic work of Bedford (1999 & 1988). This landscape approach considers regional climate, surficial geology, topography, groundwater and surface flow patterns and morphology in relationship to aquatic resources. Jefferson County has already established hydrologic units for the County based previous watershed planning efforts (i.e. 2514). This characterization study modifies these hydrologic units in order to maintain the relationship between processes and the aquatic ecosystems that they influence (i.e. process, structure and function relationship). Whereas the County hydrologic units are based primarily on the surface water boundaries of major stream and river systems, this analysis groups units based on precipitation type, subsurface and surface water flow patterns, and geology and landform

These units were also divided so that watersheds with significantly different levels/patterns of precipitation and geomorphology and were not compared to one another in the scoring. For example, because the watersheds within the Large River Unit (i.e. Big Quilcene) unit have higher precipitation levels they will score higher than the Small River unit if analyzed together. The Small River unit, however, support important aquatic ecosystems and should be characterized separately from the Large River unit so that characterization scores are not artificially suppressed by the scores for the higher precipitation levels in the watersheds of Large Rivers.

3.1 Geology

The following is a summary of the geologic and groundwater information presented by Grimstad and Carson (1981) in Water Supply Bulletin No 54. As previously identified by Grimstad and Carson, the study area for eastern Jefferson County involves 5 geographic subareas: the Olympic Mountains, Miller and Quimper Peninsula, Indian and Marrowstone Islands, Toandos and Bolton Peninsulas and the Chimacum Drift Plain (see figure 1).

The Olympic Mountains consist primarily of volcanic and sedimentary rocks that have been uplifted by tectonic activity. These formations extend eastward down into the

adjacent lowland areas. These formations are relatively impermeable except for fracture zones (primarily in volcanics). The lowland areas are comprised of glacial and interglacial derived deposits resulting from a series of glacial cycles originating in British Columbia (Cordilleran Ice Sheet). These glacial deposits overlie the older volcanic and sedimentary formations, though there are outcrops of these older formations throughout the eastern lowland portion of the County. The Olympic Mountain glaciers also expanded eastward into the study area, but only the Duckabush and Dosewallips Valleys were significantly affected.

The glacial cycles created several major types of deposits, each of which have different effects upon present day water flow processes. The deposits are generally arranged from the land surface downward, in order of age of deposition (i.e. younger deposits nearer the surface): recessional outwash, lodgement till, advance outwash, and undifferentiated deposits. Areas of alluvium, which are very recent deposits are found in river valleys. Wind, wave and water erosion has cut through these layers of glacial deposits exposing them on hillsides and bluffs. The large Chimacum Valley, for example, has an extensive alluvial deposit on the valley floor, valley walls of exposed undifferentiated deposits and highlands above consisting of lodgement till. The headwaters of this valley have large areas of recessional outwash, a relatively young deposit that has not been extensively eroded. Many marine bluff areas on the Toandos and Bolton Peninsulas have similar erosion patterns, with bluff faces comprised of undifferentiated deposits, advanced outwash fringe towards the top and lodgement till on upland areas. The landscape setting for these deposits, including how they have been shaped by wind, waves and water erosion, determines the manner in which water moves across and through the land. For example, permeable outwash deposits on hillsides can be locations for groundwater discharge for wetlands and streams. On terraces, these deposits may act as recharge areas.

The most widespread glacial deposit is lodgment till which covers the majority of the upper portion of the lowland geographic units. In general this deposit is impermeable but does include some lenses of sand and gravel. Underlying this deposit is a relatively thick deposit of advance outwash which has moderate to high permeability. Large quantities of water can be stored by this deposit and it is both a principal source of potable water and a source of groundwater discharge for aquatic resources in the County. Advance outwash deposit is predominate in the northern portion of the study area but is also present in surficial deposits in the Chimacum Drift Plain and the Toandos Miller Peninsula.

An associated deposit is recessional outwash, which also has high permeability and water capacity and is of significant importance to water flow processes. Relatively large areas of this deposit are found on the west side of the Quimper Peninsula, in the Port Hadlock area, the Chimacum Valley and West Chimacum Creek (upper portion) and above Squamish Harbor. Additionally, recessional outwash is found in the lower reaches of the rivers draining the Olympic Mountains area, with large deposits present near the mouth of the Big and Little Quilcene Rivers. In this landscape setting, recessional outwash would be critical to groundwater discharge to the Big Quilcene River.

Undifferentiated deposits consist of a variety of glacial and interglacial deposits including lacustrine and glaciolacustrine (very low permeability), outwash sands and other fluvial

deposits (moderate to low permeability). These deposits, therefore, vary greatly in their permeability and water holding capacity, but are generally considered to be of low permeability and to yield little to no water (i.e. for potable water supplies).

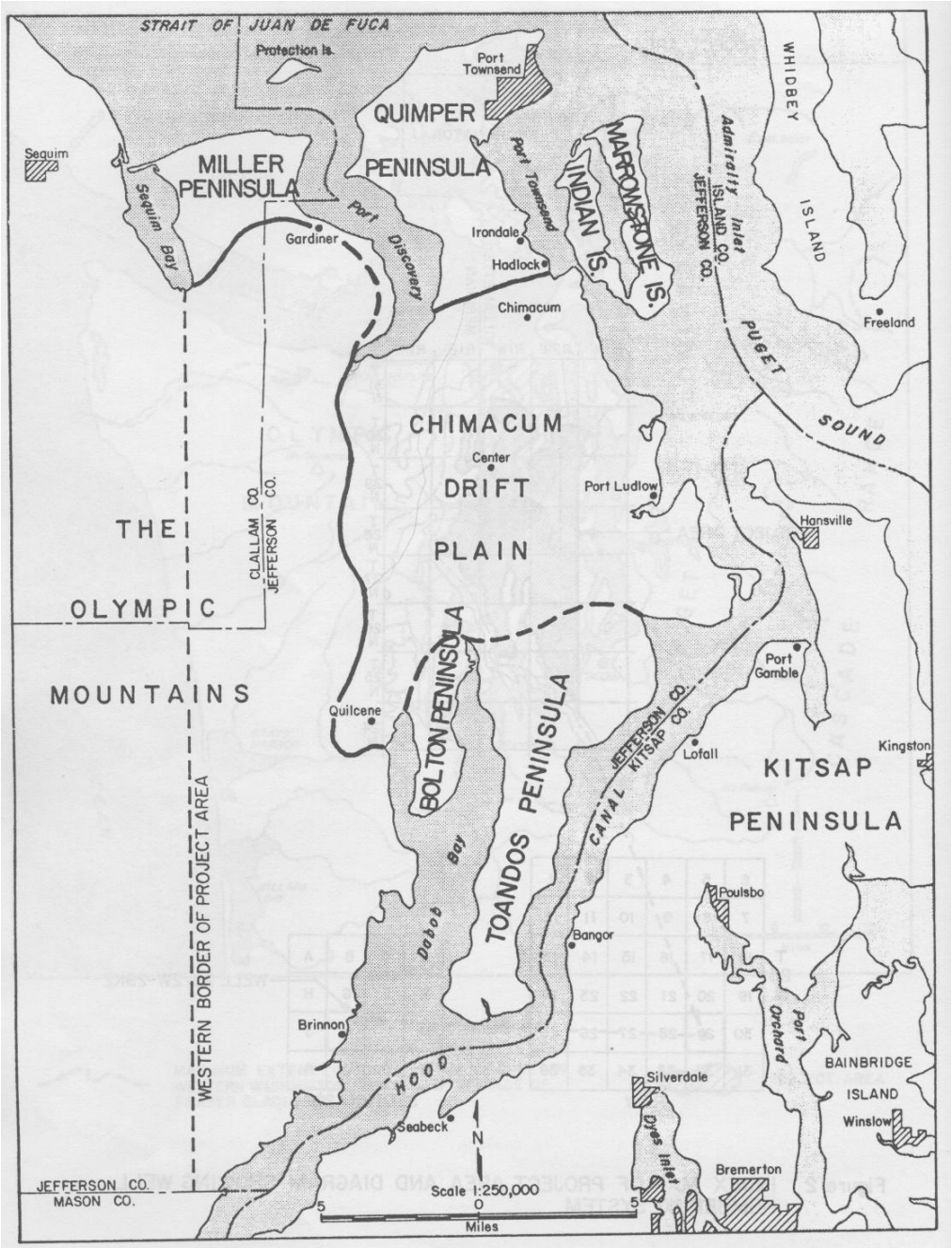


Figure 1. Map of geographic units in eastern Jefferson County. Source: Grimstad and Carson 1981

3.2 Ground Water Flow Patterns

The study area can be divided into three major groundwater flow units: the Olympic Mountains; the Chimacum Drift Plain north of Chimacum Valley headwaters; and the

Chimacum Drift Plain south of the headwaters of Chimacum Valley, including the Bolton and Toando Peninsulas. The subsurface flow pattern for the Olympic Mountains is

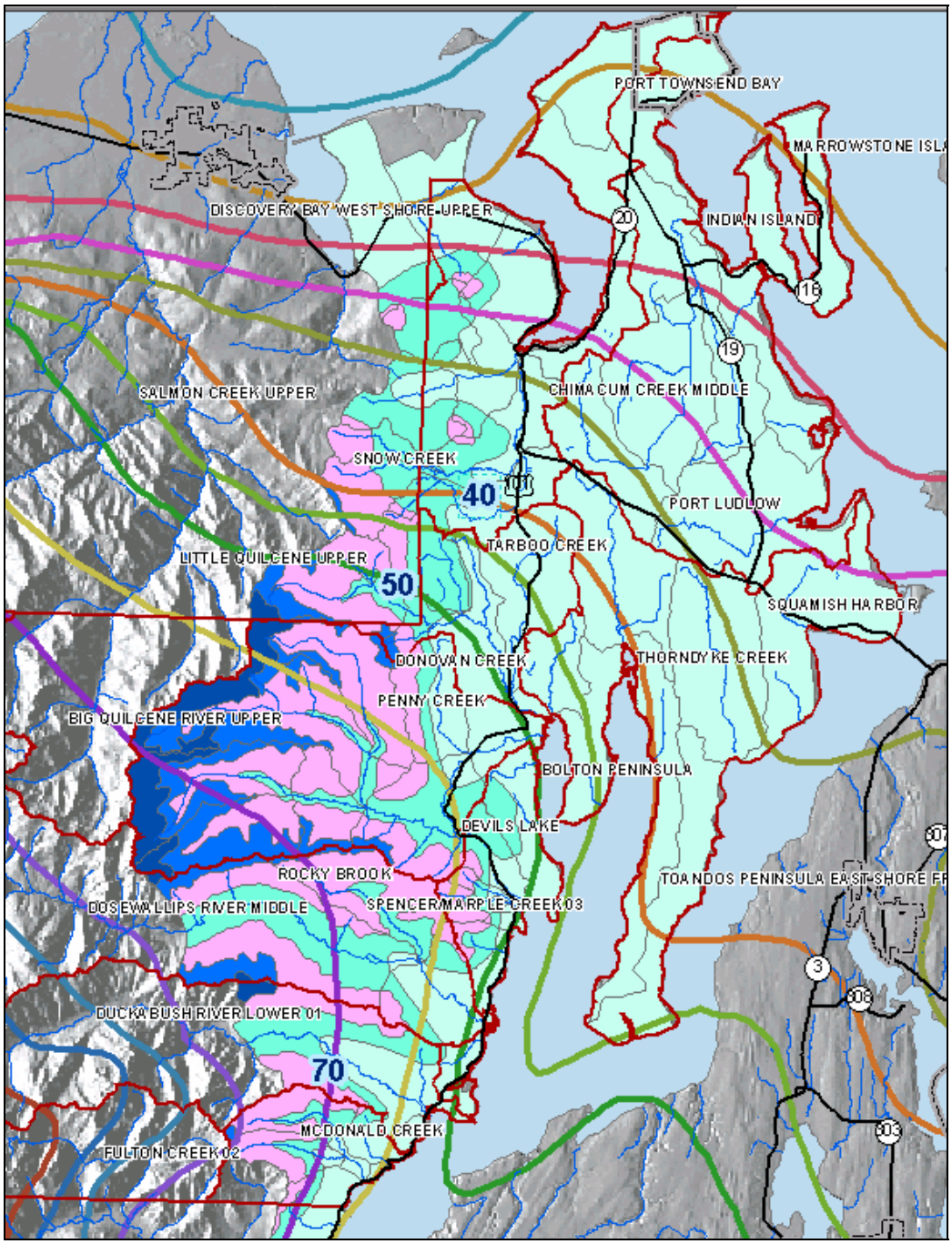


Figure 2. Map of precipitation types. Dark to medium blue = snow dominated; pink = rain-on-snow; blue-green to light blue = rain zone

predominately eastward towards the Hood Canal. For the Chimacum Drift Plain (north of headwaters) the groundwater flow is generally northward towards the Strait of Juan de Fuca and northeast and east towards the Puget Sound. For the southern portion of the Chimacum Drift Plain and Bolton and Toandos Peninsulas, the groundwater flow is generally south towards Darob Bay and Hood Canal

3.3 Precipitation Types

Figure 2 presents the precipitation types and amounts of precipitation throughout the study area. For the Olympic Mountains area, precipitation consists of snow dominated and rain-on-snow zones. The lowland areas are predominately rain zones. The precipitation is lowest in Port Townsend (20 inches), increasing in the southwesterly direction to over 70 inches per year in the Olympic Mountains portion of the study area.

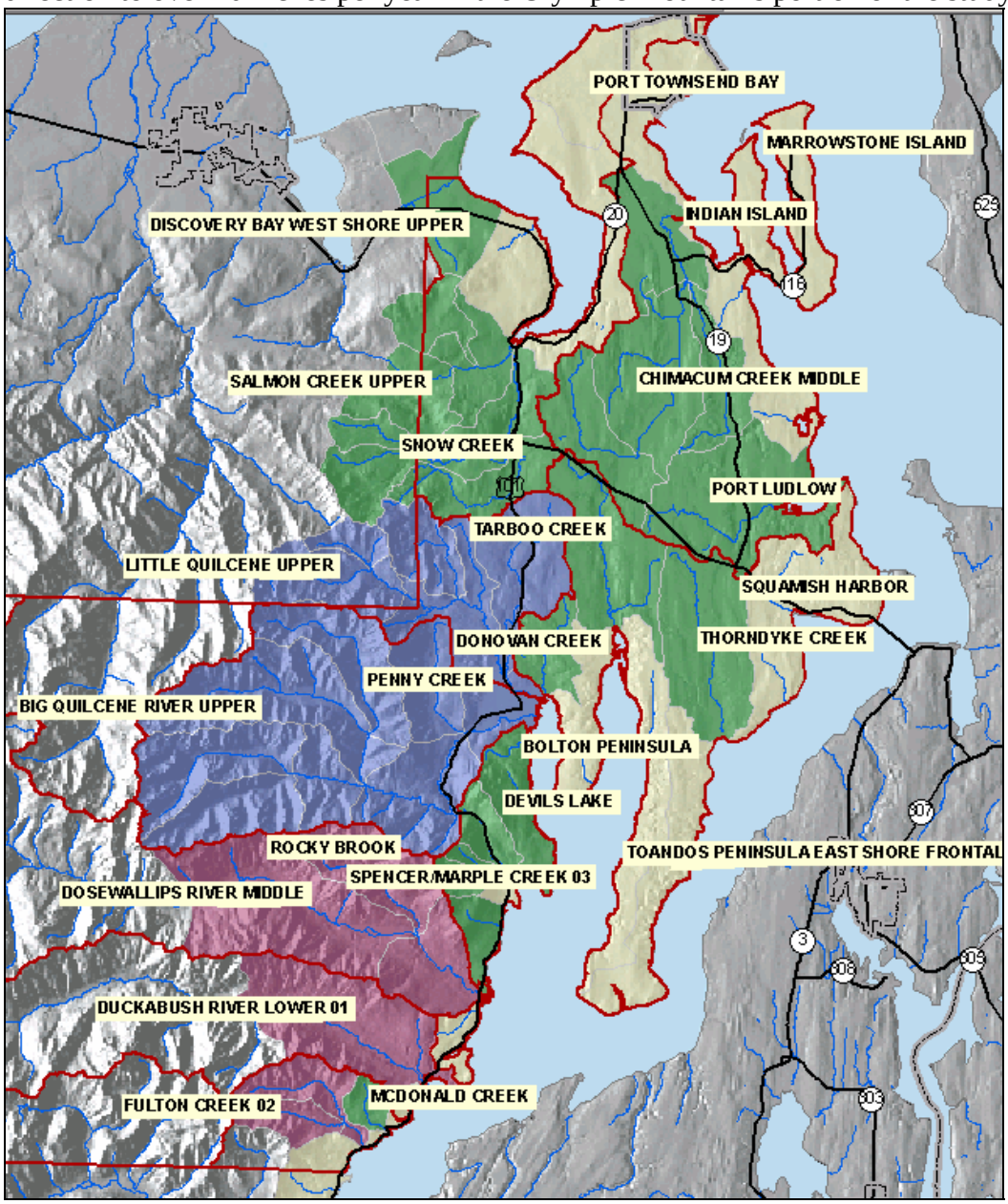


Figure 3 – Hydro-Geomorphic Units. Blue = Large Rivers; Purple = Medium Sized Rivers; Green = Small Rivers; Gray = Small Nearshore Watersheds.

3.4 Synthesis of Precipitation, Groundwater Flow Patterns, Geology and Landform Data

Figure 3 presents the hydro-geomorphic units used for watershed characterization and analysis, based on precipitation type, groundwater flow patterns, geology and landform.

Four units were developed: the large and medium sized rivers of the Olympic Mountains; the small rivers of the lowland areas; and the small nearshore marine watersheds. The analysis of water flow processes was conducted within each of these hydrogeologic units.

4.0 Results of Characterization

4.1 Areas of Importance for the Hydrologic Process

Figure 4 presents the important areas for the Hydrologic Process. Important areas represent unaltered or natural conditions prior to human influence and do not depict existing conditions that would alter these processes. The important areas for each geomorphic unit are discussed below.

Overall, the Olympic Mountains and the adjoining lowlands have the largest relative area of "high" importance to watershed processes. This is due to the presence of higher precipitation (rain-on-snow, snow dominated zones, Figure A-1) and areas important to surface and groundwater processes throughout this area (surface storage and infiltration, percolation and recharge - Figures A-4 and 5). The Little Quilcene watershed was of lower overall importance due to a higher degree of impermeable deposits and lower relative rainfall.

The headwaters for the Chimacum drift plain score as a "high importance" as do watershed areas draining to Tarboo and Quilcene Bays. The high importance of the Chimacum area is primarily due to the presence of wetlands and floodplains (Figure A-2 and A-4) and relatively large areas of permeable deposits and moderate rainfall levels. The Tarboo Creek, Thorndyke Creek, Toandos Pennisula (west side), and Donovan Creek watersheds score high due to the presence of important areas for groundwater processes (infiltration, percolation and recharge (Figure A-5).

Other areas of lower importance were primarily the small nearshore marine watersheds that are in areas of low rainfall and fewer areas for storing surface water (i.e. wetlands and streams, Figure A-2 and A-4).

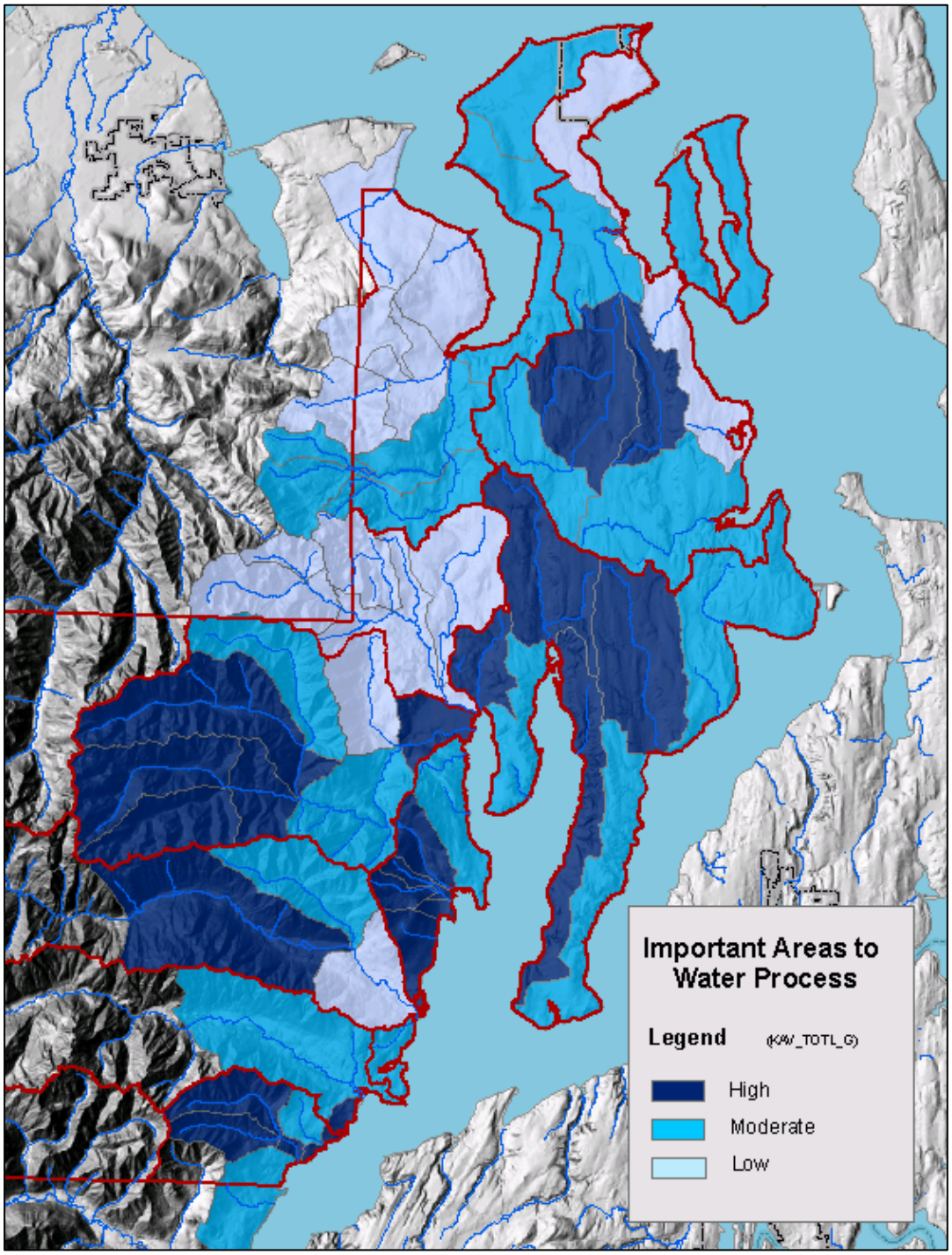


Figure 4. Important Areas for the Hydrologic Process. Dark blue represents a score of high importance; medium blue represents a score of medium importance and light blue represents a score of lower importance.

4.2 Areas of Alteration to the Hydrologic Process

Figure 5 depicts the areas of high, medium and low alteration. Important areas represent the severity of human alteration to unaltered or natural conditions that were modeled and depicted in Figure 4. Areas of alteration are scored for high, medium and low levels of alteration. Variables for alteration include areas of forest clearing, degree of wetland filling, and stream alteration.

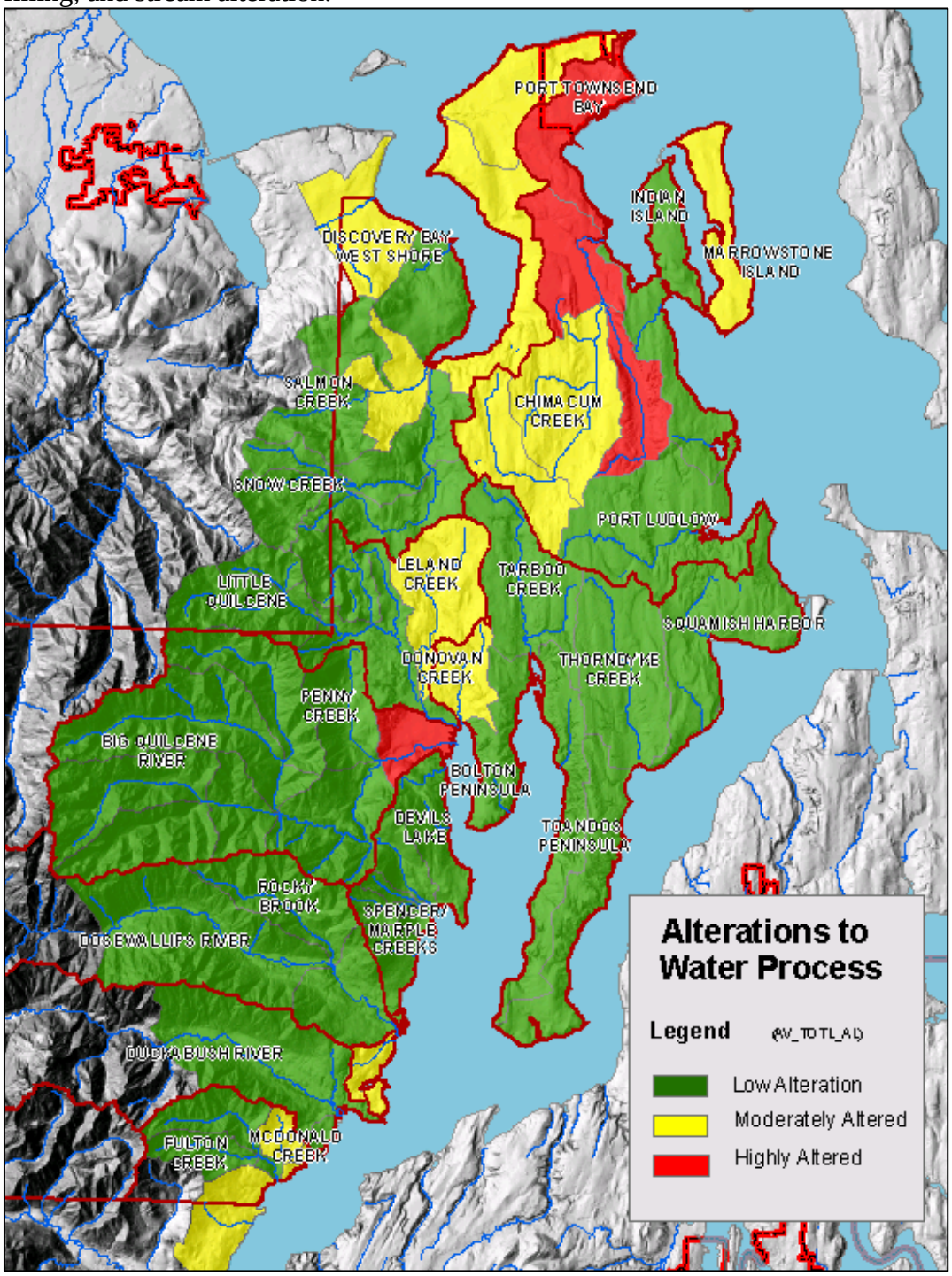


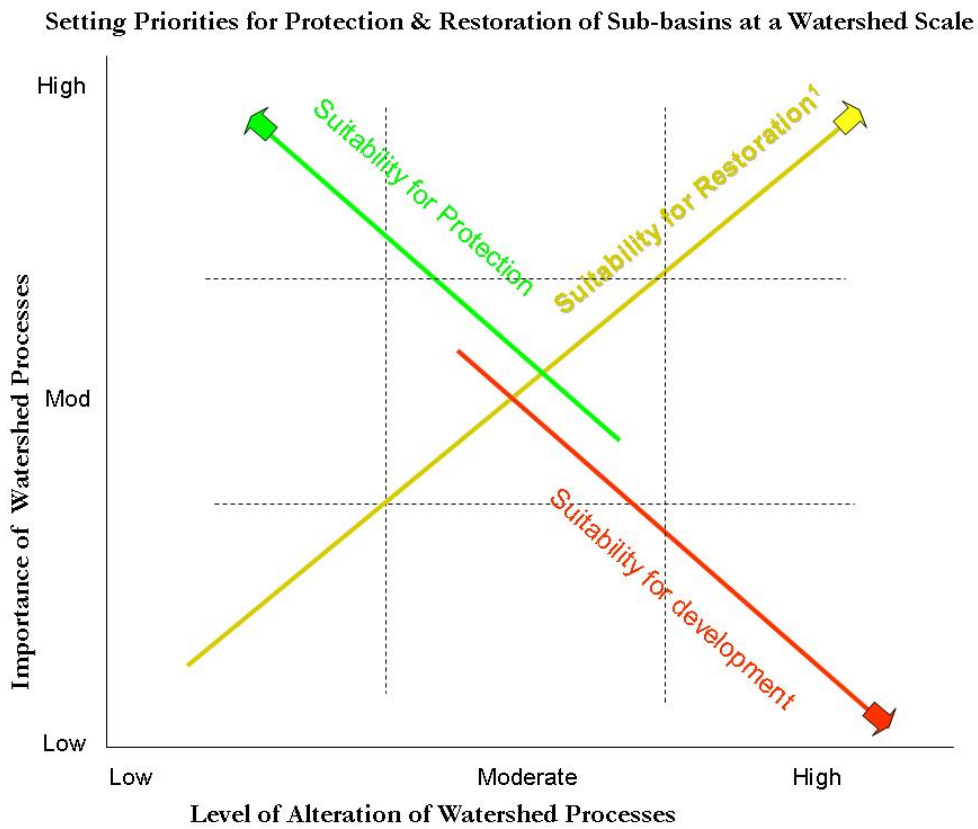
Figure 5. Areas of High, Medium and Low Alteration. Green = low levels of alteration; Yellow = medium and Red = high.

The Chimacum Valley and Port Townsend area had the largest area of "high" alteration. This is due primarily to forest clearing, wetland loss and impervious surface from urban/suburban development. The alteration to the hydrologic processes of delivery of precipitation, surface storage, groundwater recharge and discharge are shown in Figures A-9 through A-12. A significant portion of the lowland area has a "moderate" score for alteration due primarily to forest clearing and wetland loss (i.e. upper Chimacum Creek).

The Olympic Mountains, Toandos and Bolton Peninsula have large areas of low alteration, except for the mouth of the Little Quilcene and the Dosewalips due to impervious cover and forest clearing (Figures A-8 through A-12)

4.3 Synthesis Map – Areas of Protection and Restoration

Land use planning should be developed within a framework that first focuses on maintaining or restoring watershed processes (Hidding and Teunissen 2002, Dale et al. 2000, Gove et al. 2001). Such a framework for protection and restoration is presented in Figure 7. To develop map 7, the matrix presented in Figure 6 was applied. This matrix synthesizes the results of the importance and alteration maps (Figures 4 and 5).



1) Applies to areas where restoration is feasible. If the site proposed for restoration is in an existing developed urban area, or where processes are so altered (either within a sub-basin or in the upper watershed) that they cannot be adequately restored, then the site is more suitable for development and restoration should be shifted to other locations in the sub-basin that are rated high for both level of importance and level of alteration.

Figure 6. Analysis Matrix for identifying priority areas on the landscape for restoration and protection.

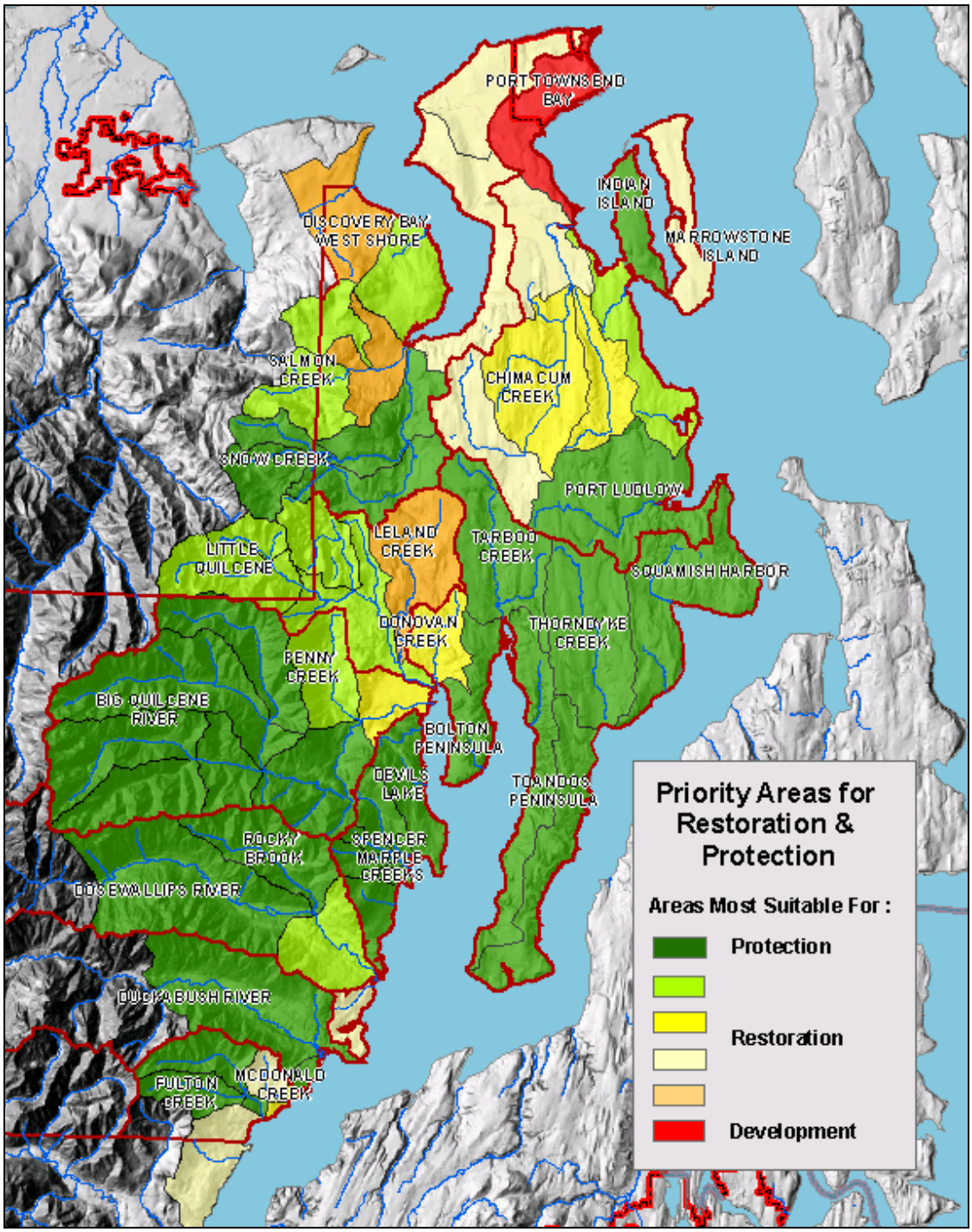


Figure 7 – Areas of Protection and Restoration for Hydrologic Process. Dark green = priority 1 protection; light green priority 2 protection; Bright yellow = priority 1 restoration; light yellow = priority 2 restoration; tan = priority 3 restoration; raspberry = processes altered. Rivers and lakes are shown in light blue.

The matrix is based on watershed based research indicating that areas with low levels of alteration to watershed processes should be protected and areas with higher levels of alteration to processes with a higher level of importance should be restored (Stanley et al 2005). Restoration should not have a high priority, however, in areas that have

permanently altered processes (urban areas). The areas of protection and restoration for the hydrologic process are discussed below.

The synthesis maps presented in this section are intended to provide an initial watershed protection and restoration framework at the watershed scale to assist land use planning efforts in Jefferson County. These maps are not intended to provide a detailed framework for the protection and restoration of functions at the site scale. Appendix A presents the detailed maps that identify important areas and their relative degree of alteration for the water flow process. In order to develop the protection and restoration map and areas suitable for development, a detailed matrix similar to that presented in Figure 6 is used to synthesize the results of the important areas and alteration maps (Figure A-13).

Figure 7 shows the areas for protection and restoration for the hydrologic process. Figure 7 can be used to guide restoration and protection planning in the County. For example, watersheds which score "restoration 1" may be priority areas for compensating for impacts in lower scoring areas such as Port Townsend watersheds. Figure 7 can also be used to determine appropriate land use designations and development standards. Areas shown as "protection" for instance, may be more suitable for low intensity development that minimizes impacts to forest cover and aquatic resources. Development standards that encourage clustering could be considered for these areas.

The Chimacum Valley and Discovery Bay watersheds constitute the largest areas for "restoration." The largest areas for "protection" includes the Olympic Mountains watersheds and watersheds for Toandos and Bolton Peninsulas, and Tarboo, Thorndyke, Port Ludlow, Snow Creek, Squamish and Indian Creek watersheds,

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Appendix A. Results for Characterization: Areas of Importance and Alteration for Hydrologic Process

This appendix presents the maps for important areas and their alterations. These maps were used to create the final summary map for protection and restoration of hydrologic process (Figures 7).

A-1.0 Areas of Importance for the Hydrologic Process

Figures A-1 through A-7 present the important areas for the hydrologic process. Important areas are a combination of physical conditions (i.e precipitation level, presence of wetlands and floodplains, permeability of geologic deposits) that are key to the delivery, movement and loss components of the Hydrologic Process.

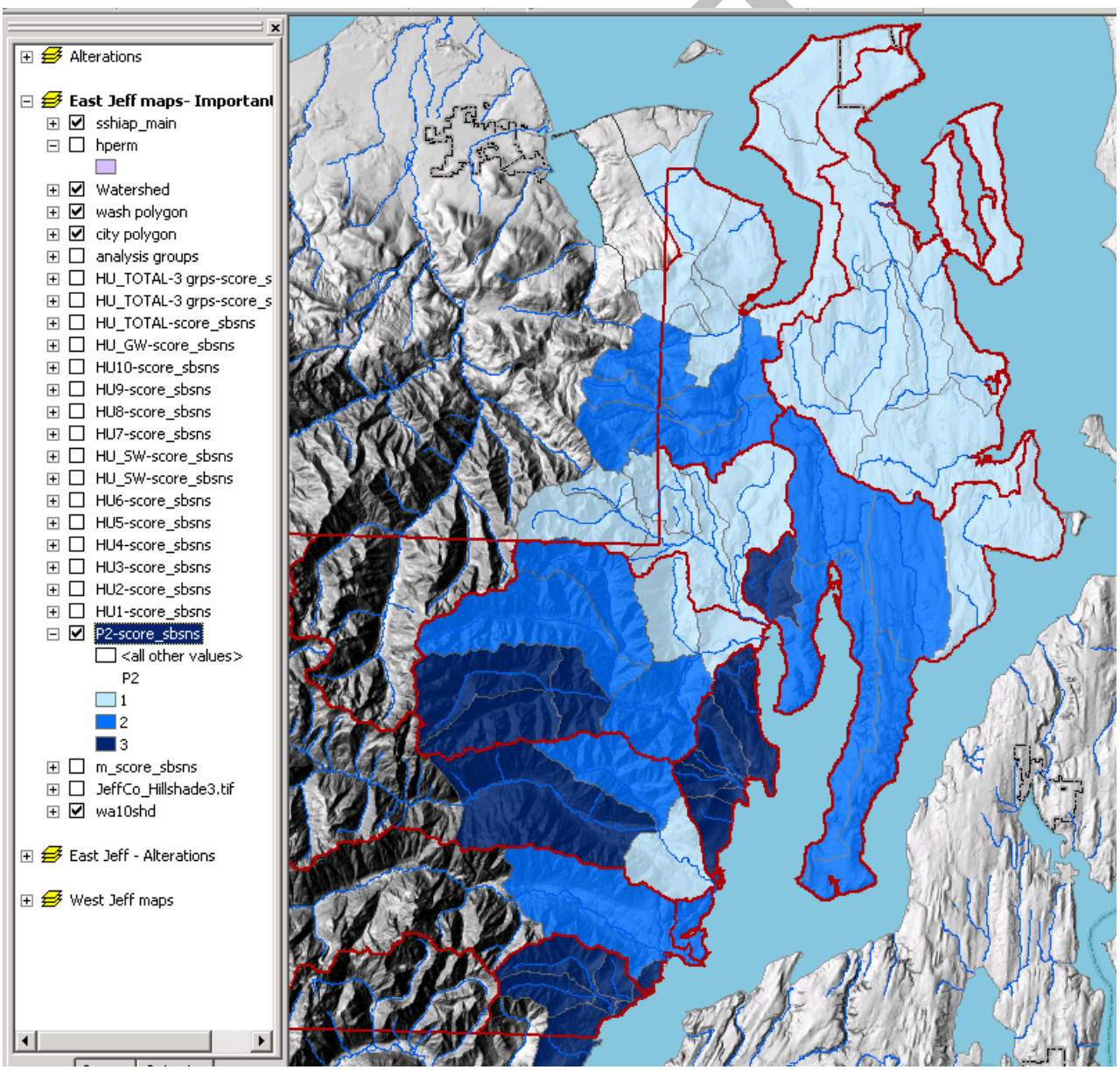

Figure A-1 – Rating for Important Areas for Precipitation; Dark Blue = high level of importance; Light Blue = lower level of importance

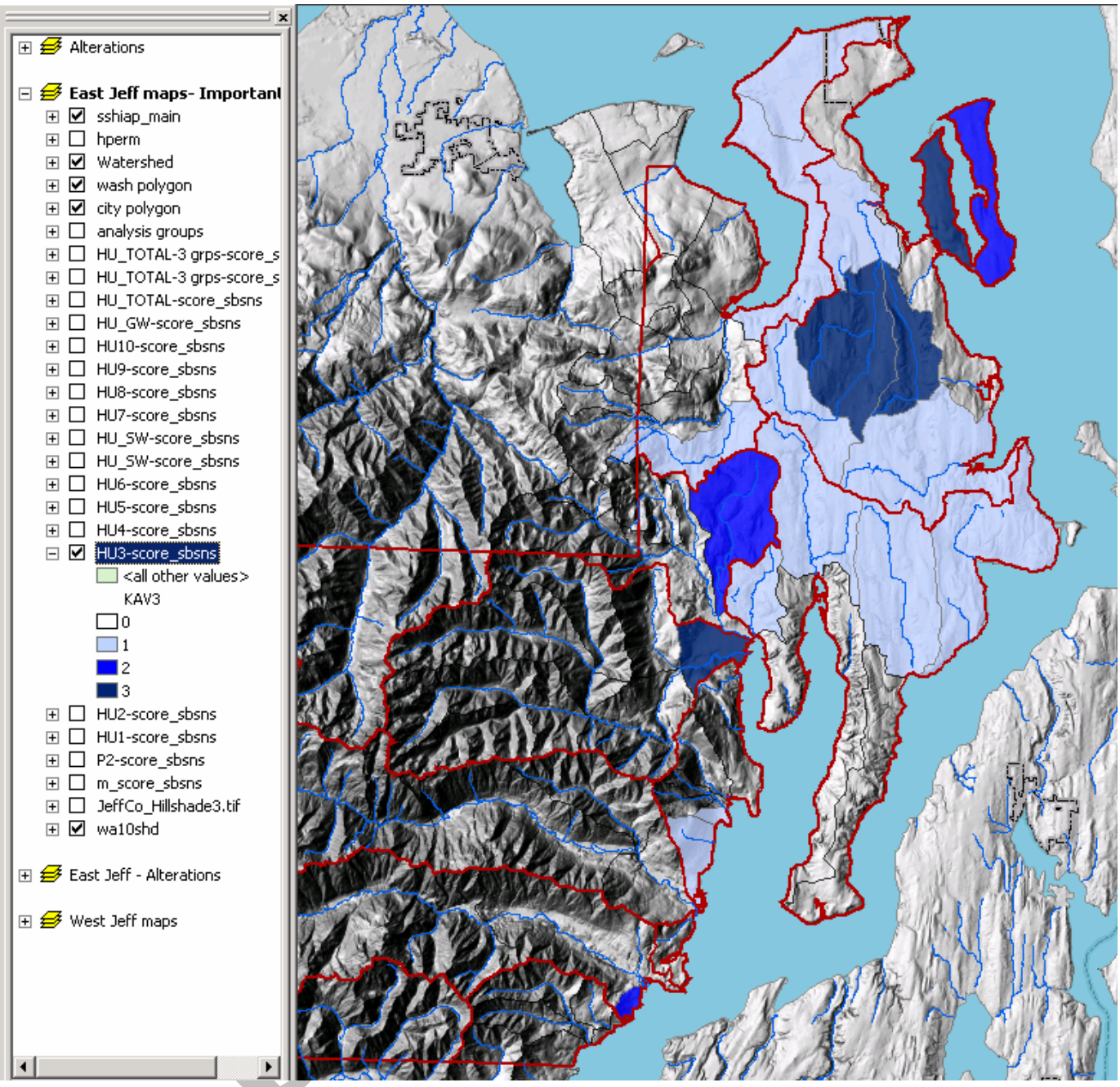

Figure A-2 Rating for Areas Important for Wetlands. Dark Blue = High; Light Blue = Lower level of importance. Areas not colored have fewer that 5% wetlands for the sub-basin analysis unit.

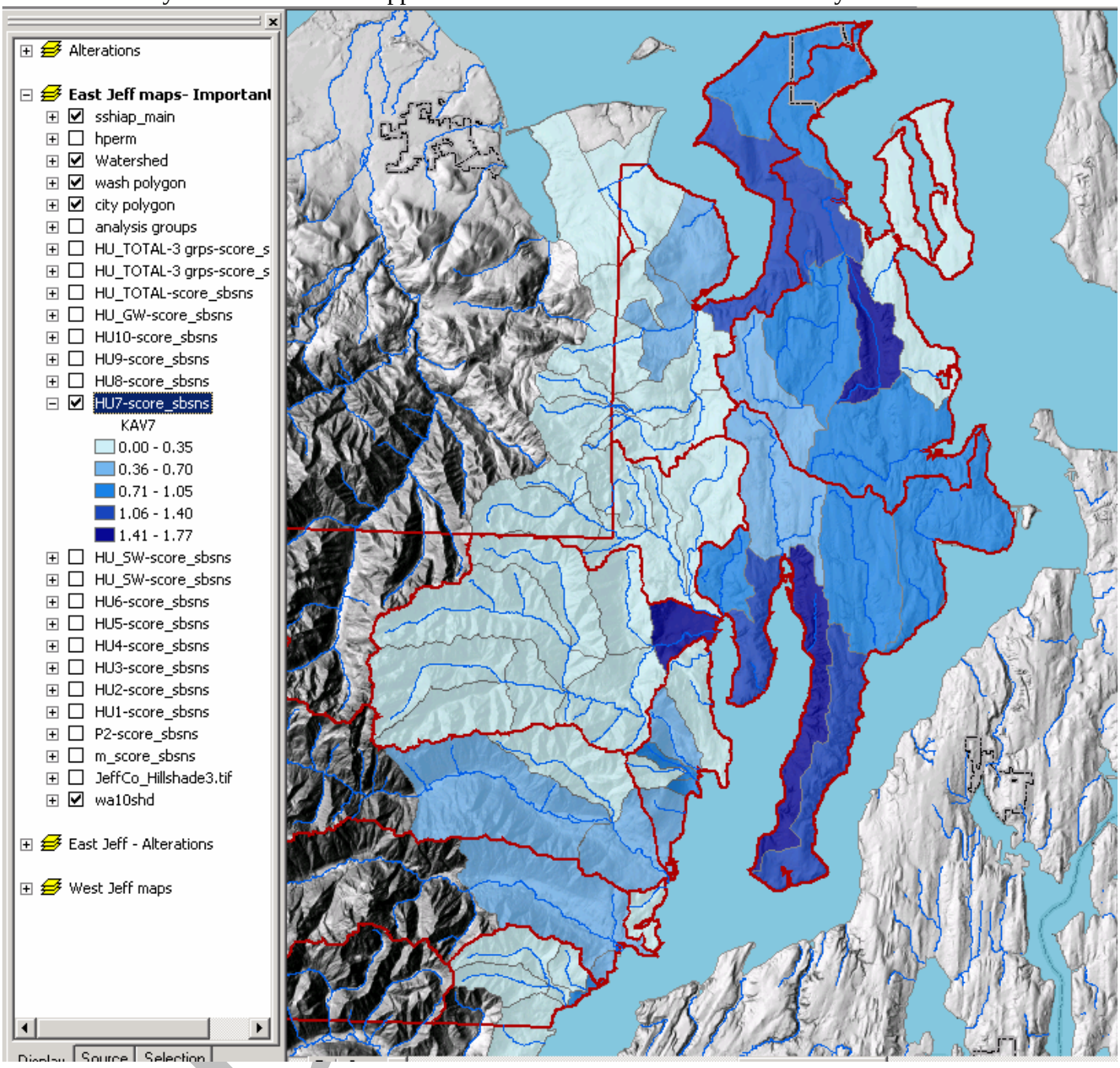

Figure A-3, Rating for Areas of Importance for Permeability. Darker blue is more important.

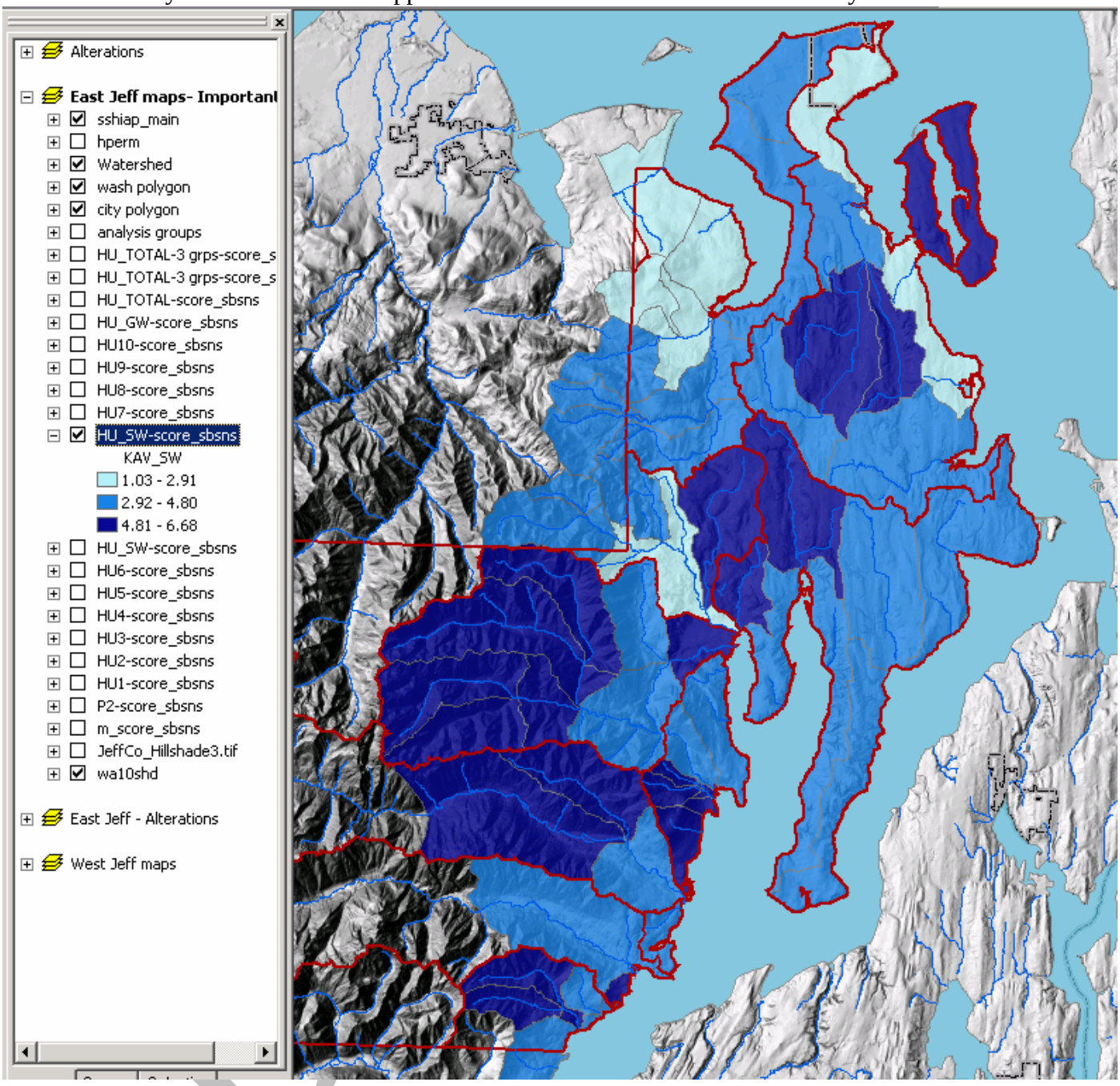

Figure A-4. Rating for Areas of Importance for Surface Water (Precipitation, Storage in Wetlands/Streams). Darker blue is more important.

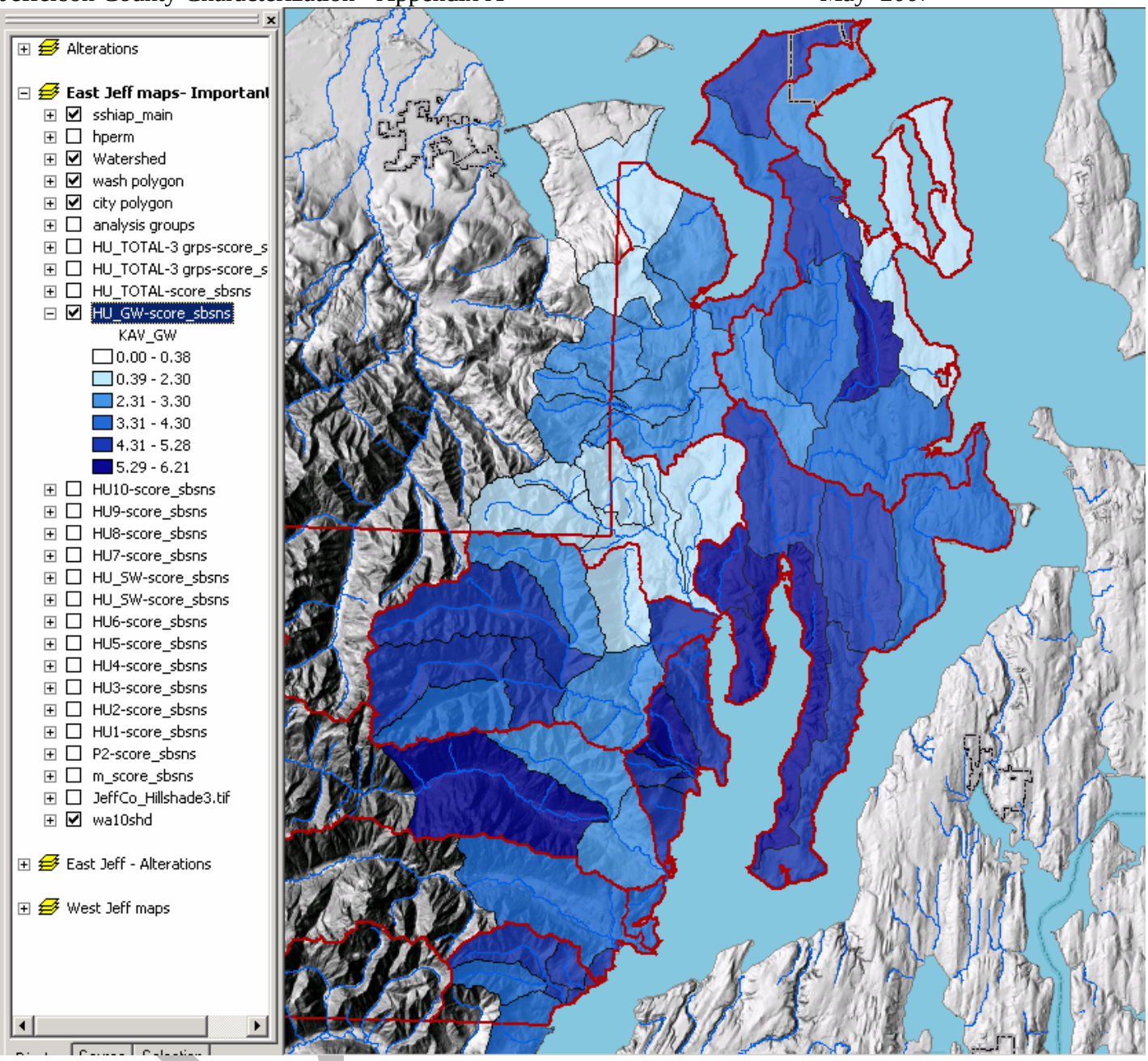

Figure A-5, Rating for areas of importance for groundwater (higher precipitation, infiltration, percolation, recharge). Darker blue is more important.

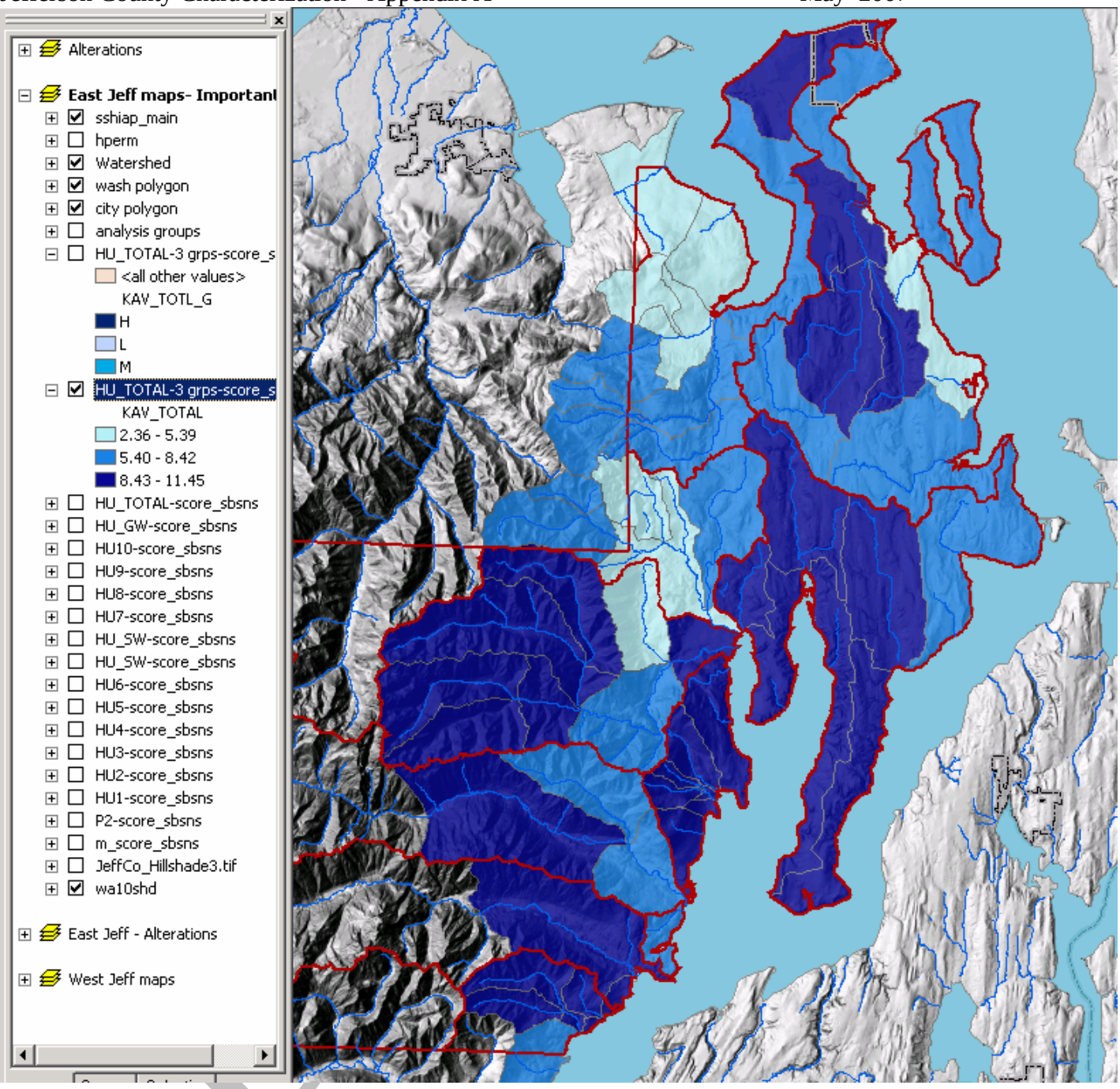

Figure A-6. Total Raw Score for Hydrologic Process.

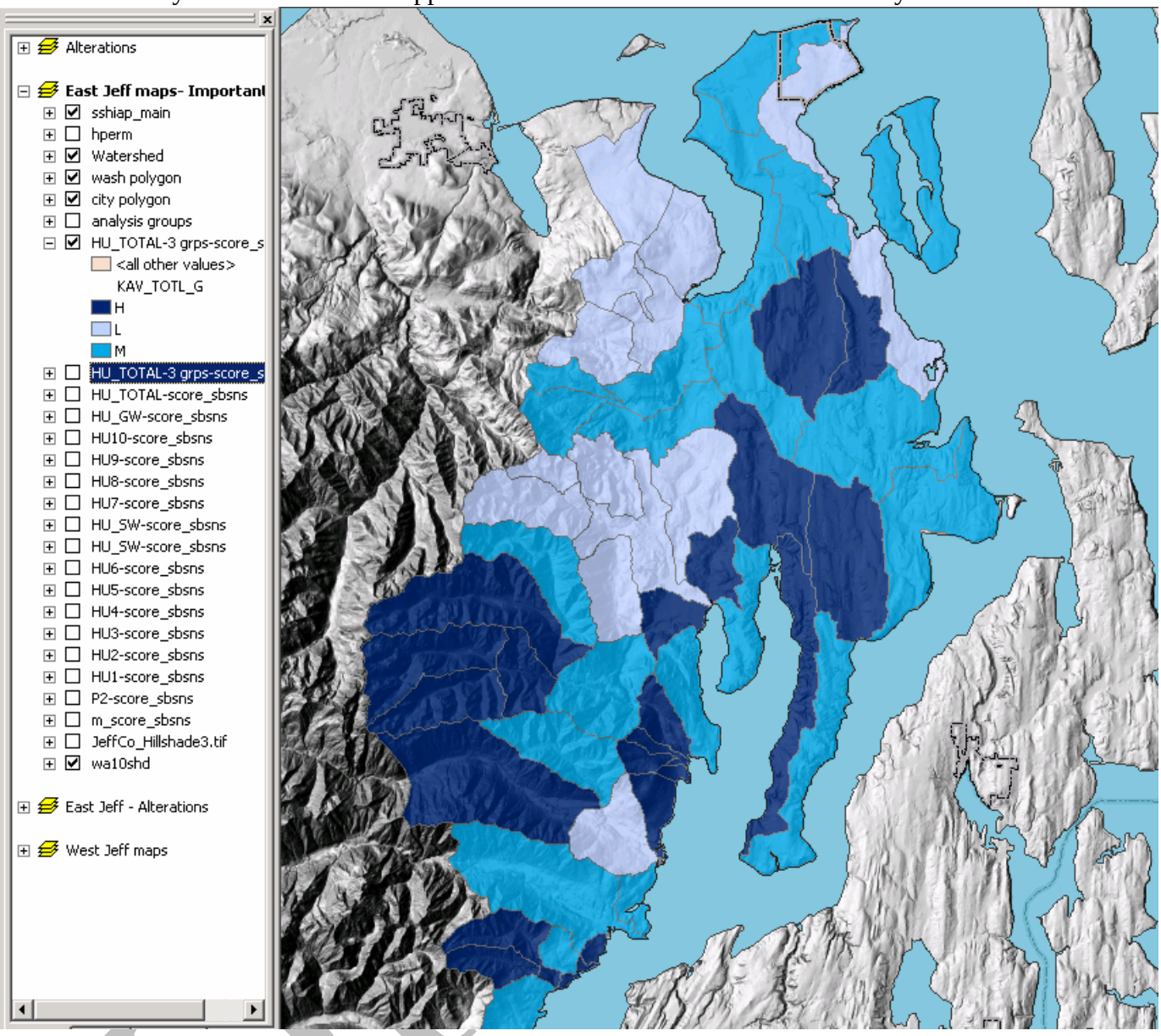

Figure A-7 – Total Score normalized within each geomorphic unit

A-2.0 Areas of Alteration to the Hydrologic Process

Figure A-8 through A-12 depicts areas of high to low alteration; darker colors represent higher levels of alteration. These areas represent the level of human alteration that were modeled and depicted in Figure 5. Variables used to determine these levels include areas of forest clearing, degree of wetland filling, and amount of stream alteration.

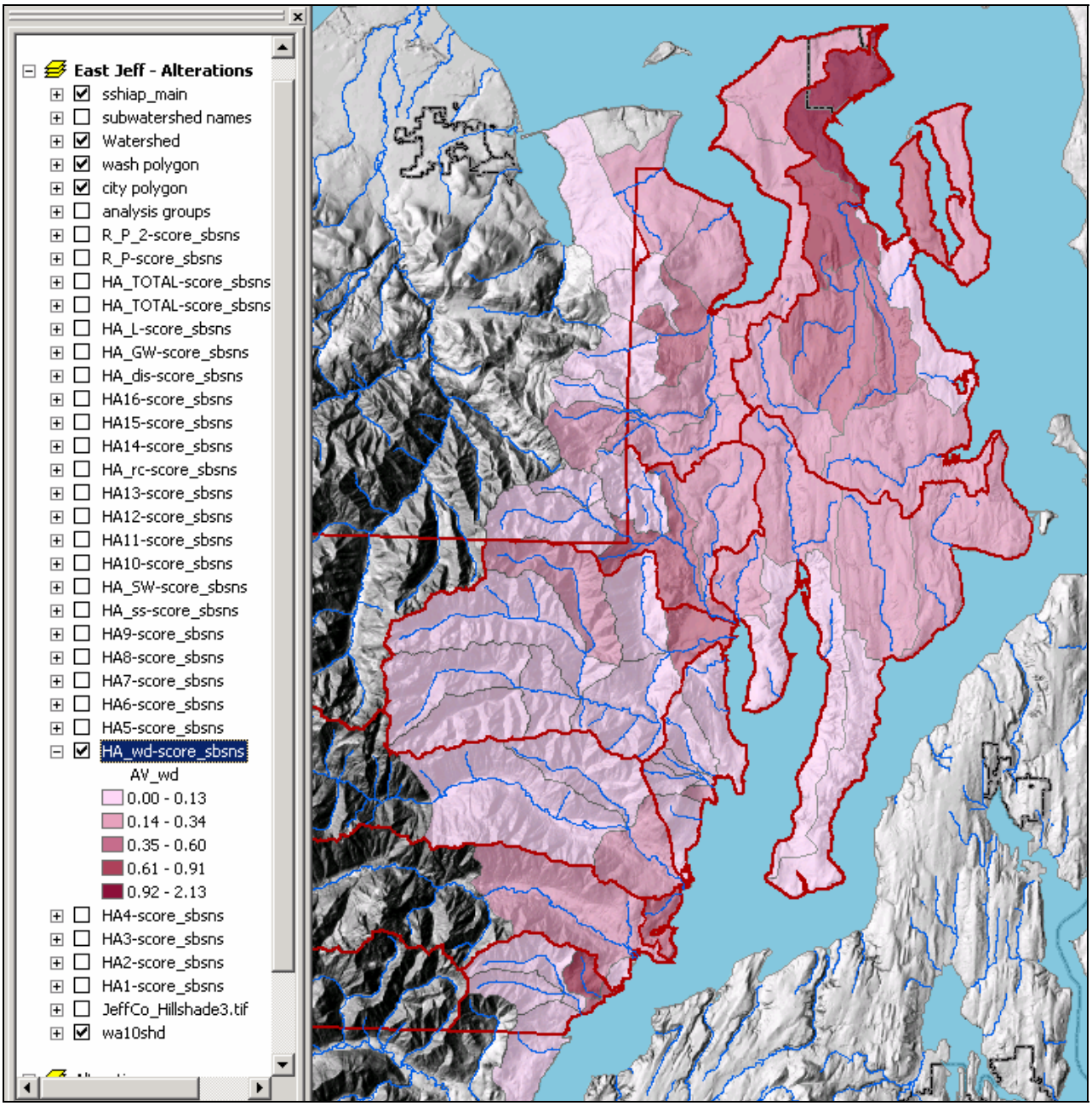

Figure A-8 – Rating for Alterations to Water Delivery. Darker colors represent a higher level of alteration

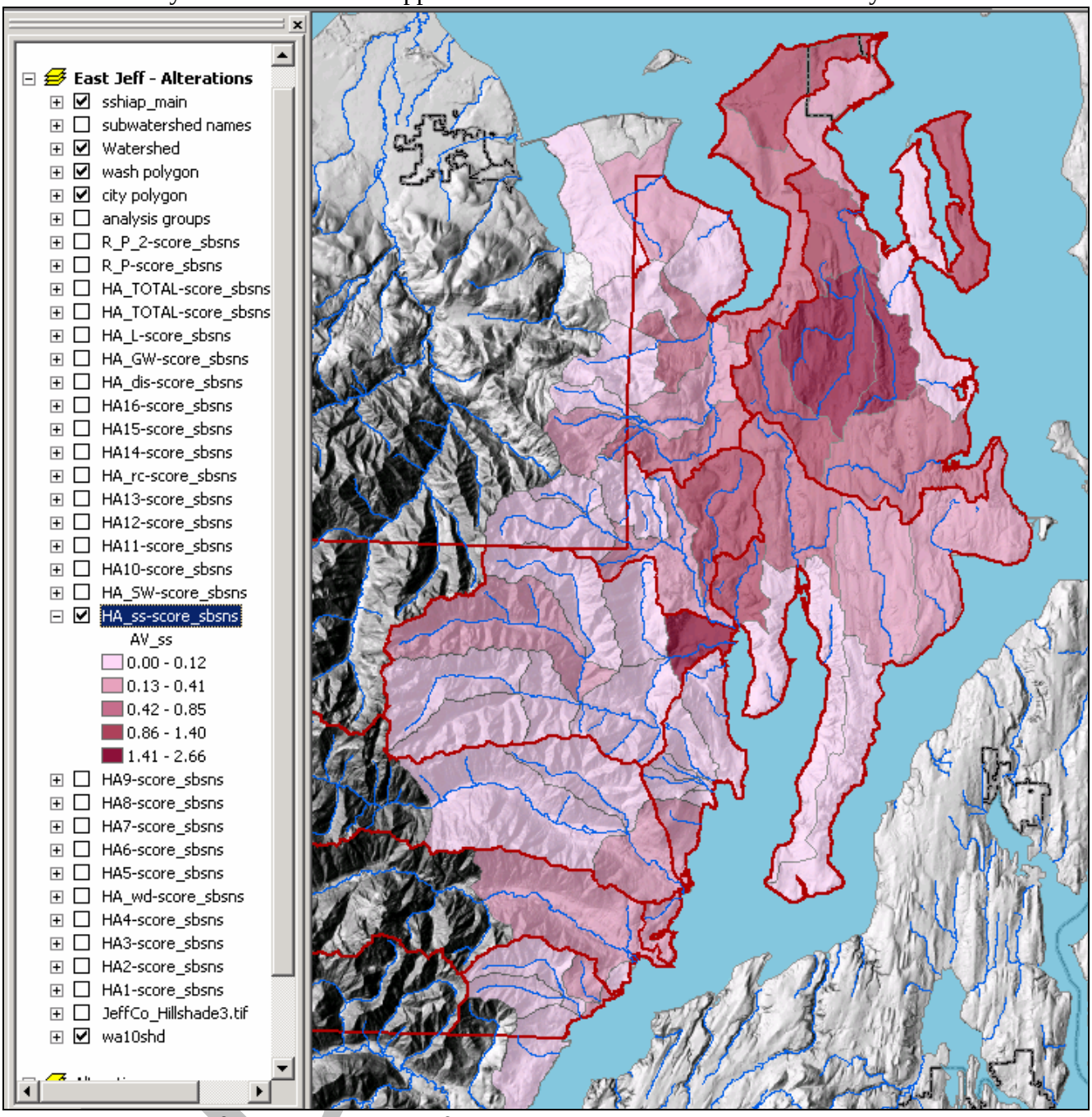

Figure A-9 - Rating for Alterations to Surface Water Storage (wetlands and streams). Darker colors represent a higher level of alteration.

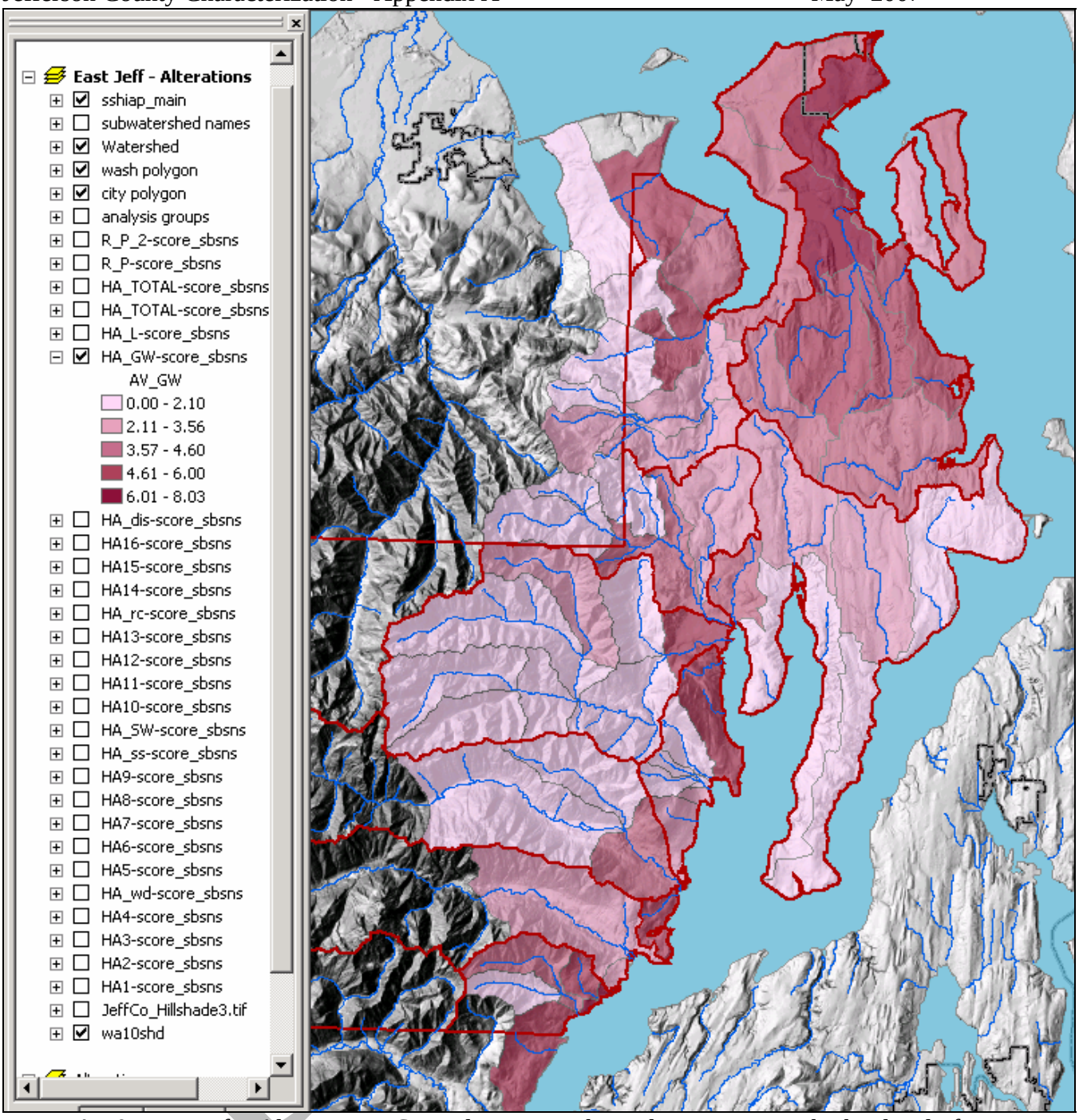

Figure A-10– Rating for Alteration to Groundwater. Darker colors represent a higher level of alteration.

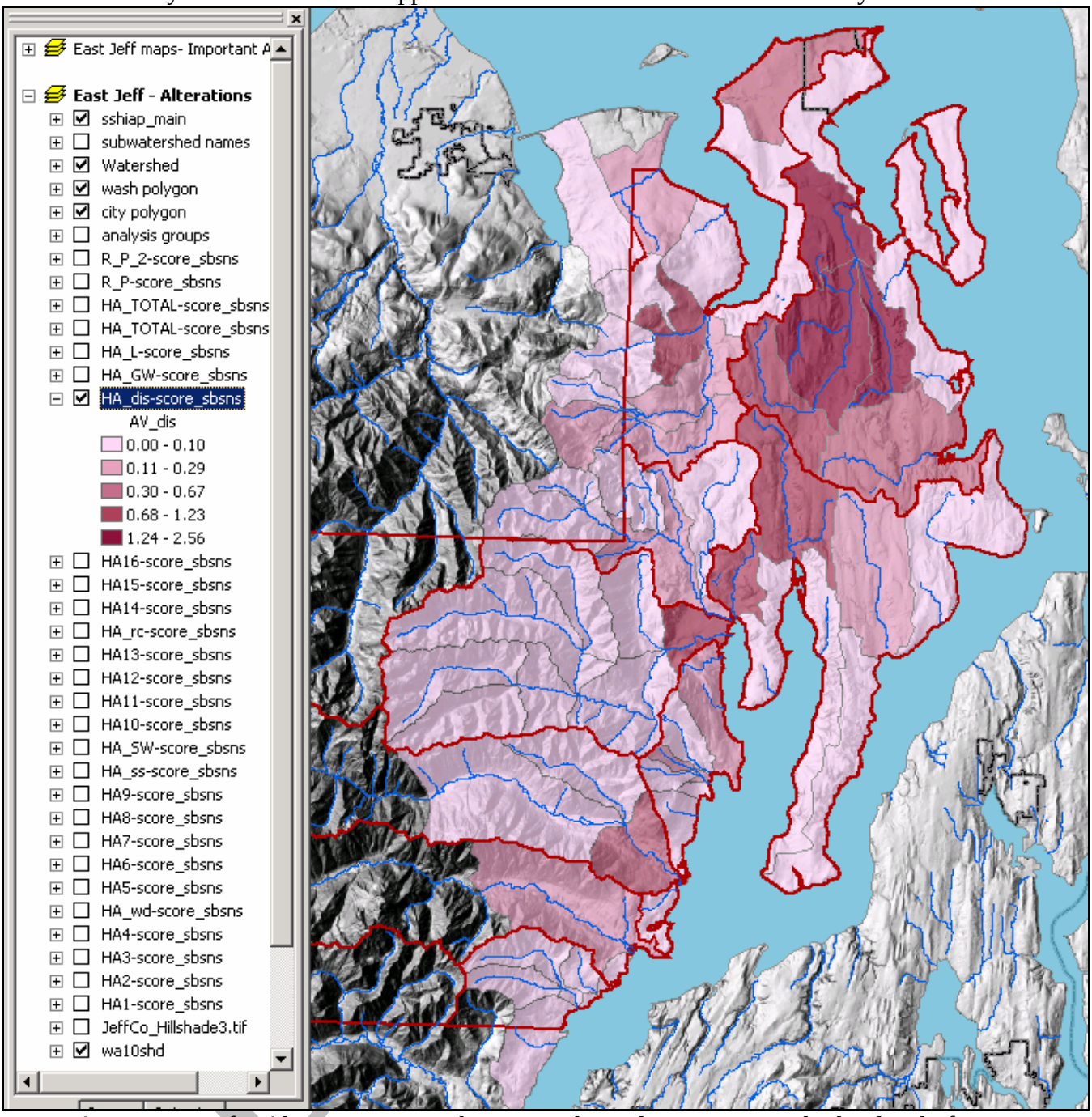

Figure A-11 - Rating for Alterations to Discharge. Darker colors represent a higher level of alteration.

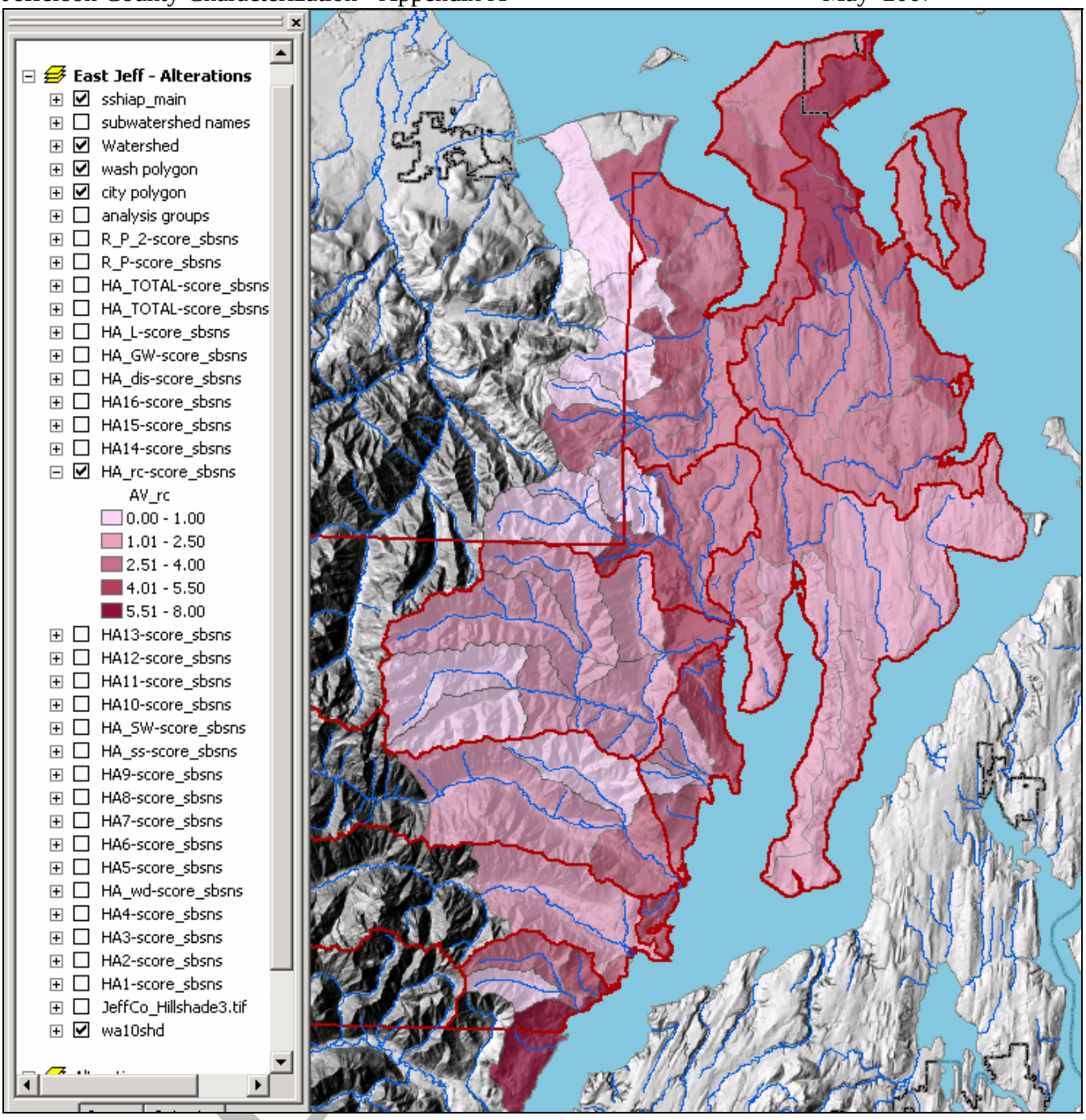

Figure 12 - Rating for Alterations to Recharge. Darker colors represent a higher level of alteration.

A-3.0 Detailed Analysis Matrix

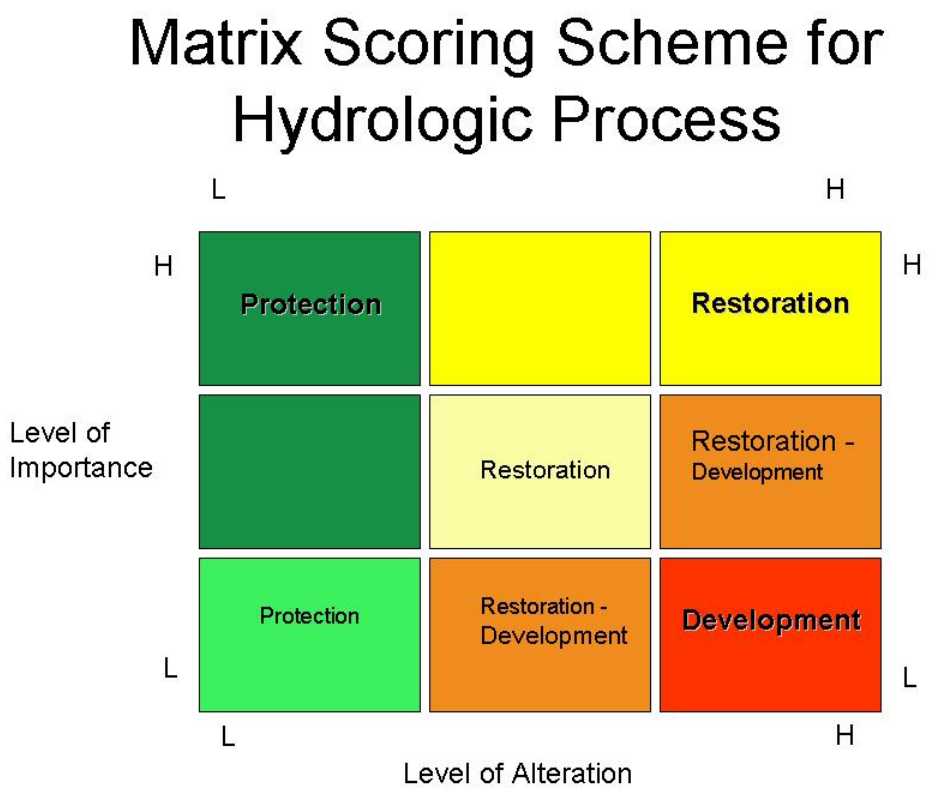

Figure A-13. Detailed analysis matrix for creating final restoration and protection map for the hydrologic and denitrificatiton processes.. (Based on figure 8)

Figure A-13 depicts the detailed matrix for synthesizing the results of the importance and alteration maps for the hydrologic process (Figures 4 and 5). The matrix is based on watershed-based research indicating that areas with low levels of alteration to watershed processes should be protected and areas with higher levels of alteration to processes with a higher level of importance should be restored (Stanley et al. 2005).

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Appendix B. Models for Understanding Watershed Processes

Models for Identifying Key Areas in a Watershed Related to the Delivery, Movement, and Loss of Water

The purpose of information developed from the two models is to guide planners in the Puget Sound area when making decisions about land use. The information developed from the models can be used to identify sub-basins where future development could have significant impacts on the hydrologic processes in the watershed, sub-basins where additional development would have the least impacts, and sub-basins where the hydrologic process might be protected and/or restored.

Introduction

The numeric models presented below are intended to provide planners with an effective way of displaying the results of methods presented in the companion watershed characterization guidance titled "Protecting Aquatic Ecosystems: A Guide for Puget Sound Planners to Understand Watershed Processes" (Ecology Publication 05-06-027).

Summary of Scoring

The qualitative description for analyzing watershed processes in appendices B through G of publication 05-06-027 provide a tabular description of how to analyze the individual components of those processes. This document provides examples of numeric models that can be constructed to identify the geographic locations in a watershed that are key to the delivery, movement, and loss of water (Appendix B Tables B-1 and B-3). These equations use the environmental characteristics described in the tables as variables in equations that establish importance.

In general, variables are assigned maximum values of 1, 2, and 3, representing low, medium, and high *importance* of a characteristic or *alteration* of a characteristic. The models are constructed so that higher total scores represent basins of greater importance for supporting a process in a watershed, or one with a higher degree of alteration to that process. The scoring is normalized to conditions specific in a watershed or basin. Thus, the models provide a comparison of the relative level of importance and alteration of process components (see Steps 3 and 4 of Ecology publication 05-06-027). The scores do not represent a specific rate (e.g., rate of removal of sediment or nitrogen) or specific level of alteration of a process that can be compared to scores outside of an analysis area. We do not have enough information at this time to calibrate models to conditions throughout the state and establish relative importance of processes and alterations among different watersheds.

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Introduction to Equations and Variables

There are two models developed to analyze the hydrologic process (delivery, movement, and loss of water) in a watershed. The first model scores the relative importance of sub-basins in maintaining the hydrologic process in an unaltered setting and the second scores the relative severity of alterations to the process in those sub-basins.

The importance and severity of alteration in the movement, delivery, and loss of water for each basin or sub-basin in a watershed is based on modeling three elements in the hydrologic process. The *importance* is characterized as the importance of a sub-basin for a particular element relative to the other sub-basins in the watershed. For example, in the equation below *importance of surface water* means the estimated importance of a specific sub-basin, relative to the other sub-basins in the watershed, in the movement of surface water.

Model 1 for overall importance of a sub-basin = importance of surface water + importance of groundwater + importance of evapotranspiration

In the model for the importance in the unaltered condition, the variables start with "HU" (Hydrologic Unaltered).

Model 2 for severity of alteration of a sub-basin = alteration to surface water + alteration to groundwater + alteration of evapotranspiration

In the model for altered conditions, variables start with "HA" (Hydrologic Altered).

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B-1.0 Model 1: Characterizing the importance of a sub-basin in the delivery, movement, and loss of water in unaltered conditions

The qualitative form of Model 1 is

Importance of a sub-basin in the hydrologic process =
Importance of sub-basin for surface water + importance sub-basin for groundwater + importance of sub-basin in evapotranspiration

Surface water is modeled as the relative volume of water falling on the sub-basin as precipitation, the timing of the delivery of that precipitation, and the relative amount of surface storage. The groundwater component is modeled by water volume (as precipitation), recharge, and discharge (see Table B-1). Furthermore, correction factors need to be incorporated based on the importance of each component within a watershed and to normalize the scores of each component because different number of variables may be used that have different scores.

Model 1 = [(Precipitation + Timing of Water Delivery + Surface Storage) + (Precipitation + Recharge + Discharge)] + (Evapotranspiration)

Note: Recharge includes shallow, subsurface flows.

In western Washington it was assumed that all sub-basins had approximately the same rate of evapotranspiration in unaltered conditions because they were all generally forested. The equation for Model 1 can therefore be simplified to:

Model 1 = (Precipitation + Timing of Water Delivery + Surface Storage) + (Precipitation + Recharge + Discharge)

Correction factors (see model below) need to be incorporated based on the importance of each component and element relative to the hydrologic process when scores for variables do not match the known or hypothesized importance. C_{H1} and C_{H2} are correction factors based on the amount of water in a watershed that moves through each component. For example, if the average annual discharge from surface water is twice the annual discharge through groundwater, then C_{H1} is twice $C_{H2.}$

$$Model\ 1_{western\ WA} = C_{H1}*[W_{H1}*(Precipitation + Timing\ of\ Water\ Delivery + Surface\ Storage)] + C_{H2}*[W_{H2}*(Precipitation + Recharge + Discharge)]$$

W_{H1} and W_{H2} are correction factors based on the maximum score possible for each element. For example, if the maximum score for surface water (Precipitation + Timing + Storage) is 12 points and the maximum score for groundwater (Precipitation + Recharge + Discharge) is 6 points, then W_{H2} is twice W_{H1}, so the maximum score for each component is the same.

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B-1.1. Variables used in Model 1

The sub-components in the equation for the hydrologic process can be broken down into individual variables (see Table 2-1) as follows:

$$Model\ 1_{western\ WA} = C_{H1}*\left(W_1* [P1 + (HU_1 + HU_2 + HU_3 + HU_4 + HU_5 + HU_6)]\right) + C_{H2}*[W_{H2} * (P1 + HU_7 + HU_8 + HU_9 + HU_{10})]$$

A descriptive summary of each variable is given below in Table 2-1. More detailed rationale for the use of each is presented in the discussion of the calculation of each variable.

W_{H1} = 1; W_{H2} = 1.33 based on the maximum score for each component if all the variables are used as described below. The values for C_{H1}, C_{H2}, and C_{H3} need to be established for each watershed separately. Data from a watershed in Whatcom County suggest that for western Washington the amount of water moving through the surface, through groundwater, and through evapotranspiration is approximately equal. Thus, until more data are available we suggest that C_{H1}, C_{H2} =1.

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Table B-1: Summary of Variables for Model 1: Delivery, Movement, and Loss of Water in Unaltered Conditions (see Table B-1 in Vol. 1).

Hydrologic Process	Component of process being modeled	Element of Process	Variable
Surface Water			
	Delivery 3	Volume of Water	P_1 rating of amount of precipitation in sub-basin relative to average precipitation in watershed
	Movement 3	Timing of Water delivery	HU_1 rating for area of snow-dominated zone HU_2 rating for area of rain-on-snow zone
	Movement 6	Surface Storage	HU_3 rating for area of depressional wetlands HU_4 rating for unconfined floodplain HU_5 rating for moderately confined floodplain HU_6 rating for confined floodplain
Groundwater			
	Delivery 3	Volume of water	P_1 rating of amount of precipitation in sub-basin relative to average precipitation in watershed
	Movement 3	Shallow Subsurface Flow & Recharge	HU_7 rating for areas of high permeability
	Loss 3	Discharge	HU_8 rating for high permeability deposit intersecting an unconfined floodplain HU_9 rating for high permeability deposit intersecting a moderately confined floodplain HU_{10} rating high permeability deposit intersecting a confined floodplain
Evapotranspira-tion	*Loss*		*Not modeled for unaltered condition*

Note: As shown in Table B-1 of Ecology Publication #05-06-027, stream or subsurface flow out of the sub-basins is not modeled directly as a "loss." This loss of surface or subsurface flows out of the basin is partially accounted for by correction factors C_{H1} and C_{H2} which attempt to account for the actual surface flow and subsurface flow quantities within a particular analysis area.

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B-1.2 Calculating Variables in Model 1

Each of the variables listed in Table B-1 can be calculated using existing data and the tools available in a GIS and Excel spreadsheet. Table B-2 lists the data layers used to calculate each variable.

Table B-2: Data used to calculate the variables listed in Table B-1.

Variable	Data Layers for GIS
Surface Water	
P_1 rating of amount of precipitation in sub-basin relative to average precipitation in watershed	Precipitation
HU_1 rating for area of snow-dominated zone HU_2 rating for area of rain-on-snow zone	Rain-on-snow
HU_3 rating for area of depressional wetlands (<2% includes riverine depressional) HU_4 rating for unconfined floodplain HU_5 rating for moderately confined floodplain HU_6 rating for confined floodplain	Wetlands Hydric soils SSHIAP confinement data SSHIAP confinement data
Groundwater	
P_1 rating of amount of precipitation in sub-basin relative to average precipitation in watershed	Precipitation
HU_7 rating for areas of high permeability	Geology
HU_8 rating for high permeability deposit adjoining unconfined floodplain HU_9 rating for high permeability deposit adjoining moderately confined floodplain HU_{10} rating high permeability deposit adjoining confined floodplain	Geology and SSHIAP confinement data

B-1.2.1 Importance of a Sub-Basin in the Delivery, Movement of Surface Water [Total possible score is 12].

Precipitation: Total possible score is 3
Precipitation is an important component of the movement and delivery of water because the amount of water available to supply surface water and groundwater can be greater in areas with higher precipitation (Cox and Kahle 1999).

The precipitation variable is the amount of rainfall in a sub-basin relative to the range of all sub-basins being analyzed. It is scaled from 1 – 3, with 1 representing sub-basins where the average rainfall is in the lowest third of the range, 2 is the middle third of the range, and 3 is the highest third of the range.

For example, the range of rainfall in the sub-basins of a watershed is 10 to 25 inches per year. Sub-basins with average rainfall of 10-15 inches would be scored a [1]; those with average rainfall from 15-20 inches would be scored a [2]; and those with average rainfall between 20-25 inches would be scored a [3].

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The average rainfall in each sub-basin is determined by calculating the area within each precipitation band, and then determining the average across the sub-basin.

Timing of Water Delivery*:* Total possible score is 3

Water Delivery is modeled as the importance of the relative area of rain-on-snow zone in a sub-basin [HU_1] + the importance of the relative area of the snow-dominated zone in a sub-basin [HU_2]

Rain-on-snow areas can significantly increase the timing and quantity of runoff relative to snow-dominated areas (Brunengo et al., 1992). Rain-on-snow events typically occur during the winter when heavy snowfall is followed by a warm, subtropical storm that results in rapid melting of the snow pack within the rain-on-snow elevation range (Ziemer and Lisle 2001) Snow-dominated zones, however, generate important spring to late summer delivery of runoff which supports shallow subsurface flow, recharge and discharge to streams, lakes, and wetlands (P. Olson, personal communication September 2005). Because the timing of water delivery is most pronounced with rain-on-snow events, this model scores those areas as a [3] and snow-dominated snows as a [2]. Delivery of precipitation in lowland rain zones is addressed in the precipitation variable described above. The rain-on-snow and snow-dominated zones change the timing of precipitation and thus are an additional element in the movement of surface water.

Water Delivery Score = $HU_1 + HU_2$

HU_1 (Importance of Snow-Dominated Zone - SD) = $\frac{\text{Area of SD} * 2}{\text{Area of sub-basin}}$

Snow-dominated zone is defined as not including rain zone or rain-on-snow areas.

HU_2 (Importance of Rain-on-Snow Zone - RS) = $\frac{\text{Area of RS} * 3}{\text{Area of sub-basin}}$

The Rain-on-Snow and Snow-Dominated zones are estimated using DNR GIS data layers.

Surface Storage: Total possible score is 6.

Surface storage is modeled as the importance of the relative area of depressional wetlands in a sub-basin and the importance of the relative miles of different widths of the floodplains in a sub-basin. Storage is given twice the weight of the water delivery and precipitation variables because research has demonstrated that depressional wetlands and floodplains play a significant role in reducing or delaying peak downstream flows (Bullock and Acreman 2003, Adamus et al. 1991, Reinelt and Taylor 1997). Floodplain storage is important because it reduces or delays flooding (Bullock and Acreman 2003).

Importance of Sub-basin for Surface Storage = relative importance of storage in wetlands (HU_3) + relative importance storage in floodplains ($HU_4 + HU_5 + HU_6$)

HU_3 (Relative Importance of Wetland Storage) = 0-3 based on percentage of sub-basin covered with depressional wetlands (both upland and riverine) in flat areas . The percentage of possible wetlands is estimated for all sub-basins using the topographic layer and the hydric soil layer. Areas with hydric soils on slopes that are less than 2% are considered to be areas where storage wetlands exist or have existed in the past. The range of percentages above 5% for all sub-basins in a watershed are tabulated and the importance is established by dividing the range into three equal sets. Sub-basins whose depressional wetlands, as a percent of total area of sub-basin, are in the bottom third of the range are scored a [1]; those in the middle are scored a [2]; and those in the top third of the range are scored a [3]. Sub-basins with less than 5% of their area in wetlands are scored a [0].

HU_4 (Relative Importance of storage in unconfined floodplain) =

$$\frac{\text{Miles of Stream in Unconfined Floodplain in sub-basin} * (3)}{\text{Total stream miles in sub-basin}}$$

Unconfined Floodplain is assigned an importance factor of 3 because they have the highest relative degree of surface storage capacity.

HU_5 (Relative Importance of storage in Moderately confined floodplain) =

$$\frac{\text{Miles of Stream in Moderately Conf floodplain in sub-basin} * (2)}{\text{Total stream miles in sub-basin}}$$

Moderately confined is assigned an importance factor of 2 because it has a moderate level of floodplain confinement and therefore has a moderate amount of surface storage capacity.

HU_6 (Relative Importance storage in confined floodplain) =

$$\frac{\text{Miles of Stream in confined floodplain in sub-basin} * (1)}{\text{Total stream miles in sub-basin}}$$

Confined floodplain is assigned an importance factor of 1 (the lowest) because it is the narrowest or most confined floodplain type and, therefore, has the least amount of surface storage capacity

Floodplain types are determined using SSHIAP data for floodplain confinement:

Unconfined floodplain = floodplains where width of valley is >4 times width of stream Moderately confined floodplain = floodplains where width of valley is 2-4 times width of stream Confined floodplain = floodplains where width of valley is < 2 times width of stream

B-1.2.2 Importance of a sub-basin in the Delivery, Movement, and Loss of Groundwater [Total possible score is 9]

Precipitation (same variable as for surface water): Total possible score is 3. Precipitation is an important component of the movement and delivery of water because the amount of water available to supply surface water and groundwater can be greater in areas with higher precipitation (Cox and Kahle 1999).

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The precipitation variable is the amount of rainfall in a sub-basin relative to the range of all sub-basins within a hydrogeologic unit. It is scaled from 1 – 3, with 1 representing sub-basins where the average rainfall is in the lowest third of the range, 2 is the middle third of the range, and 3 is the highest third of the range.

For example, the range of rainfall in the sub-basins of a watershed is 10 to 25 inches per year. Sub-basins with average rainfall of 10-15 inches would be scored a [$P_1 = 1$]; those with average rainfall from 15-20 inches would be scored a [$P_1 = 2$]; and those with average rainfall between 20-25 inches would be scored a [$P_1 = 3$].

Recharge: Total possible score is 3
The importance of recharge in a sub-basin is modeled as the relative area of high permeability. Areas of low permeability also play a role in recharge though at a reduced level. However, because the high permeability score is area based and is the converse of the area of low permeability deposits in a watershed being analyzed, it was judged unnecessary to provide a separate score for the area of low permeability deposits. Scoring the areas of low permeability will not change the relative position of sub-basins in the scoring.

Importance of Recharge in a sub-basin = HU_7

$$\mathbf{HU}_7 = \frac{\text{Area of high permeability in a sub-basin} * (3)}{\text{Area of sub-basin}}$$

Areas of high permeability are assigned a "high" importance because these deposits facilitate recharge.

Areas of high permeability are determined by looking at the permeability of surficial deposits. Deposits with coarse grains, such as recessional outwash and alluvium in lowland areas, typically have high permeability. Table B-2 summarizes these deposits and their relationship to sediment size, permeability, and hydraulic conductivity.

Discharge: Total possible score is 3

Importance of Discharge is modeled based on the relative miles of streams with different types of confinement that intersect higher permeable deposits in a sub-basin. Permeable geologic deposits adjacent to and within river valleys are important because they appear to contribute to groundwater discharge and support localized stream/river flow (Cox et al. 2005).

Importance of Discharge = $HU_8 + HU_9 + HU_{10}$
Note that the score can be "zero" if an entire basin consists of low permeable deposits.

For this equation the percentage of stream miles that intersect a permeable deposit in a sub-basin is identified. An intersecting permeable deposit would consist of outwash or alluvium and extend from the edge of the valley floor and into the upland valley wall and upland terrace (i.e., is not solely limited to Holocene Terraces that were created by stream or river processes in the last 10,000 years).

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HU_8 (Higher permeable deposits intersect unconfined floodplain) =

$$\frac{\text{Miles of streams in higher perm deposits of unconfined floodplains} * (3)}{\text{Total miles of streams in sub-basin (SSHIAP)}}$$

Streams crossing permeable deposits in unconfined floodplains are assigned an importance factor of [3] because these floodplains are the least confined and represent the largest relative area for discharge to potentially occur.

HU_9 (Higher permeable deposits intersect mod. Conf. floodplains) =

$$\frac{\text{Miles of streams in higher perm deposits of mod. Conf.} * (2)}{\text{Total miles of 2 streams in sub-basin (SSHIAP)}}$$

Streams crossing permeable deposits in moderately confined floodplains are assigned an importance factor of [2] because these floodplains are moderately confined and represent the second largest relative area for discharge to potentially occur.

HU_{10} (Higher permeable deposits intersect confined floodplains) =

$$\frac{\text{Miles of streams in higher perm deposits of confined floodplains} * (1)}{\text{Total miles of streams in sub-basin (SSHIAP)}}$$

Streams crossing permeable deposits in confined floodplains are assigned an importance factor of [1] (the lowest) because these floodplains are the most confined and represent the smallest relative area for discharge to potentially occur.

B-2.0 Model 2: Characterizing the severity of alterations to the movement, delivery, and loss of water

The qualitative form of Model 2 is:

Severity of alteration in a sub-basin = alteration of surface water in sub-basin + alteration of groundwater in sub-basin + alteration of evapotranspiration in sub-basin

Alterations to surface water are modeled as alterations to timing of water delivery and alterations to surface storage. Alterations to groundwater are modeled by alterations to recharge and discharge (see Table B-3). Alterations to evapotranspiration are modeled by the amount of impervious surface in the sub-basin. Precipitation is not included in the equation because it is assumed that this component has not been changed by land uses.

Correction factors need to be incorporated based on the importance of each component and element relative to the hydrologic process when scores for variables do not match the known, or hypothesized, importance.

Model 2 $= C_{H1}*[W_{H3}*(\text{Alterations to Timing of Water Delivery} + \text{Alterations to Surface Storage})] + C_{H2}*[W_{H4}*(\text{Alterations to Recharge}) + W_{H5}*(\text{Alterations to Discharge})] + C_{H3}*[W_{H6}*(\text{Alterations to Evapotranspiration})]$

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C_{H1}, C_{H2}, and C_{H3} are correction factors based on the amount of water in a watershed that moves through each component.

W_{H3}, W_{H4}, $W_{H5,}$ W_{H6} are correction factors based on the maximum score possible for each component if a different weighting is needed to reflect the importance of the element.

B-2.1 Variables used in Model 2

The components in the equation for the hydrologic process can be broken down into individual variables (See Table K-2) as follows:

$$\text{Model } 2_{\text{western WA}} = C_{H1}*\left(W_{H3}*[(HA_1+HA_2 + HA_3 + HA_4)/2 + (HA_5+HA_6) + (HA_7 + HA_8+ HA_9)]\right) + C_{H2}*\left([W_{H4} (* HA_{10} + HA_{11} + HA_{12} + HA_{13}+ HA_{14}) +W_{H5}(HA_{15}+HA_{16}+HA_{17})]\right) + C_{H3}*[W_{H6}*(HA_{18})]$$

W_{H3} = 2.44; W_{H4} = 1.0, W_{H5} = 3.67, and W_{H6} = 7.33 based on the maximum score for each component of the process if all the variables are used as described below. The values for C_{H1}, C_{H2} and C_{H3} need to be established for each watershed separately. Data from a watershed in Whatcom County suggest that for western Washington the amount of water moving through the surface, through groundwater, and through evapotranspiration is approximately equal. Thus, until more data are available, we suggest that C_{H1}, C_{H2}, and C_{H3} all be equal to [1].

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Table B-3. Summary of Variables for Model 2. Alterations to hydrologic processes (based on Table B-1, Vol. 1)

Hydrologic Process	Component modeled	Element of Process	Variable	Points Possible	Total Points & Weighting Factor
Surface Water				**9**	**9 x (2.44) = 22**
	Movement Delivery?	Timing Water delivery 6/2=3	HA_1 loss of forest in snow-dominated zone HA_2 loss of forest in rain-on-snow zone HA_3 loss of forest in rain-dominated areas HA_4 impervious surface in sub-basin	3 Note: if dam present see default scoring	3
	Movement	Surface Storage (loss of wetlands/ floodplains) 6 (twice as much because weighting)	HA_5 wetland alteration, urban HA_6 wetland alteration, rural/agriculture HA_7 floodplain loss **unconfined** floodplain HA_8 floodplain loss **mod. conf**. floodplain HA_9 floodplain t loss **confined** floodplain	3 3	3 3
Groundwater				**11**	**22**
	Movement	Recharge & shallow subsurface flow (loss from impervious & non forest cover)	HA_{10} impervious cover on low perm deposits HA_{11} impervious cover on high perm deposits HA_{12} loss of forest on low perm deposits HA_{13} loss of forest on high perm deposits HA_{14} road density	1 3 1 3 3	11 x (no weighting factor)
	Loss	Discharge (loss from impervious & non forest cover in adjoining floodplain)	HA_{15} loss of forest adjacent to **unconfined** floodplains HA_{16} loss of forest adjacent to **moderately confined** floodplains HA_{17} loss of forest adjacent to **confined** floodplain	3	3 x **(3.67) = 11**
Evapotranspiration				**3**	**3 x (7.33) = 22**
	Loss	Evapotranspiration	HA_{18} rel. amt of imp. surface in sub- basin	3	3

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B 2.2 Calculating Variables in Model 2

Each of the variables listed in Table B-1 can be calculated using existing data and the tools available in a GIS and Excel spreadsheet. Table B-2 lists the data layers used to calculate each variable.

Table B-4. Data used to calculate the variables listed in Table B-3.

Variable	Data Layers for GIS
Surface Water	
HA_1 loss of forest in snow-dominated zone HA_2 loss of forest in rain-on-snow zone HA_3 loss of forest in rain-dominated areas HA_4 effective impervious surface in sub-basin	Precipitation zones Land use
HA_5 wetland alteration, urban HA_6 wetland alteration, rural/agriculture	Wetlands Land use
HA_7 floodplain loss **unconfined** floodplain HA_8 floodplain loss **mod. conf**. floodplain HA_9 floodplain loss **confined** floodplain	Land use SSHIAP confinement data
Groundwater	
HA_{10} impervious cover on low perm deposits HA_{11} impervious cover on high perm deposits HA_{12} loss of forest on low perm deposits HA_{13} loss of forest on high perm deposits HA_{14} road density	Geology Land use
HA_{15} loss of forest adjacent to **unconfined** floodplains HA_{16} loss of forest adjacent to **moderately confined** floodplains HA_{17} loss of forest adjacent to **confined** floodplain	Land use SSHIAP confinement data
Evapotranspiration	
HA_{18} relative amount of impervious surface in sub- basin	Land use

B-2.2.1 Severity of Alterations to Surface Water

Total score for alterations to surface water is 9 if all variables are used as described below. However, a default scoring is used if dams are present. Because dams significantly alter the timing of the delivery of surface waters to aquatic ecosystems (Kondolf 1997), sub-basins with dams on the mainstem[1] are given a total score of "3" for variables HA_1 through HA_4. If a dam is on a tributary, then the total score would be a "2" unless the total score for HA_1 through HA_4 is greater than "2;" in this circumstance the higher score would be used. The effect of dams on downstream processes and functions is addressed in the analysis matrix (Figure 8). .

Alterations to Timing of Water Delivery: Total Score for Alteration is 3

The severity in the alteration to water delivery is modeled as the relative loss of forest within the snow-dominated zone (HA_1) and rain-on-snow zone (HA_2); the loss of forest cover in the rain-dominated zone (HA_3), and the amount of effective impervious surface in the sub-basin (HA_4).

[1] from the mouth of sub-basin to the next change in stream order would be defined as the mainstem

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Alteration Score for Water Delivery = $(HA_1+HA_2 + HA_3 + HA_4)/2$
(The denominator (2) is a correction factor added to normalize the final score to a maximum of 3.)

HA_1 [Severity of Loss of Forest in Snow-Dominated Zone (SD)].

$$= \frac{\text{Area of non-forest vegetation in SD zone} * (HU_1)}{\text{Area of SD zone}}$$

$$= \frac{\text{Area of non-forest vegetation in SD zone} * 2}{\text{Area of sub-basin}}$$

HU_1 is the score for the relative importance of rain-on-snow areas in the analysis areas. This score is multiplied by the ratio of forest removed to the total area of snow-dominated area so that the alteration score does not exceed the importance score.
Loss of forest in a snow-dominated zone is important because it can alter spring-to-late-summer runoff patterns and can affect groundwater recharge and base flow for streams at lower elevations (P. Olson, personal communication, Sept 2005).

Forest vegetation includes both scrub-shrub and forested classes.

HA_2 [Severity of Loss of Forest in Rain-on Snow-Zone (ROS)\

$$= \frac{\text{Area of non-forest veg in ROS zone} * (HU_2)}{\text{Area of ROS zone}}$$

$$= \frac{\text{Area of non-forest veg in ROS zone} * 3}{\text{Area of sub-basin}}$$

Loss of forest in a rain-on-snow area is important because it can increase snow pack outflow by 50 to 400% (Coffin and Harr 1992).

HA_3 represents the severity of alterations to timing of surface flows resulting from loss of forest cover in "rain only" areas

$$= \frac{\text{Area of non-forest vegetation in rain zone} * 3}{\text{Area of sub-basin}}$$

Removal of forest cover decreases the recharge and increases surface flow (Booth et al. 2002).

HA_4 represents the severity of alterations to timing of surface flows based on the percent of effective impervious surface in sub-basin

HA_4 = 0 if effective impervious area is 0-3% area of sub-basin
HA_4 = 1 if effective impervious area is >3 - 5% area of sub-basin
HA_4 = 2 if effective impervious area is >5 – 10%
HA_4 = 3 if effective impervious area is >10%

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Land cover data, which can include a mixture of forested and scrub-shrub classes, is used to identify the area of forest vegetation for the analysis area. Everything outside of the forest area is considered non-forest vegetation.

Alterations to Surface Storage: Total Score for Alteration is 6

Alteration to surface storage is modeled as the relative loss of surface storage of wetlands in a sub-basin and the relative loss of storage in the floodplain because of channelized streams and rivers.

Severity of Alteration in Surface Storage = relative loss of storage in wetlands (HA_5+HA_6) + relative loss of storage in floodplains (HA_7 + HA_8+ HA_9)

The severity of wetland loss is characterized in terms of wetlands that are permanently lost (filled) due to urbanization, and those temporarily lost due to extensive ditching/tiling in agricultural and rural areas. Reducing the amount of wetlands that store surface water through ditching, draining, and/or filling is important because it results in a larger quantity of water being delivered to down gradient aquatic ecosystems in a shorter period of time. As a result, water level fluctuations in aquatic ecosystems are greater (Reinelt and Taylor 1997).

An alteration factor of [3] was assigned to permanently drained wetlands within the Urban Growth Area (UGA) since these areas probably are filled and no longer can provide any storage. The losses of wetlands in rural and agricultural areas are most likely to be a result of draining. The level of the surface however, has not been filled and may still provide some storage in exceptional storms or flooding events. These losses are assigned an importance value of [2].

Modeling the loss of storage in wetlands (HA_5+HA_6)

$$\mathbf{HA_5}\text{ (loss of storage wetlands in urban areas)} = \frac{\text{Area of storage wetlands lost in urban areas} * 3 * HU_3}{\text{Total area of potential } \textbf{storage wetlands} \text{ in sub-basin} * 3}$$

$$= \frac{\text{Area of wetlands lost in urban areas} * HU_3}{\text{Total area of potential storage wetlands in sub-basin}}$$

$$\mathbf{HA_6}\text{ (loss of storage wetlands in rural areas)} = \frac{\text{Area of wetlands lost in agricultural and rural area} * 2 * HU_3}{\text{Total area of potential storage wetlands in sub-basin} * 3}$$

$$= \frac{\text{Area of wetlands lost in rural areas} * HU_3 * 0.67}{\text{Total area of potential storage wetlands in sub-basin}}$$

Modeling the severity of loss of storage in floodplains (HA_7 + HA_8+ HA_9)

$$\mathbf{HA_7} = \frac{\text{Miles of channelized stream in } \textbf{unconfined} \text{ floodplain} * (3)}{\text{Total miles in sub-basin}}$$

$$\mathbf{HA_8} = \frac{\text{Miles of channelized stream in } \textbf{moderately confined} \text{ floodplain} * (2)}{\text{Total miles in sub-basin}}$$

$$\mathbf{HA_9} = \frac{\text{Miles of channelized stream in } \textbf{confined} \text{ floodplain} * (1)}{\text{Total miles in sub-basin}}$$

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Disconnecting a river or stream from its floodplain eliminates the surface water storage provided by that floodplain (Sheldon et al. 2005). Alterations to streams and rivers, such as dikes, levees, and channelization (including incised channels), have a more significant impact on water storage in floodplains with greater surface storage (i.e., unconfined) relative to more confined floodplains. Dikes and levees of sufficient height can prevent yearly overbank flooding into the adjacent floodplain. Channelization can result in incised channels (i.e., channels that erode significantly below the historic surface elevation of the riverbed) which also prevents overbank flooding.

The effect of dikes on overbank flooding should be confirmed with local experts and/or data because some dikes no longer disconnect the river from its floodplain. These dikes may be overtopped so that the actual floodplain regains some of its former functions.

Alterations to Groundwater

Alterations to Recharge & Shallow Subsurface Flow: Total score is 15

Severity of Alterations to Recharge & Subsurface Flow = Alterations resulting from impermeable surface (HA_{10} + HA_{11}) + Alterations resulting from loss of forest cover (HA_{12} + HA_{13}) + Alterations from roads (HA_{14})

HA_{10} is severity of alterations resulting from impermeable surface on low permeability deposits. Scoring is between 0-1, based on the percent impervious surface on deposits with low permeability.

HA_{10} = 0 if total impervious cover on low permeability deposits is 0-3% area of sub-basin

HA_{10} = .5 if total impervious cover on low permeability deposits is >3 – 10%

HA_{10} = 1 if total impervious cover on low permeability deposits >10%

HA_{11} is severity of alteration resulting from impermeable surface on high permeability deposits. Scoring is between 1-3, based on the percent of effective impervious surface on deposits with high permeability.

HA_{11} = 1 if impervious cover on high permeability deposits is 0-3% area of sub-basin

HA_{11} = 2 if impervious cover on high permeability deposits is >3 – 10%

HA_{11} = 3 if impervious cover on high permeability deposits >10%

Because readily observable damage to stream resources (i.e., unstable channels) occurs if the effective impervious area (EIA) of a watershed is greater than 10%, a factor of 3 is applied for alteration to recharge and subsurface flows (Booth et al. 2002). A factor of [2] and [1] are applied for alteration to recharge and subsurface flows based on research showing that small increases in impervious surface and impermeable cover negatively affect peak discharges to streams.

<u>Severity of alterations resulting from loss of forest cover</u>

HA_{12} is severity of alterations resulting from loss of forest cover on low permeability deposits. Scoring is between 0-1, based on the loss of forest cover on deposits with low permeability

HA_{12} = 0 if loss of forest cover on low permeability deposits is 0-15% area of sub-basin
HA_{12} = .5 if loss of forest cover on low permeability deposits is >15-35%
HA_{12} = 1 if loss of forest cover on low permeability deposits >35%

HA_{13} is severity of alteration resulting from loss of forest cover on high permeability deposits. Scoring is between 0 - 3, based on the percent of loss of forest cover on deposits with high permeability.

HA_{13} = 0 if loss of forest cover on high permeability deposits is 0%
HA_{13} = 1 if loss of forest cover on high permeability deposits is >15% area of sub-basin
HA_{13} = 2 if loss of forest cover on high permeability deposits is >15-35%
HA_{13} = 3 if loss of forest cover on high permeability deposits >35%

Note: Score [0] if entire sub-basin has deposits with low permeability and is entirely forested.

Removal of any forest on high permeability deposits results in impairment of flows to aquatic resources (Booth et al. 2002). The threshold of impairment for forest clearing on impermeable deposits is approximately 35% (Booth et al. 2002). Since permeable surfaces contribute more to groundwater than areas with low permeability, impacts to permeable deposits are scored as more severe than impacts to areas of low permeability.

Land cover data, which can include a mixture of forested and scrub-shrub classes, is used to identify the area of forest vegetation for the analysis area. Everything outside of the forest area is considered non-forest vegetation.

<u>Severity of alterations resulting from roads (Total score is 3)</u>

HA_{14} is the severity of alteration resulting from roads and their associated drainage system (ditches and culverts). HA_{14} applies to roads of all classes. The maximum score for HA_{14} is 3.

$$HA_{14} = \frac{\text{miles of roads}}{\text{sub-basin in sq. miles}}$$

The scoring values of "1, 2, and 3" are assigned as follows based on road density thresholds:

HA_{14} = 1 if road density is 0 to 2 miles/mile^2
HA_{14} = 2 if road density is >2 miles to 5 miles/mile^2
HA_{14} = 3 if road density is > 5 miles/mile^2

Research suggests that forest roads may intercept subsurface flows, alter the timing of runoff and increase peak flows within those basins (Luce et al. 2001). Correlations between road densities and hydrologic changes at the sub-watershed scale have been observed in several studies in the Puget Lowlands. Road densities exceeding 3 miles/mile^2

in the Skagit watershed were found to correlate with changes to the hydrologic regime (Beamer et al. 2002). For Snohomish County, sub-basins in the Stillaguamish watershed with peak flow problems had road densities exceeding 3 km/km2 and vegetative cover consisting of >50% immature vegetation (Beamer 2000).

Severity of Alterations to Discharge: Total score for alteration is 3

Alteration to discharge is modeled as the relative loss of miles of streams and rivers of different types of confinement that intersect higher permeability deposits.

Severity of Alteration to Discharge = $(HA_{15} + HA_{16} + HA_{17}) * 3.67$

Note: the multiplier (3.67) is added to bring the total score for alterations to discharge up to the same value as alterations to recharge.

HA_{15} (Higher permeable deposits intersect unconfined floodplain 1) =

$$\frac{\text{Miles of modified streams in higher perm deposits of unconfined floodplains} * (3)}{\text{Total miles of streams in sub-basin (SSHIAP)}}$$

Higher permeable deposits and unconfined floodplains 1 are assigned an importance factor of [3] because these floodplains are the **least confined** and represent the largest relative area for discharge to potentially occur relative to the size of the stream.

HA_{16} (Higher permeable deposits intersecting moderately confined floodplain) =

$$\frac{\text{Miles of modified streams in higher perm deposits of moderately confined floodplains} * (2)}{\text{Total miles of type 2 streams in sub-basin (SSHIAP)}}$$

Higher permeable deposits and moderately confined floodplains are assigned an importance factor of [2] because these floodplains are moderately confined and represent the second largest relative area for discharge to potentially occur relative to the size of the stream.

HA_{17} (Higher permeable deposits intersect confined floodplain) =

$$\frac{\text{Miles of modified streams in higher perm deposits of confined floodplains} * (1)}{\text{Total miles of streams in sub-basin (SSHIAP)}}$$

Higher permeable deposits and confined floodplains are assigned an importance factor of [1] because these floodplains are the **most confined** and represent the smallest relative area for discharge to potentially occur to the stream.

USGS field investigations of groundwater discharge zones in the South Fork of the Nooksack suggest that coarse-grained geologic deposits (outwash, some alluvial fans. and landslides) adjacent to and within stream valleys contribute to groundwater discharge and support localized stream/river flow (Cox et al. 2005). Impervious cover on these deposits will reduce both the degree of recharge and discharge to streams and rivers. Because readily observable damage to stream resources (i.e., unstable channels) occurs if the effective impervious area (EIA) of a watershed is greater than 10%, a factor of [3] is applied for alteration to recharge and subsurface flows (Booth et al. 2002). A factor of [2] is applied for alteration to recharge and subsurface flows based on research showing that small increases in impervious surface and impermeable cover negatively affect peak discharges to streams.

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Discharge areas for $HA_{15\text{-}17}$ are calculated by intersecting high permeability surficial deposits with the stream and river hydrography layer. Those deposits that are immediately adjacent or running through high permeability deposits are considered to be the high permeability deposits used in the equations for HA_{13}. The removal of forest area is calculated as explained for $HA_{12\text{-}13}$.

Alterations to Evapotranspiration

Total maximum score for alterations to surface water is 3 if all variables are used as described below.

Alterations to evapotranspiration are modeled as the relative amount of total impervious surface present in the sub-basin

$$\textit{Change in ET} = HA_{18} * 7.33$$

Note: the multiplier (7.33) is added to bring the total score for alterations to evapotranspiration up to the same value as alterations for surface water and groundwater.

HA_{18} = 0-3 based on percentage of sub-basin covered with impervious surface

The percent of total impervious surface in each sub-basin is estimated by the percent of urban land use. Impervious surface, therefore, becomes a surrogate for the lost of evapotranspiration in a basin relative to unaltered conditions. The score is based on the assumptions that: the analysis basin was 100% forested prior to human alterations; that maximum evapotranspiration occurred during these unaltered conditions relative to altered conditions; and that the loss of evapotranspiration is proportional to the area or percentage of the basin lost. Based on these assumptions, the equation for calculating the score for evapotranspiration is as follows:

$$HA_{18} = \frac{\text{percent of impervious cover} * 3}{\text{Total area of sub-basin}}$$

The number 3 in the equation represents the maximum score for alteration that could occur in a basin (i.e., total loss of evapotranspiration which is assumed to occur with 100% urban use).

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Partial List of References for Appendix B (Complete list in Ecology publication #05-06-027):

Beamer, E,. T. Beechie, B. Perkowski, and J. Klochak. 2002. Application of the Skagit Watershed Council's Strategy, River Basin analysis of the Skagit and Samish Basins: Tools for Salmon Habitat Restoration and Protection. Working Document prepared by the Habitat Protection and Restoration Committee of the Skagit Watershed Council, 407 Main Street, Suite 205, Mount Vernon, Washington 98273.

Kondolf, G.M. 1997. Hungry water: Effect of dams and gravel mining on river channels. Environal loss of evapotranspiration which is assumed to occur with 100% urban use)

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