Protecting Aquatic Ecosystems:

A Guide for Puget Sound Planners to Understand Watershed Processes

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Executive Summary

This document provides guidance for Puget Sound planners, resource managers, and consultants on how to better protect aquatic ecosystems, such as lakes, rivers, wetlands, and estuaries, by including information about watershed processes in resource management plans and regulatory actions. (*Watershed processes* means the delivery, movement, and loss of water, sediment, nutrients, toxins, pathogens, and large woody debris.) We do this through five steps that qualitatively describe these processes. While we designed this document for use by those managing natural resources within the Puget Sound region, the steps can be applied to any region of the state.

The steps presented in this paper first identify the areas of the landscape that are important or key for maintaining watershed processes and then assess how much these areas have been altered by human activity. Finally, planners and managers can use this information to protect intact areas or restore altered areas by specifying the location, type, and density of development, as well as appropriate development standards.

The five steps use existing environmental data and land use information. We designed this method to use readily available data and to be relatively simple, rapid, and inexpensive to apply. In addition, the method is adaptable to local situations and provides products that are easy to interpret and share with others.

This method is most appropriate at the county or watershed scale. It is based on relationships at a watershed scale and so it does *not* establish a direct connection between alterations at the larger scale and ensuing impacts at the site scale. Though it does not identify site-specific restoration needs or produce mitigation plans, it is an essential step to developing these plans.

The products of this method can be used in the following ways:

- Growth Management Act
  - Support protection of critical areas (e.g., Critical Areas Ordinances) by considering key areas for watershed processes.
  - Evaluate the effect of future land use on watershed processes.
- Shoreline Management Act
  - Conduct the characterization of ecosystem-wide processes.
  - Identify areas appropriate for restoration and protection as part of the restoration plan element.
  - Identify land use designations and development standards that protect ecosystem-wide processes.
  - Meet “no net loss” requirements while allowing for mitigation flexibility.
- State Environmental Policy Act and National Environmental Policy Act
  - Consider watershed processes in the development of mitigation plans.

  - Provide information to meet the avoidance and minimization steps of "mitigation sequencing."
- Regulatory
  - Develop a predictable permitting environment.
  - Streamline the permitting process with mitigation, credits, and fees clearly established.
- Resource planning
  - Use information on watershed processes to develop site-level restoration and protection plans.
  - Use information to develop risk-reduction strategies.

How to Use this Guidance:

- If you are a **planner**, read:
  - Sections I and II to gain an overview and basic understanding of the guidance and its potential usefulness to your needs.
- If you are a **technical specialist** determining how to apply this guidance to a particular area, focus on:
  - Section II – Overview of the steps and expected products
  - Appendices A through G – Technical rationale for identifying key areas and alterations for each process
  - Appendix H – Mapping methods

The application of this guidance requires expertise in the following areas: hydrology, geology, aquatic ecology, and geographic information systems (GIS).

I. Introduction

1.1 Importance of watershed processes

To protect and restore our lakes, rivers, wetlands, and estuaries, we must consider the watershed processes that occur outside these ecosystems (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). 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.

> ***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.

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. For example, flooding of 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:

- Many restoration efforts fail when they do not consider watershed processes; success would be improved if the watershed context was considered in site-level restoration (Buffington et al. 2003, National Research Council 2001, Reid 1998, Frissell and Ralph 1998, Beechie and Bolton 1999, Kauffman et al. 1997, Roni et al. 2002).
- The design of mitigation projects needs to integrate a watershed perspective (Mitsch and Wilson 1996, Preston and Bedford 1988).
- 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).

Building on these studies, the methods presented in this guidance focus on six watershed processes that play a key role in structuring and maintaining aquatic ecosystems in the Pacific Northwest (Naiman et al. 1992, Beechie and Bolton 1999, Beechie et al. 2003). These processes are the movement of

- water
- sediment
- phosphorus and toxins
- nitrogen
- pathogens, and
- large woody debris

as they enter, pass through, and eventually leave the watershed.

This document provides guidance to planners, resource managers and consultants on how to integrate information about watershed processes into their planning and decision-making. The detailed methods of this guidance are designed for use within the Puget Sound region. However, the steps presented can be applied to any region of the state.

1.2 Steps for Understanding Watershed Processes

This document is organized around five steps that can be used to understand and incorporate information about watershed processes into planning. These steps first identify areas on the landscape that are important to maintaining watershed processes and then assess the degree to which these areas have been, or are likely to be, altered by human activities.

By using these steps, resource managers will have the information necessary to protect aquatic ecosystems by developing plans that provide protection of intact areas, restore areas where processes have been altered, and reduce the potential for degradation from future development.

We developed the steps presented in this guidance so that they would:

- use readily available data
- be relatively simple, rapid, and inexpensive to apply
- be adaptable to local situations, incorporating other data easily
- produce results useful for planning
- have transparent methods that are repeatable and easily modified by the user
- provide products that are easy to interpret and to share with others

The five steps for understanding watershed processes:

1 Identify the purpose for analyzing watershed processes
2 Map the area for analysis
3 Map key areas for watershed processes
4 Map areas where watershed processes have been altered
5 Identify potential areas for restoration and protection

The first of the five steps is to identify the *purpose* for analyzing watershed processes and to identify technical specialists to conduct the analysis. For example, you may wish to address the problem of high nutrients in a shellfish-growing area. To address this problem, you would need input from a water quality specialist, a wetland ecologist, a hydrologist, geologist, and a data analyst/mapper.

Watershed*:* The drainage area contributing water, organic matter, dissolved nutrients, and sediments to a stream, lake, wetland, or other water body. This includes the area that contributes groundwater to aquatic ecosystems, which may be different from the area contributing surface water.

The second step is to map the area on which the analysis should focus. This defines the outer boundary of the analysis area and should include any upland areas that connect to aquatic ecosystems through surface water or groundwater.

Once the area of analysis has been delineated, Steps 3 and 4 characterize each process by identifying both the key areas for maintaining that process and the alterations that may have impaired the functioning of that process. In Step 5, key areas that are relatively unaltered become candidates for protection, while those that are altered are candidates for restoration.

All five steps use existing environmental data and land use information. This includes data such as surficial geology, soils, topography, land cover, land use, hydrography and wetlands.

1.3 Describing Watershed Processes

This guidance develops predictions of how water moves within a watershed based on the concept of **hydrogeologic setting** (Preston and Bedford 1988, Bedford 1996, Winter 1988). The hydrogeologic setting of an aquatic ecosystem is determined by its position in the watershed and the surrounding topography, soils, geology, and climate. Across a watershed, these characteristics govern the patterns of surface water and groundwater flow between upland and aquatic areas. The movement of water underlies most of the other geochemical and biological processes that occur in a watershed (Winter 2001, Bedford 1996, Glasoe and Christy 2004, McClain et al. 2003), and these same hydrogeologic characteristics also play a critical role in how nutrients, toxins, pathogens, large woody debris, and sediment move within the watershed. These relationships are described in detail for the Puget Sound region in Appendices A-G.

In general, human activities alter watershed processes by changing the physical characteristics of the watershed and therefore affecting the manner in which the process occurs. For example, the building of a road may interrupt the movement of water into a wetland. In this guidance the types of activities that alter each process are initially described and a set of indicators for these activities are selected. Then these indicators can be used to map the location of the activities. Details of these relationships are also described for each process in Appendices A-G.

1.4 Methods for mapping watershed processes

The final step in this guidance is the synthesis of two sets of information: first, the areas of the watershed that are key for each process and second, the location of human activities that are likely to impair each process. This synthesis is best accomplished by overlaying these two sets of information as digital maps and identifying where they overlap. Key areas that are unimpaired are potential areas for protection. Key areas that are impaired are potential areas for restoration. Both of these areas will be identified by this mapping method.

The most efficient way to accomplish this synthesis is with a GIS (geographic information system) and digital data. The methods described in the Appendices provide suggestions for using digital data to map the key areas and the alterations identified. These data are available for the whole Puget Sound region and we provide internet links to the sources of that data. We describe the kinds of information to combine (e.g., soils and geology) and how to select combinations of attributes (e.g., hydric rating and permeability) to identify the key areas within the watershed for the functioning of each process. A similar approach is used to evaluate the alterations to these key areas. The details for completing the GIS analyses are determined by technical specialists and the level of GIS expertise available. These mapping methods are described in Appendix H.

1.5 Incorporating an understanding of watershed processes into planning

Completion of this analysis will result in identification of areas where watershed processes, and therefore the aquatic ecosystems upon which they depend, can be protected or restored. This information can be used by policy and resource managers to assess the risk of future development patterns that may affect watershed processes and their associated aquatic ecosystems.

Ideally, these methods are most effective when used in the comprehensive planning process applied at the county-wide or watershed scale. This will allow communities to consider the complete set of watershed processes and their associated aquatic ecosystems. They can also evaluate how development can be sited or designed to minimize impacts to those processes and ecosystems. See Appendix J for more discussion.

There is more uncertainty associated with predictions made across a watershed than is usually found in those made for an individual site. This means that products from analyses for an entire watershed will not always be accurate for a specific site. In addition, while these methods set the watershed context for developing plans, they do not provide the specific detail necessary for site-level design. However, the information developed from this scale of analysis is essential to effective resource management and cannot be achieved by analyzing site-specific information.

Dealing With Uncertainty – Policy and resource management decisions are based on predictions of the risk of resource impairment posed by different land uses or management actions. The goal is to **minimize these risks** by basing decisions on the best information currently available.

In this regard, the best information available today suggests it is important to integrate watershed processes into the development of plans and policies to protect aquatic ecosystems. Accomplishing this can be difficult due to the uncertainties associated with extrapolating our understanding of processes occurring at the site scale to the scale of watersheds. For example:

We understand	***But our knowledge is less certain of***
The relationship between hydrogeologic conditions and water movement.	Local hydrogeologic conditions..
Which human activities are likely to alter watershed processes (i.e., additional inputs of nutrients or change to nutrient removal mechanisms).	Spatial relationships between a land use activity and a particular habitat response. Strength of the relationship between indicators of a particular activity and changes to watershed processes.

Despite this uncertainty, consideration of watershed processes is critical to effective resource management. This guidance presents a way to integrate our current understanding of watershed processes into planning. It also allows for modifications to be made as our understanding improves.

II. Details of steps for understanding watershed processes

In this section, each of the analysis steps are discussed in more detail and illustrated with an example from Drayton Harbor. This watershed is in Whatcom County near the city of Blaine and the Canadian border. Details of the methods for each watershed process are contained in Appendices B-G. The key questions to answer, the steps necessary to answer those questions, and details for answering them are outlined below:

Key Questions	→	**Steps**	←	**Details**
Why do you need to understand watershed processes? Who will assist you with the analysis? What resources already exist to help with the analysis?	→	Step 1: Define the purpose of the analysis		
Over what area do watershed processes operate?	→	Step 2: Delineate the analysis area	←	Include surface watershed and contributing area for groundwater
Under **natural** conditions, where are the physical characteristics important to each watershed process? Where are these different areas located?	→	Step 3: Map key areas for each watershed process	←	Describe relationship between physical characteristics of a watershed and each watershed process
Which human activities can alter each watershed process? Where do these activities occur?	→	Step 4: Map types of alterations to each watershed process	←	Describe relationship between human activities and each watershed process
Where are watershed processes still intact or minimally altered? Where have watershed processes been impaired?	→	Step 5: Locate potential areas for protection and restoration	←	Overlay Map of Alterations on Map of Key Areas for each watershed process; unaltered ▸ protection altered ▸ restoration

2.1 Analysis Steps

2.1.1 Step 1: Define the Purpose of the Analysis

Key Questions:
Why do you need to understand watershed processes?
Who will assist you with the analysis?
What resources already exist to help with the analysis?

Methods:

a. Define the purpose of the analysis: The purpose of the analysis will define the geographic area over which the analysis is conducted, the watershed processes that will be assessed, and the mechanism for integrating the results into planning efforts (Table 1). We suggest that the scope of the watershed analysis be defined in consultation with a broad range of stakeholders. Some common reasons for conducting watershed analyses and associated guidance on establishing its scope are:

i. A broad watershed planning effort designed to identify future development patterns that protect and restore aquatic ecosystems. This approach is appropriate at a county-wide scale for comprehensive and shoreline plan updates or for a watershed planning effort. Usually, all watershed processes are analyzed.

ii. Planning for restoration or conservation of a particular ecosystem or species. This application would require addressing all processes in the watershed. The products can provide a foundation for developing more detailed, site-specific restoration or management plans.

iii. An effort focused on addressing a specific environmental issue. The watershed processes to be analyzed are determined by the particular environmental problem for which solutions are sought. Products of this type of analysis could be integrated into a variety of resource management plans including those for water quality, flood improvement, and mitigation.

Table 1: Relationship between purpose, analysis area, and watershed processes requiring analysis.

Purpose	Analysis area	Watershed processes
Shoreline Management Plan Comprehensive Plan Watershed Plan	Watersheds of jurisdiction	All
Mitigation Plan Conservation Plan Restoration Plan	Watershed of ecosystem or habitat	All
Plans for addressing environmental problems, e.g., TMDLs, shellfish closures, water quality violations, etc.	Watershed affecting area of concern	Processes associated with key issue

b. Identify technical specialists: Analysis of watershed processes as described in Appendices A through H requires input from technical professionals. They should include local experts in hydrology, geology, aquatic ecosystems, and GIS analysis. This group can review the steps and methods presented in this document and make any necessary modifications based on local knowledge and information.

c. Gather existing data and resources and identify key environmental issues: Once the scope of the analysis has been identified, relevant existing reports, studies, and inventories should be collected for integration into the analysis (Table 2). These resources can be used to identify key environmental issues for which solutions are being developed. Additionally, based on the GIS methods listed in Appendix H, you should evaluate the usefulness of current digital data.

Table 2: Selected sources of existing information and data

Type of information	Studies/plans	Website
TMDL studies and listings	Water bodies exceeding water quality standards (303d list)	http://www.ecy.wa.gov/programs/wq/303d/2002/2004_documents/list_by_category-cat5.html
	TMDL clean up plans	http://www.ecy.wa.gov/programs/wq/tmdl/watershed/index.html
Habitat and water quality monitoring/ assessment reports	Puget Sound Action Team list of reports on marine environments	http://www.psat.wa.gov/Publications/Pub_Master.htm
Watershed planning reports	Ecology list of watershed planning reports	http://www.ecy.wa.gov/watershed/index.html
Studies/environmental reports	Limiting Factors Reports	http://salmon.scc.wa.gov
	Site-specific studies	Literature data bases, tribal websites, agency websites

The amount of information available for any particular location varies considerably across the state. Some areas have many local studies while others have very few. It is important to evaluate the information that exists to decide how it can contribute to this analysis. What was the purpose of the study? How are the results useful?

Products:

- Geographic area and watershed processes to be analyzed
- Technical specialists identified to complete the analysis
- Compilation of existing reports, data, and resources

Example:

Below we present an example of this step for Drayton Harbor in Whatcom County.

a. Scope of the analysis: The Washington State Department of Health closed Drayton Harbor shellfish beds in the late 1990s due to fecal coliform contamination. In addition, the Puget Sound Action Team reported problems with algal blooms, indicating high nutrient levels in Drayton Harbor. As a result, this watershed analysis is to address the environmental problems of high levels of nutrients and high fecal coliform concentrations in Drayton Harbor.

The geographic area for analysis is the two watersheds that contribute to the Harbor – California and Dakota creeks. The analysis of watershed processes will focus on the delivery, movement, and loss of **water, nitrogen, phosphorus, and pathogens**. The products will provide a watershed context for prioritizing activities, such as restoration or protection, to address the fecal coliform and nutrient contamination of Drayton Harbor.

b. Identify technical specialists: To conduct these analyses, we include a GIS analyst, a wetlands ecologist, and a hydrogeologist familiar with the area.

c. Gather existing resources and data: We assess the numerous planning and scientific studies conducted in this area before we begin the watershed analysis. Extensive information on environmental conditions in Drayton Harbor can be found in a host of studies. The 303D listings on the Department of Ecology website indicate that Drayton Harbor and Dakota Creek exceed fecal coliform standards. In addition, review of the Puget Sound Action Team publication site identifies several useful studies. One document, “Blooms of Ulvoids in Puget Sound” (Frankenstein 2000), reports that Drayton Harbor had algal blooms, which are an indicator of high nutrient levels. Fecal coliform studies produced by the Northwest Indian College and Whatcom County Health Department are also consulted. In addition, we acquire all available GIS data needed for the analysis from existing state and local data sources for geology, topography, soils, precipitation, and land use.

2.1.2 Step 2: Delineate the analysis area

> ***Key Question***:
> Over what area do watershed processes operate?

Methods: This step defines the scale at which you will need to analyze watershed processes. The product, Map 1, identifies the area that contributes surface and ground water to the aquatic ecosystems. The processes associated with the movement of sediments, nutrients, pathogens, toxins, and large woody debris are assumed to operate within this same scale.

Even though groundwater and surface water are tightly linked and are equally important components of water movement, surface watersheds do not always correspond with the recharge area for ground water (Winter et al. 1998). Therefore, the area of analysis is initially delineated using surface water drainages and then is refined by determining the area that contributes to groundwater recharge.

In many locales, watershed boundaries have already been developed and used extensively in other projects. To maintain consistency, these boundaries should be adopted for this work to the extent possible. In some cases, you may need to alter these existing boundaries as, for instance, surface water drainages have been altered from their natural state or the drainages of interest are smaller than those previously delineated. You can then use elevation patterns, visible from either Digital Elevation Models (DEM) or topographic maps, to delineate watershed boundaries.

You can determine the approximate contributing area for groundwater by examining the surficial geology and topography. In glaciated landscapes, the surficial deposits are tied to and govern soil permeability and hydraulic conductivity (Vaccaro et al. 1998) (Appendix B). The grain size of a deposit is a good indicator of its conductivity except in highly consolidated formations such as till (Vaccaro et al. 1998). In general, if a deposit that is highly permeable extends beyond a surface water boundary, then the watershed boundary (or contributing area) may need to be adjusted. A local hydrologist or geologist should be consulted when developing these boundaries.

Products: Map 1– Map of the analysis area

Example:

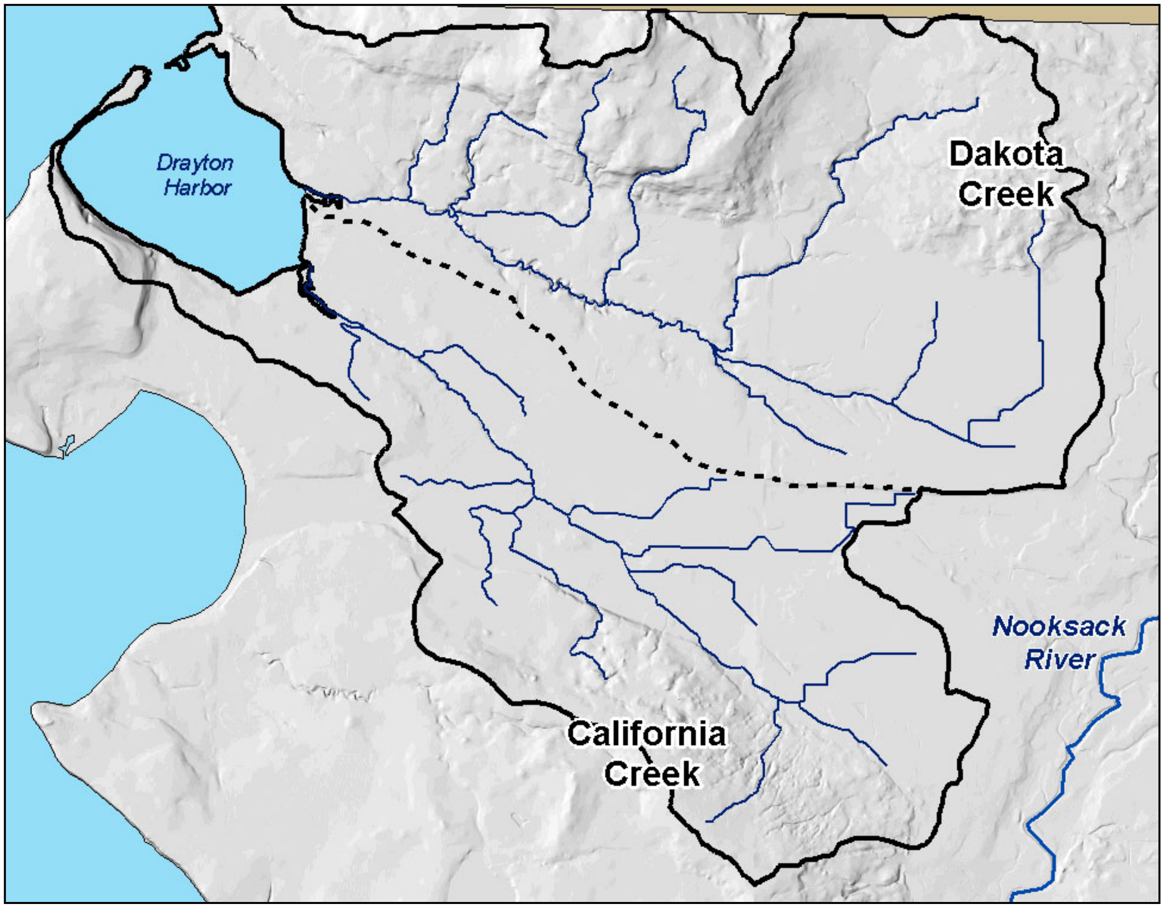

Figure II-1. Example of Analysis Area for the Drayton Harbor Watershed (Map 1). The solid black line shows the area contributing to Drayton Harbor. The major streams are the thinner, solid blue lines. Though the dashed line is the surface water boundary between the California Creek and Dakota Creek drainages, there is groundwater movement beneath this boundary.

2.1.3 Step 3: Map 'key areas' that are important for each watershed process

Key Question:
Under **natural** conditions, where are the areas with physical characteristics that are important to each watershed process?
Where are these different areas located?

Methods: This step focuses on describing the physical characteristics of the watershed, or the hydrogeologic setting, that governs the performance of each watershed process. Our current understanding of these relationships is described for each process in the key areas section of Appendices B-G. Those areas with characteristics that support each process are identified as "key areas" in the rest of this document. As the final part of this step, the places in the watershed with these physical characteristics are mapped (Map 3).

GIS analyses: Using GIS, you can map the key areas for each watershed process identified in the Appendices. Appendix H provides suggestions for using regionally available datasets to map these key areas; however, if local data exist, they may be preferable.

Products: Key Areas Map (Map 3): A separate map is produced for each process. On each map, key areas for each component of the process (i.e., delivery, movement, and loss) are mapped in different colors.

Example: Although we identified three "key" watershed processes in Step 1 for Drayton Harbor, the examples from here forward are only for the movement of **water**. In fact, to better illustrate the steps, we have focused only on the subsurface movement of water, which includes groundwater recharge.

Using Appendix B as a guide (Table B-1), the **permeability** of surficial geologic deposits in a watershed governs the subsurface movement of water. Key areas for both subsurface flow and recharge of groundwater are found where these deposits are permeable. As a result, the map of key areas for these components of water movement highlights the places where the underlying geologic deposits in the watershed have moderate to high permeability (Figure II-2).

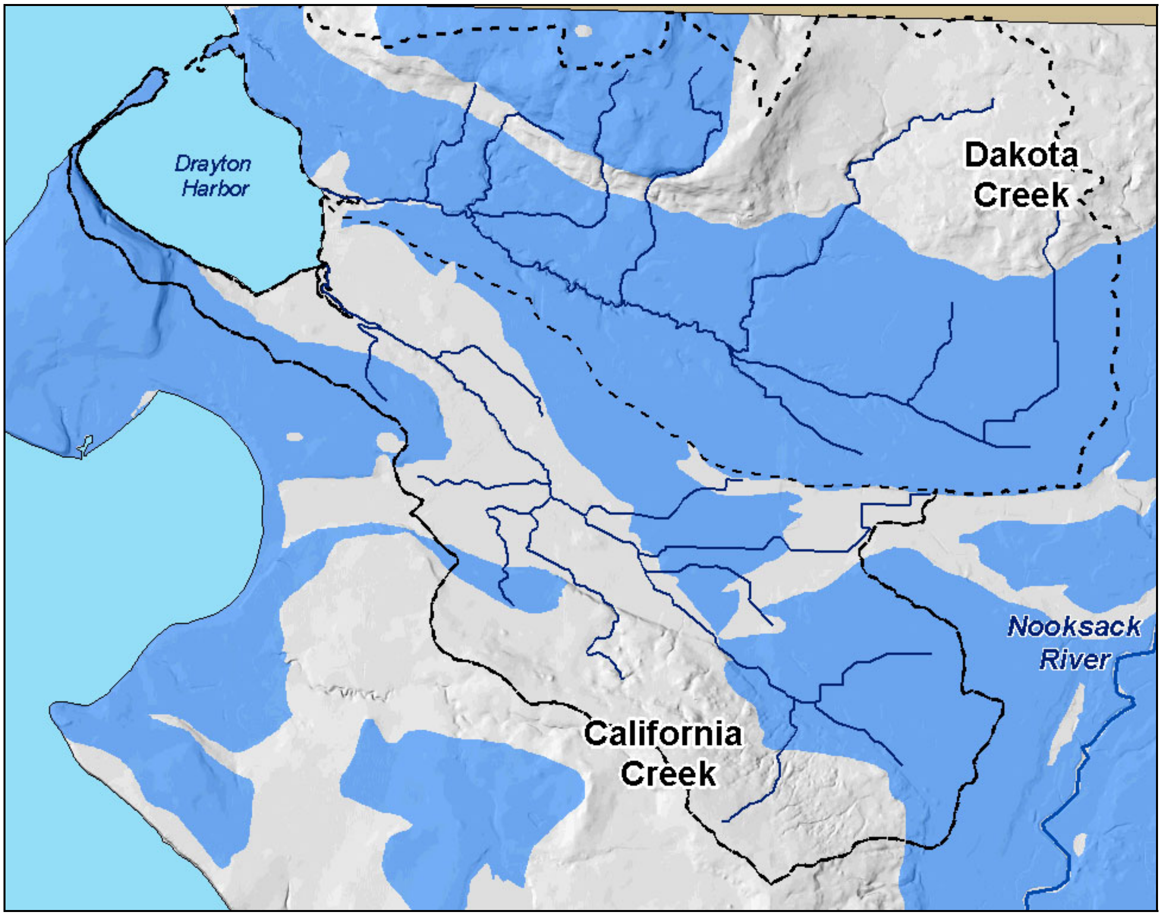

Figure II-2. Example of Map of Key Areas (Map 3) for the Drayton Harbor watershed. Blue areas show underlying geologic deposits that are more permeable.

2.1.4 Step 4: Map types of alterations to each watershed process

***Key Questions*:**
Which human activities can alter each watershed process?
What activities occur?

Methods: In this step we focus on identifying those activities that are likely to alter each watershed process. Many human activities affect the physical characteristics of a watershed, thus affecting watershed processes. For example, construction of impervious surfaces, such as roads or buildings, can prevent the downward movement of water into surficial deposits. This reduces the amount of groundwater recharge and increases the amount of surface runoff. Our current understanding of these relationships is described in illustrations for each process in the alterations sections of Appendices B-G.

The goal of this step is to map the locations of the human activities that impair watershed processes. However, many of these activities are not easy to map, such as nutrient inputs. As a result, we use indicators that strongly correspond to these activities and are easier to map (agriculture land cover). These indicators are summarized in the alterations sections of Appendices B-G.

GIS analyses: You can map indicators of human activities that impair each watershed process using GIS. These indicators are identified in the illustrations for each process in the Appendices. Appendix H provides suggestions for using regionally available datasets to map these altered areas. However, if local data exist, they may be preferable.

Products: Alteration Map (Map 4). A separate alteration map is produced for each watershed process.

Example: Again using Appendix B as a guide (Table B-3), we identify the type of human activity that degrades the subsurface flow and recharge of groundwater. In this case, it is the conversion of forest to either impervious surfaces or non-forested vegetation. Impervious surfaces clearly prevent percolation of water into the ground, thus reducing groundwater recharge. Research has also found that removal of forests is associated with a reduction in the downward movement of water, thus shifting subsurface flow to surface water runoff.

For Drayton Harbor, we use urban land cover as an indicator of impervious surfaces, and agricultural and urban land cover as an indicator for removal of forested vegetation. Forested land is used as an indicator of remaining forested vegetation. We map each of these land covers in a different color to produce an Alteration Map for these components of water movement (Figure II-3).

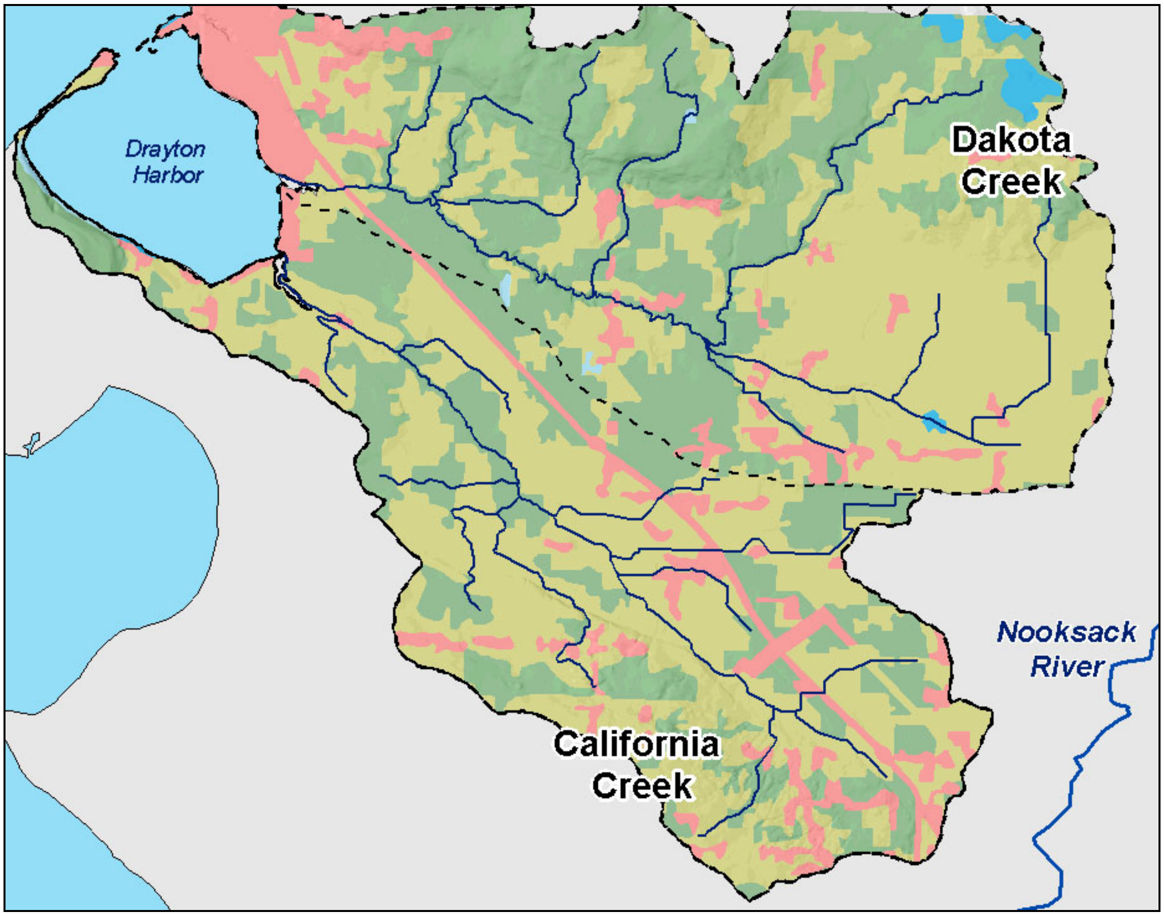

Figure II-3: Example of Alterations Map (Map 4) for Drayton Harbor. Urban land cover is **pink**, agricultural land cover is **tan,** and forested land cover is **green**. Larger wetlands and water bodies are **blue**.

2.1.5 Step 5: Locate areas for protection and restoration

> ***Key Questions***:
> Where are watershed processes still intact or minimally altered?
> Where have watershed processes been impaired?

Methods: Upon completion of steps 3 and 4, we have produced two sets of maps for each watershed process. The first map locates the key areas for each watershed process, while the second locates alterations that degrade these processes. Overlaying the Alterations Map (Map 4) on the Key Areas Map (Map 3) will highlight where each process has been impaired and where each has been minimally altered.

Key areas that have not been altered may be candidates for protection, thus ensuring that the associated watershed process will remain intact. Key areas that have been impaired may become candidates for restoration, thus increasing the likelihood that associated watershed processes will be restored. The protection and restoration of watershed processes is a critical step towards protecting the aquatic ecosystems in a watershed.

***Protection*:** Any activity that ensures that the watershed process supported by a key area is relatively unimpaired. This can encompass traditional efforts of protecting land from human activities (e.g., open space, conservation easements), but it can also extend to designing development in a way that allows the watershed process to continue with minimal impairment. For instance, an area important for recharge could be set aside from any development, or new development could be sited and designed to ensure recharge of the additional surface runoff generated by the development.

Restoration: Any activity that ensures that the watershed process associated with a key area is reinstated. This can involve restoring the natural condition of the site, but it can also include activities that restore the capacity of the important area to support the process. For instance, an area important for recharge that is covered with impervious surfaces could be modified to accommodate recharge or it could be restored to natural conditions.

The specific design of any of these activities requires further site-level analysis.

***GIS analysis**:* Overlay of the Alterations Map (Map 4) onto the Key Areas Map (Map 3) for each process

***Product**:* Map 5 - Overlay of Map 4 onto Map 3
Location of Potential Areas for Restoration and Protection

***Example**:*
As this is a data analysis and synthesis step, mapping should be done in a way that best facilitates interpretation of the data and integration into planning. There are many different ways that this can be accomplished including overlaying the Alterations Map for subsurface flow and recharge over the Key Areas Map. For more mapping ideas, see the mapping section of Appendix H.

In this example, we found it useful to present the alterations data in a different format from that shown in Step 4 (Figure II-4). Rather than using the actual locations of each land cover, we summarize the percentage of a sub-basin in each of the three land covers (urban, agriculture, and forested). This information is then displayed in a pie chart for the sub-basin. Seven sub-basins are shown to illustrate the variation within the watershed and to simplify the display.

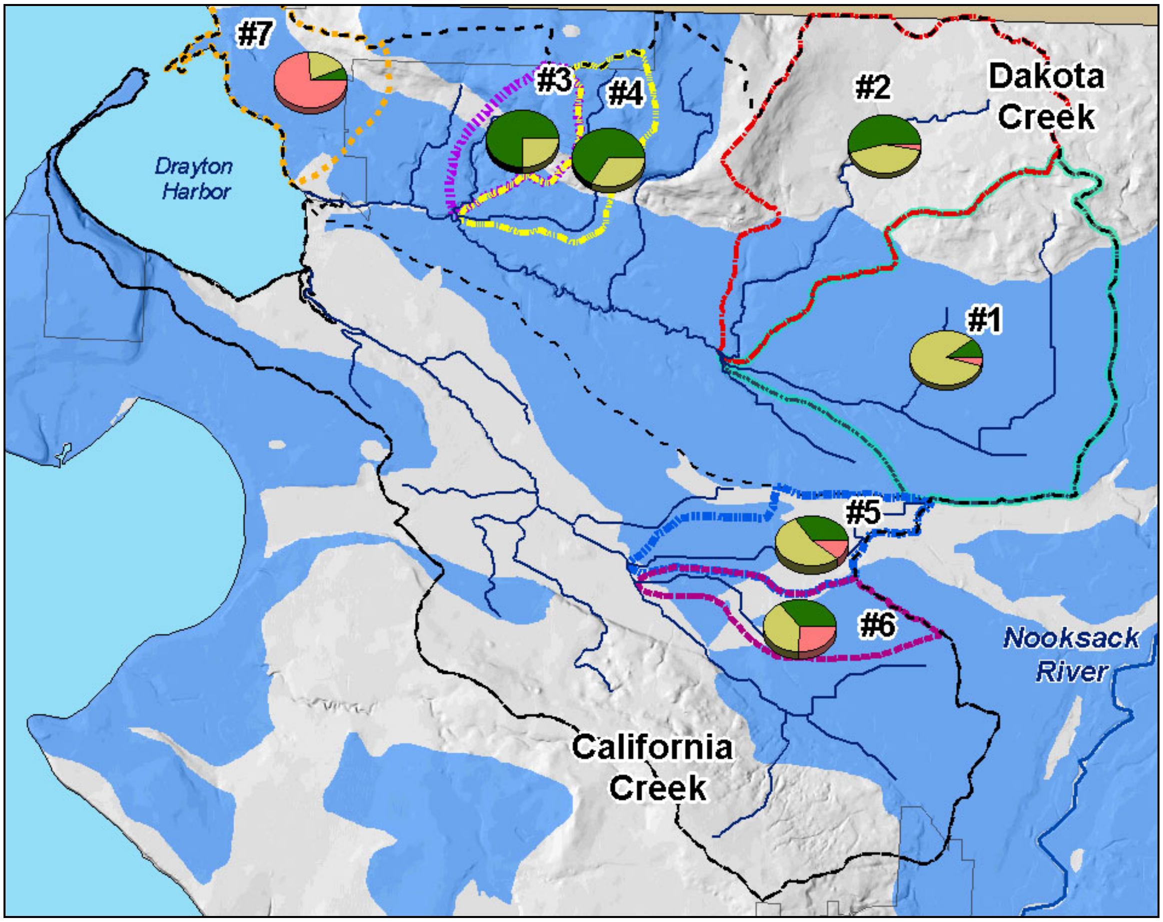

Figure II-4: Example of Map 5 using land cover alteration data. This map shows the key areas for the recharge component of the water movement process and the degree of alteration**.** The pie charts show the land cover composition of seven selected sub-basins in the Drayton Harbor watershed. The proportion of the sub-basin that is forested is green, the proportion that is non-forested is tan, and the proportion that is impervious is pink. In addition, the key areas for water movement, high to moderate permeability, are in blue.

The information on each sub-basin presented in Figure II-4 can be used to identify priorities for each sub-basin. A planner using this approach would then be able to identify which areas to prioritize for restoration of watershed processes, for restoration of site level functions, for enhancement of selected attributes, or for protection of both functions and watershed processes. In Figure II-5 we provide an example of one approach for identifying priorities for sub-basins. This approach was developed for nearshore environments (Shreffler and Thom 1993), but adapted here for freshwater ecosystems.

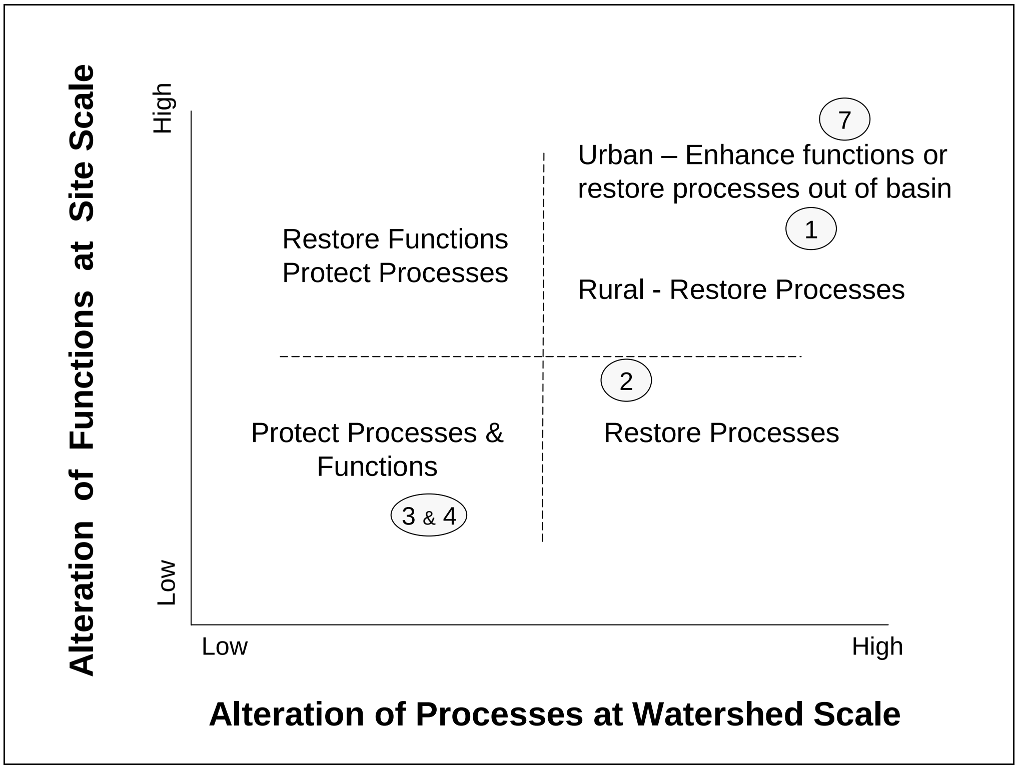

Figure II-5: Example of prioritizing restoration and protection efforts based on degree to which the watershed processes and site functions have been altered. . Numbers in circles refer to sub-basins in Figure II-4. It is assumed that alteration of processes are not permanent (i.e., paving, buildings) except for urban sub-basins (e.g., #7). Adapted from Figure 5-2 in Shreffler and Thom (1993) and Figure 9 in Booth et al. (2004).

- *What this overlay map tells us:* Sub-basins 3 and 4 have the least amount of impervious cover and a large percentage still in forest. This indicates the subsurface flow and recharge components of water movement are least altered in those sub-basins and that most of the aquatic habitat and their functions would be relatively intact. Sub-basin 7 shows the reverse with a large percentage in impervious surface. It is likely that the most-altered components of water movement in this sub-basin are subsurface flow and recharge, as well as the functions of aquatic habitat.

- *How this can integrate into plans to restore aquatic ecosystems:* This information could guide the overall objectives of restoration projects in these sub-basins by ensuring that focus is placed where it is needed most to restore water processes. Furthermore, it can guide on-the-ground activities by suggesting that they focus on restoring subsurface flow and groundwater recharge in areas where land use changes have altered these components of water movement.

  For example, restoration of processes in sub-basin 1 is appropriate given the considerable degree of process alteration (agricultural activity) but a low level of permanent alteration (impervious cover). Because sub-basin 1 also covers the largest area of permeable deposits for Dakota Creek and is located in the upper portion of the basin, restoration measures could have a significant effect on restoring water flow processes. In comparison, restoration in sub-basin 6 may not be appropriate given the higher level of impervious cover that may have permanently and significantly altered watershed processes and functions.

Compensation for future development impacts to aquatic ecosystems in sub-basins with a very high level of alteration may be more appropriately directed to less altered sub-basins. For example, compensation for impacts to wetlands in sub-basin 7 may provide more overall environmental benefit if undertaken in a less altered area, such as sub-basins 1, 2, 3, or 4.

- *How this can integrate into plans to protect aquatic ecosystems:* The information can guide future efforts to minimize alteration to water movement in sub-basins where land cover change has so far had minimal effects. For instance, planning in sub-basins 3 and 4 should focus on protecting subsurface flow and recharge. In addition, future development in sub-basins 3 and 4 could be restricted or designed to reduce impairment to both subsurface flow and groundwater recharge by clustering development and incorporating infiltration measures (Department of Ecology 2005).

2.2 Incorporation of results into existing planning efforts

The steps outlined in this guidance will produce information that is most useful when applied within a planning framework for either a governmental or a private entity responsible for land management (see Appendix J for more detail). It should be used to guide the development of a management plan so that it provides for the long-term protection and maintenance of aquatic ecosystems. Examples of possible applications for governmental entities include a comprehensive plan, shoreline management plan, watershed plan, or development plan. For private entities, this could include habitat management and conservation plans.

Now that you have a basic understanding of the five-step approach of this analysis, you can begin to review methods presented in the appendices. The details provided in the appendices are designed to help you understand how to produce the maps discussed in this section so that they can be incorporated into your planning efforts.

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Appendices

Appendix A: Overview of appendices

The delivery, movement, and loss of:

- **Appendix B: Water**
- **Appendix C: Sediment**
- **Appendix D: Phosphorous and toxins**
- **Appendix E: Nitrogen**
- **Appendix F: Pathogen**
- **Appendix G: Large woody debris**

Appendix H: Mapping methods
Appendix I: Complete references
Appendix J: Planning framework

Appendix A: Overview of Appendices B through H

In the Puget Sound region, characteristics of the landscape within a watershed can be used to predict which geographic areas are likely to be key to each of the watershed processes.

For each process the discussion in the appendix is divided into three sections:

1. A description of the watershed process and each of its components.
2. For *unaltered* conditions, a description of the controls and key areas for each of the components of the watershed process (corresponding to Step 3 in the guidance).
3. For *altered* conditions, description of the alterations to the controls and key areas (corresponding to Step 4 in the guidance).

1.1 Description of the Process

For appendices B through G we diagram (Figure A-1) and describe the delivery, movement, and loss of five watershed processes. These processes include water, sediment, phosphorous and toxins, nitrogen, pathogens, and large woody debris. The appendices present methods and supporting rational for identifying key areas in the watershed that support the **components** of each watershed process.

Component– The individual mechanisms that make up a process. For example, infiltration, percolation, recharge, and discharge are all components of the movement of water.

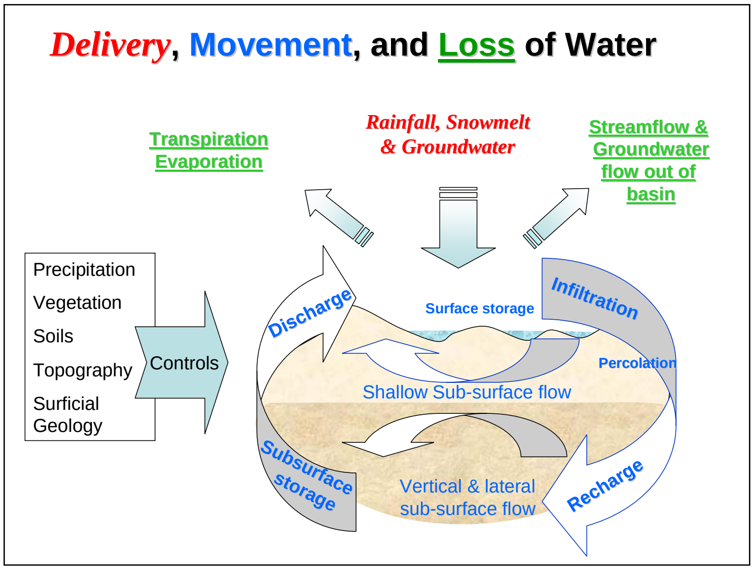

Figure A-1: Example of the components for a watershed process. This diagram illustrates the delivery, movement, and loss of *water* in watersheds of Puget Sound. The **components of delivery** are in red italics, **components of movement** are in blue, and **components of loss** are in green and underlined. The light brown area indicates near-surface material; darker brown indicates deeper material; and controls of the process are shown in black to the left of the diagram.

Mapping methods are presented in appendix H for those key areas that you can identify by using regionally available GIS data. We also provide suggestions for using local data to map key areas when regional data is not available

1.2 Unaltered Conditions - Step 3 of the Guidance

Once the description of the process is presented in the appendix, we provide a table for identifying the major controls and key areas (e.g., Figure A-2).

Major controls and key areas for the delivery, movement, and loss of water in the Puget Sound region.

Component of Process			Major Natural Controls	Key Areas
Delivery			Precipitation patterns	**Recharge areas with higher amounts of precipitation**
			Timing of snowmelt	**Rain-on-snow zones** Snow-dominated zones
Movement	*At the surface*	Overland flow	Precipitation patterns Soils	Saturated areas
		Surface storage	Topography Surficial geology Soils	**Areas on low slope** **Floodplains**

Figure A-2. Example of table presenting major controls for key areas for the delivery and movement of a process (i.e., water process, in this example). The components of the process are color coded to correspond to the diagram (Figure A-1).

The table is followed by a discussion, with supporting rationale, for each of the major natural controls and their key areas. Key areas shown in bold on the table have regionally available data for identifying and mapping them. Key areas shown without bolding require local data in order to be identified and mapped.

In cases where no key areas are identified, we judged that the component could not be readily identified and mapped by either regional or local data.

1.3 Altered Conditions - Step 4 of the Guidance

Following descriptions of the controls and key areas, the appendices present the type of alterations likely to affect processes. Appendices B through G provide a set of GIS indicators that can be used in the glaciated portion of Puget Sound to locate activities that are likely to have produced these alterations (Figure A-3) and then these appendices provide a detailed discussion of the technical rationale for the use of each of these indicators.

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Delivery			Precipitation patterns	Altered runoff	Climate change	
			Timing of snowmelt	Increase streamflow	Removal of forest vegetation in rain-on-snow zones	**Non-forested vegetation in rain-on-snow zones**
Movement	*At the surface*	Overland flow	Precipitation patterns Soils	Change timing of surface runoff Decreased infiltration	Impervious areas Rerouted drainage Filling and drainage of seasonally saturated areas	Watershed imperviousness Stormwater discharge pipes Drainage ditches in seasonally saturated areas Loss of seasonally saturated areas

Figure A-3. Example of table presenting indicators of alterations to the delivery and movement of a process (i.e., water process, in this example). The components of the process are color coded to correspond to the diagram (Figure A-1).

Because the list of indicators included in this appendix focuses on indicators that are supported across the larger Puget Sound region by literature and scientific studies, it is not all-inclusive. For instance, it does not include many of the national indicators identified by the Heinz Report (Heinz Center 2002) for biological components, but has adapted some of the physical and chemical indicators. Users of this guidance should ensure that these indicators seem reasonable for their specific planning area and add others that are supported by local studies or data.

1.4 Redundancy of Indicators

Several indicators of key areas and alterations to key areas are used multiple times. For example, depressional wetlands are indicators in Step 3 for key areas providing storage of surface water, adsorption of pathogens, and loss of nitrogen. For Step 4, straight-line hydrography (indicative of ditches or channelized streams) is an indicator of alteration to surface water storage, sediment removal, phosphorus removal, nitrogen removal, pathogen removal, and toxin removal. Despite this overlap, we have chosen to maintain the redundancy within this document for two reasons:

1. The science underlying indicators that a process is constantly changing. As a result, it is likely that at some point in the near future, there will be solid evidence that different indicators should be identified for one of the processes but not for all. Maintaining the redundancy within this document allows for transparency of the rationale for each process separately and for updating this rationale with new scientific research and findings as appropriate.

2. It is possible that users of this characterization method may be interested only in one process. Maintaining transparency within the tables and discussion makes it possible for this to occur.

Despite the need to maintain these redundancies for the purposes of this document, the user should seek ways to map key areas in an efficient manner. This may involve combining maps for several processes with similar indicators or some other approach that results in fewer maps and a more efficient display of the findings.

1.5 References

Heinz Center. 2003. The State of the Nation's Ecosystems – Measuring the Lands, Waters and Living Resources of the United States. John Heinz III Center for Science, Economics and the Environment. Available at: http://www.heinzctr.org/ecosystems/intro/toc.shtml

Appendix B: Water delivery, movement, and loss in the Puget Sound region

1. Description of the Process

Delivery of water occurs when water in the form of rain, snowmelt, or groundwater reaches a watershed. Once water falls on a land surface, it either moves above the ground as surface water or below the ground as groundwater (Winter et al. 1998, Booth et al. 2003, Harr 1977). The movement and loss patterns are controlled by physical conditions and precipitation within the watershed. This section provides a description of the delivery, movement, and loss of water in a watershed of the Puget Sound region (Figure B-1). Movement of water also plays a critical role in the movement of nutrients and pathogens to aquatic ecosystems.

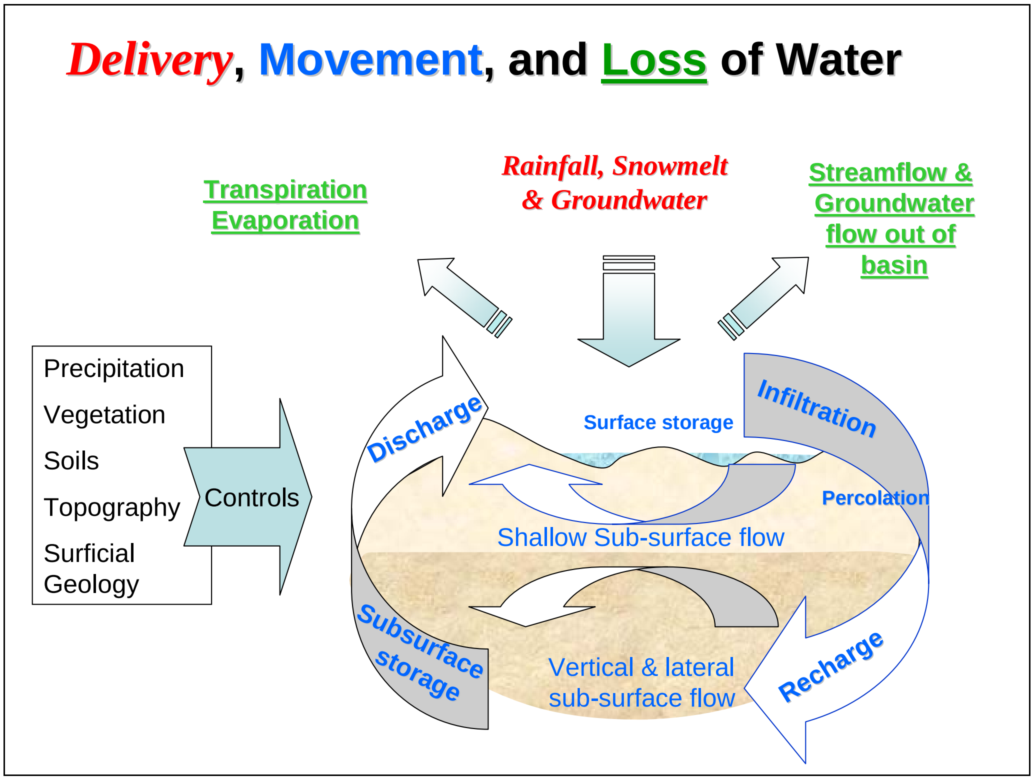

Figure B-1: Illustration of the delivery, movement, and loss of water in watersheds of Puget Sound. Controls of the process are shown in black to the left of the diagram; components of delivery are in red italics, components of movement are in blue, and components of loss are in green and underlined. The light brown area indicates near-surface material; darker brown indicates deeper material.

1.1 Delivery of water

The delivery of water to a watershed or land surface is controlled by precipitation patterns. These patterns are determined by the regional climate and include the quantity, type, and timing of precipitation and the timing of snowmelt. In certain watersheds water may also be delivered into a watershed as groundwater flow from an adjacent area. These flow patterns are determined by surficial geology and topography.

1.2 Movement of water

The movement of water begins with precipitation or snowmelt infiltrating and percolating into the soil column and underlying geologic deposits. In the Puget Sound region, as in most humid regions, the infiltrative capacity of soils greatly exceeds precipitation rates except in the most severe storms (Booth et al. 2003). As a result, water generally infiltrates into the soil, rather than remaining at the ground surface and moving down slope as overland flow (Harr 1977, Figure B-2). This also means that while soils in the Puget Sound region have varying infiltrative capacities, all but the most restrictive allow for the complete infiltration of water in most storm events if they have relatively undisturbed natural cover (e.g., forest, scrub-shrub).

Saturated areas form on the surface where water cannot infiltrate easily. These are wet areas in a watershed with the water table at or near the surface. These saturated areas can form when subsurface flow emerges at the surface as return flow, typically in valley bottoms. Precipitation falling on seasonally saturated areas cannot infiltrate, and instead moves down slope as overland flow. In general, seasonally saturated areas occupy a relatively small portion of a watershed. However, their size is variable over time, depending upon the extent of low valley areas in the watershed where they occur and storms or snowmelt that change soil moisture conditions (Dunne et al. 1975).

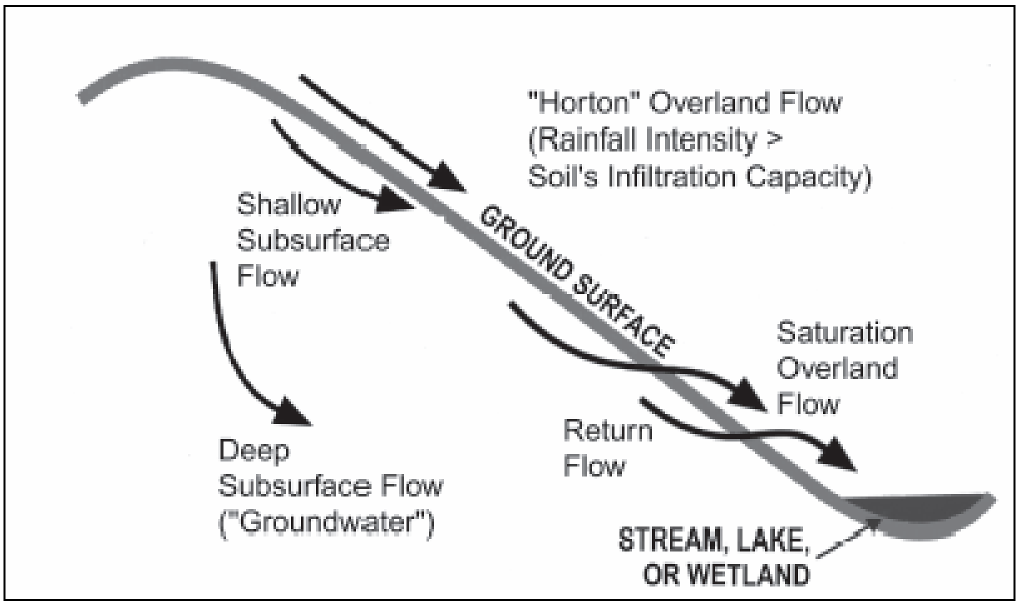

Figure B-2: Components of water movement after precipitation and snow melt reach the ground surface. Adapted from Booth et al. 2003.

Once water infiltrates the soil column, the dominant paths it takes are controlled by topography and the permeability of surficial deposits.

- In steeper areas that overlie permeable surficial deposits, some portion of this water percolates downward into the permeable deposit to recharge the groundwater, while a smaller portion continues to move laterally as shallow subsurface flow (Figure B-3).
- In steeper topography that overlies less permeable surficial deposits, the lateral movement of water as shallow, subsurface flow dominates (Figure B-4).
- In low gradient areas overlying less permeable deposits, water can move laterally, but only under high soil moisture conditions (Weiler et al. 2005). As a result, these areas can provide surface storage of water.

- In low gradient areas overlying highly permeable deposits, precipitation can still exceed infiltration if soils are fine grained (or organic) and have low permeability. These areas, often depressional wetlands, provide surface storage of water.

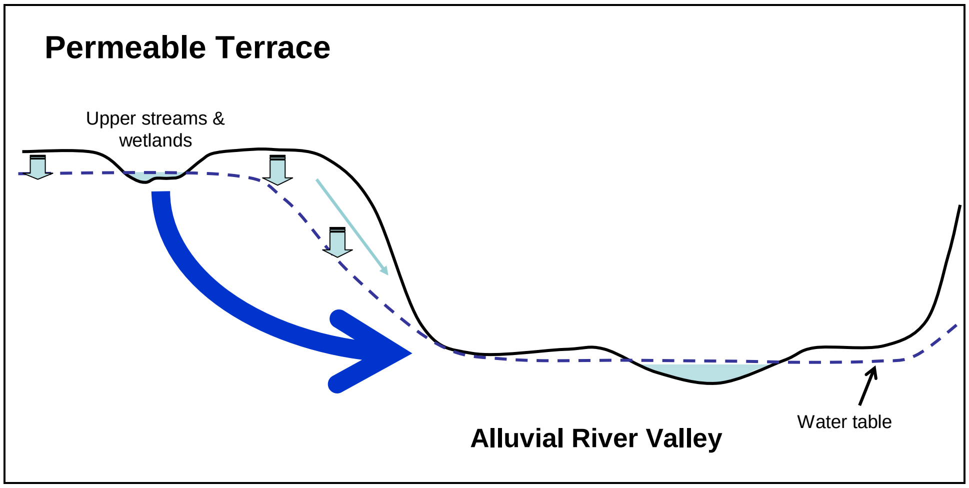

Figure B-3: Relationship of topography to water movement on permeable deposits adjacent to a river valley of Puget Sound. Blue arrows indicate movement of water. High groundwater level at base of slope of valley walls indicates discharge areas which may have wetlands with organic soils.

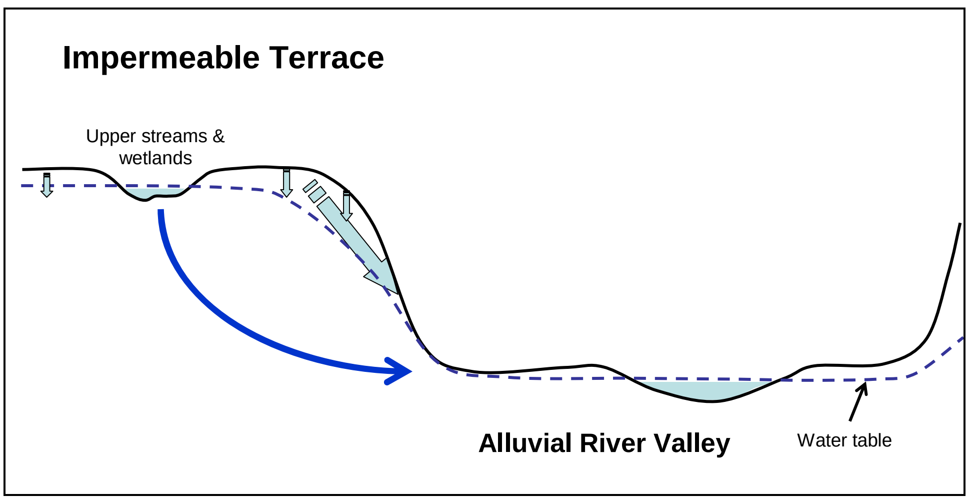

Figure B-4: Relationship of topography to water movement on impermeable deposits adjacent to a river valley of Puget Sound. Blue arrows indicate movement of water. High groundwater level at base of slope of valley walls indicates discharge areas which may have wetlands with organic soils.

During rainfall or snowfall, water stored in the soil column is forced to move down slope as subsurface flow, eventually reaching aquatic ecosystems such as streams, lakes, and wetlands (Weiler et al. 2005). Surface water in streams can be temporarily stored in floodplains, wetlands, or lakes. Once in surface storage areas, water can begin the entire cycle again by infiltrating and percolating into the soil column and underlying geologic deposits or returning to streams as instream flow.

Water that percolates deeper into the surficial geologic deposits eventually reaches the water table, providing recharge to groundwater. The scale of vertical and lateral flow of groundwater is usually described hierarchically in three levels, each with longer flow distances and therefore longer residence time: local flow, intermediate flow, and regional flow (Figure B-5).

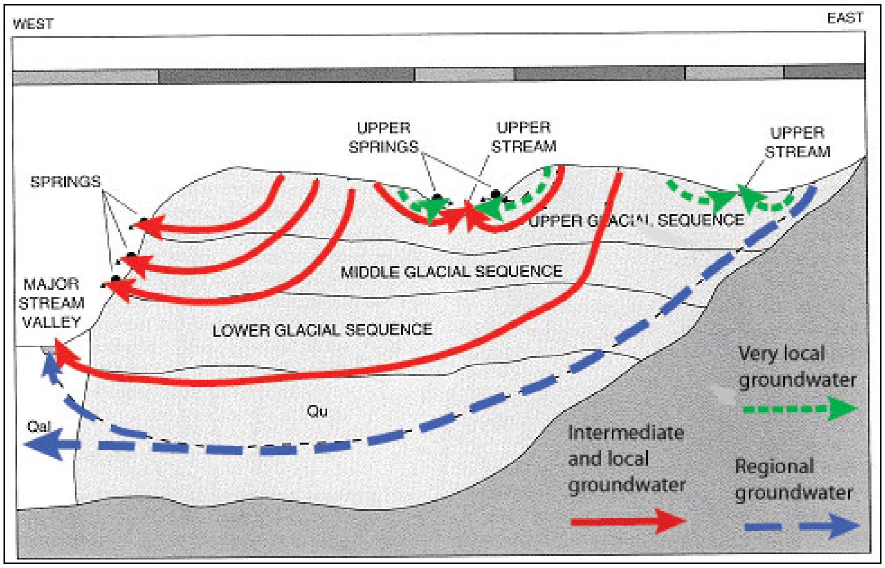

Figure B-5. Generalized cross section through typical basin in the Puget Sound Lowland, showing recharge and discharge areas and generalized directions of groundwater flow paths (taken from Morgan and Jones 1999).

In the Puget Sound basin, regional groundwater flow follows deep flow paths that are defined by large topographic features such as Puget Sound and the Cascade Range. Intermediate and local groundwater flow follows shallower flow paths defined by topography, the presence of confining layers in the surficial deposits, and the extent of salt water (Morgan and Jones 1999, Vaccaro et al. 1998). Subsurface storage of water occurs in deep, permeable surficial deposits, often providing the primary aquifers used by humans.

In some landscape settings, groundwater discharges back to the surface. This occurs as springs or seeps that are often visible at the ground surface, but it can also occur directly into surface water. Water that reaches the surface in this way re-enters the cycle described earlier for movement of water above ground.

1.3 Loss of water

Water is lost from a watershed in one of two ways: (1) it leaves as stream or subsurface flow out of the basin, connecting to another stream or marine ecosystem, or (2) it is returned to the atmosphere by evaporation or transpiration.

2. Step 3: Map key areas for the water process

Once the movement of water in a watershed is understood, key areas for supporting this process can be identified. Based on the previous illustration of the movement of water through a watershed, you can identify the controls that govern this process. Usually these controls are different physical characteristics of the watershed. "Key areas" are those parts of a watershed with these characteristics.

Table B-1: Major controls and key areas for the delivery, movement, and loss of water in the Puget Sound region.

Component of Process			Major Natural Controls	Key Areas
Delivery			Precipitation patterns	**Recharge areas with higher amounts of precipitation**
			Timing of snowmelt	**Rain-on-snow zones** Snow-dominated zones
Movement	*At the surface*	Overland flow	Precipitation patterns Soils	Saturated areas
		Surface storage	Topography Surficial geology Soils	**Areas of low gradient** **Floodplains**
	Below surface	Shallow subsurface flow	Topography Surficial geology	**Areas on geologic deposits with low permeability**
		Recharge		**Areas on geologic deposits with high permeability**
		Vertical and lateral subsurface flow		Entire watershed
		Subsurface storage	Surficial geology	Deep permeable geologic deposits
	Return to surface	Discharge	Topography Surficial geology	Slope breaks (steep above, gentle below) Stratigraphic pinchouts Contact areas between geologic deposits of different permeabilities
Loss		Evaporation/ Transpiration	Vegetation Climate	Entire watershed
		Stream or subsurface flow out of basin	Topography Surficial geology	

In this section, we discuss the controls and key areas for each component of the water process for the Puget Sound region. These are summarized in Table B-1. Key areas in bold are those that you can map using regionally available data. Mapping methods for these are provided in Appendix H. You can map key areas not in bold using local data or knowledge. If no key areas can be mapped, this column is left blank. Each component, their controls, and key areas are color coded in the table according to the colors presented in Figure B-1 for delivery, movement, and loss.

2.1 Delivery of water

The delivery of water to a watershed is controlled primarily by precipitation and groundwater flow patterns. Two aspects of these patterns are discussed here because they can affect the quantity of water available for recharge or, if natural cover is altered, change the timing of snowmelt. The relevant section of Table B-1 is shown below.

Component of Process	Major Natural Controls	Key Areas
Delivery	Precipitation patterns	**Recharge areas with higher amounts of precipitation**
	Timing of snowmelt	**Rain-on-snow zones** Snow-dominated areas

2.1.1 Precipitation patterns

The amount of water available to supply surface water and groundwater can be greater in areas with higher precipitation. This variation can have a significant effect on groundwater recharge. In models of groundwater recharge in the Puget Sound region, Vaccaro et al. (1998) estimated the recharge of the groundwater aquifer by first examining the geologic deposit and then overlaying precipitation patterns. In coarse-grained deposits, recharge related linearly to precipitation. In finer-grained deposits, recharge was initially a linear response to precipitation but eventually leveled off indicating that even increased precipitation did not produce greater recharge or groundwater flow. This pattern occurs as finer-grained materials and the overlying deposits become saturated, preventing water from moving downward to support groundwater recharge.

Precipitation amounts vary greatly across Washington (Figure B-6) and these variations can alter rates of groundwater discharge. For example, the estimated rates of mean annual groundwater recharge in Whatcom County range from 11 to 50 inches (Cox and Kahle 1999). This range of recharge corresponds with an increase in precipitation from west to east in the same area.

Key Areas: *Recharge areas (discussed in the Movement section below) with large quantities of precipitation.*

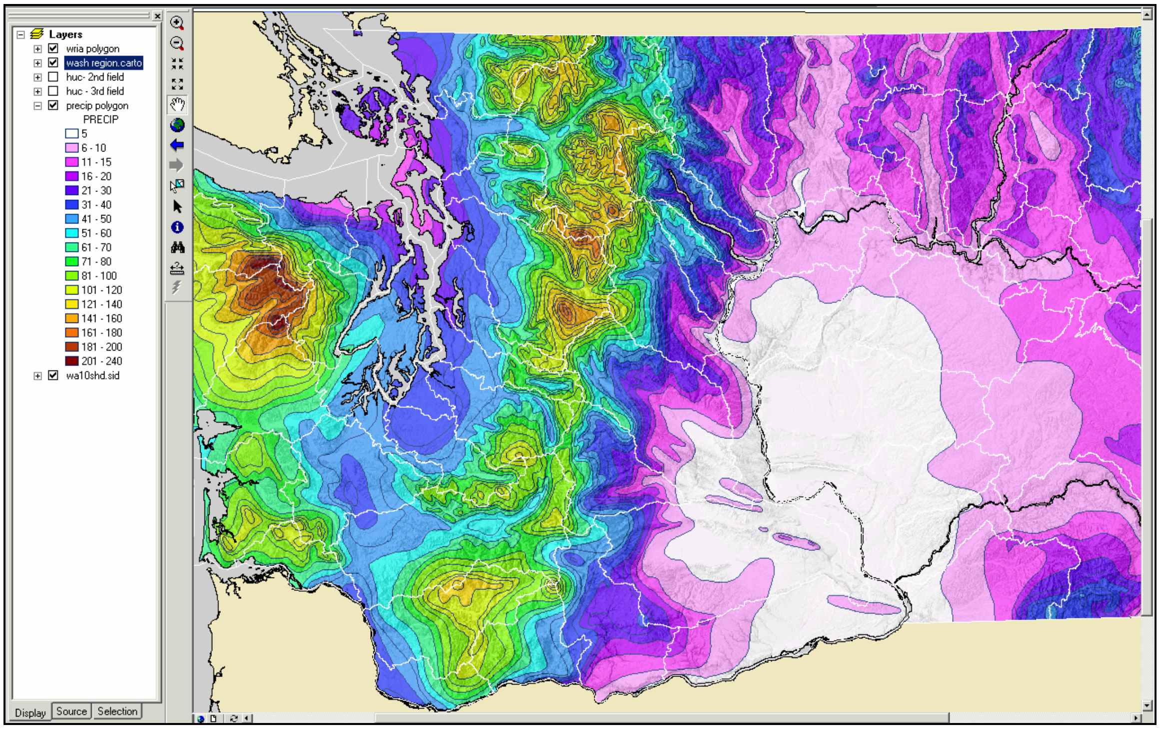

Figure B-6: Precipitation patterns across Washington State. Different colors indicate isohyetals of annual precipitation (inches). The white lines delineate WRIA's.

2.1.2 Timing of snowmelt:

Snowmelt provides an important source of water that can support baseflow and groundwater recharge, depending upon the hydrogeologic setting of a watershed. In snow-dominated zones of the Pacific Northwest, the major changes to the timing of snowmelt occur in rain-on-snow zones. These are areas with a higher probability than either rain- or snow-dominated areas of having warmer storms deposit rain in areas where snow has already accumulated. These warmer conditions cause the snow to melt at the same time that runoff from the rain is occurring (Brunengo et al. 1992). Many of the largest flooding events in Western Washington are associated with the larger amounts of runoff generated during rain-on-snow conditions.

Key Areas: *Rain-on-snow zones, as mapped by the Washington State Department of Natural Resources.*

2.2 Movement of water

The following discussion of the movement of water is divided by the location of water in the watershed: a) at the surface, b) below the surface, and c) emerging to the surface.

At the surface:

At the scale of a watershed, using regionally available data, it is not possible to accurately identify saturated areas where overland flow is likely to occur. However, it is possible to identify the places where water is likely to become subsurface flow, percolate to recharge groundwater, or be stored on the surface. Subsurface flow, recharge, and surface storage occur in all areas of the landscape to varying degrees. The discussion following the relevant section of Table B-1, shown below, highlights those areas in which one or more of these components dominates.

Component of Process			Major Natural Controls	Key Areas
Movement	*At the surface*	Overland flow	Precipitation patterns Soils	Seasonally saturated areas
		Surface storage	Topography Surficial geology Soils	**Areas of low gradient** **Floodplains**

2.2.1 Overland flow

Overland flow occurs when the precipitation rate exceeds the infiltration rate in seasonally saturated areas. These seasonally saturated areas are variable in size depending upon storm or snowmelt events. They commonly occur when shallow subsurface flow accumulates in topographic depressions or in areas with decreasing hillslope gradient (Ziemer and Lisle 1998). As these areas often play an important role in the delivery of nutrients and pathogens to aquatic resources, you should map these saturated areas. However, as it is not generally possible to identify these areas using regionally available data, you will need local data to identify them.

2.2.2 Surface storage

Depressional wetlands, lakes, and floodplains are all areas with the potential to store water during high-flow events (Sheldon et al. 2005, Hruby et al. 1999).

(a) Depressional Wetlands: The cumulative role of depressional wetlands in storing surface water has been demonstrated in numerous locations around the world. By storing water, depressional wetlands delay the release of surface waters during storms, thereby reducing downstream peak flows in rivers and streams (Adamus et al. 1991). Studies of depressional wetlands in other parts of the world also conclude that they can reduce or delay peak downstream flows (Bullock and Acreman 2003).

In King County the percentage of a watershed that contains wetlands has been found to relate to the flashiness or variability of runoff events. For example, Reinelt and Taylor (1997) found that watersheds with less than 4.5% of their area in wetlands produced a greater range of surface water level fluctuations in depressional wetlands than did those with a higher percentage of area in wetlands.

(b) Lakes: Lakes are important for storing surface water.

(c) Floodplains: Floodplains and their associated wetlands play an important role in reducing flood peaks and shifting the timing of peaks. In a review of studies from around the world, Bullock and Acreman (2003) found that 23 out of the 28 floodplain wetlands that were examined reduced or delayed flooding. In the Puget Sound region, river valleys formed by continental glaciation and those formed by fluvial action provide different levels of surface water storage and can be identified using different GIS methods.

Key areas: *Depressional wetlands, lakes, and floodplains are key areas for the surface storage of water.*

Below the surface:

Regionally available data will characterize key areas for shallow subsurface flow and recharge. You will have to use locally available data, however, to identify key areas for vertical and lateral subsurface flow and subsurface storage.

<table>
<tr><th colspan="3">Component of Process</th><th>Major Natural Controls</th><th>Key Areas</th></tr>
<tr><td rowspan="4">Movement</td><td rowspan="4">Below surface</td><td>Shallow subsurface flow</td><td rowspan="3">Topography
Surficial geology</td><td>Areas on geologic deposits with low permeability</td></tr>
<tr><td>Recharge</td><td>Areas on geologic deposits with high permeability</td></tr>
<tr><td>Vertical and lateral subsurface flow</td><td>Entire watershed</td></tr>
<tr><td>Subsurface storage</td><td>Surficial geology</td><td>Deep permeable geologic deposits</td></tr>
</table>

2.2.3 Shallow subsurface flow

Under natural conditions, after infiltrating the soil column, some water is likely to move down slope as subsurface flow, particularly in areas with underlying geologic deposits with low permeability (Booth et al. 2003).

Key areas: *Areas with surficial deposits of low permeability.*

2.2.4 Recharge

In the Pacific Northwest, areas with surficial geologic deposits of high permeability or large grain size allow precipitation to percolate directly into the groundwater (Dinicola 1990, Winter 1988). In a glaciated landscape, there is good correlation between the grain size of the surficial geology deposit and the permeability of that deposit (Table B-2, Vaccaro et al. 1998, Jones 1998). Typically, alluvium in lowland areas and glacial outwash (especially recessional outwash) are composed of coarse-grained sediment and support high levels of percolation.

Key areas: *Areas on surficial deposits with high permeability*

Table B-2: Generalized relationship between surficial geology and permeability in a glaciated landscape. [1]Vaccaro et al. 1998; [2] Jones 1998

Surficial Geology	Sediment Size	Permeability	Hydraulic conductivity[2] (ft/day)
Recessional Outwash Alluvium in lowland	Coarse Gravel/ Sand	High[1,2]	>100
Advance Outwash	Moderate Sands	Moderate[2]	15-50
Organic Deposits	Not applicable	Low to Moderate	
Moraine, Till	Varied	Low to Very Low[2]	0.005-22 ~0.0001 ft/d [1]
Lacustrine, Glacial Marine Drift, Mudflows	Fine Silts	Very Low	<10
Finer Alluvium (lower reaches of major river valleys)	Fine	Very Low[2]	1-15
Bedrock	Consolidated Deposit	Very Low	

2.2.5 Vertical and lateral flow:

The movement of water below the surface can be vertical or lateral in response to piezometric head gradients. This is an expression of both elevation and water pressure patterns. In upland terrain with unconfined aquifers, surface topography is the dominant controller of these gradients and can often be used as an indicator of likely water movement paths (McDonnell 2003). It is important to note that there are exceptions where other factors may control water movement patterns below the surface. For example, McDonnell (2003) notes that water movement on steep slopes with thin soils overlying impermeable surficial deposits may be controlled more by bedrock topography than surface topography.

Despite these exceptions, it is possible to develop a description of groundwater flow patterns in Puget Sound watersheds. Some assumptions or rules that you can apply are:

- In general, topography, the shape or geometry of the aquifer system, and the locations and amount of discharge and recharge control the movement of the uppermost layers of groundwater (Vaccaro et al. 1998).
- In general, groundwater flow follows major topographic gradients. Groundwater movement will tend to be from higher areas to lower areas (Vaccaro et al. 1998). Lows in the Puget Sound region or Puget Sound itself are generally surface water drainages.
- On slopes of less permeable geology, water will move downslope as subsurface flow. If it reaches more permeable deposits when the topography flattens, this water will then move downward to recharge groundwater.
- Lakes and large wetland areas (if not on perched water tables) and perennial streams are an expression of the water table or the emergence of groundwater at the surface.

A diagram of groundwater flow patterns can be useful for understanding the likely relationship between recharge and discharge areas and for identifying potential alterations to these patterns from human activities.

2.2.6 Subsurface storage

Permeable surficial deposits or aquifers that are deep provide for greater storage of groundwater. You can use local information on the depth and extent of aquifers to identify important areas for subsurface storage.

Return to the surface:

In the Pacific Northwest, groundwater generally is an important contributor to annual streamflow (Winter et al. 1998). However, researchers have noted the difficulty of identifying without actual measurements on a fairly local scale, whether larger-scale groundwater is discharging in a particular reach of a stream (Christensen et al. 1998). Despite these difficulties, it is possible, using locally available data as opposed to regional datasets, to identify some indicators of places where groundwater discharges to the surface. These are listed as Key Areas and are discussed following that portion of Table B-1 shown below.

Component of Process			Major Natural Controls	Key Areas
Movement	*Return to the surface*	Discharge	Topography Surficial geology	Slope breaks (steep above, gentle below) Stratigraphic pinchouts Contact areas between geologic deposits of different permeabilities

2.2.7 Discharge

Water moves from below ground to above ground at locations that are predictable based on their hydrogeologic setting. Using local data, you may be able to identify areas of:

(a) Slope breaks: At points where the topographic slope shifts from being quite steep to being far more gentle (e.g., where a valley wall intersects a valley floor), groundwater is often discharged to the surface on the shallow slope side of the intersection (Winter et al. 1998, Figure B-5)

(b) Stratigraphic pinchouts: Areas where the top of impermeable layers intersect the ground surface can become areas of groundwater discharge.

(c) Contact areas for permeable and impermeable surficial deposits: As groundwater follows a downward head gradient through a fairly permeable deposit and intersects a deposit of less permeability, it can be forced laterally or upwards and emerge at the surface (Winter et al. 1998).

Confirmation that groundwater is discharging at these areas can be obtained by examining soil data layers for organic deposits. Organic soils form when the decomposition of vegetative material is prevented or slowed. Conditions that produce this change occur with consistent, continuous, waterlogged conditions (Mitsch and Gosselink 2000), low pH, or low temperatures (A. Aldous, personal communication).

In the Puget Sound region, the presence of saturated conditions is likely the primary factor controlling the formation of organic soils. This can occur simply because precipitation exceeds evapotranspiration. However, saturated soil conditions can also occur as a result of groundwater discharge providing a continuous source of water. For example, in a portion of Whatcom County, organic soils have been found to be reliable locations of groundwater discharge (Cox and Kahle 1999).

2.3 Loss of water:

Water is lost from a watershed via four mechanisms:

- Streamflow out of the basin
- Groundwater flow out of the basin
- Evaporation
- Transpiration

None of these are included in these methods as no single area of the watershed is more important than another for these mechanisms.

Component of Process		Major Natural Controls	Key Areas
Loss	Evaporation/ Transpiration	Vegetation Climate	Entire watershed
	Stream- or subsurface flow out of basin	Topography Surficial geology	

3. Step 4: Alterations to the delivery, movement, and loss of water

Lowland areas of Puget Sound have been altered from natural conditions by human activity. However, the intensity of alteration varies significantly. Where alteration is minimal, processes are still primarily intact and functioning. Where alterations have been significant, processes are no longer functioning. The current condition of key areas can be assessed by evaluating the locations and impacts of various activities. Building upon the description of the water process, this section develops the relationship between a suite of human activities and the delivery, movement and loss of water (Figure B-7).

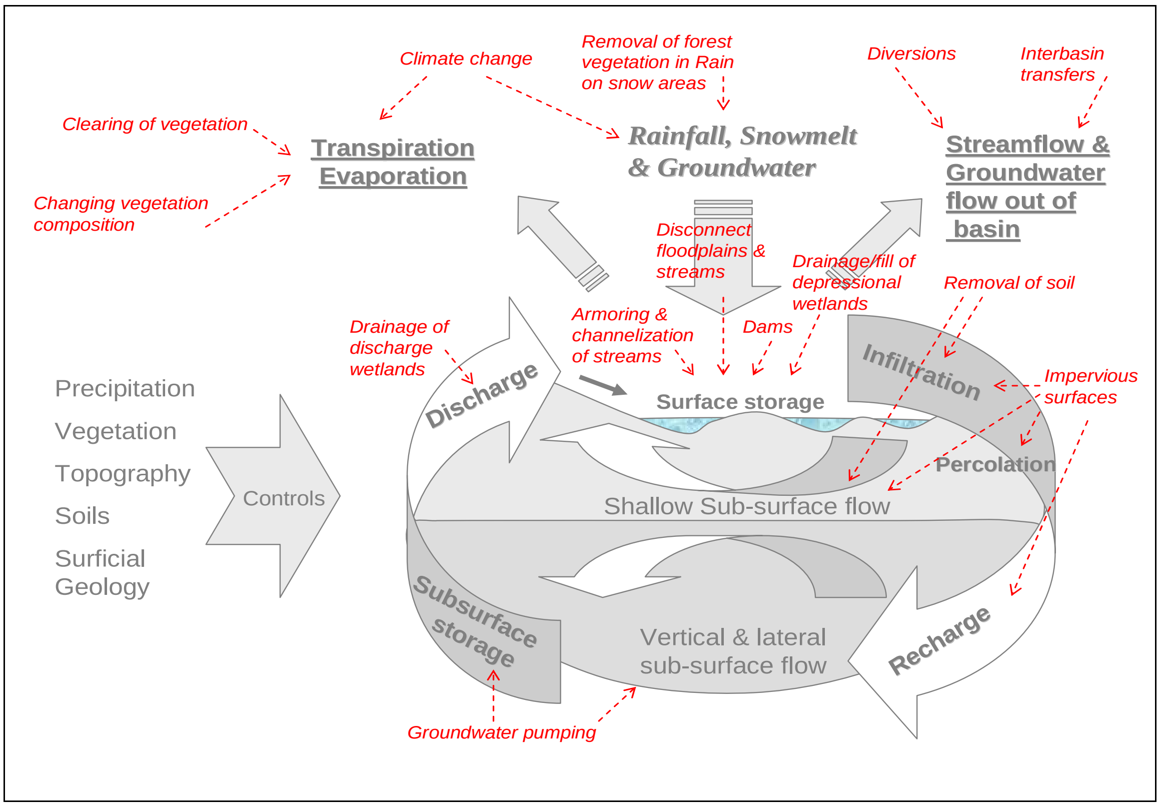

Figure B-7: Illustration of how human activities alter the delivery, movement and loss of water.

Indicators of these activities are mapped to show the locations of these alterations. This allows for an assessment of whether the activities are likely to occur in the key areas for the delivery, movement, and loss of water. Indicators for these alterations are summarized in Table B-3. Indicators in bold are those that you can map using regionally available data. Mapping methods for these are in Appendix H. You can map indicators not in bold using local data or knowledge. If no indicators can be easily mapped over an entire watershed, this column is left blank. Each component, their controls, and key areas are color coded in the table according to the colors presented in Figure B-1 for delivery, movement, and loss.

Table B-3: Indicators for the Puget Sound region that delivery, movement, and loss of water have been altered.

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Delivery			Precipitation patterns	Altered runoff	Climate change	
			Timing of snowmelt	Increase streamflow	Removal of forest vegetation in rain-on-snow zones	**Non-forested vegetation in rain-on-snow zones**
Movement	*At the surface*	Overland flow	Precipitation patterns Soils	Change timing of surface runoff Decreased infiltration	Impervious areas Rerouted drainage Filling and drainage of seasonally saturated areas	Watershed imperviousness Stormwater discharge pipes Drainage ditches in seasonally saturated areas Loss of seasonally saturated areas
		Surface storage	Topography Surficial geology Soils	Increase streamflow Decrease storage capacity Increase water transport capacity	Drainage or filling of depressional wetlands	**Loss of depressional wetlands**
						Straight-line hydrography in depressional wetlands
					Channelization of streams	**Straight-line hydrography of stream reaches with floodplains**
					Disconnection of stream from floodplain	Dikes and levees on stream reaches with floodplains
				Increase water storage capacity Decrease downstream flow	Dam operation	**Dams**

Table B-3 continued

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Movement	*Below surface*	Shallow subsurface flow	Topography Surficial geology	Convert to surface runoff	Removal or compaction of soil	New construction
					Impervious surfaces	**Land uses with impervious cover on geologic deposits of low permeability**
					Removal of forest cover	**Non-forested vegetation on geologic deposits of low permeability**
		Recharge	Topography Surficial geology	Convert to surface runoff	Removal of forest cover	**Non-forested vegetation on geologic deposits of high permeability**
				Reduce groundwater recharge	Impervious surfaces	**Land uses with impervious cover on areas of high permeability**
				Shift location of groundwater recharge Losses from water supply pipes or sewer lines, or septic drainfield discharges	Leaky pipes or irrigation canals Water supply and wastewater management	Utility lines Septic systems Unlined irrigation canals

Table B-3 continued

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Movement-	*Below surface*	Vertical and lateral subsurface flow	Topography Surficial geology	Decrease quantity of groundwater available for discharge	Groundwater pumping	Drawdown patterns Baseflow trends
				Change location of groundwater discharge	Interception of subsurface flow by ditches and roads	Constantly wet road ditches
		Subsurface storage	Surficial geology	Decrease quantity of groundwater available for discharge	Groundwater pumping	Well locations pumping rates and volumes
	Return to surface	Discharge	Topography Surficial geology	Decrease groundwater inputs to aquatic resources	Drainage of discharge wetlands	Loss of groundwater discharge wetlands Straight-line hydrography in groundwater discharge wetlands
Loss		Evaporation	Climate	Alter evaporation rates	Change temperature and precipitation patterns	
		Transpiration	Vegetation Climate	Alter evapotranspiration rates	Clearing vegetation Shifting vegetation composition	Land cover
		Streamflow out of basin	Topography	Change streamflow direction	Diversions Interbasin transfers	Diversion structures
		Groundwater flow out of basin	Topography Geology	Altering quantity and pattern of groundwater flow	Interbasin transfers Groundwater pumping Impervious surfaces Interception of subsurface flows	Baseflow trends Well locations, pumping rates and volumes

3.1 Delivery of water

Component of process	Major natural controls	Change to process	Cause of change	Indicators of alteration
Delivery	Precipitation patterns	Altered runoff	Climate change	
	Timing of snowmelt	Increased streamflow	Removal of forest vegetation in rain-on-snow zones	**Non-forested vegetation in rain-on-snow zones**

3.1.1 Precipitation patterns

An analysis of eight climate models conducted by the U.S. Global Change Research Program (2000) predicts that global climate change will alter precipitation patterns in the Pacific Northwest. All eight models concur that winters are likely to be wetter and warmer. A consensus for summer precipitation patterns was not reached by the models. These effects are not addressed in this guidance because the source of this potential change, emission of greenhouse gases, is global in scale and cannot be addressed at a watershed scale.

3.1.2 Timing of snowmelt

Removal of forest vegetation in rain-on-snow zones: During rain-on-snow events, areas in the rain-on-snow zone that have been cleared can produce 50 to 400% greater outflow from snow packs than do similar areas that are still forested (Coffin and Harr 1992). The absence of vegetation during rain-on-snow events results in more snow accumulation due to reduced interception and a higher rate of snowmelt (Brunengo et al. 1992, Coffin and Harr 1992). Both of these factors result in increased outflow from snow packs.

In rain-on-snow zones that are cleared of vegetation but are still in forestry land use, the increased flow will occur in response to rain-on-snow events until more mature forest vegetation re-establishes. However, if land cover is permanently shifted out of forest cover (i.e., through conversion to agriculture or impervious surfaces) increased outflow is a permanent response to rain-on-snow events.

Indicators of alteration: *Non-forested land cover in rain-on-snow zone*

3.2 Movement of water

At the Surface

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Movement	*At the surface*	Overland flow	Precipitation patterns Soils	Change timing of surface runoff Decreased infiltration	Impervious areas Rerouted drainage Filling and drainage of seasonally saturated areas	Watershed imperviousness Stormwater discharge pipes Drainage ditches in seasonally saturated areas Loss of seasonally saturated areas

3.2.1 Overland Flow

Seasonally saturated areas are altered by increased surface flows from upland development and by filling or drainage activities within their boundaries: Upland development decreases infiltration and increases surface flows which is usually routed into seasonally saturated areas. As a result seasonally saturated areas can expand in size. Draining and filling activities are common within these altered seasonally saturated areas. Local data are needed to identify where this has occurred.

3.2.2 Surface storage

Floodplains and depressional wetlands can be important areas for the storage of surface water runoff. Activities that reduce the spatial extent or storage capacity of these areas during peak flow events can increase the volume of water and the rate at which it reaches aquatic ecosystems (Sheldon et al. 2005, Gosselink et al. 1981, Reinelt and Taylor 1997).

Drainage or filling of depressional wetlands: In various parts of the country there is evidence reducing the amount of wetlands in a watershed results in a larger quantity of water being delivered to downgradient aquatic ecosystems in a shorter period of time. As a result, water level fluctuations in aquatic ecosystems are greater. In King County, the fluctuation of surface water levels in response to runoff events was statistically greater where less than 4.5% of the watershed area was wetland (Reinelt and Taylor 1997).

Straight channels associated with depressional wetlands or historic depressional wetlands can indicate drainage of these aquatic resources.

Indicators of alteration: *Loss of depressional wetland area and straight-line hydrography associated with depressional wetlands*

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Movement	*At the surface*	Surface storage	Topography Surficial geology	Increased streamflow Decrease storage capacity Increase water transport capacity	Drainage or filling of depressional wetlands	**Loss of depressional wetlands**
						Straight-line hydrography in depressional wetlands
					Channelization of streams	**Straight-line hydrography of stream reaches within floodplains**
					Disconnection of stream from floodplain	Dikes and levees on stream reaches with floodplains
				Increase water storage capacity Decrease downstream flow	Dam operation	**Dams**

Channelization of streams: The capacity of streams to store water within the channel is reduced when streams are channelized or straightened.

Indicators of alteration: *Straight-line hydrography of streams*

Disconnection of stream from floodplains: Dikes and levees directly disconnect the river water from the floodplain, thus removing flood storage capacity at high water levels. Unfortunately no regionally available data layer exists showing the locations of dikes or levees; local information will be needed to identify where these alterations have occurred.

Dams: The presence of dams that form reservoirs increases the surface storage of water above the dam but reduces the surface flow downstream of the dam.

Indicators of alteration*: Dams*

Below the Surface:

3.2.3 Shallow subsurface flow

Three factors are likely to alter the quantity of water that flows subsurface on less permeable deposits: removal of soils, construction of impervious surfaces, and removal of forest vegetation. Each of these activities will prevent water from infiltrating into the soil and produce instead surface runoff (Figure B-9).

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Movement	*Below surface*	Shallow subsurface flow	Topography Surficial geology	Convert to surface runoff	Removal or compaction of soil	New construction
					Impervious surfaces	**Land uses with impervious cover on geologic deposits of low permeability**
					Removal of forest cover	**Non-forested vegetation on geologic deposits of low permeability**

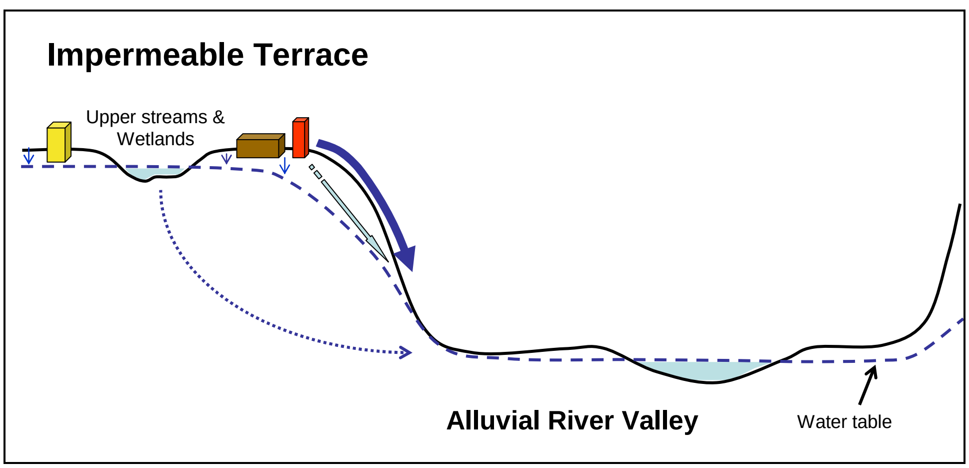

Figure B-9: Impermeable deposits and impervious surfaces: removal of soil and forest vegetation reduce subsurface flow and increase surface runoff.

<u>Removal of soil:</u> Urbanization and development typically result in the removal and compaction of soils. In areas of low permeability, soil removal results in surface runoff

since the precipitation rate usually exceeds the infiltration rate of the underlying surficial deposit (Dunne and Leopold 1978). Local data are needed to identify these alterations.

<u>Impervious surfaces:</u> Impairment of aquatic ecosystems has been documented to occur with virtually any level of impervious cover in a watershed. Furthermore, this decline progresses as the portion of the watershed with impervious cover increases (Booth et al. 2002). In the Puget Lowland, readily observable damage to stream resources (i.e., unstable channels) occurs if the effective impervious area (EIA) of a watershed is greater than 10% (Booth et al. 2002) (Table B-4).

Table B-4: Summary of thresholds associated with visible degradation of stream channels in the Puget Sound region.

Permeability of surficial deposits	Percent of watershed with:	
	Impervious cover (EIA)	Non-forest vegetation
Permeable	10	0
Impermeable	10	35

Indicators of alteration: *Land cover with impervious surfaces on areas with geologic deposits of low permeability.*

<u>Removal of forest cover:</u> There is growing evidence that simply clearing forest vegetation, even in rural areas that have little impervious cover, can produce increased streamflow as subsurface flow is converted to surface runoff (Booth et al. 2002). In the Puget Sound region, visibly altered (or unstable) stream channels are associated with watersheds in which the 2-year peak flow that occurs under current conditions ($Q_{2\ developed}$) is greater than the 10-year peak flow ($Q_{10\ forested}$) that occurs under natural conditions (Booth et al. 2002). While the precise reason for this equivalency is not yet understood, the relationship has been confirmed in numerous watersheds in King County.

Modeling efforts have found that on the most common, impermeable deposits (i.e. glacial till), the $Q_{2\ developed}$ discharge can be maintained at less than the $Q_{10\ forested}$ discharge if less than 35% of the forested cover in a watershed has been removed (Booth et al. 2002). The modeling also demonstrated that the conversion of forest to suburban development (primarily lawns) affected peak discharges more significantly than small increases in impermeable cover associated with low-density rural development (i.e., 4% EIA).

Indicators of alteration: *Non-forested vegetation on areas with geologic deposits of low permeability*

3.2.4 Recharge

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Movement	*Below surface*	Recharge	Topography Surficial geology	Convert to surface runoff	Removal of forest cover	**Non-forested vegetation on geologic deposits of high permeability**
				Reduce groundwater recharge	Impervious surfaces	**Land uses with impervious cover on areas of high permeability**
				Shift location of groundwater recharge Losses from water supply pipes or sewer lines, or septic drainfield discharges	Leaky pipes or irrigation canals Water supply & wastewater manage-ment	Utility lines Septic systems Unlined irrigation canals

<u>Removal of forest cover:</u> Although the $Q_{2\ developed}$ can be maintained at less than the $Q_{10\ forested}$ on impermeable deposits if less than 35% of the forested cover in a watershed has been removed, this relationship cannot be maintained with any forest clearing on permeable deposits because so little surface runoff occurred naturally. As a result, the threshold of forest clearing at which aquatic resources are impaired is likely much lower for the permeable deposits than impermeable. The modeling also demonstrated that the conversion of forest to suburban development (primarily lawns) affected peak discharges more significantly than small increases in impermeable cover associated with low density rural development (i.e., 4% EIA) (Booth et al. 2002).

Indicators of alteration: *Non-forested vegetation on areas with geologic deposits of high permeability*

<u>Impervious surfaces:</u> The construction of impervious surfaces on areas that are important for recharge can reduce the quantity of recharge as well as increase surface runoff (Table B-4, Figure B-10). Studies of the Puget Sound region indicate that recharge in "built-up

areas" (appx. 95% impervious surfaces) is reduced by 75% while that of residential areas (appx. 50% impervious surfaces) is reduced by 50% (Vaccaro et al. 1998).

A given amount of impervious cover can produce a greater percentage increase in runoff if it is located on permeable surficial deposits than if it is on impermeable surficial deposits (Booth et al. 2002). However, in such areas with permeable deposits, development designs that include measures to increase infiltration are also most effective at reducing the amount of surface runoff (U.S. EPA 1999, Washington State Department of Ecology 2005).

Indicators of alteration: *Land uses with impervious cover on areas with geologic deposits of high permeability*

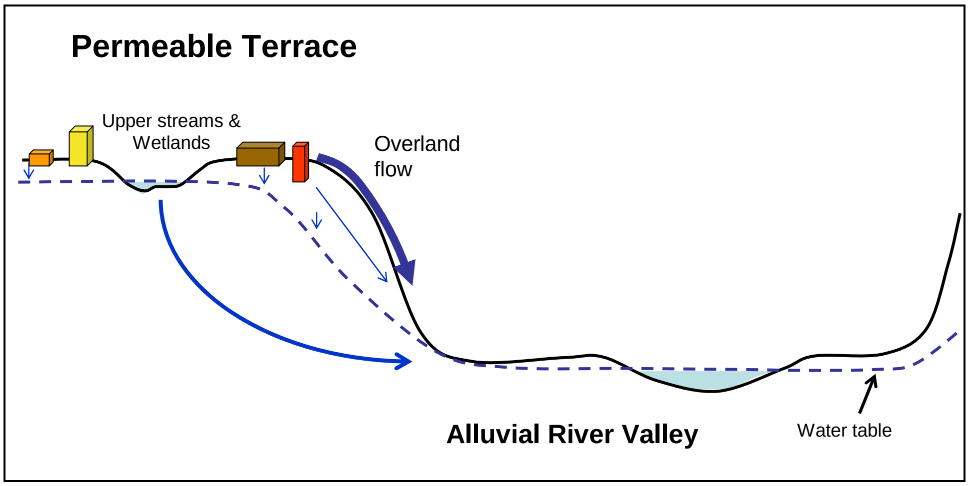

Figure B-10: Permeable deposits and impervious surfaces: recharge is reduced and surface runoff is increased.

<u>Leaky utility lines, septic systems or irrigation canals:</u> The location of recharge areas can be shifted by the presence of utility lines, septic systems or irrigation canals that leak water. Local information will be needed to locate these situations and to evaluate their significance.

3.2.5 Vertical and lateral subsurface flow

<u>Groundwater pumping:</u> The pumping of groundwater at wells can, depending upon the subsurface stratigraphy, have a significant effect upon the flow patterns of groundwater. Identifying these changes and assessing their significance require local data. Local studies of the effects of large groundwater extraction projects may provide useful information for conducting this assessment. Additionally, local information suggesting that baseflow trends are declining can suggest that up-gradient activities have reduced the amount of groundwater reaching streams, possibly as a result of alterations to the subsurface flow patterns.

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Movement-	*Below surface*	Vertical and lateral subsurface flow	Topography Surficial geology	Decrease quantity of groundwater available for discharge	Groundwater pumping	Drawdown patterns Baseflow trends
				Change location of groundwater discharge	Interception of subsurface flow by ditches and roads	Constantly wet road ditches

Interception of subsurface flow by ditches and roads: The movement of relatively shallow subsurface flow can be affected by road and drainage ditches (Ziemer and Lisle 1998). This interception can convert water to surface runoff and alter the location at which it discharges into aquatic ecosystems. Local data are needed to identify these conditions.

3.2.6 Subsurface storage

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Movement	*Below surface*	Subsurface storage	Surficial geology	Decrease quantity of groundwater available for discharge	Groundwater pumping	Well locations pumping rates and volumes

Groundwater pumping: The volume of water stored below the surface can be reduced by groundwater pumping and this can affect the amount of water available for discharge to aquatic resources. Local patterns of the volume of water pumped by wells over time can help to identify areas where groundwater pumping may be altering the quantity of groundwater stored.

3.2.7 Discharge

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Movement	*Return to surface*	Discharge	Topography Surficial geology	Decrease groundwater inputs to aquatic resources	Drainage of discharge wetlands	Loss of groundwater discharge wetlands Straight-line hydrography in groundwater discharge wetlands

Drainage of discharge wetlands: Drainage of wetlands maintained by groundwater discharge has the potential to cause two major changes. First, it can change the way water from groundwater discharge areas moves to other aquatic ecosystems, potentially altering such water quality characteristics as temperature. Second, it can alter the amount of groundwater that discharges at a particular location as the water table is lowered and the piezometric gradient is shifted. Local data and knowledge of where these groundwater discharge wetlands occur is needed. Once they are mapped, straight-line hydrography and the amount of discharge wetland area that has been lost can be used to indicate that alterations have occurred.

Indicators of alteration: *Straight-line hydrography associated with and loss of discharge wetlands*

3.3 Loss of water:

Component of process		Major natural controls	Change to process	Cause of change	Indicators of alteration
Loss	Evaporation	Climate	Alter evaporation rates	Change temperature and precipitation patterns	
	Transpiration	Vegetation Climate	Alter transpiration rates	Clearing vegetation Shifting vegetation composition	Land cover
	Streamflow out of basin	Topography	Change streamflow direction	Diversions Interbasin transfers	Diversion structures
	Groundwater flow out of basin	Topography Geology	Alter quantity and pattern of groundwater flow	Interbasin transfers Groundwater pumping Impervious surfaces Interception of subsurface flows	Baseflow trends Well locations, pumping rates and volumes

3.3.1 Evaporation and transpiration

While both evaporation and transpiration can be altered by human activities, reliable indicators for these activities may not be available unless locally determined. Land cover type may be a potential indicator of alterations to transpiration.

3.3.2 Streamflow out of basin

Natural patterns of water loss from a watershed can be altered with interbasin transfers or diversions that transfer water to a different watershed. You will need local data to identify these activities.

3.3.3 Groundwater flow out of basin

Natural patterns of water loss from a watershed can be altered by a series of alterations. This starts with impervious surfaces, which reduces recharge and groundwater storage and flow. Groundwater pumping removes groundwater and in many cases moves water directly to sewer plants and discharge to marine waters. Inter-basin transfers derived from groundwater wells can also reduce change groundwater flow patterns out of a basin. You will need local data to identify these activities.

4. References

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Appendix C: Sediment delivery, movement, and loss in the Puget Sound region

1. Description of the Process

This section provides a description of the process for the movement of sediment in a watershed of the Puget Sound region (Fig. C-1). This discussion deals with the input of sediment to aquatic systems from sources within the watershed and not with loss of sediment from the watershed.

1.1 Delivery of sediment

Under natural conditions, sediment reaches aquatic ecosystems through three primary mechanisms in the Puget Sound region:

1. Surface erosion. This mechanism operates primarily in upland areas and delivers sediment to aquatic ecosystems.
2. Mass wasting events. This mechanism occurs in upland areas and, depending upon topography, sediment can be delivered to aquatic ecosystems.
3. In-channel erosion. This mechanism involves erosion of sediment from stream banks and stream beds, and gravel bars.

Sediment delivery to aquatic ecosystems is a natural phenomenon with a natural range of variability; however, excessive amounts of sediment can undermine the condition of many types of aquatic ecosystems (Edwards 1998).

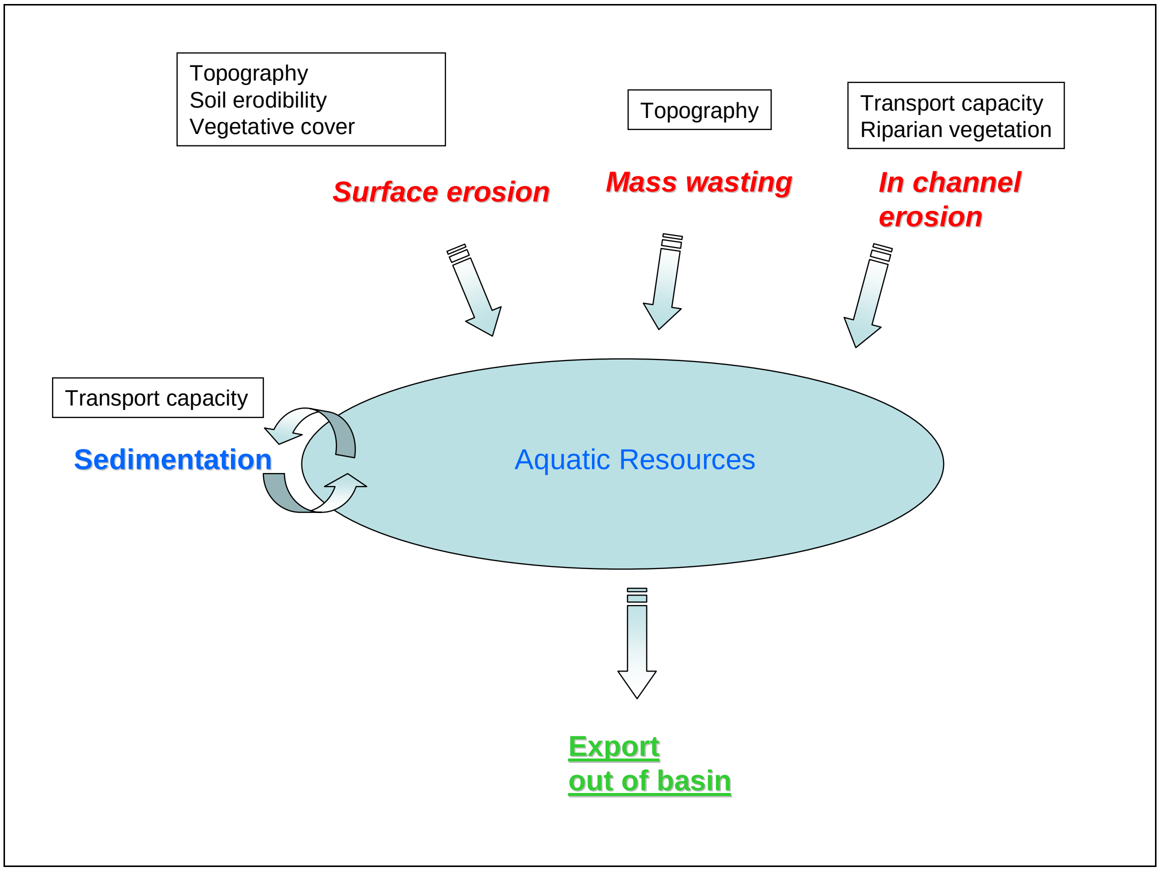

Figure C-1: Illustration of the Figure C-1: Illustration of the delivery, movement, and loss of sediment in watersheds of Puget Sound. Red italics are components of delivery, blue text is movement, and black text in boxes is controls. Blue polygon represents water bodies in a watershed.

1.2 Movement of sediment

Sediment is rarely removed entirely from the watershed; however, it is deposited and temporarily stored in areas where the water has low transport capacity (i.e. low water velocity).

1.3 Loss of sediment

Sediment is removed from a watershed when it moves into another basin or into estuarine areas.

2. Step 3: Map key areas for the sediment process

Once the movement of sediment in a watershed is understood, key areas for supporting this process can be identified. Based on the diagram (Figure C-1) of how sediment is delivered to, moves through, and leaves a watershed, controls can be identified that govern this process. Usually these controls are different physical characteristic of the watershed. Key areas are those parts of a watershed with these characteristics.

In this section, for each component of the sediment process, the controls and key areas are discussed for the Puget Sound region. These are summarized in Table C-1. Key areas in bold are those that you can map using regionally available data. Mapping methods for these key areas are provided in Appendix H. You can map key areas not in bold using local data or knowledge. If no key areas can be mapped, this column is left blank.

Table C-1: Major controls and key areas for the delivery, movement and loss of sediment.

Components of Process		Major natural control	Key areas
Delivery	Surface erosion	Topography Soil erodibility Vegetative cover	**Steep slopes with erodible soils**
	Mass wasting	Topography	**Hazard areas for shallow, rapid landslides**
	In channel erosion	Transport capacity (velocity) Riparian vegetation	**Unconfined channels**
Movement	Storage	Transport capacity (velocity)	**Depressional wetlands** **Floodplains and depositional channels** **Lakes**
Loss		Transport capacity (velocity)	Use local data

2.1 Delivery of sediment

2.1.1 Surface erosion

The potential for hillslope erosion is largely a function of the erodibility of soils, the steepness of slopes, and the cover of vegetation. Assuming natural conditions in which the cover of vegetation has not been altered, this analysis follows the example of the Washington Forest Practices Board (WFPB) methods. It combines the erodibility of soils, indicated by the K factor, with the gradient of the slope adjacent to aquatic ecosystems to predict areas at risk for sediment delivery (Table B-1, WFPB 1997**)**.

Table C-2: Combinations of both slope and K factor that indicate a moderate to high potential for soil erosion (gray boxes)			
Slope/ K factor	**<0.25**	**0.26-0.4**	**>0.4**
<30%			
30-65%			
>65%			

Key areas*: Areas with steep slopes and erodible soils (gray areas in Table C-2)*

2.1.2 Mass wasting

In some parts of the landscape, delivery of sediment to aquatic ecosystems is dominated by mass wasting events (Gomi et al. 2002). Areas at higher risk for mass wasting can be identified throughout the Puget Sound region using the Shaw Johnson model for slope stability (Shaw and Johnson 1995). In this model, predictions of the potential for landslides are based upon two factors: the slope gradient and the form (or curvature) of the slope[1]. This model is a good initial predictor of the relative risk of different areas to mass wasting events; however, slope stability conditions at the site level will need to be determined by a qualified expert.

Key areas*: High mass wasting hazard areas as identified by the Shaw Johnson model*

2.1.3 In-channel erosion

Stream channels that are low-gradient and unconfined (i.e., pool riffle and dune ripple channel types) (Buffington et al. 2003) have greater potential for bank erosion, depending upon the discharge levels and condition of the riparian vegetation (Montgomery and Buffington 1993).

Key areas*: Unconfined channels or those with gradients less than 4%*

2.2 Movement of sediment

2.2.1 Storage

<u>Depressional wetlands</u>: Particularly those without an outlet, are the most effective wetland areas for removing fine sediments (Hruby et al. 1999 and 2000). Even though conclusive studies have yet to be completed in Washington, depressional wetlands in a

[1] Field verification of this model in the Upper Lewis watershed indicates that the model over predicts risk of mass wasting in formations with significant deposits of volcanic ash (P. Olson, personal communication, April 2005).

floodplain setting are also believed to be effective in removing sediment as they slow the velocity of water flow during high flow events (Hruby et al. 1999, Adamus et al. 1991).

Floodplains and depositional stream channels: Channels with slopes less than 4% (i.e., pool riffle and dune ripple channel types, Buffington et al. 2003) also provide a greater opportunity for sediment storage than do other channel types (Montgomery and Buffington 1993). During high flows, floodplains associated with these channels can also provide storage of sediment (Buffington et al. 2003).

Lakes: Lakes are also areas where sediment can be stored, due to the low transport capacity of water (i.e. low water velocity).

Key areas*: Depressional wetlands, floodplains, depositional stream channels, and lakes*

3. Step 4: Alterations to the delivery, movement, and loss of sediment

Lowland areas of Puget Sound have been altered by varying degrees from natural conditions by human activity. However, the intensity of alteration varies significantly. Where alteration is minimal, processes are likely still primarily intact and functioning. Where alterations have been significant, processes are no longer functioning. The current condition of key areas can be assessed by evaluating the locations and impacts of various activities. Building upon the diagram of the sediment process, this section diagrams the relationship between a suite of human activities and the delivery, movement, and loss of sediment (Figure C-2).

We map indicators of these human activities to show the locations of these alterations. This allows for an assessment of whether the human activities are likely to occur in the key areas for the delivery, movement, and loss of water. We summarize indicators for these alterations in Table C-3. Indicators displayed in bold are those that you can map using regionally available data. We provide mapping methods for these in Appendix H. You can map indicators not in bold using local data or knowledge. If no indicators can be easily mapped over an entire watershed, this column is left blank.

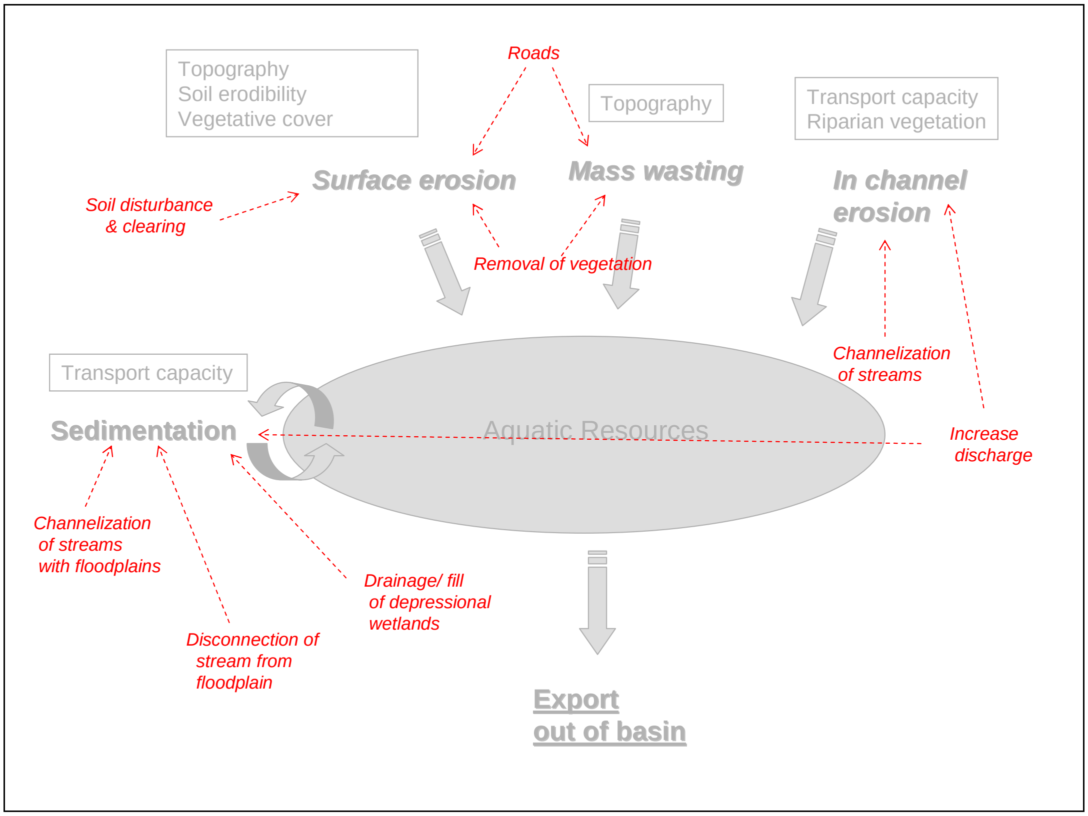

Figure C-2: Illustration of how human activities alter the delivery, movement, and loss of sediment.

Table C-3: Indicators that the delivery, movement, and loss of sediment have been altered for the Puget Sound region

Component of process		Major natural controls	Change to process	Cause of change	Indicators of alteration
Delivery	Surface erosion	Topography Soil erodibility Vegetative cover	Increase delivery of fine sediment to aquatic resources	Removal of vegetation	**Non-forested land cover on highly erodible slopes adjacent to aquatic resources**
				Soil disturbance and clearing	New construction draining to aquatic resources Row crop agriculture draining directly to aquatic resources
				Roads increasing stream network	**Roads within 200' of aquatic resources**
	Mass wasting	Topography	Increase delivery of sediment to aquatic resources	Roads triggering landslides	**Roads in high mass wasting hazard areas**
				Removal of vegetation	**Non-forested land cover on high mass wasting hazard areas**
	In-channel erosion	Transport capacity Riparian vegetation	Alter fine sediment delivery to streams	Channelization of streams	**Straight-line hydrography in unconfined channels**
				Increase in stream discharge	**Urban land cover**

Table C-3 *continued*

Component of process		Major natural controls	Change to process	Cause of change	Indicators of alteration
Movement	Sedimentation	Transport capacity	Decrease sediment storage	Drainage or filling of depressional wetlands	**Loss of depressional wetlands**
					Straight-line hydrography in depressional wetlands
				Channelization of stream reaches with floodplains or that are depositional zones	**Straight-line hydrography on stream reaches with floodplains or depositional channels**
				Disconnection of streams from floodplains	Dikes and levees on stream reaches with floodplains
				Increase streamflow[1]	
			Increase sediment storage	Dams	**Dams**
Loss		Transport capacity	Decrease or increase in sediment storage	Same causes for movement	Use local data

[1]Addressed in the delivery, movement, and loss of water discussion (Appendix B)

3.1 Delivery of sediment

3.1.1 Surface erosion

Removal of vegetation: The Washington Forest Practices Board (WFPB 1997) identifies gradient, erodibility of soils (K factor), and vegetative cover as the three factors governing surface erosion. The gradient and erodibility of soils are used to identify areas with a high likelihood of delivering fine sediment. If the vegetative cover of these areas has been cleared, they are more prone to erosion.

Indicator of alteration*: Non-forested land cover on highly erodible slopes adjacent to streams*

Soil disturbance and clearing: Both row crop agriculture and clearing for construction sites can produce increased fine sediment loads with the potential to reach aquatic resources.

Agricultural land use accounts for up to 50% of the total sediment load, generated by human activity, which reaches U.S. surface waters annually (Willett 1980). Depending upon the use and effectiveness of best management practices, soil disturbance associated with row crop agriculture is likely to produce erosion of fine sediments. However, you will need local data to evaluate whether this sediment is likely to be delivered to aquatic ecosystems.

Soil disturbance from clearing of construction sites is the largest source of sediment to aquatic resources in urban areas undergoing development (U.S. EPA 1993). Urban lands undergoing construction, without best management practices in place, can produce 50 to 100 times the sediment load of agricultural land (Jones and Gordon 2000). Construction contributes disproportionately to the sediment loads in the streams of the US. While it accounts for 10% of the sediment loads of that contributed by row-crop agriculture, construction activities occur on only 0.0007% of land area (Willett 1980). This higher rate of sediment loading is due to the high erosion rate of the cleared land and the presence of stormwater systems that effectively transport sediment to surface water bodies (Burton and Pitt 2002). Similar findings occurred in the Issaquah Creek watershed: construction and other land clearing activities produced more sediment per unit area of land than any other land use in this rapidly urbanizing area (Nelson and Booth 2002).

No regionally available data exist to identify where construction activity is occurring or the likelihood that sediment from these sites would reach aquatic resources. You will need local data, such as county growth rates (see Nelson and Booth 2002), to identify the locations of these activities.

Roads increasing stream network: The Washington Forest Practices Board (WFPB 1997a) indicates that roads further than 200' from a water body are unlikely to contribute surface erosion directly into aquatic ecosystems. Within that buffer, the presence of ditches and culverts and the relative absence of places to remove the sediment increase the likelihood that sediment will be delivered from the roads to the streams.

***Indicator of alterations**: Roads within 200' of aquatic ecosystems or road crossing*

3.1.2 Mass wasting

Roads triggering landslides: The presence of roads through mass wasting hazard areas is a major source of management-induced landslides (Swanson et al. 1987).

***Indicator of alteration**: Roads in high mass wasting hazard areas*

Removal of vegetation: Altering the vegetative composition of unstable slopes can further destabilize conditions. Roots of trees can serve to anchor thin, overlying layers of soil to bedrock or to create a membrane of intertwined roots that provides lateral stability to soil (Sidle 1985, Chatwin et al. 1994).

***Indicator of alteration**: Non-forested land cover in high mass wasting hazard areas*

3.1.3 In-channel erosion

Channelization of streams: Channelization of unconfined channels that provide important sources of sediment can result in an alteration of the sediment delivery process. This can also occur is these channels are armored to prevent erosion.

***Indicator of alteration**: Straight-line hydrography in unconfined channels*

Increase in streamflow: Increased stream discharges can cause channel erosion as the channel adjusts in width and depth to the increased water volume and energy. Nelson and Booth (2002) found that in the rapidly urbanizing Issaquah Creek drainage, urbanization contributed at least 20% of the sediment load to the watershed as a result of increased discharge and associated in channel erosion. These findings are similar to another study conducted in San Diego by Trimble (1997) in which over 65% of the sediment load was due to this effect of urbanization. The San Diego study area was approximately 50% urban whereas the Issaquah Creek watershed is approximately 19% urban. These studies suggest that the relative contribution of urbanization to the sediment load of a watershed is proportional to its urban cover.

***Key areas**: Urban land cover*

3.2 Movement of sediment

3.2.1 Storage

Drainage or filling of depressional wetlands: Removal of fine sediments is facilitated in wetlands as water velocity slows and vegetation and coarse sediment promote the settling and filtration of suspended solids (Kadlec and Knight 1996). This capability is impaired when alterations prevent water velocity from slowing or reduce the area of wetland available for sediment removal. Additionally, numerous research studies have demonstrated the relationship between wetland area in a watershed and the percentage of the water-borne sediment that is removed (summarized by Sheldon et al. 2005).

Indicators of alterations*: Straight-line hydrography in and loss of area of depressional wetland*

Channelization of stream reaches with floodplains or that are depositional zones: Channelization of streams can often disconnect the floodplain from the main channel, thus reducing the area for sediment deposition during high flows. When these channelized areas are located downstream of inputs of either sediment, the removal capacity of wetlands and floodplains has been impaired. As a result, sediment in the system will have the potential to move and impair aquatic resources further downstream.

Indicators of alteration*: Straight-line hydrography on unconfined stream reaches*

Disconnection of streams from floodplains: Dikes and levees directly disconnect the river water from the floodplain, thus reducing the area for sediment deposition during high flows. Local data will be needed to locate these alterations.

Dams: The presence of dams can alter the dynamics of sediment movement within a fluvial system by removing sediment from the water column above the dam. This trapping of sediment shifts the size distribution of substrate both above and below the dam, changing the habitat structure and complexity (Dubé 2003).

Indicators of alteration*: Presence of dams*

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Appendix D: Phosphorus and toxin delivery, movement, and loss in the Puget Sound region

1. Description of the Process

1.1 Delivery of phosphorus and toxins

Under natural conditions, phosphorus enters a watershed through the weathering of rocks and precipitation of dust-laden air. Once on the ground, phosphorus moves through the watershed to aquatic ecosystems in two forms, either as dissolved phosphorus or as particulate phosphorus. Dissolved phosphorus moves in water from upland areas to aquatic ecosystems, in either surface or sub-surface runoff. This is the most available form of phosphorus to biota which makes it of primary concern in such problems as eutrophication or algal blooms. Particulate phosphorus is attached to either soil particles (i.e. clays) or organic material. This form of phosphorus reaches aquatic ecosystems along the same pathways as fine sediment.

Natural toxins are naturally occurring metals such as copper, lead, zinc mercury, cadmium and nickel. In the Pacific Northwest toxic metals are in relatively low concentration in Puget Sound lowland streams. According to Welch et al. (1998) bedrock type does not influence metal concentrations in streams. In some unusual circumstances pH and atmospheric deposition can result in higher metal levels (Welch 1998). Therefore, natural processes are not considered a significant source of toxic metals for Puget Sound aquatic ecosystems.

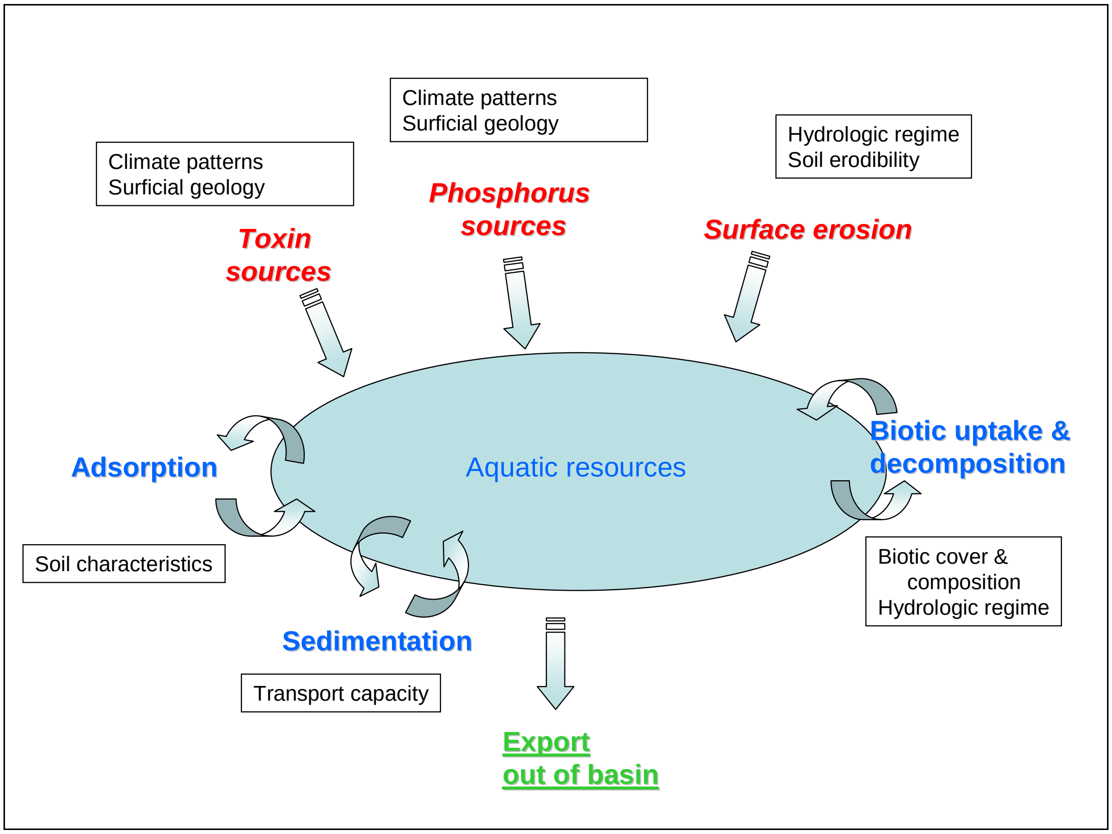

Figure D-1: Illustration of the delivery, movement, and loss of water in watersheds of Puget Sound. Red italics are components of delivery, blue are movement, green underlines are loss, and black text in boxes are controls.

1.2 Movement of phosphorus and toxins

Dissolved phosphorus can be temporarily removed from water via four mechanisms: 1) uptake by biota, 2) adsorption to aluminum (Al) and ferric (Fe) oxides and hydroxides and subsequent precipitation out of solution (Walbridge and Struthers 1993), 3) adsorption to soil particles, 4) the trapping of sediment that has adsorbed phosphorous. Adsorption to soil particles is most likely to occur in finer soils, such as clays, that have a phosphorus deficit (Sheldon et al. 2005). These soils can occur in either aquatic or upland settings. In general, aquatic settings, such as wetlands with mineral soils, are likely to remove dissolved phosphorus from surface water while upland settings are likely to remove dissolved phosphorus from water that percolates into the sub-surface deposits (Axt and Walbridge 1999). Wetlands may release phosphorous from sediment during long periods of anoxia (Adamus et al. 1991).

Once dissolved phosphorus has been converted to particulate phosphorus, it is temporarily stored or removed from aquatic ecosystems through the "movement" components of the sediment process. For example, since depressional wetlands are effective at removing sediment, they are also effective at removing phosphorous (Sheldon et al. 2005). This mechanism is described further in Appendix C.

Metals are most likely to be temporarily stored through adsorption to wetland soils with high cation exchange capacities (Sheldon et al. 2005, Kadlec and Knight 1996). These types of soils are those with high organic contents and clays, although it is not yet clear whether glacially derived clays provide the same conditions as weathered clays (Sheldon et al. 2005).

1.3 Loss of phosphorus and toxins

While both toxins and phosphorus can stored for extended periods of time by the mechanisms describe above, neither can be permanently removed from a watershed unless they are exported in streamflow to a different watershed.

2. Step 3: Map key areas for processes for phosphorous and toxins

Once the delivery, movement, and loss of phosphorus and toxins in a watershed are understood, key areas for supporting this process can be identified. Based on the diagram of how phosphorus and toxins are delivered to, move through, and leave a watershed (Figure D-1), controls can be identified that govern this process. Usually these controls are different physical characteristic of the watershed. Key areas are those parts of a watershed with these characteristics.

For each component of the phosphorus and toxin process, the controls and key areas are discussed below for the Puget Sound region. These are summarized in Table D-1. Key areas in bold are those that can be mapped using regionally available data; mapping methods for these are provided in Appendix H. Key areas not in bold can be mapped using local data or knowledge. If no key areas can be mapped, this column is left blank.

2.1 Delivery of phosphorus and toxins

- **Phosphorus sources:** No key areas are identified for this component of phosphorus delivery

- **Toxin sources:** No key areas are identified for this component of toxin delivery
- **Surface erosion:** Key areas for the erosion of particles to which phosphorus or toxins are attached are those that are easily erodible. This is discussed more fully in Appendix C.

Table D-1: Major controls and key areas for the delivery, movement, and removal of phosphorus and toxins in the Puget Sound region. P= phosphorus; T= toxins

Components of Process		Major natural controls	Key areas
Delivery	Phosphorus sources	Climate patterns Surficial geology	
	Toxin sources		
	Surface erosion	Hydrologic regime Soil erodibility	Steep slopes with highly erodible fine soils[1]
Movement	Biotic uptake and decomposition	Biotic cover and composition Hydrologic regime	
	Adsorption (P)	Soil characteristics	**Depressional wetlands with mineral soils** **Upland areas, with clay soils, adjacent to aquatic ecosystems**
	Adsorption (T)	Soil cation exchange capacity	**Depressional wetlands with organic or clay soils**
	Sedimentation	Water transport capacity (velocity)	**Depressional wetlands, lakes, floodplains, depositional channels[1]**
Loss	Export out of the basin	Hydrologic regime	

[1] Addressed in Appendix C: delivery, movement, and loss of sediment

2.2 Movement of phosphorus and toxins

2.2.1 Biotic uptake and decomposition

As no single part of a watershed is more important than any other for this component of phosphorus and toxin movement, no key areas are identified.

2.2.2 Adsorption of phosphorus

Adsorption of phosphorus is most likely to occur in depressional wetlands with mineral soils or in upland areas with clay soils. While the presence of Al and Fe oxides and hydroxides can enhance phosphorus removal, no good indicators of the presence of these compounds can be found. For upland areas, Axt and Walbridge (1999) report that phosphorous is likely to be removed from water that percolates sub-surface. Since clay soils have a greater capability to adsorb phosphorous, it is suggested that upland areas with clay soils are key to removing phosphorous.

***Key areas**: Depressional wetlands with mineral soils and upland areas with clay soils.*

2.2.3 Adsorption of toxins

Adsorption of toxins is most likely to occur in depressional wetland areas with soils of high cation exchange capacity (Kadlec and Knight 1996). These are usually soils with high organic or clay content (Sheldon et al. 2005).

***Key areas**: Depressional wetlands with clay or organic soils.*

2.2.4 Sedimentation

Sedimentation, due to lower water velocities, results in the removal and storage of phosphorus in aquatic ecosystems. See Appendix C for further discussions of the sedimentation mechanism.

2.3 Loss of phosphorus and toxins

Both phosphorus and toxins remain within a watershed, unless they are transported to another basin by streamflow.

3. Step 4: Alterations to the delivery, movement, and loss of phosphorus and toxins

Lowland areas of Puget Sound have been altered from natural conditions, to varying degrees, by human activity. However, the intensity of alteration varies significantly. Where alteration is minimal, processes are likely intact and functioning. Where alterations have been significant, processes are no longer functioning. The current condition of key areas can be assessed by evaluating the locations and impacts of various activities. This appendix diagrams the relationship between a suite of human activities and the delivery, movement, and loss of these compounds (Figure D-2).

Indicators of these human activities are mapped to show the locations of these alterations. This allows for an assessment of whether the human activities are likely to occur in the key areas for the delivery, movement, and loss of phosphorus and toxins. Indicators for these alterations are summarized in Table D-2. Indicators in bold are those that can be mapped using regionally available data; mapping methods for these are provided in Appendix H. Indicators not in bold can be mapped using local data or knowledge. If no indicators can be easily mapped over an entire watershed, this column is left blank.

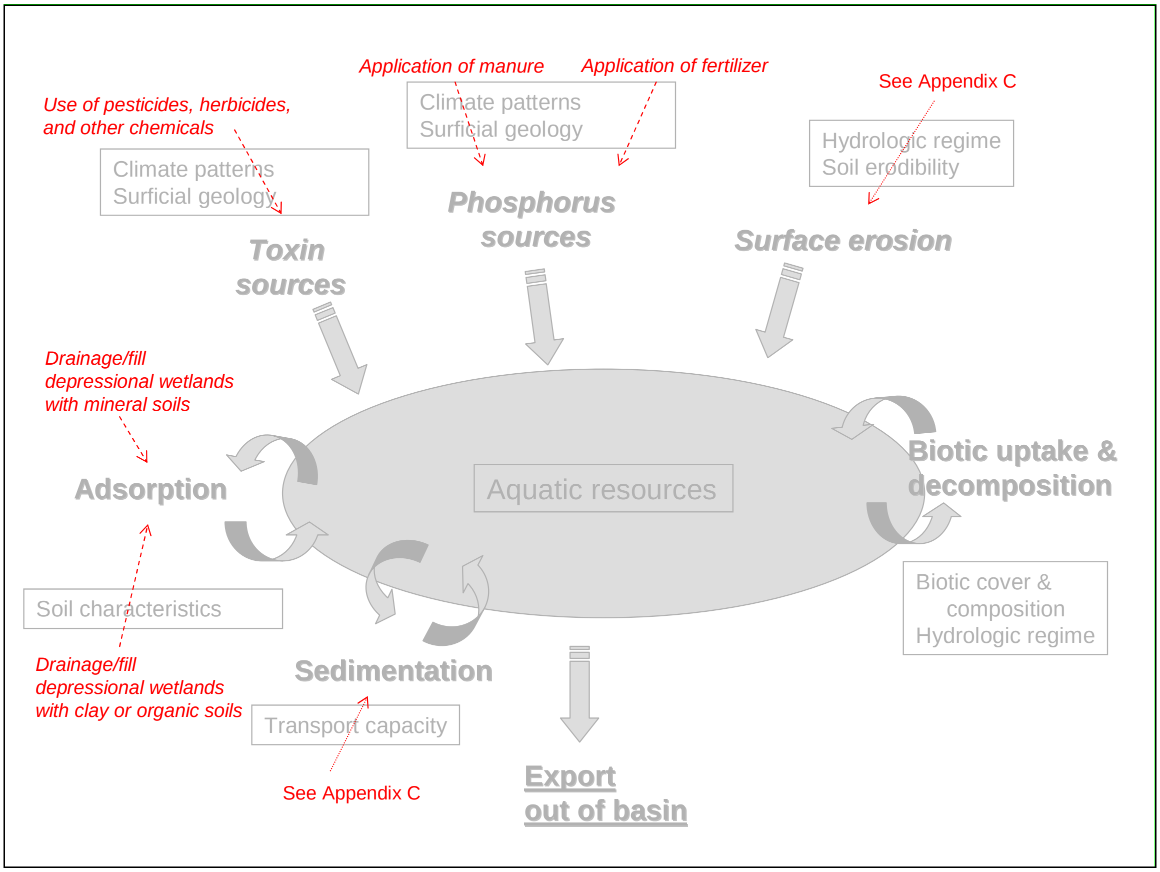

Figure D-2: Illustration of how human activities alter the delivery, movement, and loss of phosphorus and toxins.

Table D-2: Indicators that the delivery, movement, and loss of phosphorus and toxins have been altered for the Puget Sound region.

	Component of process	Major natural controls	Change to process	Cause of change	Indicators of alteration
Delivery	Phosphorus sources	Climate patterns Surficial geology	Additional sources	Application of fertilizer	**Urban land use** **Agricultural land use**
				Application of manure	**Agricultural land use adjacent to dairies**
	Toxin sources		Additional sources New toxins	Use of pesticides, herbicides, and other chemicals	**Urban land use** **Row crop land use**
	Surface erosion[1]	Soil type Hydrologic regime Soil erodibility			
Movement	Biotic uptake and decomposition	Biotic cover & composition Hydrologic regime			
	Adsorption (P)	Soil characteristics	Reduced phosphorus adsorption	Draining or filling of depressional wetlands with mineral soils	**Straight-line hydrography in depressional wetlands with mineral soils** **Loss of depressional wetlands with mineral soils**
				Loss of upland areas with clay soils	**Urban land cover in areas of clay soils adjacent to aquatic ecosystems**
	Adsorption (T)	Soil cation exchange capacity	Reduced toxin adsorption	Draining or filling of wetlands with organic and clay soils	**Straight-line hydrography in wetlands with organic or clay soils**
					Loss of wetlands with organic or clay soils
	Sedimentation[1]	Water transport capacity (velocity)	Reduced storage of phosphorous & toxins	(see Appendix C)	**(See Appendix C)**

[1]Addressed in Appendix C: Delivery, movement, and loss of sediment.

3.1 Delivery of phosphorus and toxins

3.1.1 Phosphorus inputs

Application of fertilizers: In a study of Puget Sound, no single land use could be strongly correlated with high total phosphorus concentrations (Ebbert et al. 2000). It appears that both urban and agricultural land uses can be associated with substantial increases in phosphorus loads.

In agricultural areas this input is largely from the use of fertilizers (Sheldon et al. 2005). In developed areas of Washington, phosphorus levels in streams are five to ten times higher than in forested areas (Reckhow and Chapra 1983). Additionally, total phosphorus (both dissolved and particulate phosphorus) in Puget Sound lowland streams is correlated to the percent of the basin in impervious cover (Bryant 1995). The source of phosphorus enrichment in these developed areas appears to be from fertilizers, detergents and wastewater (Welch 1998).

***Key areas**: Urban and agricultural land use*

Application of manure: The application of manure to fields results in a buildup of phosphorous levels in soils and a subsequent increase of phosphorous in storm runoff (Carpenter et al. 1998). Application of manure can also increase the result of phosphorous from soil in sub-surface flows (Kleinman et al. 2005). Manure application is usually associated with dairy operations in the Puget lowlands.

***Key areas**: Agricultural land use adjacent to dairies*

3.1.2 Toxin inputs

Use of pesticides, herbicides, and other chemicals: The primary toxins addressed by this document are heavy metals and pesticides/herbicides. Tetra Tech (1988) identified a suite of pesticides of concern that can be transported to riverine and marine waters: 2-4D, dicamba, alachlor, tributyltin, bromacil, atrazine, triclopyr, carbaryl, and diazinon.

In Puget Sound, most herbicide and pesticide levels in streams were higher in urban areas than in any other land use area; however, atrazine and diethylatrizine levels were also high in agricultural areas (Staubitz et al. 1997). Urban areas most commonly violate standards for organochlorines, semi-volatile organics and most herbicides and pesticides (Ebbert et al. 2000). Many of the contaminants in the urban areas are from the use of pesticides, wood preservatives (pentachlorophenol), and petroleum-based products that leak or drip from vehicles (polycyclic aromatic hydrocarbons) (Galvin and Moore 1982).

***Indicators of alteration**: Urban land use and row crop land use*

3.1.3 Surface erosion

Discussed in Appendix C (delivery, movement, and loss of sediment).

3.2 Movement of phosphorus and toxins

3.2.1 Adsorption of phosphorus

Draining or filling of depressional wetlands with mineral soils: Adsorption of phosphorus is facilitated in depressional wetlands with mineral soils as water velocity slows. This capability is impaired when alterations prevent water velocity from slowing or reduce the area of wetland available for phosphorus adsorption.

***Indicators of alteration**: Straight-line hydrography in and loss of area of depressional wetlands with mineral soils*

3.2.2 Adsorption of toxins

Draining or filling of wetlands with organic or clay soils: Adsorption of toxins is facilitated in depressional wetlands with clay or an organic soil as water velocity slows. This capability is impaired when alterations prevent water velocity from slowing or reduce the area of wetland available for toxin adsorption.

***Indicators of alteration**: Straight-line hydrography in and loss of area of depressional wetlands with organic or clay soils*

3.2.3 Sedimentation

Discussed in Appendix C (delivery, movement, and loss of sediment).

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Appendix E: Nitrogen delivery, movement, and loss in the Puget Sound region

1. Description of the Process

This section provides a description of the process of movement of nitrogen through a watershed of the Puget Sound region (Figure E-1).

1.1 Delivery of nitrogen

Nitrogen occurs in several forms: gaseous nitrogen (numerous forms including N_2, NH_3, N2O, NO_2, and N_2O_4), ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-). The focus of most environmental efforts is on ammonium and nitrate, as they are most available for use by biota and most soluble in water, and therefore most often associated with eutrophication. Nitrate is generally more mobile than is ammonium.

Under natural conditions, all nitrogen originally becomes available to biota after it is fixed from atmospheric nitrogen, either by lightning or biota (Schlesinger 1997).

Lightning creates pressure and temperature conditions under which atmospheric nitrogen (N_2) can combine with O_2. This component of nitrogen fixation is believed to be quite small, perhaps less than 3 X 10^{12} g N/year globally (Schlesinger 1997). Far more atmospheric nitrogen is fixed by biota, on the order of 140 X 10^{12} g N/ year or 10 kg N/year for each hectare on the planet (Schlesinger 1997).

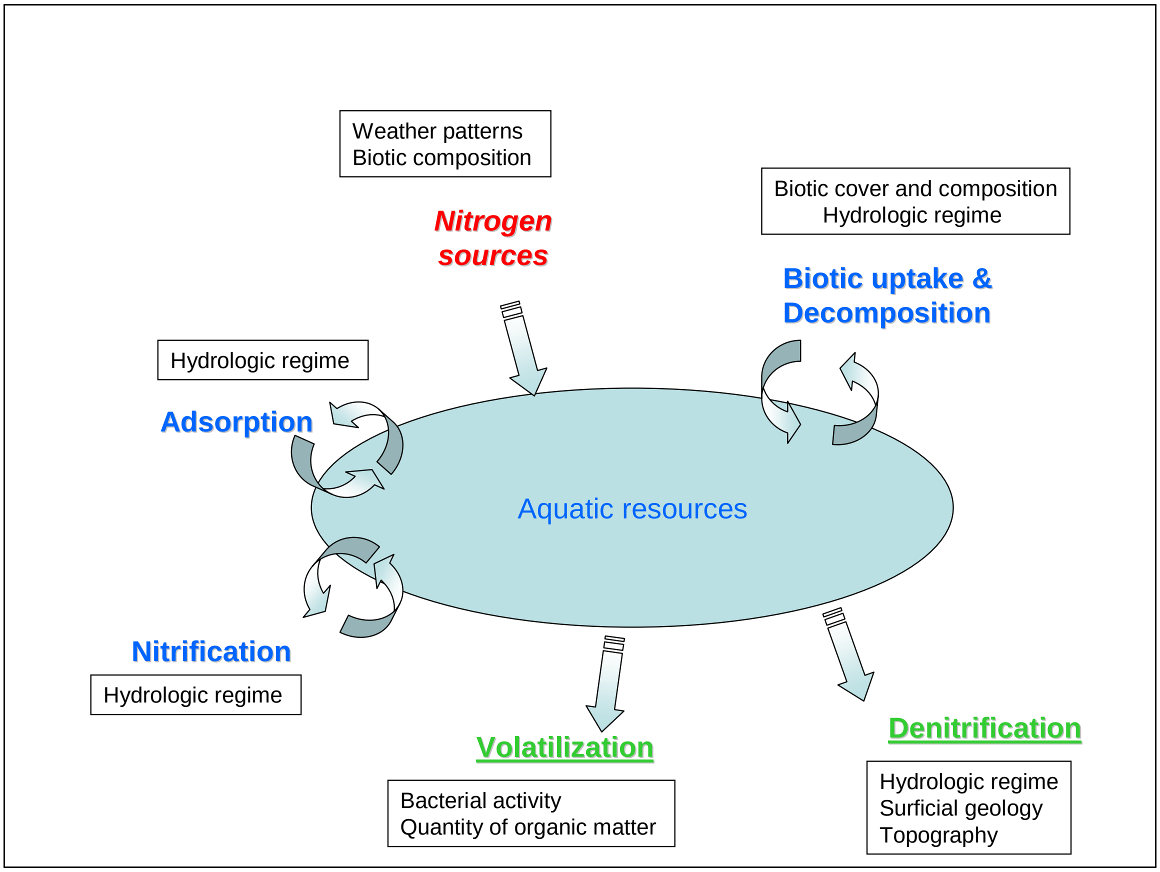

Figure E-1: Illustration of the delivery, movement, and loss of nitrogen in watersheds of Puget Sound. Red italics are components of delivery, blue text is movement, and black text in boxes is controls. Blue polygon represents water bodies in a watershed.

1.2 Movement of nitrogen

Once it has reached a watershed, nitrogen can be temporarily stored or transformed from one form to another through one of three mechanisms: 1) nitrification, 2) biotic uptake, or 3) adsorption. As nitrogen moves through a watershed, it will likely be assimilated and then released numerous times, a process called nutrient cycling.

Nitrification is the transformation of ammonium (NH_4^+) to nitrate (NO_3^-). This transformation is important because nitrate can be permanently removed from a watershed. Nitrification depends upon two species of bacteria and occurs in aerobic environments. In general, this means it occurs in upland settings, although recent work suggests that some smaller headwater streams can also support this transformation (Peterson et al. 2001). In wetlands it is the location of the oxic/anoxic interfaces that governs where nitrification transformation occurs; however, the mechanisms controlling nitrification in stream ecosystems are not yet understood (Grimm et al. 2003).

Photosynthetic and heterotrophic biota (i.e., fungi and bacteria) can assimilate both ammonium and nitrate. Once these organic materials decompose, the assimilated nitrogen is returned to the system as ammonium.

Finally, some ammonium can become adsorbed to fine sediments in stream bottoms (Peterson et al. 2001) and on upland soils (Grimm et al. 2003). Study of this phenomenon is still ongoing and work conducted by Peterson et al. (2001) indicates that this particular mechanism may account for a major portion of the ammonium removal occurring in small streams.

1.3 Loss of nitrogen

Under natural conditions, ammonium is removed from a watershed through volatilization while nitrate is removed via denitrification.

Volatilization occurs as bacteria and ammonia (the gas, NH_3) process decaying organic matter and ammonia (the gas, NH_3) is released. It occurs in marshes with excessive algal blooms (Mitsch and Gosselink 2000). There is recent evidence that ammonium may also be converted to nitrogen gas in anaerobic conditions by specific bacteria via the annamox reaction (Shivaraman and Shivaraman 2003). While this reaction was first identified in wastewater treatment plants, studies in the oceans are reporting this to be potentially an ecologically significant transformation (Rysgaard et al. 2004). However, our understanding of this process and the conditions under which it occurs is still emerging.

Denitrification occurs as a by-product of respiration by microbes that live in anaerobic conditions. As anaerobic zones are most common in wet areas, this nitrogen removal process is more likely to occur in aquatic ecosystems than in terrestrial ecosystems (Grimm et al. 2003). In order for denitrification to occur, three conditions must be met:

1. Reactive sites in anaerobic conditions must be present. Generally, these are carbon (e.g., in organic deposits) that support the metabolism of the denitrifying microbes. These deposits are often found in the rooting zone of plants and in buried organic deposits in areas that have received fluvial action (i.e., the migration of stream channels).
2. Water must have time to interact with these reactive sites. The residence time of water or the rate at which it moves through substrates must allow for interaction between the nitrate-laden water and the carbon deposits.
3. Nitrate (NO_3^-) must be present in the water. This is important for identifying areas that play a significant role at a watershed scale as nitrogen sinks or places where nitrogen is removed from the system. In some studies, the efficiency with which an area removes nitrates is measured and reported. However, the role that this area plays in the nitrogen budget of the larger watershed is critically

dependent upon the flux of nitrate to that location. In other words, it is possible for an area to have high nitrate removal efficiency but to receive little or no nitrate-laden waters much of the year (Vidon and Hill 2004). Nitrate reaches aquatic ecosystems both through the transport of nitrate (NO_3^-) in water and as a product of the nitrification transformation.

Transformations that depend upon microbes, such as denitrification, occur at very high rates in hot spots within a watershed. Many of these hot spots are located at the interface between terrestrial and aquatic ecosystems (McClain et al. 2003). This is likely because all the conditions are provided for biogeochemical transformations to occur: movement of water into an area, high flux of compounds such as nitrates or ammonium, and reactive sites for the transformations (McClain et al. 2003).

2. Step 3: Map key areas for the nitrogen process

Once the delivery, movement, and loss of nitrogen in a watershed are understood, key areas for supporting this process can be identified. Based on the diagram of how nitrogen moves through a watershed (Figure E-1), controls can be identified that govern this process. Usually these controls are different physical characteristic of the watershed. "Key areas" are those parts of a watershed with these characteristics.

Table E-1: Major controls and key areas for the delivery, movement, and loss of nitrogen.

Components of Process		Major natural controls	Key areas
Delivery	Nitrogen sources	Weather patterns Biotic composition	
Movement	Biotic uptake and decomposition	Biotic cover and composition Hydrologic regime	**Headwater streams***
	Nitrification	Hydrologic regime	**All depressional wetlands (excluding bogs and fens)**
	Adsorption	Hydrologic regime	**Headwater streams**
Loss	Denitrification	Hydrologic regime	**All depressional wetlands (excluding acidic wetlands)**
		Surficial geology Hydrologic regime Topography	Riparian areas with a consistent supply of shallow groundwater
	Volatilization	Bacterial activity Quantity of organic matter	

*We define ***headwater streams*** as 3rd order or less. (Elliot et al. 2004).

In this section, for each component of the nitrogen process, the controls and key areas are discussed for the Puget Sound region. These are summarized in Table E-1. You can map key areas in bold using regionally available data. We provide mapping methods for these in Appendix H. You can map key areas not in bold using local data or knowledge. If no key areas can be mapped, this column is left blank.

2.1 Delivery of nitrogen

Nitrogen sources: No key areas are identified for this component of nitrogen delivery.

2.2 Movement of nitrogen

2.2.1 Biotic uptake and decomposition

Recent work within 12 small streams (<10 m) from across the United States confirmed that they play an important role in removing ammonium from watersheds (Peterson et al. 2001). This work found that one of the two most consistently important mechanisms for this storage was assimilation by biota. Smaller streams are more important than larger streams due to their shallow water depth and large surface-to-volume ratios that allow biota to grow near the streambed.

Key areas*: Headwater streams*

2.2.2 Nitrification

Recent work suggests that small headwater streams may also perform more nitrification than expected (Peterson et al. 2001). The rate of nitrification was quite variable between watersheds and the two primary mechanisms for nitrogen (i.e. ammonium) removal in small streams were adsorption and assimilation. As a result, we have not included headwater streams as key areas for nitrification. However, the seasonal edges of depressional wetlands do provide the aerobic conditions necessary for nitrification to occur (Sheldon et al. 2005).

Key areas*: Depressional wetlands*

2.2.3 Adsorption

The shallow depth and small discharge of headwater streams provides opportunity for ammonium to become adsorbed to streambed sediments. Peterson et al. (2001) identified this as one of the two most important mechanisms in small streams for ammonium removal.

Key areas*: Headwater streams*

2.3 Loss of nitrogen:

2.3.1 Denitrification

Wetlands: The saturated areas within depressional wetland provide the anaerobic conditions necessary for denitrification to occur (Sheldon et al. 2005, Mitsch and Gosselink 2000). Wetlands that have a low pH are unlikely to have high denitrification rates as the acidity inhibits microbial activity (A. Aldous, personal communication, July 2005).

Riparian areas: Recent advances have been made in efforts to predict the hydrogeologic settings of riparian areas that are most likely to meet the three conditions for denitrification: the presence of reactive sites in anaerobic conditions, the time for water to interact with the reactive sites, and nitrates in the water. The results of two of these studies are described below:

(a) Riparian areas with shallow hydric alluvium or hydric outwash conditions. In the glaciated portion of northeastern United States, researchers from the University of Rhode Island concluded that nitrate removal occurs primarily in shallow hydric riparian soils and not in deeper deposits (Rosenblatt et al. 2001, Gold et al. 2001, Kellogg et al. 2005). Their conclusions are as follows:

- Glacial till is unlikely to support the groundwater movement necessary for denitrification to occur. Due to the low hydraulic conductivity of till, groundwater often emerges on the outside edge of river valleys as surface seeps, rather than moving through the biologically active riparian zone where denitrification occurs.
- Hydric alluvial and outwash deposits both support greater denitrification rates. These areas are subject to fluvial action and therefore have buried organic deposits. This, in conjunction with higher hydraulic conductivities, provides an opportunity for groundwater to interact with the carbon deposits and for the microbes to perform denitrification. The exception to this occurs when groundwater is able to move through the riparian area at depth, bypassing the rooting zone or the buried organic deposits. These researchers suggest that the denitrification will occur in shallow hydric outwash and alluvial deposits that are underlain by a less permeable deposit, thus preventing this bypass of the likely areas for denitrification.

(b) Riparian areas linked to thick upland aquifers. In glaciated Ontario, researchers from York University identified riparian areas as important nitrogen sinks if they had a high flux of nitrate (Vidon and Hill 2004, Hill et al. 2004). Their conclusions are as follows:

- The importance of an area as a nitrogen sink due to denitrification is a function of the ability of nitrogen-laden water to reach the site for much of the year and the ability of the site to perform denitrification. The yearly flux of nitrogen-laden waters reaching a site is determined in large part by the size of the upland aquifer and its connectivity to the riparian area.

- Denitrification efficiencies can be high in non-hydric alluvial and outwash deposits, as well as hydric deposits. In Ontario, few of the riparian areas develop hydric soils and yet they find high denitrification efficiencies in non-hydric soils.

Using these findings, important areas for denitrification within a watershed can be identified by locating riparian areas with all of the following characteristics:

1. *Adjacent to a deep upland aquifer.* The size of this water source governs the potential magnitude and duration of sub-surface flow from the upland area into the riparian area. Vidon and Hill (2004) suggest that this upland aquifer should be greater than 2m deep. You will need local knowledge or data to locate these areas.
2. *Connected via a steep slope to the upland area.* This ensures a large hydraulic gradient from the upland to the riparian area, thus providing opportunity for a large flux of water and nitrates to move into the riparian area. A good indicator of this condition is incised river valleys (i.e., the area between the valley floor and upland is a steep valley wall). Vidon and Hill (2004) suggest an overall slope in this transition area of 5% but also indicate that it can be over 15% in local areas. You will need local topographic maps or local knowledge to identify these areas.
3. *Permeable riparian deposits that are not deep.* Riparian deposits that are alluvium or outwash no deeper than 6m would be good indicators of these areas (Vidon and Hill 2004, Rosenblatt et al. 2001, Gold et al. 2001, Kellogg et al. 2005). You will need local data or knowledge to identify these areas.

Very coarse deposits can have such a high hydraulic conductivity that water moves very quickly through the deposit. This means that the distance required for a given amount of denitrification to occur may be longer than in finer deposits. As a result, it is possible that a particular riparian area of coarse deposits could have a width that is inadequate to allow large quantities of denitrification to occur. The methods presented here could overestimate the areas where denitrification occurs and site-level study will be needed to confirm the potential of an actual site.

Although Vidon and Hill (2004) feel that their conclusions are likely to hold in other glacial till and outwash areas, it is important for the user of this guidance to know that this is a rapidly evolving area of study and so it is likely that new advances will be made that may change the recommendations presented in this document.

***Key areas**: Riparian areas with a consistent supply of shallow groundwater and non-acidic depressional wetlands.*

3. Step 4: Alterations to the delivery, movement, and loss of nitrogen

Lowland areas of Puget Sound have been altered to varying degrees from natural conditions by human activity; however, the intensity of alteration varies significantly. Where alteration is minimal, processes are likely still intact and functioning. Where alterations have been significant, processes are no longer functioning. You can assess the current condition of key areas by evaluating the locations and impacts of various activities. Building upon the description of the nitrogen process in the previous section, this section develops an illustration of the relationship between a suite of human activities and the delivery, movement and loss of nitrogen (Figure E-2).

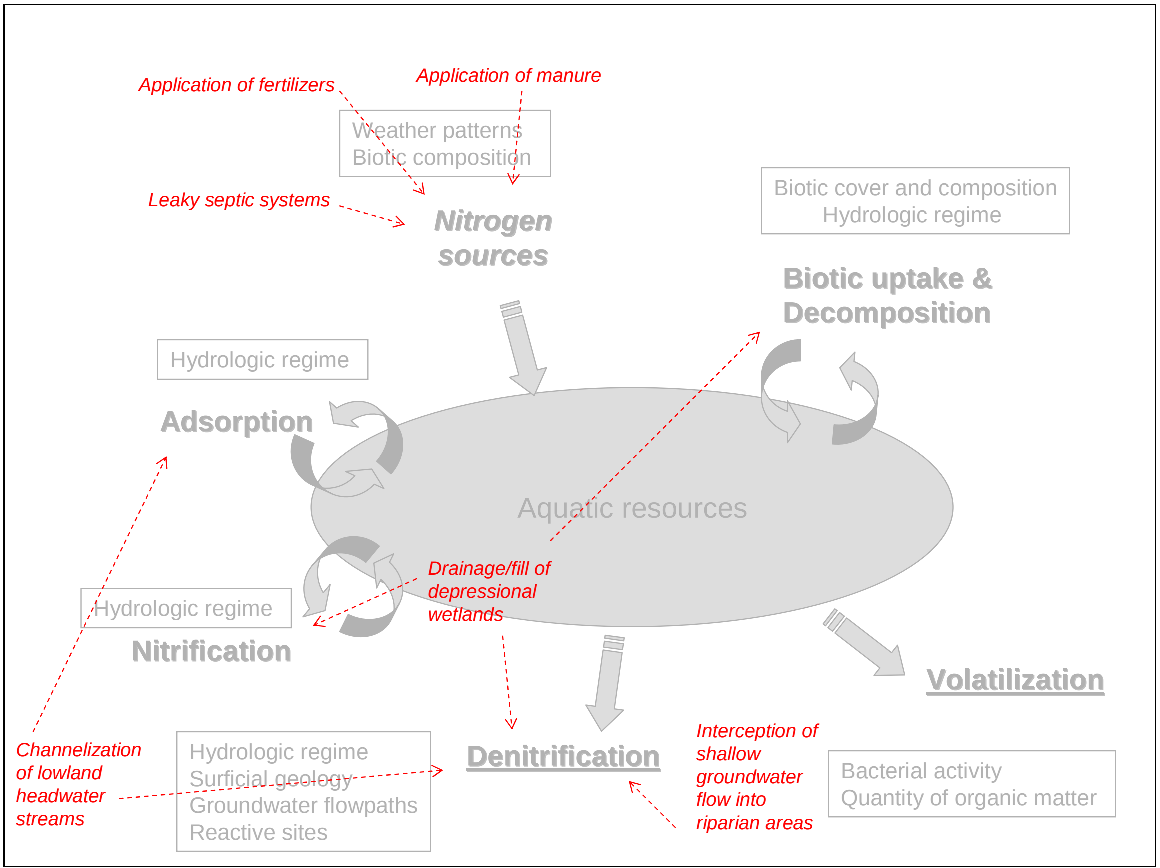

Figure E-2: Illustration of how human activities alter the delivery, movement and loss of nitrogen.

You will map indicators of these human activities to show the locations of the alterations. This allows for an assessment of whether the human activities are likely to occur in the key areas for the delivery, movement, and loss of nitrogen. Indicators for these alterations are summarized in Table E-2. Indicators displayed in bold are those that you can map using regionally available data. We provide mapping methods for them in Appendix H. You can map indicators not in bold using local data or knowledge. If indicators over an entire watershed cannot be easily mapped, the column is left blank.

Table E-2: Indicators that the delivery, movement, and loss of nitrogen have been altered for the Puget Sound region.

Component of process		Major natural controls	Change to process	Cause of change	Indicators of alteration
Delivery	Nitrogen sources	Weather patterns Biotic composition	Additional sources	Application of fertilizer	**Agricultural landuse**
				Application of manure	**Agricultural landuse**
				Septic systems	Rural residential landuse
Movement	Biotic uptake and decomposition	Biotic cover and composition Hydrologic regime	Increase stream discharge and depth	Channelization of headwater streams	**Straight-line hydrography in headwater streams**
	Nitrification	Hydrologic regime	Reduced area with seasonal flooding	Draining or filling of depressional wetlands	**Straight-line hydrography in depressional wetlands**
					Loss of depressional wetlands
	Adsorption	Hydrologic regime	Increase stream discharge and depth	Channelization of headwater streams	**Straight-line hydrography in headwater streams**
Loss	Denitrification	Hydrologic regime	Reduced area for denitrification	Draining or filling of depressional wetlands	**Straight-line hydrography in depressional wetlands**
					Loss of depressional wetlands
		Surficial geology Groundwater flow paths Reactive sites	Loss of hydrologic connectivity between upland and riparian area	Interception of shallow groundwater flow into riparian areas	

3.1 Delivery of nitrogen

3.1.1 Nitrogen sources

Nitrogen pollution is recognized as a significant global problem by an increasing number of ecologists and policy makers around the world (Giles 2005a). Since the Industrial Revolution, human activities have converted large amounts of unreactive nitrogen gas from the atmosphere into reactive forms of nitrogen. This conversion results largely from: 1) the production of fertilizers derived from the Haber-Bosch process or mining of phosphate deposits (Galloway et al. 2004) and; 2) the burning of fossil fuels (Giles 2005b). Indicators in the Puget Sound region of high nitrogen loads are:

<u>Application of fertilizers and livestock manure</u>. Agriculture has resulted in significant changes to terrestrial nitrogen dynamics resulting in increased levels of dissolved inorganic nitrogen in streams (Webster et al. 2003). Excessive nitrogen inputs from agricultural runoff can result in lower water quality in adjacent streams (Edwards 1998). Agriculture is also the leading source for nutrient loading in U.S. lakes (Burton and Pitt 2002). In a Puget Sound region study, Ebbert et al. (2000) found that areas with agricultural land use produced 40 times the nitrogen concentrations than did forested areas and twice the concentrations of urban areas. The significance of agricultural use of fertilizers as a source of nitrogen pollution may actually be much greater since current methods for estimating emissions of nitrous oxide from fertilizer use may be underestimating actual emissions by as much as 50% (Giles 2005b).

Commercial agriculture operations (such as row crop production, feedlots, rangeland, or dairies) are the leading source of pollution, including nutrients, in surveyed streams across the country (U.S. EPA 2000). If it is possible, use local data to separate agricultural land uses into commercial production and rural agriculture.

Indicators of alterations*: Agricultural land use*

<u>Septic systems</u>. Rural residential land use adjacent to water bodies is used as an indicator of likely locations of leaky septic systems. The U.S. EPA estimates that 10 to 30% of septic systems are not functioning properly nationally (U.S. EPA 2001) and would, therefore, be a potential source of nitrogen. Because most rural areas are not connected to sewer systems and each residence requires a septic system, rural residential land use is used as an indicator of the presence of septic systems. This is a surrogate for having actual data on the location and condition or age of septic systems.

Indicators of alteration*: Rural residential land use adjacent to water bodies*

3.2 Movement of nitrogen

3.2.1 Biotic uptake and decomposition:

Increased stream discharge or depth. Channelization of small streams increases their discharge and depth, reducing the ability of ammonium to be assimilated by biota (Peterson et al. 2001).

***Key areas**: Straight-line hydrography on lowland headwater streams*

3.2.2 Nitrification

Draining or filling of depressional wetlands. Reducing the area of depressional wetlands reduces the potential area that is seasonally wet, thus providing aerobic conditions needed for nitrification to occur (Hruby 2004).

***Indicator of alteration**: Straight-line hydrography in or loss of area of depressional wetlands*

3.2.3 Adsorption

Increased stream discharge or depth: Channelization of small streams increases their discharge and depth, reducing the ability of ammonium to be adsorbed to streambed sediments (Peterson et al. 2001).

***Indicator of alteration**: Straight-line hydrography on lowland headwater streams*

3.3 Loss of nitrogen

3.3.1 Denitrification

Draining or filling of depressional wetlands. Reducing the area of depressional wetlands reduces the potential area of anaerobic conditions needed for denitrification to occur (Hruby 2004).

Interception of shallow groundwater flow into riparian areas. It is important that the retention time of groundwater remains intact in areas with either high organic content or other electron donors that support denitrification (Tesoriero et al. 2000). In addition, drainage activities generally lower the water table below the critical organic zone where biological activity transforms nitrogen (Gold et al. 2001).

***Indicators of alteration**: Straight-line hydrography in or loss of area of depressional wetland*

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Appendix F. Pathogen delivery, movement, and loss in the Puget Sound region

1. Description of the Process

This section provides a description of the delivery, movement, and loss of pathogens in a watershed of the Puget Sound region (Figure F-1).

1.1 Delivery of pathogens

Under natural conditions, pathogen delivery to aquatic ecosystems results from fecal material of wildlife deposited within upland areas that drains into aquatic ecosystems or is deposited directly into them (Sherer et al. 1992). Pathogens include bacteria, protozoans, and viruses.

1.2 Movement of pathogens

The movement of pathogens includes three components: transport, adsorption, and sedimentation. Adsorption and sedimentation play an important role in temporarily removing sediment and pathogens from the water column and storing them within the aquatic ecosystem. Natural events, such as high flood flows, can re-suspend sediments and pathogens and transport them downstream into other aquatic ecosystems. Depressional wetlands are key areas for removing sediments and pathogens due to low water velocities, high residence times, filtering vegetation, and soils suitable for adsorption.

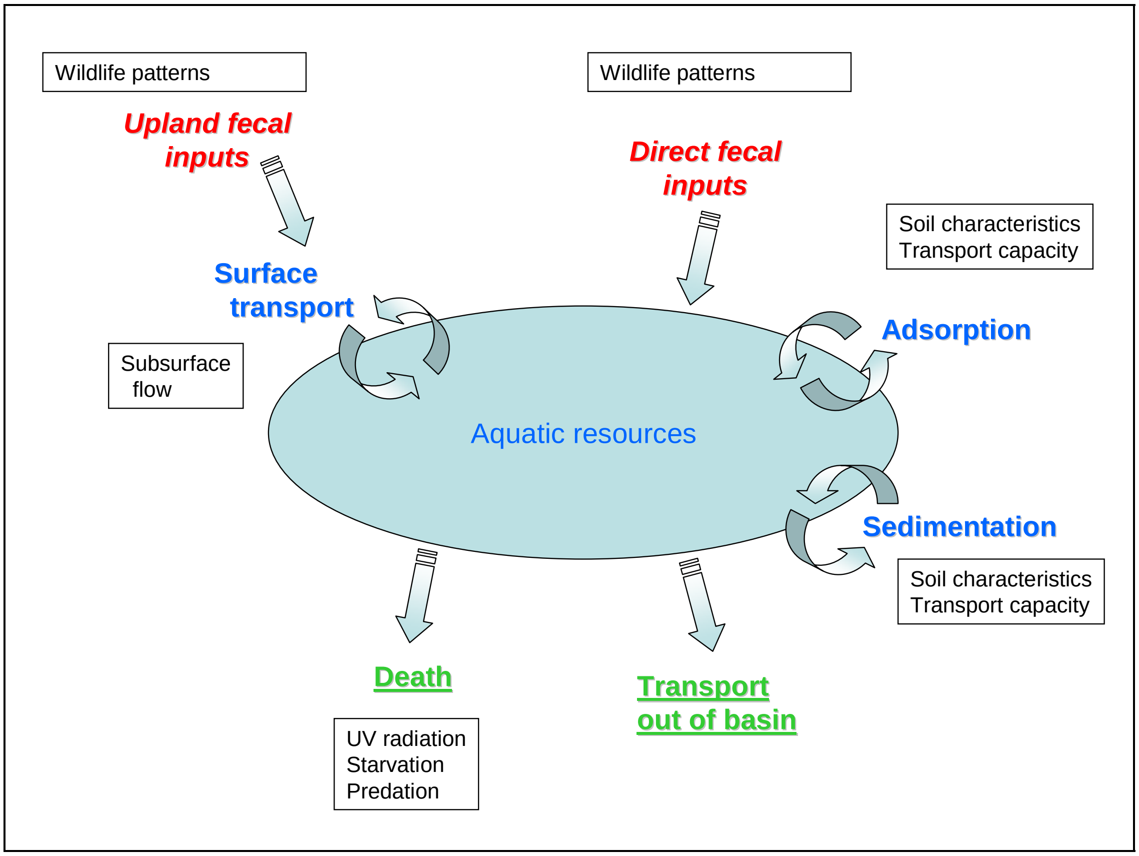

Figure F-1: Illustration of the delivery, movement, and loss of pathogens in watersheds of Puget Sound. Red italics are components of delivery, blue are movement, green underlined are loss, and black text in boxes are controls. Blue polygon represents water bodies in a watershed.

1.2.1 Surface transport

Pathogens are transported by overland, sub-surface, and surface flows (Glasoe and Christy 2004, Hemond and Benoit 1988). Rainstorms that produce overland flow are one of the primary mechanisms for transporting pathogens from uplands deposits to aquatic ecosystems. Shallow sub-surface flows can also play a role. Once in an aquatic ecosystem, pathogens are transported primarily by surface flows. This includes streams, rivers, and wetlands directly connected to these systems. These mechanisms are addressed in Appendix B (i.e. water processes).

1.2.2 Adsorption

Upon reaching aquatic ecosystems, most pathogens (bacteria and viruses) adsorb onto fine-grained, high-organic charged clays and muds (Indest 2003). Aquatic ecosystems with fine sediment and organic material have been found to support *E. coli* populations three times larger than ecosystems with sandy sediment (Tate 1978). Because sediments afford protection from predation and supply needed nutrients, they extend the survival of pathogens (Indest 2003). Organic matter may further extend the length of survival of pathogens. Tate (1998) reports an increased survival of fecal coliform in organic soils relative to mineral soils. The extension of pathogen survival is also suggested for marine sediments (*E. coli*) and river water contaminated by sewage (Gerba et al. 1976, Hendricks 1972).

Pathogens that are adsorbed to soil particles have the potential to be re-suspended if the velocity of the water becomes adequate to remobilize the sediment particles (Sherer et al. 1992). Gary and Adams (1985) found that the mean concentration of fecal coliform increased by 2.7 times when stream sediment was disturbed.

1.2.3 Sedimentation

There is some indication that fecal pathogens survive for considerably longer periods of time in water with sediment than without (Sherer et al. 1992). In sediment-laden waters, fecal coliform had a half-life of 11-30 days while fecal streptococci had a half life of 9-17 days (Sherer et al. 1992). Therefore, the mechanisms that remove sediment from the water column play an important role in the temporary storage of pathogens in aquatic ecosystems. These mechanisms would include filtration by vegetation and velocity reduction. Velocity reduction causes sediment to “settle out” and occurs predominantly in depressional wetlands (Sheldon et al. 2005). Sediment movement is addressed in the sediment processes section of this guidance.

1.3 Loss of pathogens

Permanent loss of pathogens occurs through their death. The primary factors causing death of these organisms are UV radiation, temperature, pH, salinity, predation, and starvation (Roszak and Colwell 1987). Marino and Gannon (1991) report that bacterial and protozoan predation are major factors determining fecal coliform and fecal streptococci survival. Tate (1978) demonstrated that protozoans played a significant role in reducing *E. coli* populations in muck soils over a 10-day period. Hemond and Benoit (1988) reported that detention time and predation by micro-organism in wetlands results in the loss of pathogens. This suggests that aquatic ecosystems that allow predation of pathogens to occur over a longer period of time play a key role in eliminating pathogens. This would include aquatic ecosystems with low water velocities and high residence times such as depressional wetlands.

2. Step 3: Map key areas for the delivery, movement and loss of pathogens

Once the delivery, movement, and loss of pathogens in a watershed are understood, key areas for supporting this process can be identified. Based on the description of the process of how pathogens move through a watershed, controls can be identified that govern this process. Usually these controls are different physical characteristic of the watershed. "Key areas" are those parts of a watershed with these characteristics.

Table F-1: Major controls and key areas for the delivery, movement and loss of pathogens

Component of process			**Major natural controls**	**Key areas**
Delivery	Fecal inputs		Wildlife patterns	Aquatic resources Upland areas with hydrologic connectivity to aquatic resources
Movement	Transport	Overland flow	Precipitation patterns Soils	Seasonally saturated areas[1]
		Surface flows	Topography Surficial geology Soils	**Streams, rivers and connected wetlands**
		Subsurface flows & Recharge	Topography Surficial geology	**High permeability geologic deposits**
				Low permeability geologic deposits
	Adsorption		Mineral and organic soils Surface water transport capacity (velocity)	**All depressional wetlands**
	Sedimentation			
Loss	Death		Predation UV radiation Starvation pH Temperature Salinity	**All depressional wetlands**

[1]Addressed in Appendix B: delivery, movement, and loss of water

In this section, for each component of the pathogen process, the controls and key areas are discussed for the Puget Sound region. These are summarized in Table F-1. Key areas in bold are those that you can map using regionally available data. Mapping methods for these are in Appendix H. You can map key areas not in bold using local data or knowledge. If no important areas can be mapped, this column is left blank.

2.1 Delivery of pathogens

Under natural conditions, the primary input of pathogens is the fecal material of wildlife. We judge the alteration to these inputs, however, to be most important due to the significantly greater pathogen load that they deliver to aquatic ecosystems than existed naturally (e.g., dairy farms, septic systems). Therefore, you should not map key areas for the natural delivery of pathogens. Key areas for delivery of pathogens (e.g., dairies, septic systems) will be mapped under the alteration section.

2.2 Movement of pathogens

2.2.1 Transport

Overland Flow: Overland flow occurs when precipitation exceeds infiltration in seasonally saturated areas. These seasonally saturated areas are variable in size depending upon storm events. They commonly occur when shallow subsurface flow accumulates in topographic depressions or in areas with decreasing hill slope gradient (Ziemer and Lisle 1998). As these areas often play an important role in the delivery of nutrients and pathogens to aquatic resources, you should map these saturated areas. However, as it is not generally possible to identify these areas using regionally available data, you will need local data to identify these areas**.**

Surface Flow: Streams, rivers and wetlands directly connected to streams and rivers form the surface water network for transport of pathogens.

Key areas*: streams, rivers and wetlands (with surface water connection)*

Shallow sub-surface flow and recharge: Areas with shallow sub-surface flows are located on geologic deposits with low permeability. Areas that provide recharge are located on geologic deposits with high permeability. Both of these areas in their unaltered state (native vegetation and no surface hydrologic modification) route pathogens through a longer flow path relative to overland and surface flow. See Appendix B, water flow processes, for a discussion of these key areas.

Key areas*: Areas of low and high permeability. (See Appendix B, water flow processes, for description and mapping of these key areas.)*

2.2.2 Adsorption and Sedimentation

Depressional wetlands contain mineral and organic hydric soils that have high adsorptive capacity. Therefore, these soils can remove pathogens from surface waters. Depressional wetlands can also remove pathogen bearing sediment in surface waters through the mechanisms of filtration and sedimentation (Borst et al. 2001, Sherer et al. 1992).

Key areas: *Depressional wetlands with mineral and organic soils.*

2.3 Loss of pathogens

Pathogens are removed from the watershed via mortality. Increasing the residence time of water is a critical mechanism by which pathogens such as fecal coliform can be removed from the ecosystem. Studies conducted in stormwater wetlands indicate that standing water promotes physical, chemical, and biological processes that increase the removal of bacteria from surface waters (Borst et al. 2001). This may be due to increased microbial competition with or predation on pathogens such as fecal coliform and fecal streptococci (Marino and Gannon 1991). Due to their ability to hold water back, depressional wetlands can provide longer residence time for surface waters relative to streams and rivers.

Key areas*: Depressional wetlands with mineral soils*

3. Step 4: Map Alterations to the delivery, movement and loss of pathogens

Lowland areas of Puget Sound have been altered from natural conditions to varying degrees by human activity. However, the intensity of alteration varies significantly. Where alteration is minimal, processes are likely still intact and functioning. Where alterations have been significant, processes are no longer functioning. The current condition of key areas can be assessed by evaluating the locations and impacts of various activities. Building upon the description of the pathogen process in Section 1, this section develops a description of the relationship between a suite of human activities and the delivery, movement, and loss of pathogens (Figure F-2).

You should map indicators of these human activities to show the locations of these alterations. This allows for an assessment of whether the human activities are likely to occur in the key areas for the delivery, movement, and loss of pathogens. Indicators for these alterations are summarized in Table F-2. Indicators displayed in bold are those that you can map using regionally available data. Mapping methods for these are in Appendix H. You can map indicators not in bold using local data or knowledge. If no indicators can be easily mapped over an entire watershed, this column is left blank.

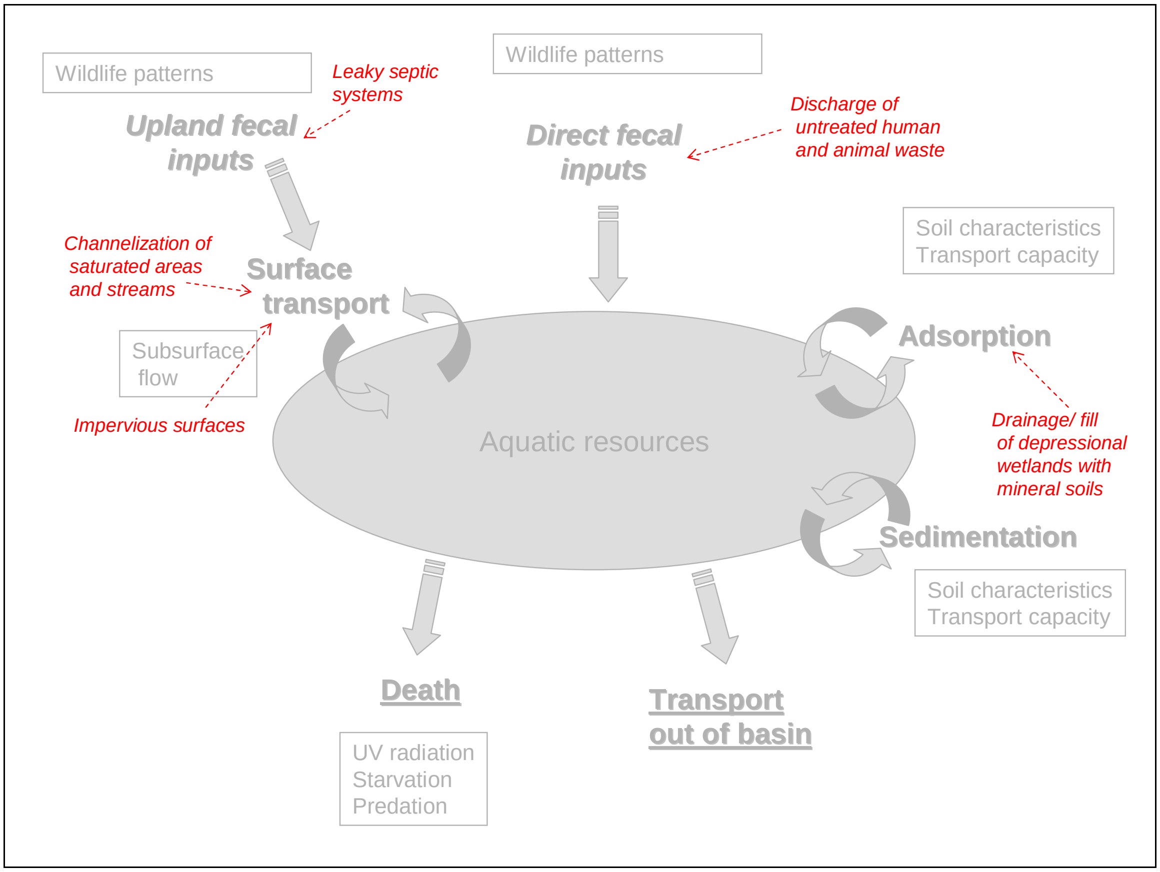

Figure F-2: Illustration of how human activities alter the delivery, movement and loss of pathogens.

Table F-2: Indicators that the delivery, movement, and loss of pathogens have been altered for the Puget Sound region.

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Delivery	Fecal inputs		Wildlife	Additional fecal inputs	Failed septic systems	**Rural residential land use**
					Discharge of untreated human and animal waste	
Movement	Transport	Overland flow	Precipitation patterns Soils	Channelized flow	Ditching & draining of saturated areas	
		Surface flows	Topography Surficial geology Soils	Increased velocity and erosion of streambed	Channelization of streams	**Straight-line hydrography**
		Subsurface flows & Recharge	Topography Surficial geology	Conversion to surface flows	Impervious cover Ditching in areas of low permeability	**Urban land cover and/or impervious cover** **Ditching on geologic deposits of low permeability**
	Adsorption		Mineral and organic soils Surface water velocity	Reduce storage of pathogens	Ditching, draining or filling depression wetlands with mineral and organic soils	**Loss of depressional wetlands** **Straight-line hydrography in all depressional wetlands**
	Sedimentation[2]					
Loss	Death		UV radiation Starvation Predation	Reduce residence time	Draining or filling of depressional wetlands with mineral and/or organic soils	**Loss of depressional wetlands.**

[1]Addressed in Appendix B: delivery, movement, and loss of water; conversion of sub-surface flow to surface runoff.

[2] Addressed in Appendix C: delivery, movement, and loss of sediment

3.1 Delivery of pathogens

3.1.1 Fecal inputs

Pathogens include bacteria and viruses which contaminate waters from both human and animal fecal matter.

Failed septic systems: Septic systems have been associated with high levels of pathogen contamination (Lipp and Rose 2001, Lipp et al. 2001, Glasoe and Christy 2004). The U.S. EPA estimates that 10 to 30% of these systems are not functioning properly (U.S. EPA 2001). Septic systems installed on poorly draining soils (low permeability deposits) are often ditched and drained to tidal creeks increasing transport of pathogens (Duda and Cromartic 1982). Duda and Cromartic also determined that septic system densities of greater than one system per seven acres resulted in closure of shellfish beds in a coastal North Carolina watershed.

Discharge of untreated human and animal waste: Animal waste from concentrated animal feeding operations contains pathogens such as cryptosporidium and campylobacter (Cole et al. 1999).

Indicators of alteration*: Rural residential land cover and dairy farms/feedlots.*

3.2 Movement of pathogens

Transport, adsorption, and sedimentation (the three components of movement) are primarily altered by ditching, channelization, impervious cover, and filling of wetlands within a watershed. Alterations to the movement of pathogens (Glasoe and Christy 2004) indicate that, while impervious cover is highly correlated with shellfish contamination, even areas of little development can impair shellfish integrity if the watershed hydrologic processes have been significantly altered. In particular, land use activities such as ditching and draining can be responsible for contaminating shellfish beds. Agricultural and roadside ditches by-pass the pathogen removal processes of wetlands and speed up the movement of water contaminated with pathogens to estuarine waters. White et al. (2000) found even low levels of impervious cover could contaminate aquatic ecosystems with fecal coliform if there was a high degree of hydrologic connectivity between sources and the aquatic ecosystems. Mallin (2001, 2000) found that watersheds with extensive wetland cover, relative to those with reduced/altered wetland cover, did not exhibit fecal coliform counts and turbidity during rainfall events.

3.2.1 Transport

Overland Flow. Ditching and draining of saturated areas: Ditching and draining of saturated areas can route pathogen-bearing waters directly to streams and storm drain systems, bypassing riparian wetlands. As a result, pathogen populations may not be reduced since they are not subject to the mechanisms of sedimentation and adsorption.

Indicators of alteration*: Straight-line hydrography within saturated areas.*

Surface Flows. Channelization of streams: Channelization of streams is done to reduce flooding of adjacent rural and urban land uses. This is accomplished by forcing flood waters to remain in the main stream channel and prevent overbank flooding into the adjacent floodplain. This in turn increases the velocity and erosive power of the stream. Channelization relies on increased bank heights (i.e., dikes, levees) and hardening and straightening of stream channels. As a result of channelization, the pathogen removal capacity of floodplain wetlands is eliminated and more sediment and pathogens are transported downstream. Additionally, channelization increases the velocity of storm flows which in turn erodes and re-suspends sediments and desorption of pathogens from those sediments (Indest 2003).

Indicators of alteration*: Straight-line hydrography in riverine settings*

Sub-surface Flows and Recharge. Impervious cover and ditching: Numerous studies have examined the relationship between urbanization and the contamination of shellfish harvest areas by fecal coliform bacteria and other pathogens, including viruses. The percentage of the catchment area that drains into the nearshore waters and is impervious seems to offer a good correlation with the integrity of the marine habitat and the healthiness of shellfish beds (Glasoe and Christy 2004). The Center for Watershed Protection (2003, 2004) modeled the relationship between impervious cover and shellfish habitat degradation. Supported by numerous other studies, they indicate that if more than 10-25% of the watershed is impervious, then bacterial standards will be frequently, if not continuously, exceeded during wet weather conditions.

The primary effect of impervious surfaces appears to be increased stormwater runoff and movement of water from source areas (e.g., pets, livestock, septic systems, waste water treatment plants, combined sewer overflow facilities) to critical habitat areas (Glasoe and Christy 2004).

Hydrologic alterations (i.e., ditching, impervious cover) on permeable geologic deposits may have a significant effect on the transport of pathogens. Unaltered flows within these deposits are typically deeper and have a longer flow path than in geologic deposits of low permeability. The longer flow path may reduce pathogen levels through adsorption. Based on research in the Buttermilk Bay watershed of Massachusetts, Weiskel et al. (1996) recommended that stormwater runoff be routed to a groundwater pathway in order to reduce bacterial levels. Alterations on these deposits, especially impervious surface, significantly reduce recharge and the longer flow path afforded by them (see Figure B-3 and B-10 in appendix B). Refer to Appendix B for methods and maps of these key areas and alterations to them.

Low permeability deposits have shallow sub-surface flows which have a shorter flow path than provided by permeable geologic deposits. Hydrologic alterations on low permeability deposits also reduce the flow path length (see figure B-5 and B-9). These areas may be even more susceptible to accelerated transport of pathogens. Lipp et al. (2001) reported that sub-surface flow was the principle mechanism for transporting pathogens to Sarasota Bay from residential septic systems. Refer to Appendix B for methods and mapping of these key areas and alteration to them.

***Indicators of alteration**: Impervious land cover of greater than 10% and ditching on low permeability geologic deposits.*

3.2.2 Adsorption and Sedimentation

Depressional wetlands are key areas for removing sediments and pathogens from surface water due to low water velocities, high residence times, filtering vegetation, and soils suitable for adsorption. Alteration to depressional wetlands, such as ditching and draining, reduces the residence time of water. This reduces the effectiveness of sedimentation and filtration mechanisms within the wetland. Filling of depressional wetlands eliminates contact of surface waters with soils that have a capacity for high absorption.

***Indicators of alteration**: Straight-line hydrography or loss of area in depressional wetlands with mineral soils*

3.3 Loss of Pathogens

Depressional wetlands are key areas for loss of pathogens from soils due to high residence times. The higher residence time allows for increased predation on pathogens by other microbes. Alteration to depressional wetlands, such as ditching and draining, reduces the residence time of water. This reduces the effectiveness of predation upon pathogens and their subsequent loss from the aquatic ecosystem. White (2000) concluded that hydrologic modifications (ditching and channeling) in the Jumping Run Creek watershed of Carteret County, North Carolina, resulted in runoff moving through the pocosin wetlands in hours instead of weeks, reducing the ability of this wetland system to reduce pathogens through natural processes.

***Indicators of alteration**: Straight-line hydrography or loss of area in depressional wetlands with mineral soils*

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Appendix G: Large woody debris delivery, movement, and loss in the Puget Sound region

1. Description of the Process

This section provides a description of the process of delivery, movement, and loss of large woody debris in a watershed of the Puget Sound region (Figure G-1).

1.1 Delivery of large woody debris

Large woody debris is just one form of organic inputs to aquatic ecosystems; however, it is a principal factor in structuring habitat characteristics in many of these ecosystems of Puget Sound (Naiman et al. 1992). Large woody debris is delivered to aquatic ecosystems by one of three mechanisms:

- Mass wasting which can move not only sediment, but also trees that were growing in the slide area
- Windthrow
- Bank erosion

1.2 Movement of large woody debris

Once in the stream or water body, large woody debris is transported when there is enough energy in the water for the wood to be moved. Wood becomes entrained within aquatic ecosystems when this transport capacity no longer exists.

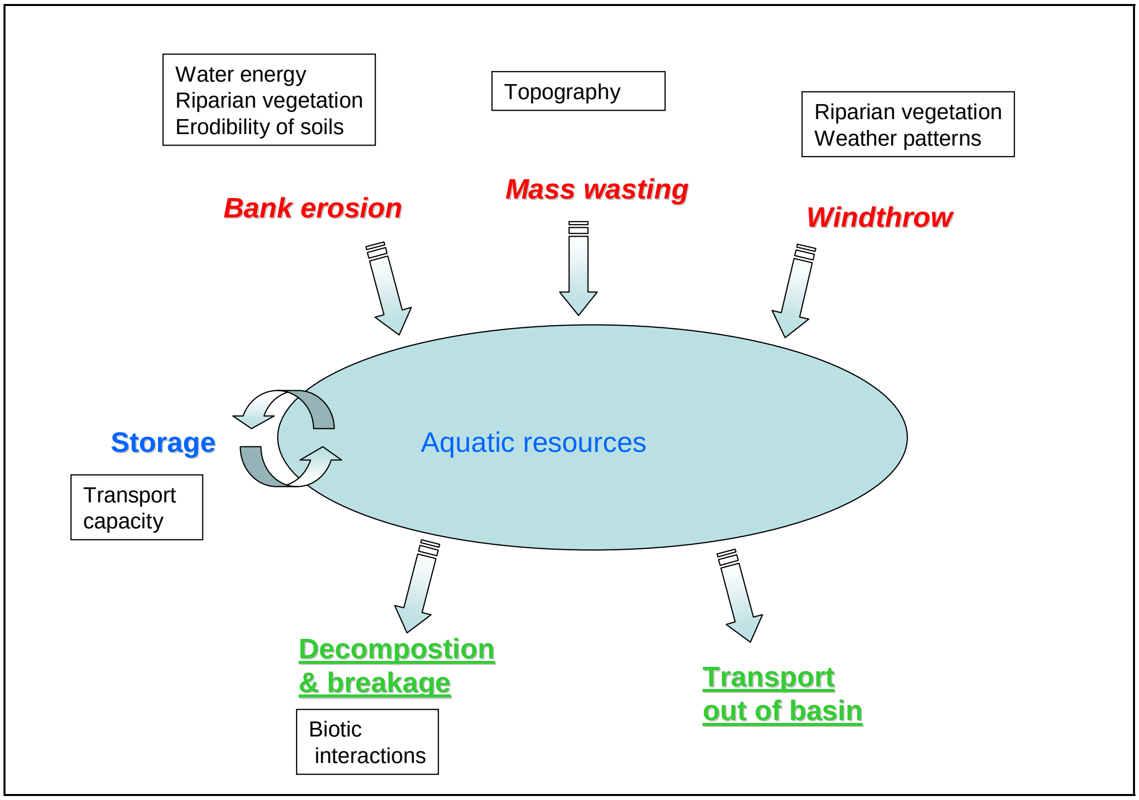

Figure G-1: Illustration of the delivery, movement, and loss of water in watersheds of Puget Sound. Red italics are components of delivery, blue are movement, green underlined are loss, and black text in boxes are controls. Blue polygon represents water bodies in a watershed.

1.3 Loss of large woody debris

The habitat-forming function of wood can be reduced as it breaks, decomposes or is moved out of the basin.

2. Step 3: Map key areas for large woody debris process

Once the delivery, movement, and loss of large woody debris in a watershed are understood, key areas for supporting this process can be identified. Based on the diagram of how large woody debris moves through a watershed, controls can be identified that govern this process (Figure G-1). Usually these controls are different physical characteristic of the watershed. Key areas are those parts of a watershed with these characteristics.

In this section, for each component of the large woody debris process, the controls and key areas are discussed for the Puget Sound region. These are summarized in Table G-1. Key areas in bold are those that you can map using regionally available data. We provide mapping methods for these in Appendix H. You can map key areas not in bold using local data or knowledge. If no important areas can be mapped, this column is left blank.

Table G-1: Major controls and key areas for the delivery, movement, and loss of water in the Puget Sound region.

Component of process		Major natural controls	Key areas
Delivery	Stream bank erosion	Water energy Riparian vegetation Erodibility of soils	**Unconfined channels**
	Mass wasting	Topography	**Mass wasting areas** that are likely to deliver debris to the stream
	Windthrow	Riparian vegetation Weather patterns	**Forest within 100' from aquatic resources**
Movement	Storage	Transport capacity of water	**Channels with <4% gradient**
Loss	Breakage/ decomposition	Biotic interactions	

2.1 Delivery of large woody debris

2.1.1 Streambank erosion

In unconfined channels, the amount of wood recruited increases as channels actively migrate in areas of erodible soils (any substrate other than bedrock, cobbles, or boulders) (May and Gresswell 2003).

2.1.2 Mass wasting

Where mass wasting or landslides occur directly upslope of the stream channel, these events can provide a significant amount of wood. In studies of three stream systems from

California to Washington, between 65-80% of instream wood came from upslope areas (Reeves et al. 2003, Benda et al. 2002b). A similar result was found for smaller headwater streams in southwest Oregon by May and Gresswell (2003).

2.1.3 Windthrow

In lower gradient channels (<10%-Benda and Cundy 1990, cited in Reeves et al. 2003, <20% cited in WFPB 1997b), delivery of wood to a channel is primarily from individual treefall within the streamside zone. Tree fall or windthrow is also an important source of wood in steeper small channels (May and Gresswell 2003). In western Washington, trees within 100' of the stream are likely to reach the channel if they fall (WFPB 1997b).

Key areas: *Unconfined channels, mass wasting areas, and the area 100' from all water bodies and streams.*

2.2 Movement of large woody debris

2.2.1 Storage of large woody debris

Low-gradient channels can play an important role in the storage of wood within the floodplain and stream channel system. Channels with less than 4% slope are more responsive to wood within the channel because wood is more likely to be stored in these areas and to play an important role in habitat formation (Montgomery and Buffington 1993, Buffington et al. 2003).

Key areas*: Channels with less than 4% slope or unconfined channels*

2.3 Loss of large woody debris

No key areas are identified for loss of large woody debris.

3. Step 4: Alterations to the delivery, movement, and loss of large woody debris

Lowland areas of Puget Sound have been altered to varying degrees by human activity. However, the intensity of alteration varies significantly. Where alteration is minimal, processes are likely still intact and functioning. Where alterations have been significant, processes are no longer functioning. You can assess the current condition of key areas by evaluating the locations and impacts of various activities. Building upon the diagram of the large woody debris process, this section describes the relationship between human activities and the delivery, movement, and loss of large woody debris (Figure G-2).

Indicators of these human activities are mapped to show the locations of these alterations. This allows for an assessment of whether the human activities are likely to occur in the key areas for the movement of large woody debris. We summarize indicators for these alterations in Table G-2. Indicators displayed in bold are those that you can map using regionally available data. We provide mapping methods for them in Appendix H. You can map indicators not in bold using local data or knowledge. If no indicators can be easily mapped over an entire watershed, this column is left blank.

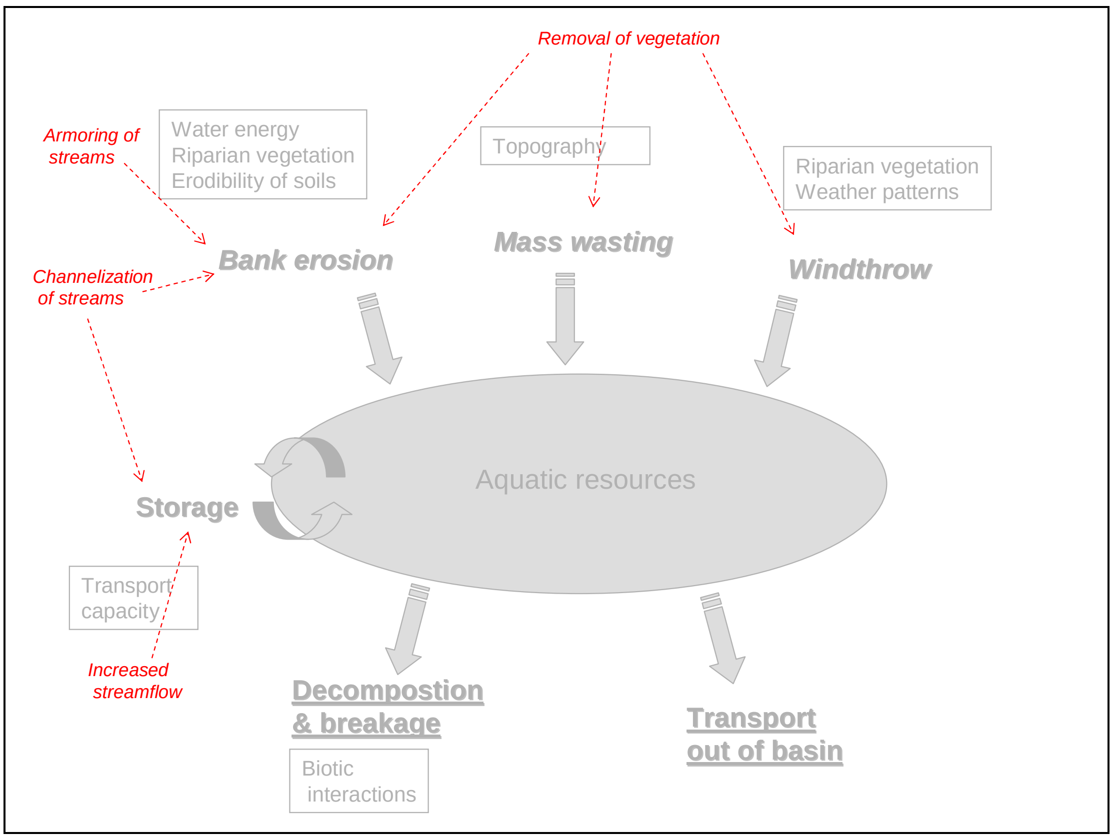

Figure G-2: Illustration of how human activities alter the delivery, movement, and loss of large woody debris.

Table G-2: Indicators that the delivery, movement, and loss of large woody debris have been altered for the Puget Sound region.

Component of process		Major natural controls	Change to process	Cause of change	Indicators of alteration
Delivery	Streambank erosion	Water energy Riparian vegetation Erodibility of soils	Reduce bank undercutting	Channelization of streams in unconfined reaches	Dikes and levees
					Straightline hydrography in floodplains
				Armoring of streams	
			Reduce LWD available to reach stream	Remove riparian vegetation	**Non-forested land cover within 100' of stream in a floodplain**
	Mass wasting	Topography	Reduce LWD available to reach stream	Remove forest vegetation on high mass wasting hazard areas	**Non-forested land cover on high mass wasting hazard areas**
	Windthrow	Riparian vegetation Weather patterns	Reduce LWD available to reach stream	Removal of vegetation adjacent to stream	**Non-forested land cover within 100' of streams**
Movement	Storage	Transport capacity of water	Reduce capacity of stream to store wood	Channelization of streams in unconfined reaches	Dikes and levees
					Straightline hydrography in floodplains
				Increased streamflow[1]	
Loss	Breakage/ Decomposition	Biotic interactions			

[1] Addressed in Appendix B: delivery, movement, and loss of water

3.1 Delivery of large woody debris

3.1.1 Stream bank erosion

Delivery of large woody debris to low-gradient channels is impaired when there is either inadequate large woody material to fall into the channel or when channel migration and bank erosion processes are impaired, preventing existing trees from falling more frequently into the channel. Indicators that these two factors have been altered are:

- Channelization of streams: The delivery of available wood to a stream is increased by the erosion of banks as channels migrate. Channelization, ditching, and diking are all factors that prevent the bank erosion process and remove the associated delivery of wood. Straight-line hydrography can be used to identify streams that have likely had banks hardened.

  ***Indicators of alteration**: Straight-line hydrography on unconfined channels*

- Armoring of streams: Armoring also reduces the delivery of wood to stream channels by preventing the migration of channels; however, no regional indicators of armoring exist so you will need local data to identify these areas.

- Removal of riparian vegetation: In unconfined channels, alteration of the wood recruitment process can occur when the availability is decreased within 100' of the stream channel. Coe (2001) and Hyatt et al. (2004) found that in unconfined channels of the Nooksack River, inadequate large woody debris recruitment was associated with urban (77%), agricultural (85%), and rural (60%) zoning. Beechie et al. (2003) found similar results in the Skagit River watershed. Agricultural, urban/industrial, and rural land uses were associated with less than half of the riparian areas being fully functioning.

  ***Indicators of alteration**: Non-native land cover adjacent to stream*

3.1.2 Mass wasting

- Removal of forest vegetation on high mass wasting hazard areas: The wood recruitment process is altered when forest is removed from potential landslide areas.

  ***Indicators of alteration**: Non-forested land cover on high mass wasting hazard areas.*

3.1.3 Windthrow

- Removal of vegetation adjacent to stream: Recruitment of large woody debris by windthrow depends upon the availability of standing trees within one tree length of the stream channel. Any cover other than forested land cover within 100' of the stream is unlikely to ensure availability of future large woody debris for the stream channel.

***Indicators of alteration**: Non-forested land cover within 100’ of streams*

3.2 Movement of large woody debris

3.2.1 Storage

- Straightening streams: Unconfined channels that have been straightened have lost the areas with lower transport capacity in which large woody debris is stored. Similar channels with dikes or levees have also lost these storage areas, but you will need local data to locate these areas since no regional indicators of these changes exist

  ***Indicators of alteration**: Straight-line hydrography in unconfined channels*

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Appendix H: Mapping Methods

The previous six appendices (Appendices B-G) have identified key areas (step 3 of guidance) for each watershed process (Tables B-1, C-1, D-1, E-1, F-1, and G-1) and human activities that alter (step 4) each process (Tables B-3, C-3, D-2, E-2, F-2, and G-2). In the last column of each of these tables, we have highlighted entries you can map using regionally available GIS data. This appendix provides guidance for using these data to map both key areas for watershed processes (Section 1) and alterations to them (Section 2).

1. Mapping key areas for watershed processes using regionally available data (Step 3)

Overview:
Methods for mapping key areas for each watershed process are based upon the relationships described in the previous appendices (Table H-1, column 3). You can map these key areas using a suite of GIS analyses with regionally available datasets (Table H-1). Many of these analyses are used to map key areas for more than one watershed process (Table H-2). We provide details for conducting the analysis in the subsequent discussion. Each analysis is discussed in the order seen in Table H-1.

Table H-1: Mapping methods using regional datasets: Key areas for each process in the glaciated region of Puget Sound. The types of areas that are important for each watershed process and the GIS analyses need to identify these areas using regional datasets are indicated. Also suggested are the GIS data layers to be used, the factors to be assessed from each of those layers and the category of areas on the landscape to be mapped. Websites for obtaining these GIS layers are at the end of this Appendix.

Watershed Process	Natural Controls of Process	Relationship of key areas to controls	GIS ANALYSIS METHODS: Data layers	Factor assessed	Categories mapped
Water Delivery	Precipitation patterns	Recharge areas with higher precipitation have potential for greater recharge	Precipitation isohyetals Recharge areas (see Page H-3)	Relative amounts of precipitation in recharge areas	Recharge areas with higher amounts of precipitation
	Timing of snowmelt	Removing vegetative cover in rain on snow (ROS) zones changes quantity and timing of peak flows	Rain on snow zones	Rain on snow zones	Rain on snow zones
Water Movement / *At the surface* / *Surface storage*	Topography Surficial geology	Areas of low gradient can provide surface storage of water	Soils Slope	Depressional wetlands	Hydric soils on <2% slope
			Lakes	Lakes	Lakes
		Floodplains store surface water during peak flow events	DEM Hydrography	Large floodplains	Lowland floodplains of Nooksack, Skagit, Stillaguamish, Snohomish/ Snoqualmie, Green/Duwamish, and White/Puyallup Rivers
			SSHIAP channel segments	Unconfined channels likely to have floodplains	Unconfined channels

Table H-1 ***(continued)***

Watershed Process			Natural Controls of Process	Relationship of key areas to controls	GIS ANALYSIS METHODS		
					Data layers	**Factor assessed**	**Categories mapped**
Water Movement	*Below Surface*	*Shallow sub-surface flow*	Topography Surficial geology	Subsurface flow can occur in all areas of the watershed	Surficial geology	Permeability of surficial geology deposits	Areas with surficial geologic deposits of low permeability
Water Movement	*Below Surface*	*Recharge*	Topography Surficial geology	Permeable deposits support greater recharge of groundwater than other areas	Surficial geology	Permeability of surficial geology deposits	Areas with surficial geologic deposits of higher permeability
Sediment Delivery		*Surface erosion*	Topography Soil erodibility Vegetative cover	Generally, erosion of fine sediments is greater on steeper slopes with highly erodible soils; if these slopes are adjacent to aquatic ecosystems, delivery potential is high	Slope Soil map with erodibility index (K) Hydrography Lakes Wetlands	Potential for soil erosion and delivery to aquatic ecosystems	Areas intersected by aquatic ecosystems with: • <30% slope, K>.40 • 30-65% slope, K> .25 • >65% slope, all K factors apply
Sediment Delivery		*Mass wasting*	Topography	Areas adjacent to streams with concave slopes and steep gradients are more prone to risk of shallow, rapid landslides (mass wasting)	Shaw Johnson model of risk areas for shallow-rapid landslides Hydrography Lakes Wetlands	Potential for mass wasting material to be delivered to aquatic ecosystems	Areas with high mass wasting risk intersected by aquatic ecosystems

Table H-1 *(continued)*

Watershed Process & Components		Natural Controls of Process	Relationship of key areas to controls	GIS ANALYSIS METHODS		
				Data layers	Factor assessed	Categories mapped
Sediment Delivery continued	*In- channel erosion*	Transport capacity Riparian vegetation	Unconfined channels have greater potential for bank erosion of sediment	SSHIAP channel segments	Unconfined channels	Unconfined channels
Sediment Movement	*Storage*	Transport capacity	Areas with reduced transport capacity have greater potential for storage of sediment	Soils Slope	Depressional wetlands	Hydric soils on <2% slope
				SSHIAP channel segments	Unconfined channels	Unconfined channels
				Lakes	Lakes	Lakes
Phosphorus / Toxin Movement	*Adsorption (Phosp)*	Soil charac-teristics	Depressional wetlands with mineral soils have greater potential for adsorbing phosphorus	Soils Slope	Depressional wetlands with mineral soils	Hydric soils on <2% slope with mineral soils
			Upland areas with clay soils allow for adsorption of phosphorus; these areas adjacent to aquatic ecosystems are important points of sediment storage	Soils Hydrography Lakes Wetlands	Clay soils intersected by aquatic ecosystems	Upland clay soils intersected by aquatic ecosystems
	Adsorption (Toxins)	Soil cation exchange capacity	Depressional wetlands with organic or clay soils have greater potential for adsorbing metals	Soils Slope	Depressional wetlands with organic or clay soils	Hydric soils on <2% slope with either organic or clay soils

Table H-1 *(continued)*

Watershed Process		Natural Controls of Process	Relationship of key areas to controls	GIS ANALYSIS METHODS		
				Data layers	Factor assessed	Categories mapped
Nitrogen Movement	*Biotic uptake and decomposition*	Biotic composition and cover Hydrologic regime	Small, headwater streams are important areas for assimilation of nitrogen	Hydrography	Headwater streams	Streams of 3rd order or less
	Nitrification	Hydrologic regime	Seasonal fringes of depressional wetlands have a high potential for performing nitrification.	Soils Slope	Depressional wetlands	Hydric soils on <2% slope
	Adsorption	Hydrologic regime	Small, headwater streams have a higher potential for adsorption of nitrogen (ammonium) to sediment.	Hydrography	Headwater streams	Streams of 3rd order or less
Nitrogen Loss	*Denitrification*	Hydrologic regime	Saturated areas within depressional wetlands support denitrification	Soils Slope	Depressional wetlands	Hydric soils on <2% slope (exclude low pH wetlands, such as bogs)
Pathogen Movement	*Adsorption* *Sedimentation*	Mineral & organic soils Transport capacity (velocity)	Pathogens adsorb to mineral and organic soils and sediment. Areas with longer water retention times have greater potential to remove pathogen bearing sediment from water column.	Soils Slope	Depressional wetlands with either mineral or organic soils	Hydric soils on <2% slope with either mineral or organic soils

Table H-1 *(continued)*

Watershed Process		Natural Controls of Process	Relationship of key areas to controls	GIS ANALYSIS METHODS		
				Data layers	**Factor assessed**	**Categories mapped**
Large woody debris Delivery	*Streambank erosion*	Water energy Riparian vegetation	Delivery of wood as a result of streambank erosion is more likely in unconfined channels	SSHIAP channel segment Hydrography	Unconfined reaches	Unconfined channels
	Mass wasting	Topography	Delivery of wood as a result of mass wasting is more likely in channels adjacent to mass wasting areas	Mass wasting risk areas Hydrography Slope	Mass wasting risk areas that intersect streams	All areas with high mass wasting risk intersected by streams
	Windthrow	Riparian vegetation Weather patterns	Delivery of wood via windthrow requires a riparian stand along streams	Hydrography	Buffer on aquatic ecosystems	100’ buffer on either side of streams
Large woody debris Movement	*Storage*	Transport capacity of water	Streams with lower transport capacity store large woody debris; wood also plays an important function in habitat formation in these streams	SSHIAP channel segment Hydrography	Channel gradient	Channels with <4% gradient

Table H-2: Watershed processes and corresponding GIS analyses to identify key areas. Del= delivery; Mvt= movement

GIS Analysis	Watershed Processes										
	Water		**Sediment**		**Phosphorus**	**Toxin**	**Nitrogen**		**Pathogen**	**LWD**	
	Del	**Mvt**	**Del**	**Mvt**	**Mvt**	**Mvt**	**Mvt**	**Loss**	**Mvt**	**Del**	**Mvt**
Permeability of surficial geology deposits (recharge areas)	X	X									
Precipitation patterns	X										
Rain-on-snow zones	X										
Depressional wetlands		X		X			X	X			
• Mineral soils					M	M			M		
• Clay soils					C	C					
• Organic soils					O	O			O		
Lakes		X		X							
Large floodplains		X									
Unconfined channels		X	X	X						X	
Potential for soil erosion (K) and delivery to aquatic ecosystems (slope)			X								
Mass wasting areas intersected by aquatic ecosystems			X							X	
Clay uplands					X						
Headwater streams							X				
Buffer on aquatic ecosystems										X	
Channel gradient											X

1.1 Details of mapping key areas:

This section describes the mapping methods included in Table H-1. Before describing the individual analyses, we include a discussion on slope information.

Slope data – Several of the individual analyses use slope data as a component of the mapping category. An example of this is 'wetlands on < 2% slope' that is used as a factor in surface storage for water movement. Slope data is generated from Digital Elevation Models (DEM), ideally with a 10 meter grid or better. This guidance assumes the need for a GIS analyst who will be familiar with the use of this data. A statewide 10 meter grid is available from the University of Washington. (http://duff.geology.washington.edu/data/raster/index.html)

Several slope categories are needed for the analyses, including: <2%, <4%, <30%, 30-65%, and >65%. It is most efficient to develop the slope data layers prior to beginning the individual analyses.

Next, we discuss each entry in the column titled 'factor assessed' in Table H-1. Since many of these factors are used for the analysis of different processes, we describe these factors in the order used in Table H-1. This same order is repeated in Table H-2, which summarizes the analyses by watershed processes.

- Permeability of surficial geology deposits:
  We assign low or high permeability classes to each of the deposits in the surficial geology layer. Though the indicators in the guidance document specify using low and high permeabilities, you should evaluate moderate permeability deposits and determine whether they should be included in the low or high permeability category. While you can obtain some general guidance on interpreting geologic maps by using Table B-2, 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.

- Relative amounts of precipitation in recharge areas:
  Precipitation isohyetals are overlain with the recharge areas identified below to identify recharge areas that have relatively high quantities of precipitation.

- Rain-on-snow zones:
  This digital layer represents the areas most prone to rain-on-snow events. This data is available from the Washington State Department of Natural Resources.

- Depressional Wetlands: (organic, mineral, and clay soils)
  You can estimate potential wetland areas, including both existing and historic wetland extent, by using hydric soils from NRCS soil surveys. Depressional wetland areas can be estimated using the hydrogeomorphic characteristics of the potential wetlands. We have found good correlation between areas with less than 2% slope that have hydric soils, according to the NRCS soil survey, and known potential depressional wetlands.

  The SSURGO soils data has a table (*component*) with soil names (*component name*) that links to the spatial data layer. The soil description, from the county soil survey reference manual, will provide information to determine whether the soil type is mineral, organic, or clay.

- Lakes:
  You can use existing GIS data layers to map lakes.

- Large floodplains
  No single GIS layer exists that is adequate for delineating the floodplains associated with large rivers. As a result, you need to delineate these areas using a topographic contours or a Digital Elevation Model (DEM) to identify the large, lowland valleys associated with six major tributaries to Puget Sound: the Nooksack, Skagit, Stillaguamish, Snohomish/Snoqualmie, Green/Duwamish, White/Puyallup and Nisqually rivers.

- Unconfined channels:
  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’ in the SSHIAP data are used to identify reaches likely to have floodplains and provide surface water storage.

- <u>Potential for soil erosion and delivery to aquatic ecosystems:</u>
  To locate areas that are prone to surface erosion, use the STATSGO soils data and slope (calculated from a DEM) to map areas with the combination of slope and K factor shown in Table H-3. Intersect these areas with layers for streams, lakes, and wetlands to assess potential for delivery to water bodies.

Table H-3: Combinations of both slope and K factor that indicate a higher potential for soil erosion (WFPB, 1997a)

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

- <u>Mass wasting risk areas that intersect aquatic ecosystems:</u>
  Map the output of the Shaw Johnson model for the Puget Sound region and show areas as having low, moderate, or high risk of mass wasting events. This model will identify key areas which have high or moderate risk for mass wasting and that intersect streams, lakes or wetlands.

- <u>Clay uplands</u>: Map areas adjacent to aquatic ecosystems that have clay soils. These would be soils that have a minimum of 40% clay soil particles (less than 0.002 millimeters in diameter), less than 45% sand (1.0 to 0.10 mm diameter) and less than 40% silt (0.05 mm to 0.002 mm diameter). This information can be obtained from either local soil surveys or by reading the soil series description. The SSURGO soils data has a table (*component*) with soil names (*component name*) that links to the spatial data layer. The soil description, from the county soil survey reference manual, can now be used to provide information to determine whether the soil type in the SSURGO data base is mineral, organic, or clay.

- <u>Headwater streams:</u> These generally represent streams of 3rd order or less in a stream network. The scale of your analysis area will determine what level of streams you include since the stream network for a large city will be much different than the network for a county. A hydrologist familiar with the area should be consulted in this decision. (http://www.sierraclub.org/cleanwater/whitepaper_intro.pdf)

- <u>Buffer on aquatic ecosystems:</u> A buffer of 100' on all aquatic ecosystems can identify the area important for windthrow. One hundred feet is used as a surrogate for the site potential tree height on the west side of the Cascades. If the area of interest has trees of a different site potential height, that value should be used instead.

- <u>Channel gradient:</u> In most watersheds of the Puget Sound region, the SSHIAP (Salmon and Steelhead Habitat Inventory and Assessment Program) has developed data layers that group the gradient of stream segments. Stream segments classified as less than 4% in the SSHIAP data are used to identify reaches that would have less water velocity to transport wood through the stream system and thus have more capacity to store wood.

2. Mapping alterations to watershed processes using regionally available data (Step 4)

Overview:

Methods for mapping alterations to the key areas for each watershed process are based upon the relationships described in the previous appendices (A-G). You can map the indicators of these alterations using a suite of regionally available datasets (Table H-4). Some of the GIS analyses used to map these indicators are used for more than one process (Table H-5). We provide details for conducting the analysis in the subsequent discussion. We discuss each analysis in the order seen in Table H-5.

Table H-4: Mapping methods using regional datasets: Indicators of alterations to key areas for each process in the glaciated region of Puget Sound. This table includes the changes that occur to each watershed process, the cause of that change, and the indicators of the change that link to alterations by humans. Websites for obtaining these GIS layers are at the end of this Appendix.

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Water Delivery			Timing of snowmelt	Increase streamflow	Removal of forest vegetation in rain- on-snow zones	**Non-forested vegetation in rain-on-snow zones**
Water Movement	*At the surface*	Surface storage	Topography Surficial geology Soils	Increase streamflow Decrease storage capacity Increase water transport capacity	Drainage or filling of depressional wetlands	**Loss of depressional wetlands**
						Straight-line hydrography in depressional wetlands
					Channelization of streams	**Straight-line hydrography of stream reaches with floodplains**
				Increase water storage capacity Decrease downstream flow	Dam operation	**Dams**

Table H-4 ***continued***

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Water Movement	*Below surface*	Shallow subsurface flow	Topography Surficial geology	Convert to surface runoff	Impervious surfaces	**Land uses with impervious cover on geologic deposits of low permeability**
					Removal of forest cover	**Non-forested vegetation on geologic deposits of low permeability**
		Recharge	Topography Surficial geology	Convert to surface runoff	Removal of forest cover	**Non-forested vegetation on geologic deposits of high permeability**
				Reduce groundwater recharge	Impervious surfaces	**Land uses with impervious cover on areas of high permeability**
Sediment Delivery		Surface erosion	Topography Soil erodibility Vegetative cover	Increase delivery of fine sediment to aquatic ecosystems	Removal of vegetation	**Non-forested land cover on highly erodible slopes adjacent to aquatic ecosystems**
					Roads increasing stream network	**Roads within 200' of aquatic ecosystems**
		Mass wasting	Topography	Increase delivery of sediment to aquatic ecosystems	Roads triggering landslides	**Roads in high mass wasting hazard areas**
					Removal of vegetation	**Non-forested land cover on high mass wasting hazard areas**

Table H-4 *continued*

Component of process		Major natural controls	Change to process	Cause of change	Indicators of alteration
Sediment Delivery continued	In-channel erosion	Transport capacity (velocity) Riparian vegetation	Alter fine sediment delivery to streams	Channelization of streams	**Straight-line hydrography in unconfined channels**
				Increase in stream discharge	**Urban land cover**
Sediment Movement	Sedimentation	Transport capacity (velocity)	Decrease sediment storage	Drainage or filling of depressional wetlands	**Loss of depressional wetlands** **Straight-line hydrography in depressional wetlands**
				Channelization of stream reaches with floodplains or that are depositional zones	**Straight-line hydrography on stream reaches with floodplains or depositional channels**
			Increase sediment storage	Dams	**Dams**
Phosphorous Delivery	Phosphorus sources	Climate patterns Surficial geology	Additional sources	Application of fertilizer	**Urban land use** **Agricultural land use**
				Application of manure	**Agricultural land use adjacent to dairies**
	Toxin sources		Additional sources New toxins	Use of pesticides, herbicides, and other chemicals	**Urban land use** **Row crop land use**

Table H-4 *continued*

Component of process		Major natural controls	Change to process	Cause of change	Indicators of alteration
Phosphorous Movement	Adsorption (P)	Soil characteristics	Reduced phosphorus adsorption	Draining or filling of depressional wetlands with mineral soils	**Straight-line hydrography in depressional wetlands with mineral soils** **Loss of depressional wetlands with mineral soils**
				Loss of upland areas with clay soils	**Urban land cover in areas of clay soils adjacent to aquatic ecosystems**
	Adsorption (T)	Soil cation exchange capacity	Reduced toxin adsorption	Draining or filling of wetlands with organic and clay soils	**Straight-line hydrography in wetlands with organic or clay soils**
					Loss of wetlands with organic or clay soils
	Sedimentation[1]	Water transport capacity (velocity)	Reduced storage of phosphorous & toxins	(see Appendix C)	**Loss of depressional wetlands** **Straightline hydrography in depressional wetlands**
Nitrogen Delivery	Nitrogen sources	Weather patterns Biotic composition	Additional sources	Application of fertilizer	**Agricultural landuse**
				Application of manure	**Agricultural landuse**
Nitrogen Movement	Biotic uptake and decomposition	Biotic cover and composition Hydrologic regime	Increase stream discharge and depth	Channelization of headwater streams	**Straight-line hydrography in headwater streams**

Table H-4 *continued*

Component of process			Major natural controls	Change to process	Cause of change	Indicators of alteration
Nitrogen Movement continued		Nitrification	Hydrologic regime	Reduced area with seasonal flooding	Draining or filling of depressional wetlands	**Straight-line hydrography in depressional wetlands**
						Loss of depressional wetlands
		Adsorption	Hydrologic regime	Increase stream discharge and depth	Channelization of headwater streams	**Straight-line hydrography in headwater streams**
Nitrogen Loss		Denitrification	Hydrologic regime	Reduced area for denitrification	Draining or filling of depressional wetlands	**Straight-line hydrography in depressional wetlands**
						Loss of depressional wetlands
Pathogen Delivery		Fecal inputs	Wildlife	Additional fecal inputs	Failed septic systems	**Rural residential land use**
Pathogen Movement	*Transport*	Surface flows	Topography Surficial geology Soils	Increased velocity and erosion of streambed	Channelization of streams	**Straight-line hydrography**
		Subsurface flows & Recharge	Topography Surficial geology	Conversion to surface flows	Impervious cover Ditching in areas of low permeability	**Urban land cover and/or impervious cover** **Ditching on geologic deposits of low permeability**

Table H-4 *continued*

Component of process		Major natural controls	Change to process	Cause of change	Indicators of alteration
Pathogen Movement c	Adsorption	Mineral and organic soils Surface water velocity	Reduce storage of pathogens	Ditching, draining or filling depression wetlands with mineral and organic soils	**Loss of depressional wetlands** **Straight-line hydrography in all depressional wetlands**
	Sedimentation[2]				
Pathogen Loss	Death	UV radiation Starvation Predation	Reduce residence time	Draining or filling of depressional wetlands with mineral and/or organic soils	**Loss of depressional wetlands.**
Large woody debris Delivery	Streambank erosion	Water energy Riparian vegetation Erodibility of soils	Reduce bank undercutting	Channelization of streams in unconfined reaches	**Straightline hydrography in floodplains**
			Reduce LWD available to reach stream	Remove riparian vegetation	**Non-forest land cover within 100' of stream in a floodplain**
	Mass wasting	Topography	Reduce LWD available to reach stream	Remove forest vegetation on high mass wasting hazard areas	**Non-forest land cover on high mass wasting hazard areas**
	Windthrow	Riparian vegetation Weather patterns	Reduce LWD available to reach stream	Removal of vegetation adjacent to stream	**Non-forest land cover within 100' of streams**
Large woody debris Movement	Storage	Transport capacity of water	Reduce capacity of stream to store wood	Channelization of streams in unconfined reaches	**Straightline hydrography in floodplains**

Table H-5: Watershed processes and corresponding GIS analysis to identify alterations to important areas. Del= delivery; Mvt= movement

GIS Analysis	Watershed Processes											
	Water		Sediment		Phosp/Toxin		Nitrogen		Pathogen		LWD	
	Del	Mvt	Del	Mvt	Del	Mvt	Del	Mvt	Del	Mvt	Del	Mvt
Non-forest vegetation or land cover on:												
○ Rain on snow zones	X											
○ Areas of high permeability		X										
○ Areas of low permeability		X										
○ Highly erodible slopes adjacent to aquatic ecosystem			X									
○ Mass wasting hazard areas			X								X	
○ Within 100' of aquatic ecosystems											X	
Land use with impervious cover on:												
○ Areas of higher permeability		X										
○ Areas of low permeability		X										
Loss of area in:												
○ Depressional wetlands		X		X				X				
○ Groundwater discharge wetlands		X										
○ Depressional wetlands with mineral soils					X				X	X		
○ Wetlands with organic or clay soils					X				X			
Dams		X		X								
Straight-line hydrography in:												
○ Depressional wetlands		X		X				X				
○ Stream reaches with floodplains		X		X								
○ Saturated areas		X										
○ Groundwater discharge wetlands		X										
○ Unconfined channels			X								X	X
○ Depressional wetlands with mineral soils					X				X	X		
○ Wetlands with organic or clay soils					X							
○ Headwater streams								X				
○ Streams									X	X	X	

Table H-5 *(continued)*

GIS Analysis	Watershed Processes											
	Water		**Sediment**		**Phos/Toxin**		**Nitrogen**		**Pathogen**		**LWD**	
	Del	**Mvt**	**Del**	**Mvt**	**Del**	**Mvt**	**Del**	**Mvt**	**Del**	**Mvt**	**Del**	**Mvt**
Roads within:												
○ 200' of aquatic ecosystems			X									
○ High mass wasting hazard areas			X									
Land use												
○ Urban			X		X					X		
○ Urban on clay soils adjacent to aquatic ecosystem						X						
○ Row crop agriculture					X							
○ Agricultural					X		X					
○ Rural residential									X			
Non-forest cover adjacent to aquatic ecosystems											X	

2.1 Details of mapping alterations:

- Non-forest vegetation or land cover:

  Use any land cover other than forest. If the data is accurate enough to identify scrub-shrub areas, this should be included in the forest cover as it typically is mixed with forest types.

- Land use with impervious cover:

  Table H-6 shows the common land use categories and associated estimates of percent effective imperviousness (Table H-6). By showing each of these categories in different colors (e.g., on a scale from 1 to 5), you may be able to identify areas in which specific processes are more altered. An alternative mapping approach is to show the percent impervious, percent forest and percent not forest in a pie chart for individual sub-basins (see figure II-4).

Table H-6 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

- Loss of area in various wetland types:

  Rather than calculating the percentage of each watershed that is still in wetland coverage, which can be somewhat cumbersome, we suggest mapping where depressional wetland area has been lost and then manually highlighting those areas with major losses.

  To obtain a rough estimate of the amount of wetland area lost, use palustrine wetlands in the National Wetland Inventory data layer (and/or local wetland inventories) as the current wetland extent. An estimate of the potential historic wetland area can be achieved by using hydric soils on slopes of less than 2% (this was created in the key areas analysis). Then compare the difference in coverage from these two data layers. Depressional wetlands have likely been lost anywhere the hydric soil layer extends beyond the NWI (and/or local wetland inventory) layer. Potential wetlands were identified previously and mapped in Step 3 (see methods for depressional wetlands).

- Dams:
  Map presence of known dams in the contributing area. Use USGS maps and local information.

- Straight-line hydrography in various settings:
  Visually examine the hydrograph layer and manually identify those areas that have clearly been straightened.

- Roads within specific areas:
  Alterations to sediment processes involve roads within 200 feet of aquatic ecosystems and roads in areas of high potential for mass wasting. Intersect road layers with mapped aquatic ecosystems and areas of mass wasting.

- Agricultural land use, daires and row crops:
  Use agricultural land cover to indicate delivery of nutrients. Dairies can be specifically identified by using local land use data. More intense agricultural use that uses fertilizers and pesticides (such as row crops) can be identified through farm plans that are required by the Soil Conservation Service. These lands are frequently mapped by some counties.

- Urban land use:
  Urban land use can be used to indicate the delivery of toxins and nutrients and transport of pathogens. Use table H-5 to identify these areas. It is suggested that development in the medium density (1 unit per acre) can be considered urban.

- Non-forest cover adjacent to aquatic ecosystems:
  Map urban, agricultural or rural zoning or land use that occurs adjacent to aquatic ecosystems.

- Loss of area of wetlands with organic soils:
  Mapping methods: Use the data layer showing wetlands with organic soils that you developed when identifying key areas for the removal of phosphorus as the full extent of wetlands with a capacity for removing phosphorus through adsorption

3. Web sites for obtaining regional data

Overview:
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 hard copy maps. However, using digital data is more 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 following table lists major sources for the digital data layers that are used in this guidance.

Table H-7. 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	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 (Elevation)	10 Meter	University of Washington	http://duff.geology.washington.edu/data/raster/index.html

Data	Scale	Agency	Web Site
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 Comission	http://www.wdfw.wa.gov/hab/sshiap/index.htm
Mass wasting (Shaw Johnson landslide risk model)	10 Meter (Western WA) 30 Meter (Eastern 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://landcover.usgs.gov/nlcd/show_data.asp?code=WA&state=Washington

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.

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Appendix J: Framework for Planning at the Landscape Scale

1. Introduction

The guidance presented in the main document, along with Appendices A through H, describes one way that local jurisdictions can characterize the watershed processes that maintain the aquatic ecosystems across the landscape. Figure J-1 shows a general outline of a larger planning framework (adapted from Granger et al. 2005) that incorporates adaptive management principles. A more detailed discussion of this planning framework is presented in Guidance for Protecting and Managing Wetlands in Western Washington, Volume 2, Chapters 4 and 5 (Granger et al. 2005).

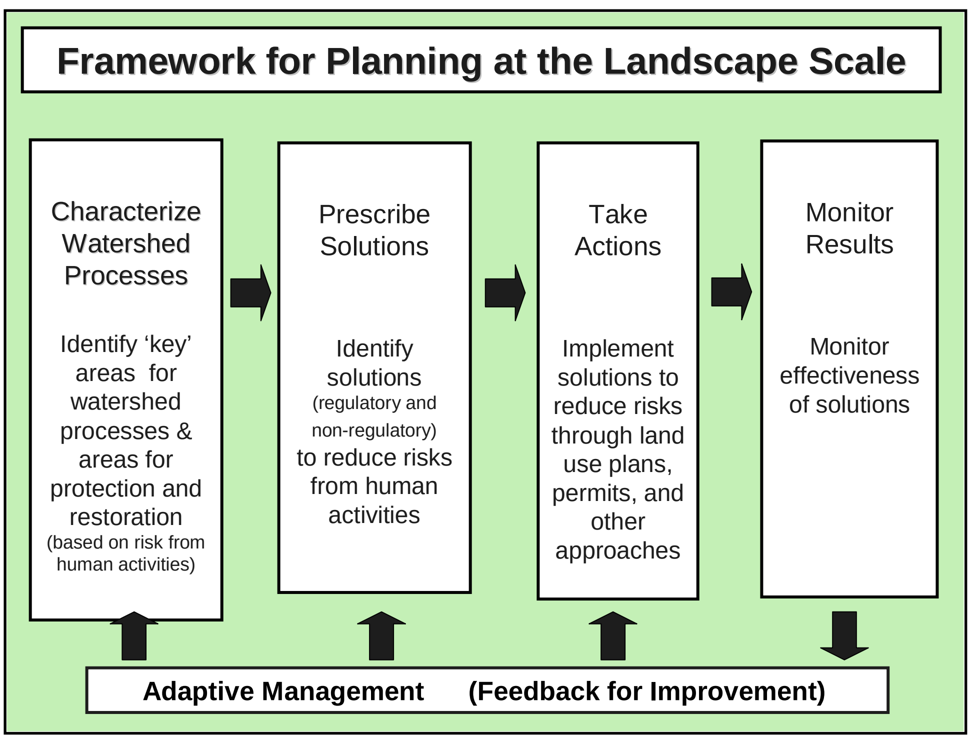

Figure J-1. A general framework for planning at the landscape scale. This represents a suggested framework that local governments could use in protecting and managing aquatic ecosystems through land use planning.

The methods for describing and mapping key areas for watershed processes presented in this document address the first box of Figure J-1, "Characterize Watershed Processes." The products of the characterization are synthesized to identify potential areas for protection and restoration. Planners can use that information to develop preliminary solutions (box 2, "Prescribe Solutions") or alternatives for development/ management scenarios. Examples include identifying appropriate land use designations and development standards that would maintain the watershed processes in the key areas.

When the development and management scenarios are fully analyzed, reviewed, and revised using public and agency input, the solutions can be implemented in the "Take Actions" step of Figure J-1. This could include land use and/or management plans with appropriate development standards and use regulations. The final, and most important step in the framework, is monitoring results of the adopted plan to determine if it is effectively protecting and/or restoring aquatic ecosystems. Feedback from this monitoring effort can be used to modify or "adapt" the plan to correct those aspects that are not meeting restoration and protection objectives.

A description of how this framework can be used within the context of state planning laws is presented below

2. State planning laws and how they affect using this landscape planning framework

When used in the context of the adaptive management framework presented in Figure J-1, the methods for described in this document can assist **planners** in meeting the planning goals for resource protection contained in state and local environmental laws and regulations. This includes the Growth Management Act (RCW 36.70A.060) and the Shoreline Management Act (RCW 90.58). Furthermore, these methods are an acceptable approach to completing a "characterization of functions and ecosystem wide processes" as specified in WAC 173-26-201(3)(d)(i).

Additionally, this landscape planning framework is useful to **non-profit organizations** and other governmental entities that restore, manage, or conserve aquatic resources. A detailed discussion of the application of landscape planning to the protection of wetland ecosystems is presented in chapters 2, 6 and 7 of Granger et al. (2005).

<u>Growth Management Act</u>. The Growth Management Act (GMA) requires local governments to develop comprehensive plans and to adopt critical area regulations in order to meet the thirteen GMA planning goals. Comprehensive plans are intended to promote wise use of the state's resources, including the conservation and protection of our environment and economic development that is sustainable (RCW 37.70A.010). Comprehensive plans are intended to be a cooperative and coordinated approach amongst jurisdictions and private parties. The methods set forth in this document are ideally

suited for helping local governments meet these goals in a cooperative manner because they:

- Identify watershed processes operating across jurisdiction boundaries.
- Support protection of critical areas by considering key areas for watershed processes.
- Evaluate the effect of future land use on watershed processes.

This type of information will provide an understanding of the most appropriate areas for effective protection and restoration, and how existing or future land uses, both within and outside particular jurisdictional boundaries, may alter watershed processes.

Additionally, this guidance will allow local governments to develop Critical Area Ordinances (CAO's) that are specifically tailored to local environmental conditions and problems. Presently, most local governments adopt regulations for critical areas that propose a relatively standard set of provisions for protecting the resource or mitigating impacts. For example, mitigation ratios and buffer widths for wetland resources may be set according to the wetland category as set forth in state guidance documents. Site-specific mitigation based on general guidance does not allow decisions to be based on maintaining the processes that drive the wetland or aquatic ecosystem.

Application of this framework to the development of CAO's would allow jurisdictions to identify:

- both existing and future local or regional environmental problems that would affect aquatic resources
- higher priority areas where actions would be most effective in addressing these local/regional environmental problems.

This information could result in the identification of key areas for mitigation that would allow the establishment of innovative measures such as mitigation banks. Such an approach would result in more flexibility for the development community and greater assurance that aquatic resources are being protected or restored over the long term.

Shoreline Management Act. The Shoreline Management Act (SMA)states that "shorelines of the state are among the most valuable and fragile of its natural resources and that there is great concern throughout the state relating to their utilization, protection, restoration, and preservation." Similar to the stated purpose of the GMA, the SMA goes on to state that there is "a clear and urgent demand for a planned, rational, and concerted effort, jointly performed by federal, state, and local governments, to prevent the inherent harm in an uncoordinated and piecemeal development of the state's shorelines."

Ecology adopted new Shoreline Master Program Guidelines in 2003 that require jurisdictions to incorporate information on the physical, chemical, and biological processes and functions that drive shoreline resources.

The new guidelines implement the policy of the Shoreline Management Act for the protection of shoreline natural resources through the protection and restoration of ecological functions and ecosystem-wide processes necessary to sustain these natural resources. The guidelines specifically state that effective management of shorelines depends on sustaining the functions provided by: (1) **ecosystem-wide processes** (i.e., flow and movement of water, sediment, and organic materials and movement of fish and wildlife); and (2) individual components and localized processes such as those associated with shoreline vegetation, soils, and water movement through the soil and across the land (WAC 173.26.201(2)(c)).

Further, the new guidelines require that SMP policies and regulations ensure "no net loss" of ecological functions necessary to sustain shoreline ecosystems. Updated SMPs must regulate new development in a manner that is protective of existing ecological functions and provide policies that "promote restoration of impaired ecological functions" (WAC 173.26.201(2)(c) and (f)).

Because the shoreline guidelines contain many of the same landscape principles that are addressed by this document, the methods presented for describing and mapping key areas for watershed processes can be useful to local governments updating their SMP. Specifically, under the new guidelines these methods can be used to:

- Conduct the characterization of ecosystem-wide processes (WAC 173.26.201(3)(d)(i)).
- Identify areas appropriate for restoration and protection as part of the restoration plan element (WAC.173.26.201(2)(f)).
- Identify land use designations and development standards that protect ecosystem-wide processes (WAC 173.26.201(3)(f)).
- Meet "no net loss" requirements while allowing for mitigation flexibility (WAC 173-26-186(8) and 173.26.201(3)(d)(i)(E).
- Address cumulative impacts in developing master programs (WAC 173.26.201(3)(d)(iii).

For more information on the updated SMP guidelines, see: http://www.ecy.wa.gov/programs/sea/SMA/index.html

3. Other approaches

Various methods have been developed to analyze individual aquatic resources and the nearby landscape in which they occur. The methods for analyzing the functions and characteristics of individual wetlands have been extensively tested in the State (Hruby et al. 1999, 2000, Hruby 2004a, b). Appendix A-2 of Granger et al. (2005) also discusses other methods that have been used to analyze individual wetland sites. Methods for analyzing specific stream reaches have been developed by natural resources agencies (e.g., NOAA's properly functioning conditions). However, methods for analyzing the larger geographic scales are only starting to be developed and applied in Washington.

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