# Protecting Aquatic Resources Using Landscape Characterization: A Guide for Puget Sound Planners

**Draft for Review**

May 2005

Ecology Publication #05-06-013

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This document is available on the Department of Ecology web site at
http://www.ecy.wa.gov/

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# Acknowledgements

The production of this document would not have been possible without the generous contribution of time and energy by numerous individuals. In particular we wish to thank several Ecology employees within the Shorelines Program: Andy McMillan, for his vision and commitment in supporting the landscape approach as an effective way to protect aquatic resources in the State of Washington; Jeannie Summerhays, for her tireless efforts to help create and support the establishment of a landscape program at Ecology; Tom Hruby, for his invaluable scientific insights and careful editing of the document; Patricia Olson, for her thorough review of the methods for characterizing the processes of water flow, sediment and large woody debris; Lauren Driscoll, for her expert review and comments on the drafts and continued support and encouragement for the landscape approach; and Richard Robohm, for providing timely and essential comments that greatly improved this guidance.

Whatcom County Planning played a major role in bringing this guidance to fruition. We are indebted to Hal Hart and Jeff Chalfant for their continued support for applying a “landscape approach” to their Shoreline Plan update, and to Peter Gill for his technical input and exceptional GIS skills. Input on the landscape approach from the Whatcom County SMP Technical Advisory Committee has also assisted greatly in the evolution of this guidance.

We are extremely grateful to Margaret Clancy, Chip Maney and David Sherrard of Parametrix for their patient application of the emerging methods to the Whatcom County Shoreline Plan update. Their scientific and planning expertise coupled with their application of and feedback on the methods was tremendously useful in developing this draft document.

Joseph Jones and Sue Kahle, of the USGS, were instrumental in evaluating our early concepts for this document and helping us formulate its overall scientific framework.

We are also indebted to Dick Gersib for his pioneering work in this field which established the foundation at Ecology for developing this guidance.

The funding of the work for this document was made possible by the EPA and Puget Sound Action Team. We wish to thank Linda Storm, of the EPA, and Doug Meyers, of the Puget Sound Action Team, for recognizing both the value of and need for taking a landscape approach to protecting our aquatic ecosystems within the state of Washington.

# Preface

To sustain aquatic ecosystems we must take a holistic, comprehensive approach. This means consideration of environmental factors outside of the currently accepted "human defined" boundaries of aquatic systems. These boundaries (i.e. based on scientific classification schemes) have boxed aquatic systems into convenient categories such as bogs, lakes, streams, marshes, rivers, salt marshes, and marine shorelines. As a result of these defined boundaries, our laws have evolved primarily to protect each of these categories in isolation from the whole. In implementing these laws we have found that many of our efforts to protect and manage aquatic resources have been unsuccessful.

Continuing scientific research has revealed that these aquatic systems represent a "continuum" across the landscape. It has become clear that they are all driven and controlled by similar environmental factors. These environmental factors exist, to a large degree, outside of the boundaries of our defined aquatic resources. We now understand that our unsuccessful protection/management efforts are in large part due to a lack of consideration of these environmental factors.

The Washington State Department of Ecology has now incorporated the concept of "holistic" management of aquatic resources into Volumes 1 and 2 of "Best Available Science" for freshwater wetlands. It is termed the "landscape approach." A four step "framework" for adaptive management, including analysis and characterization of resources, prescribing solutions, taking action, and monitoring, was proposed for wetlands (see Figure I-1).

This guidance document expands on the first two steps of this framework by describing a landscape approach to these steps. It applies to all freshwater aquatic resources, but does not yet address marine shorelines. Specific guidance is provided for the first step (analysis and characterization). For the second step, specific examples are provided of how to apply the characterization results to a variety of planning efforts (non-governmental and governmental).

Unless specified otherwise, use of the term "framework" in this document will refer to all elements of this guidance including analysis and characterization steps, scoping, application of results and planning examples.

# I. Introduction

The purpose of this document is to provide guidance to planners on how to protect aquatic resources by integrating information about landscape processes into planning and regulation (e.g., comprehensive plan updates, site specific plans, land use plans). The Washington State Department of Ecology developed this framework with input from a variety of other professionals in aquatic resources and hydrology.

A characterization of ***landscape processes*** provides a way to understand environmental processes that occur at larger geographic scales, their relationship to aquatic resources, and how they have been altered by human activities. This understanding will help select measures needed to maintain and protect those resources.

***Landscape Processes*** - In this document, this term refers to dynamic environmental factors that form and maintain the landscape at larger geographic scales such as basins, sub-basins, and watersheds. These processes include the input, movement, and loss of water, sediment, nutrients, pathogens, toxicants, and energy or heat.

The interaction of landscape processes with the physical environment creates specific geographic locations where groundwater is recharged, flood waters are stored, stream water is oxygenated, sediment is deposited, pollutants are removed, and wetlands are created.

Although biota often affect these interactions, we do not address this relationship here. We hope to explore this in the future in collaboration with the Washington State Department of Fish and Wildlife.

This document describes one way that local jurisdictions can analyze the landscape and its aquatic resources within an adaptive management framework to planning. Figure I-1 provides a general outline of this larger framework (adapted from Granger et al, 2005). This document addresses how to accomplish the analysis and provides suggestions on how to begin prescribing solutions.

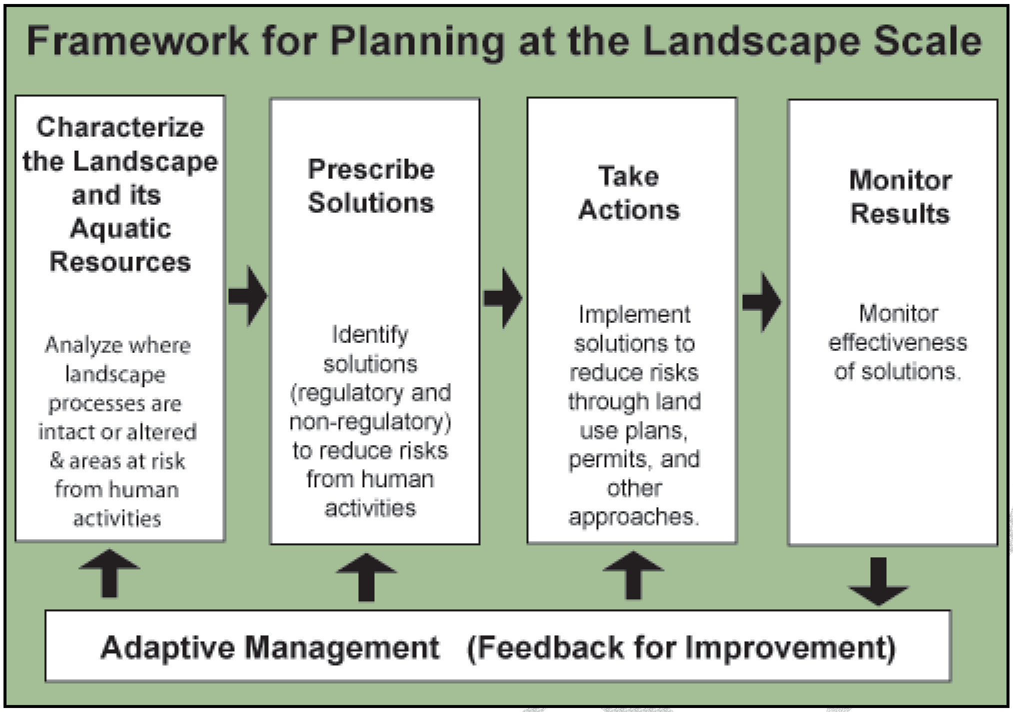


**Figure I-1. A general framework for planning at the landscape scale.** This represents a suggested framework that local governments could use in protecting and managing aquatic resources through land use planning.

## A. Why integrate information on landscape processes into plans for protecting and managing aquatic resources?

### 1. Importance of landscape processes

The management and/or regulation of aquatic resources typically concentrate on the biological, physical, and chemical characteristics of those resources and not the larger scale environmental processes that control these characteristics.

In the Pacific Northwest larger-scale processes (landscape processes) important to aquatic resources have been grouped into five broad categories (Naiman et al. 1992). They are the movement of:

1. water (surface and subsurface);
2. sediment;
3. nutrients and other chemicals (salts, toxic contaminants);
4. large woody debris; and
5. energy (in the form of sunlight).

These processes interact with landscape features, climate, and each other to produce the structure and functions of aquatic resources (e.g. such as habitat) that society is interested in protecting (Kaufman et al. 1997; Beechie and Bolton 1999). This “process-structure-function” model is depicted in Figure I-2 and described in more detail by Beechie and Bolton (1999), Gersib (2001), and Stanley and Grigsby (2003). Even though many of these processes operate far from aquatic resources, they are essential to forming the structure and maintaining the functions provided by aquatic systems.

The “process-structure-function” model assumes that changes in land use affect processes such as the delivery of water, nutrients, sediment, and toxics to aquatic systems (Poiani et al. 1996; Mallin et al. 2000). These in turn affect structure and functions within the aquatic systems.

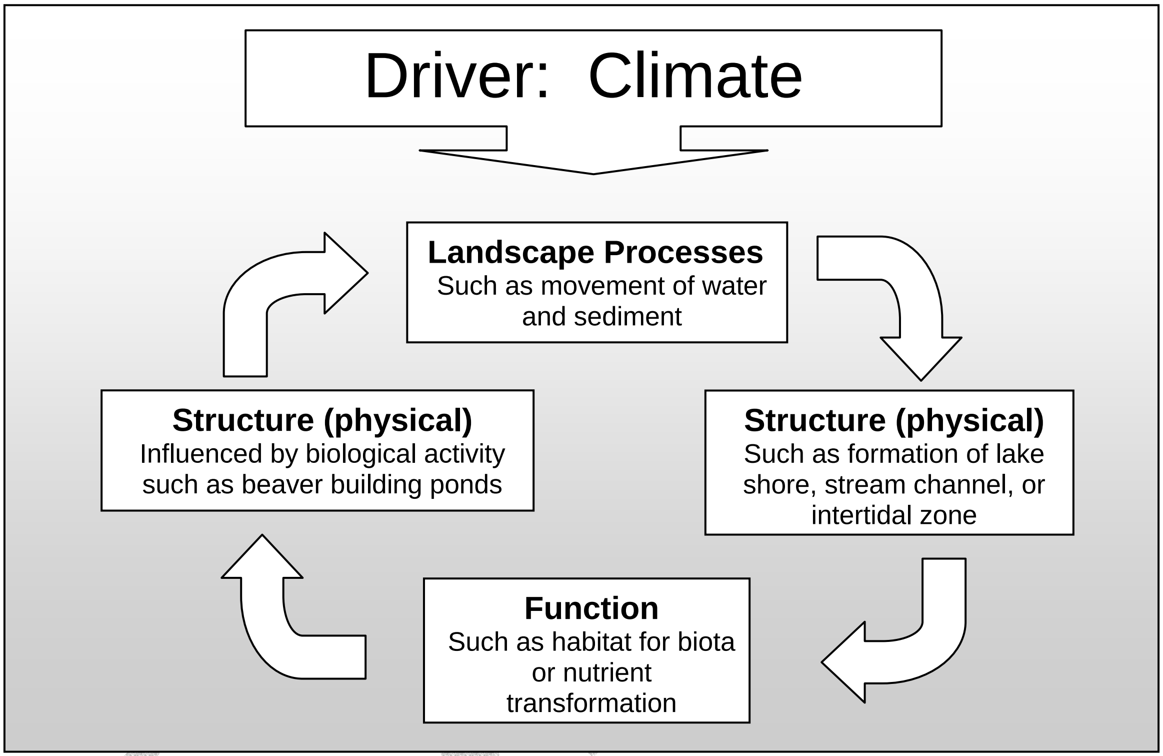


**Figure I-2. The relationship between landscape processes and the structure and function of aquatic resources.** Landscape processes such as sediment or water movement create and maintain a variety of aquatic resources, each with a different physical structure. These differences in structure affect the types of functions performed by given resources. Sometimes those functions in turn alter the structure, which then feeds back into altering the landscape processes themselves.

This guidance does not present methods for assessing the functions of individual aquatic sites. There are many ongoing efforts to develop tools for analyzing individual sites. For example, more information on how to assess functions in wetlands is found in the Department of Ecology’s *Methods for Assessing Wetland Functions* (Hruby et al, 1999 and Hruby et al, 2000). Additionally, Volumes 1 and 2 of “Wetlands in Washington State” provide a detailed discussion of wetland functions and the environmental factors that control functions and how human disturbances affect these functions (Sheldon et al, 2005 and Granger et al, 2005).

***Processes, Structure and Function***

***Processes*** – dynamic environmental factors that cause changes to occur in the structure and function of aquatic resources. Processes occur at the scale of both the larger landscape and individual sites. This guidance deals primarily with processes at the larger scale (e.g., the input, movement, and loss of water, sediment, nutrients, toxicants, pathogens, large wood debris, and energy).

***Structure*** – the physical, biological, chemical, or geologic features of the ecosystem at a site (e.g., percent open water or area of forest in a wetland; the number of pools or pieces of wood within a 2 mile reach of stream).

***Function*** – physical, chemical, biological, and geologic interactions among different components of the environment that occur within the aquatic resource. (e.g., nutrient filtering, flow moderation, habitat)

## 2. Successful management of aquatic resources requires an understanding of processes

Managing natural resources and developing plans for future uses of the land require consideration of environmental processes and conditions at multiple scales (Gersib 2001; Gove et al. 2001; Poiani et al. 1996; Dale et al. 2000). Unfortunately, information about larger-scale processes has rarely been integrated into land-use planning. This is in part because our understanding of the relationship between the processes and the resources being managed is not as precise as we would like. Additionally, until recently, methods have not been available to facilitate such integration. It is now clear that these larger-scale processes are critical for supporting natural resources and that ignoring them in planning may leave natural resources unprotected (Dale et al. 2000; Sheldon et al. 2005).

Since the 1970's aquatic resources have been managed primarily at the site scale with little consideration of the external factors that affect their functions. Wetlands researchers have concluded, however, that a "site scale" management of aquatic resources through the regulatory process has compromised the effectiveness of mitigation efforts and does not successfully address many of the true causes of impairment (Mitsch and Wilson 1996, Preston and Bedford 1988, Buffington et al, 2003; Beschta ). Reid (1998) has reported that specific restoration projects fail because managers neglect to look beyond the symptoms at the site scale and evaluate them at a larger scale. Similarly, Frissell and Ralph (1998) conclude that restoration efforts are hampered by a clear understanding of how human activities have altered processes operating at the watershed scale.

A growing number of studies and review panels have emphasized the need to manage aquatic resources by including an understanding of key landscape processes and how they have been altered (Dale et al. 2000; Bedford and Preston 1988; Detenbeck et al. 2000; Roni et al. 2002; Buffington et al. 2003). The National Research Council (2002) suggests that restoration should focus first on restoring altered processes. Similarly, Hidding and Teunissen (2002) suggest focusing land use planning on preventing fragmentation of key processes, particularly those related to the movement of water. In response, scientists, land use managers, and regulators are now trying to incorporate environmental processes into their management of aquatic resources through a watershed or landscape approach.

***Using the appropriate geographic scale for analysis*** – Planners must consider not only the factors that are critical to maintaining ecosystems but also the scale that is most relevant or appropriate (Poiani et al, 1996). Sometimes these factors operate at the site scale and sometimes at a larger landscape scale. Understanding the aquatic resources and the key processes maintaining them helps to identify the appropriate scales for analysis and for managing and protecting the resource.

## 3. Tools for analysis across larger scales

Tools such as ***landscape characterization*** and ***risk assessment*** are being developed to facilitate integration of information on larger-scale processes into management, restoration, and protection. These tools identify the processes within the landscape that are critical to a particular aquatic resource, the areas on the landscape that are important to the operation of these processes, and how much these areas have been, or are likely to be, altered by human activities. They provide an understanding of where processes likely need restoration and where they likely are still intact. This allows for the development of more environmentally sustainable land use plans. If an area still supports a critical process, plans can define the type, location, and amount of development that can occur without impairing the processes.

A landscape characterization in conjunction with a r**isk assessment** provides the tools needed to integrate information on larger scale processes, complete with their uncertainties, into decision making and planning (Granger et al. 2005, Gentile et al, 2001; Bedford and Preston, 1988). The goal is to minimize the risks to the resource that result from human activities.

This approach provides either quantitative or qualitative predictions of the risk posed by various human activities to natural resources. The fundamental component of these tools is the conceptual model that describes the relationships between landscape features, human activities, and the condition of natural resources. Relationships that are understood in depth are described quantitatively, while those that are less well understood are described qualitatively. Policy decisions or land-management plans are based on predictions of the risk posed by different land uses or management actions. As scientific understanding improves and these predictions are tested, they can be refined through the approach called “adaptive management” (for more information see Chapters 10 and 12 in Granger et al. 2005).

***Dealing With Uncertainty*** – Often our understanding of processes and environmental factors at larger geographic scales is not as certain, defined, or conclusive as it is at individual sites. This results in a degree of "uncertainty" that is inherent in planning at larger scales. This is due to the following:

- Information and data a about landscape processes is not as detailed as that available at the site level.
- The processes that maintain the resources of concern are complex and operate over a much larger area and therefore the analyses are not as detailed as those done at the site-scale
- It is not possible to monitor all the major processes over sufficiently large areas and for adequate lengths of time to fully understand the interactions between processes and the aquatic resources they affect.

The risk management approach provides a means of integrating the understanding that we do have of landscape processes into regulations and plans. Adaptive management provides a means of ensuring our understanding evolves and that this uncertainty is reduced.

## B. What is this framework?

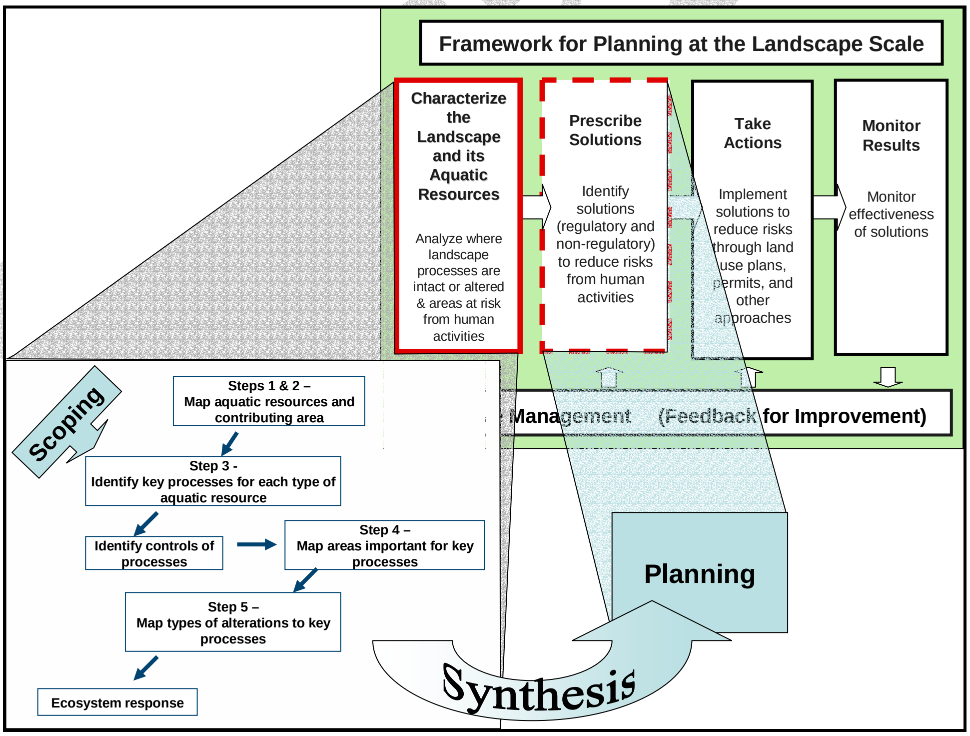


**Figure I-3. How this framework fits in planning**. The relationship between the landscape characterization presented in this document and a generalized framework for planning at a landscape scale (first presented in Figure I-1).

The framework presented in this document addresses the first two steps of the *general framework for planning at a landscape scale* that was presented as Figure I-1. The relationship between these two is shown in Figure I-3. This document presents a specific approach to accomplish the landscape analysis, which we call a characterization. A scoping phase provides direction for that analysis. The products of the analysis are synthesized to develop preliminary solutions, which can be included in the subsequent planning phase.

The Department of Ecology has developed a way to characterize landscape processes that allows planners and resource managers to incorporate such information into their work to protect aquatic resources. This characterization allows users to identify:

- the relationship between landscape-scale processes and aquatic resources within a project area or jurisdiction;
- the relative importance of different geographic areas for maintaining the key processes that underlie the integrity of aquatic ecosystems;
- the risk that various human activities pose to these processes and resources; and
- measures that are likely to maintain the key processes, and thus the aquatic ecosystems.

Ecology's five-step approach (Figure I-4) uses existing environmental data and land use information. This includes surficial geology and geologic hazards, soil types, topography, land cover and land use, water quality and quantity, and mapping of critical habitats. The approach begins with the development of a general model of the relationships between key landscape processes and aquatic resources. The geographical areas important to maintaining these processes are identified. The approach then uses specific indicators, such as land use, land cover, channelization, and road networks, to describe the degree of alteration to these processes. This information is synthesized to identify those areas important for a particular process that have been altered and those that remain intact. From this, the type of planning needed to either maintain (protect) or restore a process can be determined.

The five step characterization:

1. Map aquatic resources
2. Map area that contributes surface and ground water to aquatic resources
3. Identify key processes critical to the maintenance of the aquatic resources
4. Map areas important for sustaining key processes
5. Map type of alterations to key processes

**Figure I-4. Five steps of the landscape characterization**

## C. Why use this framework?

### 1. 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.

### 2. What does this framework offer?

The framework outlined in this guidance is designed specifically for use by NGOs and local governments managing natural resources within the Puget Sound Lowlands. In particular, it can be helpful for local governments planning under the Growth Management Act and the Shoreline Management Act. It is intended to assist in identifying patterns for future development that will sustain, rather than degrade, aquatic resources. The information generated by this guidance should allow local governments to:

- Identify and avoid development patterns that are difficult and expensive to correct;
- Reduce cost of infrastructure for future development by identifying key areas for: controlling stormwater, improving water quality, and protecting and restoring habitat;
- Streamline local permitting

Additionally, this guidance has been developed to meet the following objectives:

- Uses readily available and existing data
- Relatively easy, rapid, and inexpensive to apply
- Adaptable to local situations and can accommodate other data easily
- Produces useful results for planning
- Transparent methods that the user has control over – easy to modify as needed
- Products are easy to interpret and to share with others
- Covers multiple types of aquatic resources

### 3. How can this framework benefit planning in Washington state? (Creating a "Green Development" Strategy)

This framework can assist **planners** in meeting the planning goals for resource protection of state and local environmental laws and regulations. This includes the Growth Management Act (RCW 36.70A.060) and Shoreline Management Act (RCW 90.58). In addition it can prove 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 resources is presented in chapters 2, 6 and 7 of Granger et al (2005).

*Growth Management Act.* 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. The 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 framework presented in this guidance is ideally suited for helping local governments meet these goals in a cooperative manner since it identifies:

- landscape processes operating across jurisdiction boundaries
- linkages between landscape processes and aquatic resources
- linkages between land use activities, alteration of processes, and the response of aquatic resources;
- important areas for protection and restoration.

This type of information will provide an understanding of how existing or future land uses, both within and outside particular jurisdictional boundaries, may alter landscape processes. It can indicate how these activities negatively impact the aquatic resources that are "linked" to those processes. As a result, , it can indicate the most appropriate areas for effective protection and restoration.

Additionally, this framework 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.

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 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."

On December 17, 2003, Ecology adopted new Shoreline Management Program (SMP) guidelines 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 (SMA) for the protection of shoreline natural resources through the protection and restoration of ecological functions (and 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 (RCW 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 SMP's must regulate new development in a manner that is protective of existing ecological functions and provide policies that "promote restoration of impaired ecological functions" (RCW 173.26.201(2)(c) and (f)).

Because these shoreline guidelines contain many of the same landscape principles that are incorporated into this framework, this approach can be useful to local governments updating their SMP. The relationship between landscape processes and shoreline functions, as referenced in the Shoreline Guidelines, is presented in Appendix C. For more information on the updated SMP guidelines, see: http://www.ecy.wa.gov/programs/sea/SMA/index.html.

## D. Using this document

If you need basic information about the value of including information on landscape processes, read Section I. It answers three questions: 1) Why is it important to integrate information about landscape processes into the protection and restoration of aquatic resources? 2) What is the general outline of the approach? and 3) What advantages are offered by this approach?

If you are a planner who wants to know if this approach would be useful in your jurisdiction, focus on Sections II, III, and IV. Section II describes the overall framework developed by the Washington State Department of Ecology for analyzing landscape processes, while Section III provides the details of how to apply the method. Section IV describes how to integrate the products of this approach into planning.

If you are a planner who has decided to use this approach, Appendices A and B describe the GIS analysis that can be used to implement this framework in Puget Sound and give detailed technical justification for the indicators suggested in this region.

If you are a planner in a very urbanized and/or relatively small jurisdiction, Appendix C presents an alternative landscape approach for developed areas where protection of aquatic resources may not be feasible because they have already been severely degraded. To understand the general approach, however, you still need to read Sections II and III of this document.

If you are a technical reviewer or interested in the rationale for the indicators used in this approach, we suggest that you focus on:

- Section II – Overview of the steps and expected products
- Appendix A – Technical rationale for identifying important areas for processes (Step 4)
- Appendix B – Technical rationale for identifying alterations to processes (Step 5)
- Appendix D – Relationship between landscape processes to shoreline functions (as defined by the Shoreline Guidelines)
- Appendix E – Rationale for linking aquatic resources to key processes (Table 2)

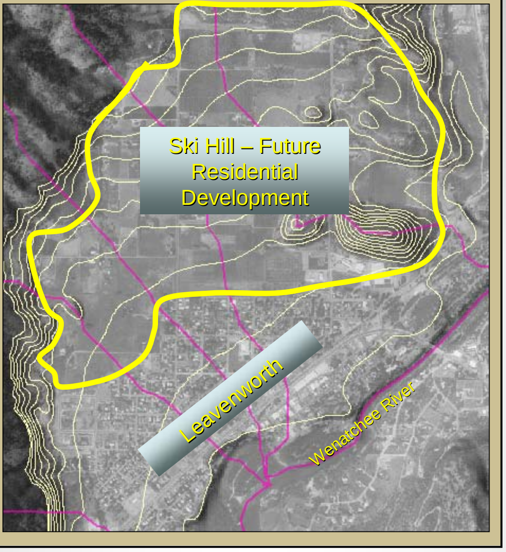
# Example of Using a Landscape Characterization.

## City of Leavenworth Flooding Problem

### Goals of Landscape Analysis

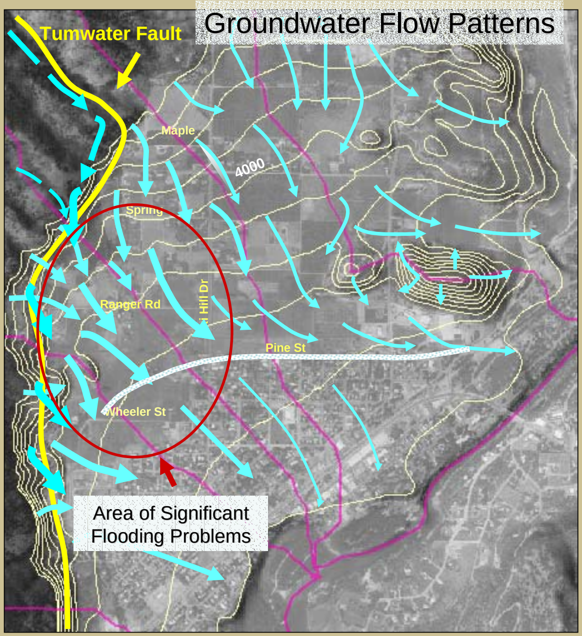
City wishes to develop a green infrastructure plan for residential development in Ski Hill. The plan must show:

- ✓ Areas most suited for development
- ✓ Areas to be protected
- ✓ Area suitable for restoration



The City of Leavenworth, in Eastern Washington, has experienced increased flooding since the early 1990's in the Ski Hill area north of the commercial core. Residents felt that the flooding was the result of increased development and clearing in the upper watershed.

In 2003 the City contacted the Department of Ecology to conduct a landscape characterization to address the flooding problem and help plan future development in the Ski Hill area.



### Conclusions:

1) A wetter climate cycle starting in early 1990's increased overall subsurface and subsurface flows.

2) Area of significant flooding is also an area of higher groundwater discharge caused by groundwater moving along fault zone.

3) Surface flooding increased by combination of ditches, foundations intercepting groundwater and converting to surface flows

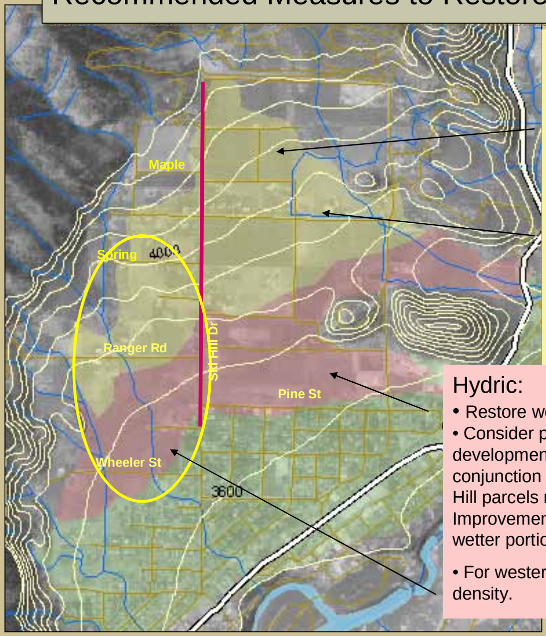
4) Historic groundwater flows along Pine Street morain have been altered

Using the methods described in this guidance for surface and ground water processes, Ecology conducted a landscape characterization requiring approximately one week's time. This included review of existing studies, a field visit with a local hydrogeologist, and some analysis of existing data layers. From this analysis it was concluded that the apparent increase in flooding was most likely due to a wetter climatic cycle in combination with probable historic water flow patterns. The analysis suggested that a fault zone acts as a conduit for groundwater moving from several sub basins creating significant discharge in a localized area.

**Figure I-5. Example of using a landscape characterization – City of Leavenworth**.

# City of Leavenworth Flooding Problem

## Recommended Measures to Restore Water Flow Processes



Older Alluvium :

- Eliminate ditching & develop measures to facilitate recharge of surface flows into alluvium (See C St. Design in Seattle):
- Eliminate or redesign features (i.e. basements, french and curtain drains, ditching) in new construction that interrupt groundwater flow and create surface flow (See above).
- Deep till or rip soils and plant areas with native shrubs and trees. Soil has developed shallow compacted layer due to farming.

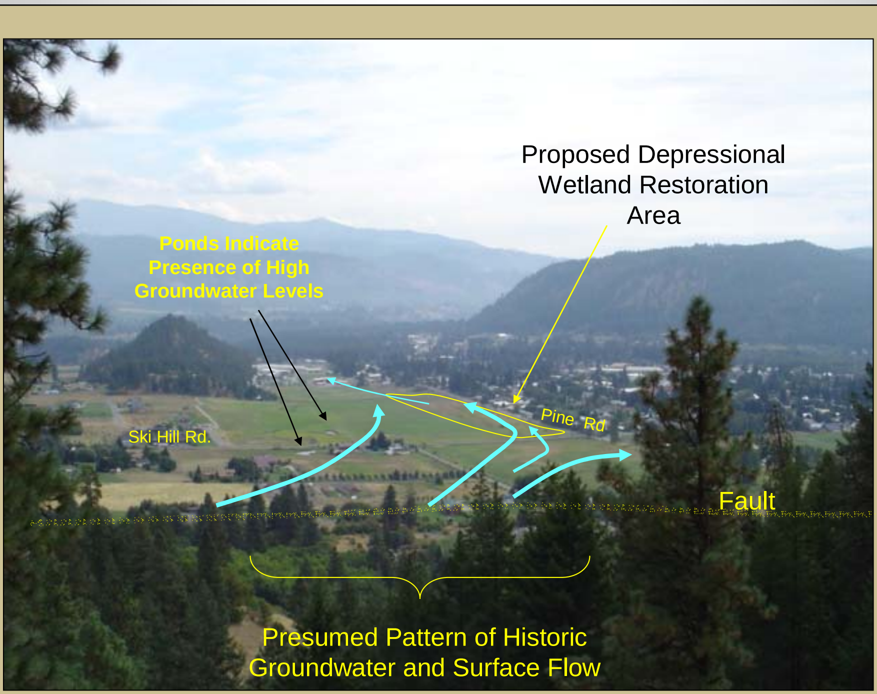
Hydric:

- Restore wetlands in wetter areas
- Consider protective measures such as transfer of development rights or conservation easements in conjunction with a system of in lieu fees on other Ski Hill parcels not affected (e.g. form a Local Improvement District) to compensate land owners in wetter portions.
- For western portion consider lower development density.

The analysis also identified development options, restoration measures, and a potential wetland for restoration that could reduce flooding.

On the basis of this landscape analysis the City wrote a grant for incorporating this information into a green infrastructure plan for the Ski Hill area.

A grant was awarded to the City by CTED in 2004 and the City is presently in the process of hiring a consultant to develop a green infrastructure plan.



View of Proposed Restoration Area (Looking Southeast From Tumwater Mtn.)

**Figure I-5. Cont.**

# II. Overview of the approach to characterize landscape processes

This section describes the approach to characterize landscape processes, its purpose, and a broad overview of its application within any area of the state. Specific details for applying this approach in the glaciated Puget Sound region are presented in Section III. Section IV includes general suggestions for incorporating the results of the approach into a range of planning efforts.

## A. Purpose

This approach to characterize landscape processes has been designed to integrate our current knowledge and understanding of landscape-scale processes into plans for the protection and restoration of aquatic resources. The method has been developed to meet the following goals:

- *Be easily adaptable for use in other regions:* This document provides specific details for application of this framework in the glaciated portion of Puget Sound but the framework itself can be used in any region.
- *Be flexible in the types and complexity of data that can be used in the analysis:* The discussion in this document is centered on indicators that are generally valid throughout the glaciated Puget Sound region. More local, detailed information, however, can easily be integrated into the framework so that the analyses can be as meaningful as possible
- *Support an approach to land use planning that focuses on adaptive management:* The concepts and understanding incorporated into this approach can easily be refined and improved through a process of monitoring and adaptive management.

## B. Scoping

A scoping phase is recommended to produce meaningful results, to conduct an efficient analysis, and to facilitate the incorporation of the results into effective land use planning efforts. Initially, this phase will identify the aquatic resources of interest and the environmental problems that need to be addressed. This will focus the information gathering phase by defining the geographic extent of the analysis area and the kind of information or data that are needed. Existing reports, studies, and inventories should be used as a baseline of information. Currently available digital data should be inventoried, collected, and evaluated for usefulness.

It is advisable to identify interested parties and their roles. At a minimum, planners from affected jurisdictions within the study area should be contacted. This communication with other jurisdictions and stakeholders is essential to coordinate efforts, share information, respond to local concerns, and facilitate the use of results in local planning efforts. This group can be used to review the guidance steps, methodology, and indicator tables in this document and make any necessary additions/changes, based on local knowledge and information.

## C. Approach to characterization and analysis

The approach to characterizing landscape processes is built around three questions that are discussed in greater detail below (Figure II.-1):

i. What are the landscape-scale processes that are key to maintaining aquatic resources and their functions?
ii. Which geographic areas on the landscape are important for maintaining each key process?
iii. Have the important areas already been altered by human activities such that the key processes are impaired?

Addressing these three questions sets the stage for developing landscape-scale plans for restoring and protecting aquatic resources. After the key processes have been identified the method identifies the areas on the landscape that play an important role in how those processes operate. Subsequently, those important areas are analyzed to determine whether they can still support the key processes or whether they are in need of restoration. Similarly, these important areas and their relationship to aquatic resources can be used to guide how new areas are developed and the conditions that are placed upon future development activities (Figure II.-1)

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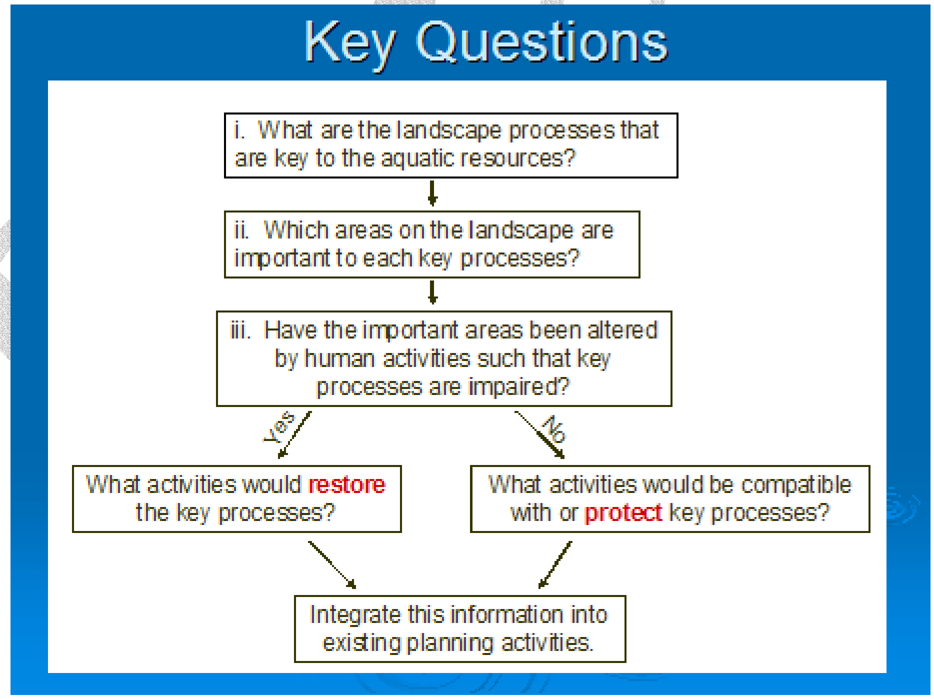


**Figure II.-1. Key Questions of the landscape characterization.** Three questions serve as the basis for integrating information on landscape processes into the restoration and protection of aquatic resources.

## i. Which landscape processes are key to aquatic resources?

In the Pacific Northwest, aquatic resources can generally be divided into six different types, based on their hydrogeomorphic (HGM) characteristics (Table 1). Using this approach, the full suite of aquatic resources within the watershed(s) is identified based on physical characteristics (geomorphology, soils) that would support their formation. This allows for the identification of *potential* aquatic resources – those that would exist naturally but that may not currently exist due to human activities. Marine ecosystems, which are clearly important in Puget Sound, are not addressed in these methods. Efforts will begin in the near future to develop a similar approach to support planning for the restoration and protection of marine resources.

**Table 1: Types of aquatic resources based on their hydrogeomorphic (HGM) characteristics**.

| **Aquatic Resource** | **Description** |
|---|---|
| Riverine | All aquatic resources within the floodplain of rivers and streams (including, but not limited to, riverine wetlands, riparian areas, overflow channels, old oxbows, streams, depressional wetlands, etc). |
| Estuarine | All aquatic resources within the tidally influenced area of rivers/streams and area of mixing of marine waters and freshwater. |
| Marine | The aquatic resource found in marine (salt) waters outside the area of mixing with freshwater (estuarine). This includes the oceanic, intertidal and subtidal habitats. |
| Lacustrine | The aquatic resource associated with lakes greater than 20 acres in area or more than 7 feet deep. It includes lakes, reservoirs, and wetlands found along the shorelines. |
| Depressional Wetland | All aquatic resources associated with topographic depressions |
| Slope Wetland | All aquatic resources that occur on a slope associated with groundwater discharge or surface flow. |

*Flats wetlands may occur in the Puget Lowlands, but because they encompass a limited area, they are not dealt with in this document.

Each of these aquatic resources is maintained, to varying degrees, by a suite of processes that occur at the landscape scale (Table 2). In order to integrate current understanding of these processes into protection and restoration efforts, it is important to focus on those processes that are both fundamental to maintaining the resource and also likely to be altered by human activities. These criteria can be used to focus the analysis to a limited number of key processes. The importance of the processes to each type of aquatic resource and the likely response of the resource to changes in these processes are detailed in Appendix E. Although the discussion that follows focuses upon the specific set of processes highlighted in bold in Table 2, users of this method should verify these conclusions for their specific planning area and modify this list based on local knowledge, local studies and information.

**Table 2. Landscape processes that maintain aquatic resources in the Puget Sound Lowlands.** Processes in bold are those that are both critical to sustaining the aquatic resources and are also likely to be altered by human activities. These are the processes addressed by this characterization. Climate affects all processes but is not included as it operates at a scale larger than the region.

| **Aquatic Resource** | **Key Landscape Processes** |
|---|---|
| Riverine | **Surface water runoff**<br>**Groundwater movement**<br>**Sediment delivery and removal**<br>**Phosphorus delivery and removal**<br>**Nitrogen delivery and removal**<br>*Mammalian pathogen delivery and removal*<br>**Toxin delivery and removal**<br>**Large woody debris delivery and removal** |
| Estuarine | *Tidal range*<br>*Salinity gradient*<br>*Sediment delivery and removal*<br>*Phosphorus delivery and removal*<br>**Nitrogen delivery and removal**<br>**Mammalian pathogen delivery and removal**<br>**Toxin delivery and removal**<br>*Large woody debris delivery and removal* |
| *Marine* | *Not yet developed* |
| Lacustrine | *Surface water runoff*<br>*Groundwater movement*<br>*Sediment delivery and removal*<br>**Phosphorus delivery and removal**<br>**Nitrogen delivery and removal**<br>*Mammalian pathogen delivery and removal*<br>**Toxin delivery and removal** |
| Depressional wetland | *Surface water runoff*<br>**Groundwater movement**<br>*Sediment delivery and removal*<br>**Phosphorus delivery and removal**<br>**Nitrogen delivery and removal**<br>*Mammalian pathogen delivery and removal*<br>**Toxin delivery and removal**<br>*Large woody debris delivery and removal* |
| Slope wetland | **Groundwater movement** |

### ii. Which geographic areas are important for each key process?

Successful management of aquatic resources requires identifying the geographic areas of the landscape that are important for maintaining the key environmental processes. Plans for future land use need to outline development and management scenarios that will ensure these important areas remain protected from degradation even with future development. The relationships between the key processes and these important areas can also guide the identification of restoration locations and options.

Using the relationships between landscape features and environmental processes, areas on the landscape can be highlighted that are likely to be important for sustaining each key process (Table 3). The dynamics of the key landscape processes can be described in terms of the input, movement, and loss (or removal) of environmental factors such as groundwater, surface water, sediment, nutrients, mammalian pathogens, toxins, and large woody debris (Table 3, column 1). The input, movement and loss component of each process is governed by a suite of environmental controls (Table 3, column 2). These controls are often associated with specific features on the landscape that can be mapped (e.g. depressional wetlands, permeable surficial deposits, or steep gradients). The geographic location of these specific features is used to identify the places that are more likely than others to be important to the dynamics of a specific process (Table 3, column 3).

Controls that are addressed in this guidance for the Puget Sound Basin are highlighted in bold in Table 3. There are several reasons that the other controls are not included in this guidance. First, several of them are not likely to be altered by local human activities (e.g. precipitation patterns and gradient). Secondly, some controls are dependent on others, and thus not repeated. For example, since surface and groundwater movement are addressed separately as key processes, they are not repeated in the nutrient or large woody debris sections. Thirdly, no regionally reliable relationships between landscape features and the control could be found. Finally, the important areas for inputs of phosphorous, nitrogen, pathogens, and toxins are the entire "contributing area" or watershed; as this is a large area and does not help to refine an area of focus, these are not mapped. These inputs are addressed in more detail when process alterations are identified.

Although the discussion that follows focuses upon the specific set of controls highlighted in bold in Table 3, users of Ecology's approach should verify that these are appropriate for their planning area. Modifications should be made if local data, knowledge, or other studies indicate the general guidance is not appropriate. The technical justification for identifying these important areas and the specific GIS methods for mapping them are presented in Appendix A.

**Table 3: The important areas for each key process, in terms of the "input, movement, or loss" of specific environmental factors and the major controls of the process.** Controls highlighted in **bold** are the focus of this document. Those not in bold: (a) are not readily altered by human activities at a local scale; (b) are addressed by another key landscape process; or (c) did not have regionally reliable relationships with landscape features.

| Key Landscape Process | | Major controls of process | Important areas for process |
|---|---|---|---|
| Surface water runoff | *Input* | Precipitation[a] | |
| | | Groundwater discharge[b] | |
| | *Movement* | **Snowmelt/runoff** | **Rain on snow zones** |
| | | **Surface storage** | **Depressional wetlands**<br>**Lakes**<br>**Floodplains** |
| | *Loss* | Evapotranspiration[c] | |
| | | **Recharge** | **Areas with soils of low water yield on permeable surficial deposits** |
| Groundwater movement | *Input* | **Recharge** | **Areas with soils of low water yield on permeable surficial deposits**<br>**Areas with higher rainfall** |
| | *Movement* | **Storage capacity** | **Deep surficial deposits of permeable material** |
| | *Loss* | **Discharge**[c] | |
| Sediment delivery and removal | *Input* | **Soil erosion** | **Steep slopes with erodible soils** |
| | | **Mass wasting** | **Hazard areas for shallow, rapid landslides** |
| | *Movement* | Surface water flow[b] | |
| | | Gradient[a] | |
| | *Loss* | **Water velocity** | **Depressional wetlands**<br>**Floodplains** |
| Phosphorus delivery and removal | *Input* | **Natural sources** | **Contributing area** |
| | *Movement* | Surface water flow[b] | |
| | *Loss* | **Water velocity** | **Depressional wetlands** |
| | | **Adsorption** | **Wetlands with organic soils** |
| Nitrogen delivery and removal | *Input* | **Natural sources** | **Contributing area** |
| | *Movement* | Surface/ground water flow[b] | |
| | *Loss* | Plant uptake[c] | |
| | | **Denitrification** | **Hyporheic areas**<br>**Seasonal wetlands**<br>**Wetlands with organic soils**<br>**Riparian areas with shallow groundwater** |
| Mammalian pathogen delivery and removal | *Input* | **Wildlife** | **Contributing area** |
| | *Movement* | Surface water flow[b] | |
| | *Loss* | **Water velocity** | **Depressional wetlands with mineral soils** |
| Toxin delivery and removal | *Input* | **Natural sources** | **Contributing area** |
| | *Movement* | Surface water flow[b] | |
| | *Loss* | Chemical precipitation[c] | |
| | | Biological transformations[c] | |
| | | **Adsorption** | **Wetlands with organic soils** |

*Table 3 continued*

| | | | |
|---|---|---|---|
| Large woody debris delivery and removal | *Input* | **Stream bank erosion** | **Unconfined channels where mass wasting is unlikely** |
| | | **Mass wasting** | **Channels adjacent to mass wasting hazard areas that are likely to deliver debris to the stream** |
| | | **Windthrow** | **100’ on either side of channels where mass wasting is unlikely** |
| | *Movement* | Surface water flow[b] | |
| | | Gradient[a] | |
| | *Loss* | Breakage/decomposition[c] | |

### iii. Have the important areas been altered by human activities such that the key processes are impaired?

Areas on the landscape that are important for each key process warrant further attention in a management plan to ensure that the process is either maintained or restored. In this next stage, an analysis is made of the degree to which these areas have been altered and the related process has been impaired. Those areas that have been altered could be considered candidates for restoration while those that remain unaltered could be candidates for protection.

Human activities can degrade the key processes, particularly if they occur in an important area and impair a control of the process (Table 4, column 4). The response of aquatic resources to changes in a key process can serve as a good indicator that a process has been altered if the response has been monitored and is known. However, not every key process is monitored and usually only those resource responses that interfere with human activities are well known and noted. This absence of information can be overcome by using recent research that links landuse and other indicators to alterations of landscape processes (Table 4, column 5).

Using these relationships, it is possible to identify areas where the processes have likely been impaired and restoration may be warranted. The same relationships can be used to make some associations between future land uses and the likely changes in key processes. Guidance can be developed to ensure that the role of an important area is maintained and future degradation of key processes is prevented.

Technical justification for indicators of process alteration in the Puget Sound Basin is provided in Appendix B. However, more specific information will likely exist within particular areas of the state. Users of this approach should verify the contents of Table 4 for their region, and modify as needed for their specific project area based upon local knowledge, studies, and data.

**Table 4: Summary of "important areas", alterations caused by humans, and indicators of these alterations used in this method**. The first two columns are the same as in Table 4. See Table A-1 in Appendix A for the rationale underlying identification of important areas; see Table B-1 in Appendix B for rationale underlying the choice of indicators of alteration. Not all indicators of human alteration are included: indicators listed are those for which adequate documentation exists and data layers are readily available. * indicates local data required; @ indicates an indicator of the cumulative effects of alterations; (-) indicates that the alteration reduces the control; (+) indicates that the alteration increases the control.

| **Key Landscape Process** | | **Major controls of process** | **Important areas where process is controlled** | **Human alteration of process** | **Indicators of process alteration** |
|---|---|---|---|---|---|
| Surface water runoff | *Movement* | Snowmelt/runoff | Rain on snow zones | Forest cover removed | Non-forest land cover (+) |
| | | Surface storage | Depressional wetlands<br>Lakes<br>Floodplains | Streams disconnected from floodplains | Dikes or levees* (-)<br>Straightline hydrography in streams (-) |
| | | | | Depressional wetlands filled or drained | Straightline hydrography in depressional wetlands (-)<br>Loss of depressional wetlands in the watershed (-) |
| | | | Contributing area | Damming of rivers | Dams (+) |
| | *Loss* | Recharge | Areas with soils of low water yield on permeable surficial deposits | Construction of impervious surfaces – roads, roofs, sidewalks | Impervious land cover (-) |
| Groundwater movement | *Input* | Recharge | Areas with soils of low water yield on permeable surficial deposits<br>Areas with higher rainfall | Construction of impervious surfaces – roads, roofs, sidewalks | Impervious land cover (-) |
| | *Movement* | Storage capacity | Deep surficial deposits of permeable material | Groundwater pumping | Land use –varies (-)<br>Well locations* (-)<br>Reduced baseflow*$^{@}$ (-) |
| | *Loss* | *Locally determined* | | | |

***Table 4 continued:***

| **Key Landscape Process** | | **Major controls of process** | **Important areas where process is controlled** | **Human alteration of process** | **Indicators of process alteration** |
|---|---|---|---|---|---|
| Sediment delivery and removal | *Input* | Soil erosion | Steep slopes with erodible soils | Native vegetation removed | Non-forest land cover (+) |
| | | | Contributing area | Soil disturbance and clearing<br>Roads built near streams | Row crop landuse draining to aquatic resources* (+)<br>New construction draining to aquatic resources* (+)<br>Roads within 200' of streams (+)<br>High turbidity loads*[@] (+) |
| | | Mass wasting | Hazard areas for shallow, rapid landslides | Roads built in mass wasting hazard areas | Roads in mass wasting hazard areas (+) |
| | *Loss* | Water velocity | Depressional wetlands | Depressional wetlands filled or drained | Straightline hydrography in depressional wetlands (-)<br>Loss of area of depressional wetland (-) |
| | | | Floodplains | Disconnection of floodplain from river channel | Dikes and levees* (-)<br>Straightline hydrography of streams (-) |
| | | | Contributing area | Damming of rivers | Dams (+) |
| Phosphorus delivery and removal | *Input* | Natural sources:<br>Weathering of rock<br>Dust and precipitation | Contributing area | Application of fertilizer, dairies | High BOD and low DO * (+)<br>Algal blooms* (+)<br>High phosphorus loads*[@] (+) |
| | *Loss* | Water velocity | Depressional wetlands | Depressional wetlands filled or drained | Loss of area of depressional wetlands (-)<br>Straightline hydrography in depressional wetlands (-) |
| | | Adsorption | Wetlands with organic soils | Wetlands with organic soils filled or drained | Loss of area of wetlands with organic soils (-) |

***Table 4 continued:***

| **Key Landscape Process** | | **Major controls of process** | **Important areas where process is controlled** | **Human alteration of process** | **Indicators of process alteration** |
|---|---|---|---|---|---|
| Nitrogen delivery and removal | *Input* | Natural sources:<br>Nitrogen fixing by vegetation<br>Lightning<br>Decomposition of organic matter | Contributing area | Application of fertilizers and livestock manure | Agricultural land use (+) |
| | | | | Leaky septic systems | Residential land use adjacent to water bodies (+) |
| | | | | Shifting riparian vegetation from conifers to deciduous and herbaceous species | Disturbed riparian corridors* (+) |
| | | | | | High nitrate/ammonia loads*$^{@}$(+) |
| | *Loss* | Denitrification | Hyporheic areas | Hyporheic zones degraded:<br>• Disconnection of stream waters from floodplain | Stream incision* (-)<br>Dikes and levees* (-)<br>Straightline hydrography in streams (-)<br>Urban or agricultural land cover adjacent to or in floodplain (-) |
| | | | | • Filling of hyporheic area with sediment | High fine sediment or turbidity loads * (-) |
| | | | Seasonal wetlands | Seasonal wetlands filled or drained | Loss of seasonal wetland area (-) |
| | | | Wetlands with organic soils | Wetlands with organic soils filled or drained | Loss of area of wetlands with organic soils (-) |
| | | | Riparian areas with shallow groundwater | Shallow groundwater bypasses riparian zones | Roads or straightline hydrography intercepting shallow groundwater (-) |
| | | Assimilation, sorption, denitrification | Small streams | Channelization<br>Diverting of small streams | Straightline hydrography (-) |

*Table 4 continued:*

| Key Landscape Process | | Major controls of process | Important areas where process is controlled | Human alteration of process | Indicators of process alteration |
|---|---|---|---|---|---|
| Mammalian pathogen delivery and removal | *Input* | Wildlife | Contributing area | Leaky septic systems<br>Discharge of untreated human and animal waste | Rural land use (+)<br>Impervious land cover (+)<br>Shellfish closures in estuaries*<br>High fecal coliform loads*$^{@}$ (+) |
| | *Loss* | Water velocity | Depressional wetlands with mineral soils | Streams channelized<br>Depressional wetlands with mineral soils filled or drained | Straightline hydrography in streams or depressional wetlands with mineral soils (-)<br>Loss of area with depressional wetlands with mineral soils (-) |
| Toxin delivery and removal | *Input* | Natural sources:<br>Weathering of geologic substrates | Contributing area | Additional sources of toxins:<br>Heavy metals<br>Petrochemicals<br>Pesticides<br>Herbicides | Urban landuse (+)<br>Agricultural landuse (+)<br>Contaminant levels:* (+)<br>eg: toxic levels in sediment or PCB contamination of fish |
| | *Loss* | Adsorption | Wetlands with organic soils | Filling or draining of wetlands with organic soils | Straightline hydrography in wetlands with organic soils (-)<br>Loss of area of wetlands with organic soils (-) |
| Large woody debris delivery | *Input* | Stream bank erosion | Unconfined channels where mass wasting is unlikely | Stream banks hardened<br>Streams channelized<br>Removal of trees from stream banks | Dikes and levees* (-)<br>Straightline hydrography (-)<br>Non-forested land use adjacent to streams (-) |
| | | Mass wasting | Channels adjacent to mass wasting hazard areas that are likely to deliver debris to the stream | Vegetation cleared on mass wasting hazard areas | Non-forest land cover in mass wasting hazard areas adjacent to streams (+) |
| | | Windthrow | 100’ on either side of channels where mass wasting is not likely | Vegetation cleared in 100’ buffer | Non-forest land cover in 100’ buffer (-) |

# III. Details for using this approach to characterization and analysis

In an effort to present the essential guidance in the main document, additional very detailed guidance and technical rationale are contained in the Appendices. These are referred to where appropriate in this section.

Following a scoping process (part 1 of the framework outlined in Section II), five steps have been developed to lead planners through the approach (Figure III-1). The end product of these steps is a series of maps that provides answers to the three questions described in the previous section. This information can then be integrated into plans for restoring or protecting aquatic resources (Figure I-3). In this section, each of the analysis steps are discussed in more detail and illustrated with an example from the Drayton Harbor area of Whatcom County, near Bellingham.

The details in this guidance are based on factors and indicators that are appropriate for use throughout the glaciated portion of Puget Sound. Planners should modify the tables and GIS methods as needed based on local information. If these methods are applied outside the Puget Sound region, the tables must be adapted to reflect local conditions. Documenting these changes and the rationale for them is encouraged. NOTE: This document, once it is peer reviewed, can serve as the technical justification for using the indicators suggested within; therefore, as modifications are made, the local planner should provide support for their changes.

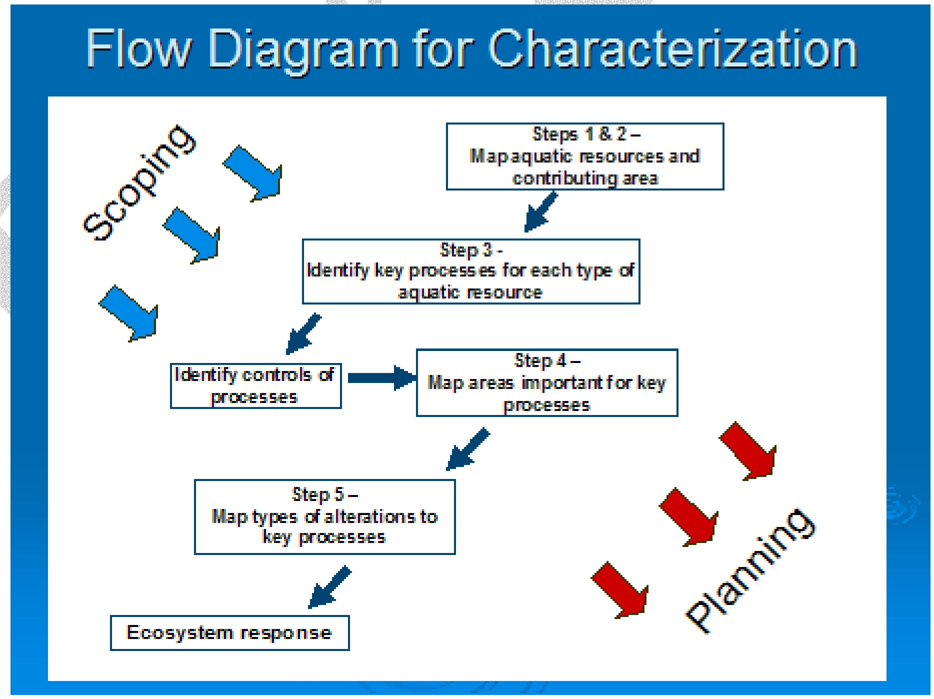


**Figure III-1. Overview of the framework for this guidance.**

## A. Analysis Steps

### Step 1: Map existing and potential aquatic resources:

*Objective:* To map all of the aquatic resources within the region for which plans are being developed (Map 1) and to group them into categories defined by hydrogeomorphic characteristics.

*Methods:* Map 1 will contain all of the aquatic resources, including those that may have been impacted or destroyed, within a jurisdiction or area of management (Figure III-2). These resources are classified into one of six categories that are defined by hydrogeomorphic (HGM) characteristics (Table 1). Each HGM category is linked with a suite of key processes in Table 2..

Appendix F describes GIS methods for mapping the different HGM type of aquatic resources.

*Products:* Map 1 – All aquatic resources mapped as one of six HGM categories

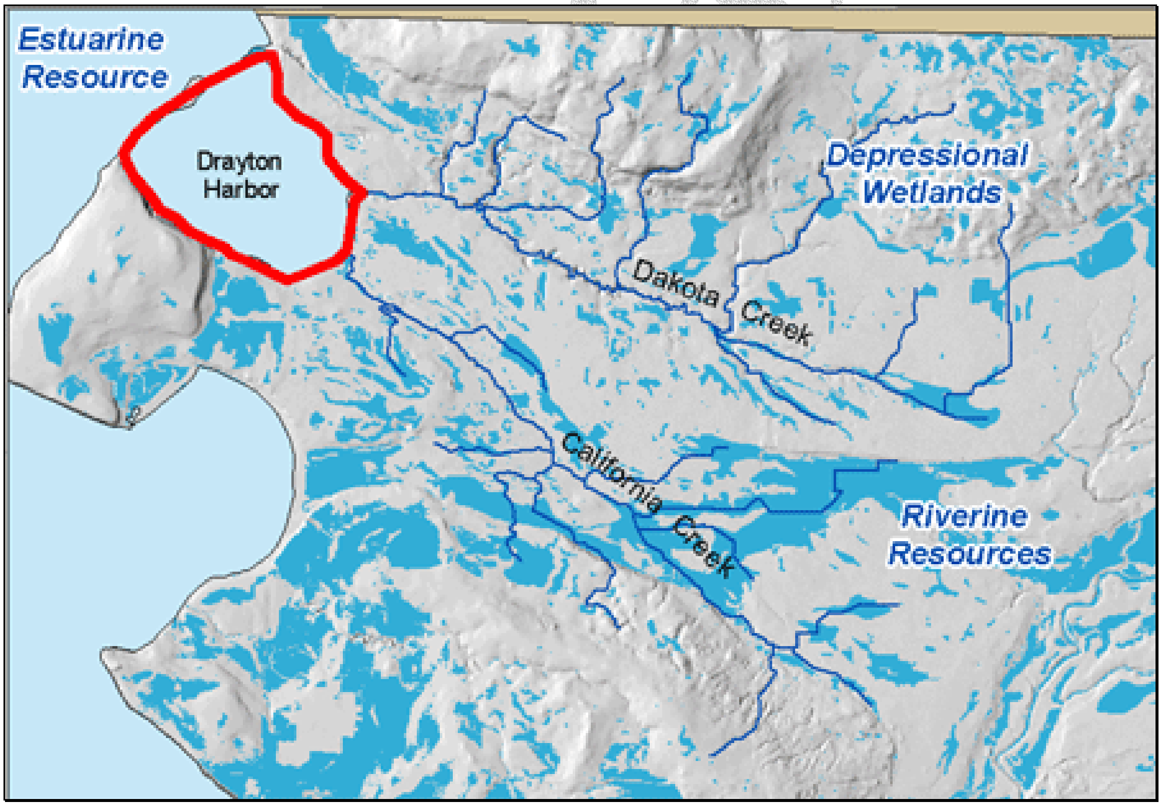


**Figure III-2. Example of Map 1: potential estuarine, riverine, and depressional wetland resources of the Drayton Harbor watershed.** (Marine resources are not addressed here.)

## Step 2: Map the contributing area:

*Objective:* To identify and map the area that contributes surface and ground water to the aquatic resources.

*Methods:* This step is critical as it provides an initial definition of the scale at which landscape processes affect the aquatic resources in the area of concern. The product, Map 2, identifies the area that contributes surface- and ground- water to these aquatic resources (Figure III-4). The other processes associated with sediment, nutrient, pathogen, toxin and wood delivery and removal are assumed to operate within the scale defined by the water movement processes.

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

In most cases, surface water drainage boundaries have already been developed for a particular location and are used extensively in other projects. To maintain consistency, these boundaries should be adapted for this work to the extent possible. In some cases, these existing boundaries are not suitable as, for instance, surface water drainages have been altered from their natural state or the drainages of interest are smaller than those previously delineated. Elevational patterns, visible on either Digital Elevation Models (DEM's) or topographic maps, can then be used to delineate drainage boundaries.

Begin to determine if the contributing area of ground water should be expanded beyond that indicated by surface water basin boundaries. This can be done by examining generalized regional groundwater flow paths developed for the Puget Sound area by the US Geological Survey (Vaccaro et al, 1998) (Figure III-3).

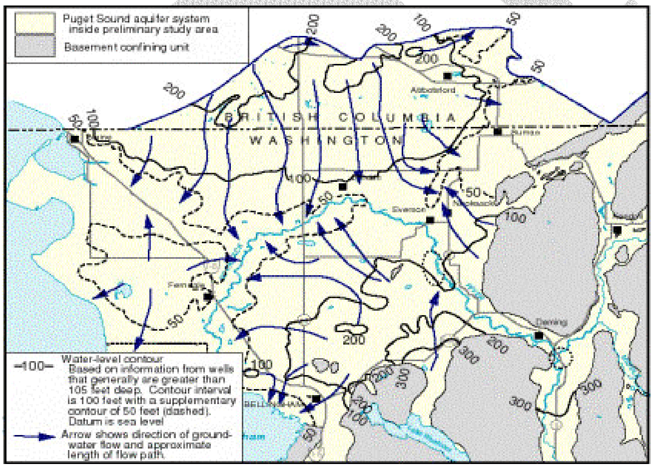


**Figure III-3. Groundwater flow paths for the Nook sack River, Whatcom County.** Figure from **xxxxx**; permission requested

If these flow lines are relevant to the region of interest, the broadest extent of groundwater contributing area could be inferred from the extent of these lines.

However, if these existing groundwater flow paths are not appropriate to the area of interest, it is possible to determine the contributing area for groundwater by examining surficial geology or soil permeability information for an area larger than that defined by the surface water drainages. In glaciated landscapes, the surficial deposits are integrally tied to and govern soil permeability and hydraulic conductivity (Vaccaro et al, 1998) (Table 4 of Appendix A); except in highly consolidated formations such as till, grain size of the deposit is a good indicator of the conductivity of a deposit (Vaccaro et al, 1998). In general, if a deposit that is highly permeable extends beyond a surface water boundary, it is likely that the contributing area for groundwater needs to be expanded to include the full extent of this deposit.

*Products:* Map 2 – Map of the contributing area

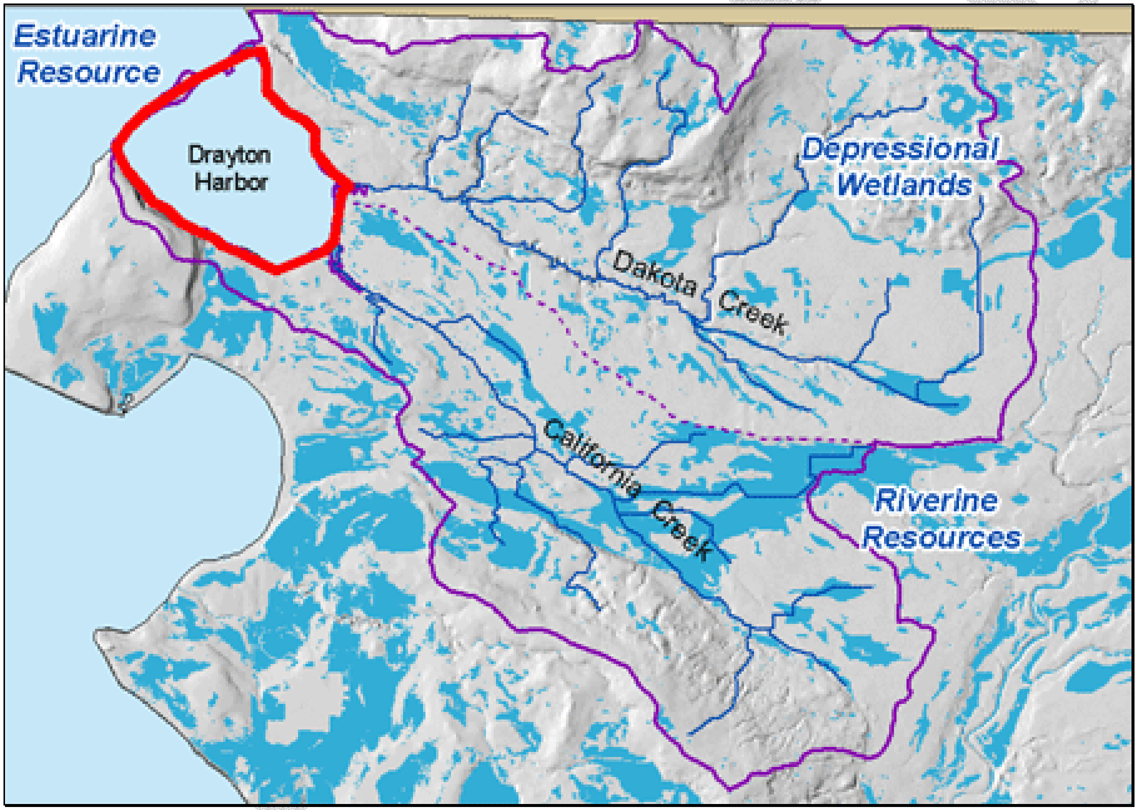


**Figure III-4. Example of Map 2: the contributing basin.** This map of the Drayton Harbor watershed shows the contributing basin, based on surface and subsurface water flow patterns supporting depressional, riverine and estuarine resources.

## Step 3: Identify the key processes for each type of aquatic resource

*Objective:* Identify the suite of key processes associated with each type of aquatic resource. These will be the processes that need to be protected or restored.

*Methods:* Each of the six types of aquatic resources is dependent upon a suite of landscape processes. Based on available scientific information for the Puget Sound region, **key** processes are those that are: essential to maintaining the aquatic resource; are readily altered by human activities; and when altered result in impairment of the aquatic resource.

For the Puget Sound region, key processes for each type of aquatic resource were indicated in Table 2. These selections are discussed in Appendix E. They were chosen because their importance to a particular aquatic resource is supportable in a broad, general manner throughout Puget Sound. Local information may support the identification of additional processes. If these are added, documentation of the rationale should be provided and modifications should be made to Table 2.

*GIS analysis:* None

*Products:* Table 2, modified if need be for the specific area of study, and rationale for modifications

## Step 4: Map areas within the contributing area that are important for key processes:

*Objective:* For each key process, identify and map the important areas on the landscape. Two types of maps are produced in this step: one, produced for each process, indicates why each area is important for the process (Map 3 – termed an 'important area map') and the other indicates the number of processes for which each area is important (Map 4 – termed a 'multiple process map').

*Methods:* Completion of this step is best accomplished through a series of sub-steps. Initially, the key processes that were identified in Step 3 are described in terms of input, movement, and loss of some factor such as surface water, nitrogen nutrients, or large woody debris (Table 4, column 1). Each process is governed by a set of controls which determine these inputs, movements, or losses (Table 4, column 2). These controls are associated with specific features on the landscape (Table 4, column 3). These features, termed 'important areas', are those that are more likely than other areas to be important to a particular process; it is not to say that these controls do not occur in other areas on the landscape, just that the role of other areas is relatively minor. In the description of the general framework, Section II of this document outlines those controls considered in the Puget Sound region.

For each key process, Table 4 provides a description of the type of areas on the landscape that are likely to be important for the associated controls. However, to create the maps for this step, it is necessary to identify these areas using indicators from readily available GIS data. These indicators are shown in Table A-1 of Appendix A, along with suggested GIS analyses for mapping these indicators. In addition, Appendix A contains the rationale and technical justification for the selection of these indicators in the Puget Sound region. If local data support the use of additional indicators, these should be integrated into the analysis by indicating such changes in Table 4 and providing justification of the new indicators.

Using the GIS methods in Appendix A, the important areas listed in Table 4 can be mapped in two ways:

> Map 3: Important areas map (Figures III-5 to III-7): In this map the areas important to each control of the process are mapped in a different color. By using moderately transparent colors, it is possible to see areas important to multiple controls of the same process. By converting all of these important areas to one color, a "summary map" can be created that will be used in step 5.
>
> Map 4: Multiple Process map (Figure III-8): This map highlights those areas on the landscape that are important to multiple processes. These areas can have regional significance since multiple processes can be more critical to sustaining aquatic resources downstream.

*GIS analyses:* The GIS analysis for each key process is outlined in Table A-1 Appendix A.

*Products:* Map 3 – Important areas map for each key process.
Map 4 – Multiple process map showing important areas for all processes.
Table 4 and Table A-1 for the specific area of study, including rationale for any additional indicators included in the analysis.

## Example of Map 3 – Important Areas map for Surface Water Runoff

On Map 3, the important areas map below (Figure III-5), the important areas are mapped separately for each control, as they are linked in Table 3 (shown below for surface water runoff)

| Process | Major Controls of the Process | Important Areas for the Process | Map Color | |
|---|---|---|---|---|
| | | | Single | Overlay* |
| Surface Water Runoff | Surface storage | Floodplains | Yellow | Orange |
| | | Depressional wetlands | Red | Purple |
| | Recharge | Permeable deposits | Blue | |
| | Snowmelt | Rain on snow zone | Not present ▪ | |

∗ Orange areas are important to **both** depressional wetlands **and** floodplains, providing surface storage

∗ Purple areas are important to **both** depressional wetlands **and** permeable deposits, providing floodplain storage **and** recharge capacity

▪ No Rain on Snow areas were present in this example

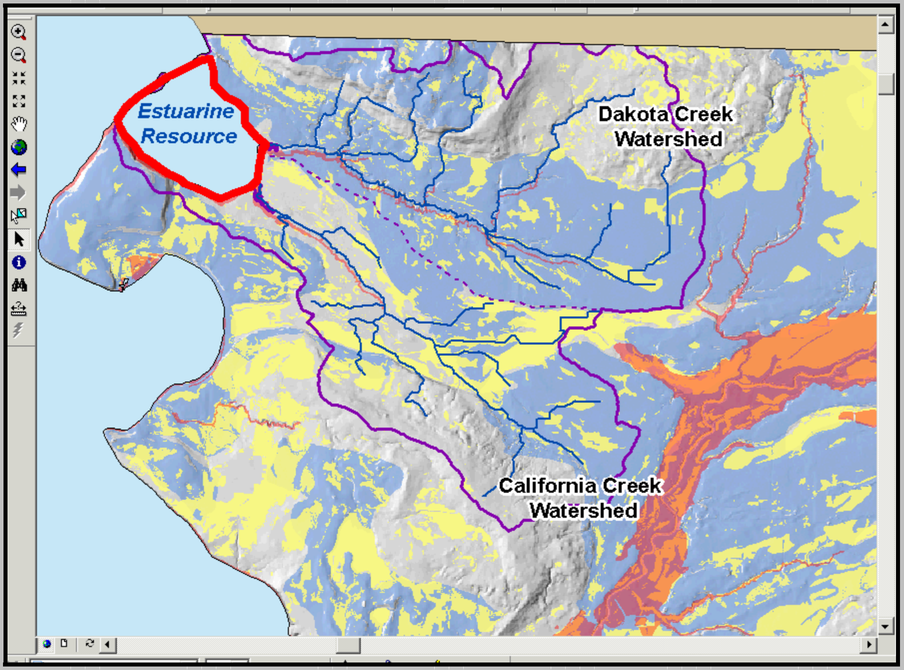


**Figure III-5. Example of Map 3: important areas map for the surface water runoff process.** In this map of the Drayton Harbor watershed, different colors indicate the way these important areas affect the process (control)..

## Example of Map 3 – Summary map of Important Areas for Surface Water Runoff

Here the important areas are shown as one color to simplify the information for further analysis. This is useful in the next step when this information will be overlayed with alterations (See Figure III-12).

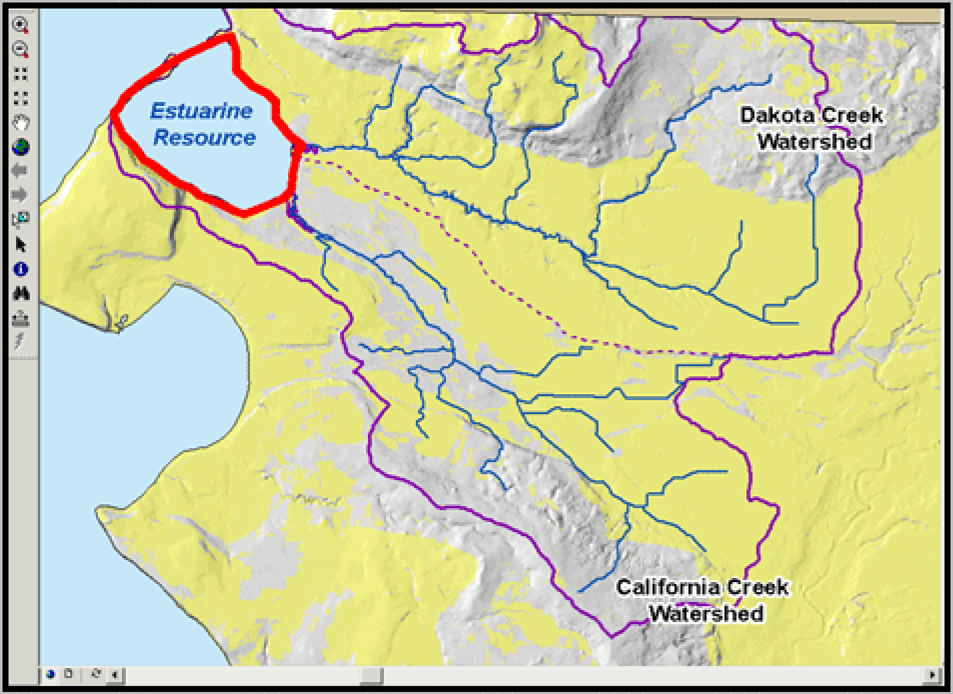


**Figure III-6. Example of Map 3: summary map of important areas for surface water runoff.** This map of the Drayton Harbor watershed, shows all areas of importance for the surface water runoff process as one color.

## Example of Map 3 – Important areas map for Nitrogen Delivery and Removal

The important areas are mapped separately by color for each control that it corresponds to in Table 3.

| Process | Major Controls of the Process | Important Areas for the Process | Map Color |
|---|---|---|---|
| Nitrogen | *Loss* - Denitrification | Hyporheic areas | Yellow |
| | | Seasonal wetlands | Green |
| | | Wetlands with organic soils | Pink |
| | | Riparian areas with shallow groundwater | Blue |
| | *Input* - Natural sources | Contributing area | Basin boundary |

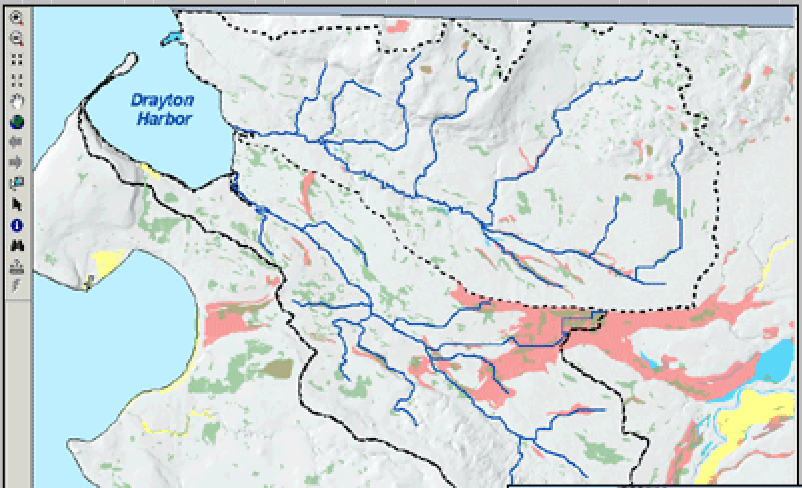
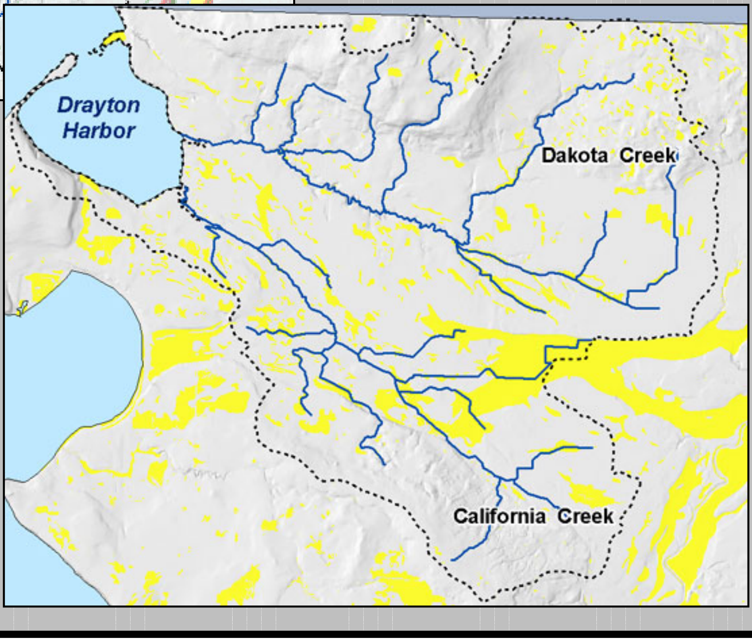


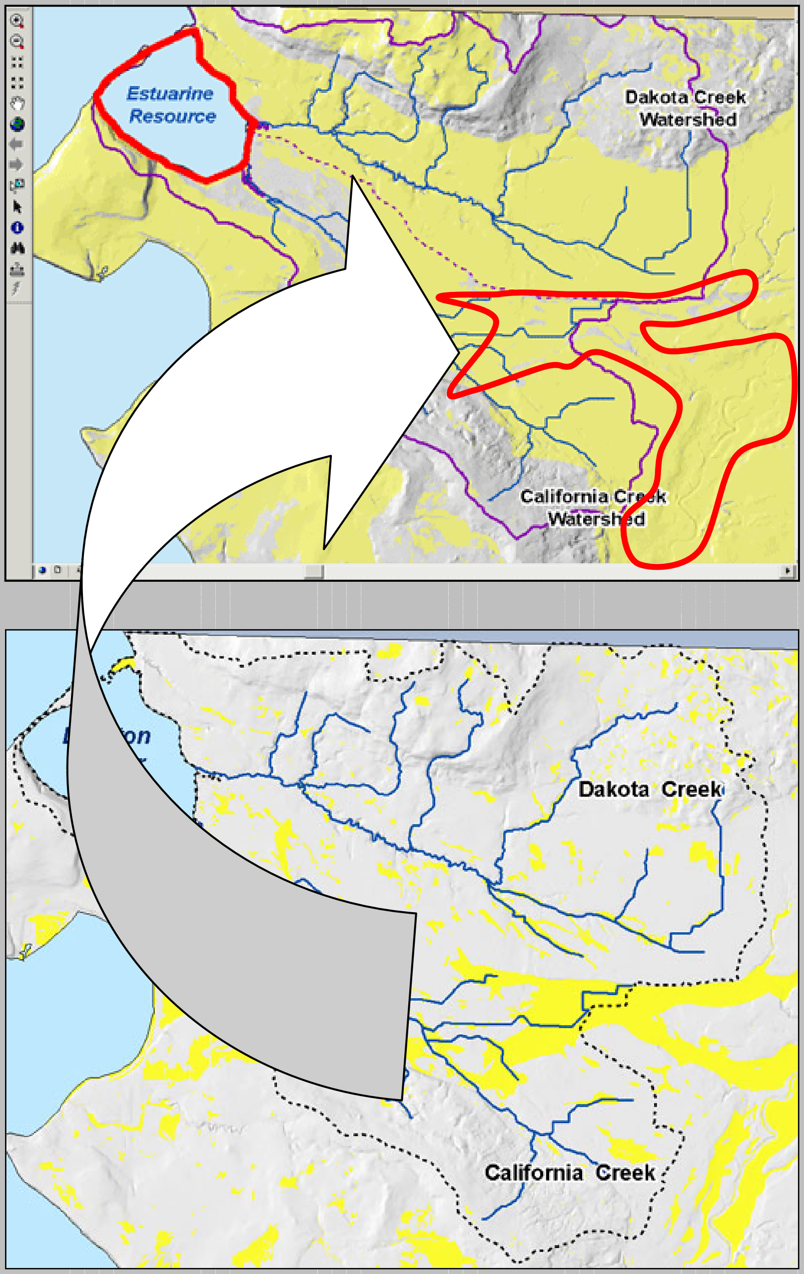
**Figure III-7a. Example of map 3: important areas map for nitrogen delivery and removal :** For the Drayton Harbor watershed , important areas are displayed in colors for each control



The above map can be displayed as one color to highlight all areas important for removal of nitrogen. This simplified map will be used in Step 5 when overlaying alterations

**Figure III-7b. Example of Map 3: summary map for nitrogen delivery and removal** . For the Drayton Harbor watershed, important areas are displayed in one color.

## Example of Map 4: Multiple Processes in One Geographic Area



A. Important Areas for Surface Water Runoff Process

B. Important Areas for Nitrogen Delivery and Removal Process

**Figure III-8. Example of Map 4: multiple process map showing important areas for several processes.** When comparing the maps for the two processes, surface water runoff and nitrogen removal process, the area outlined in red is important for two processes. Such an area could be of regional significance.

## Step 5: Map types of alterations to key processes:

*Objective:* For each key process, map the alterations that are caused by human activities, occur in important areas and are likely to impair the process. Two types of maps are produced in this step: one is a map of the relative amount of alteration in each sub-basin in the study area (Map 5 - termed a 'general alteration' map) and the other, produced for each process, is a map of specific alterations (Map 6 – termed a 'detailed alteration' map.

*Methods:* Map 5, the general alteration map, uses non-forest cover as an indicator of the general degree to which a sub-basin has been altered (Figures III-10). This is based on the assumption that removal of natural cover is accompanied by activities such as building of roads, ditches, septic systems and impervious surfaces which can alter the key processes. This does not mean that a specific relationship between changed land cover and the processes exists. Instead this map is meant to be used as a coarse but easily developed tool to identify those sub-basins that are least altered and those that are most altered; this can provide an initial indication of where protection or restoration should be considered, especially when overlayed with an important areas map (see Figure III-12).

This map is similar to the indices maps used by Tiner in his work on the Nanticoke River watershed (Tiner 2005). It is made by calculating the percentage of each sub-basin not in forested cover using the following formula: (1- forested area/area of sub-basin) x 100. Different colors are then used to indicate ranges of alteration in individual sub-basins; the categories mapped are based on an analysis of the frequency distribution of the percent alteration in the individual sub-basins.

Map 6, the detailed alteration map, illustrates the location and type of alterations for each process (Figure III-11). It should be used in conjunction with the general alteration map (Map 5) to develop planning measures including those that identify specific locations and types of restoration.

Producing Map 6 for each process builds upon the work done in Step 4 and the framework developed in Table 4. Columns 4 and 5 of Table 4 indicate the types of human activities that are likely to alter the key processes and general factors that can indicate alterations have occurred. However, to create the detailed alteration map (Map 6), it is necessary to identify and locate alterations using a series of indicators that are easily mapped from readily available GIS data (Table B-1 of Appendix B). Appendix B also contains the rationale and technical justification for the selection of these indicators in the Puget Sound region. If local data support the use of additional indicators, these should be integrated into the analysis by indicating such changes in Table B-1 and providing justification of the new indicators.

When creating the detailed map of alterations (Map 6), it is useful to categorize the indicators into one of the following three groups (Figure III-9). These categories will assist in the integration of this information into management plans for aquatic resources.

- INPUT indicators: Source areas, generally upstream or upgradient of aquatic ecosystems, are where alterations have been made or could be made in the future that would change the inputs associated with a process. These are the indicators in Table 4 that control the input of water, sediment, nutrients, pathogens, toxins and wood. Similarly, future sources would be identified as places where inputs are likely to be changed by planned landuse activities.

- MOVEMENT indicators: Transport areas are those that control the transmission of changes in the source areas to the aquatic resources. These include indicators of altered landscape elements that control the movement of water, sediment, nutrients, pathogens, toxins and wood through the landscape. Transport areas are generally located in areas identified in Step 4 as important for the removal or moderation of various inputs.

- RESPONSE indicators: These include data on the effect of an alteration on the target aquatic resource.

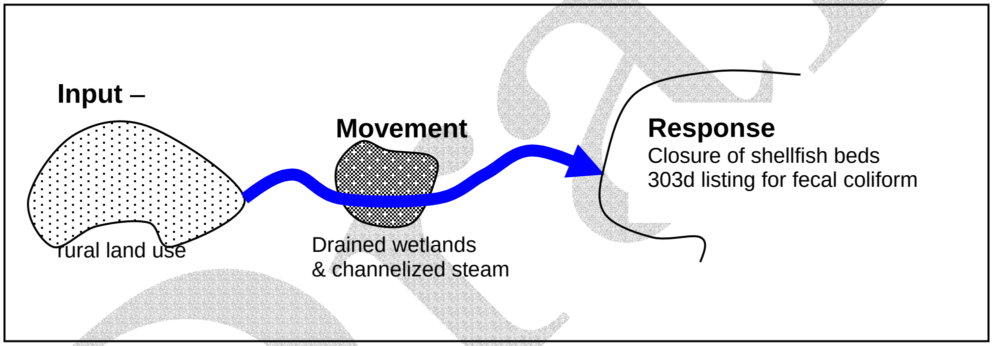


**Figure III-9. Example of categorizing indicators of alteration into input, movement and response** . This example show how to use these categories to describe the pathogen delivery and removal process in the Drayton Harbor watershed

*GIS analyses:* Analyses needed are described above to produce Map 5 and in Appendix B to produce Map 6 for each process.

*Products:* Map 5 – General alteration map for the study area
Map 6 – Detailed alteration map for each key process
Table 4 and Table B-1 (Appendix B) for the specific area of study, including rationale for any additional indicators included in the subsequent analysis

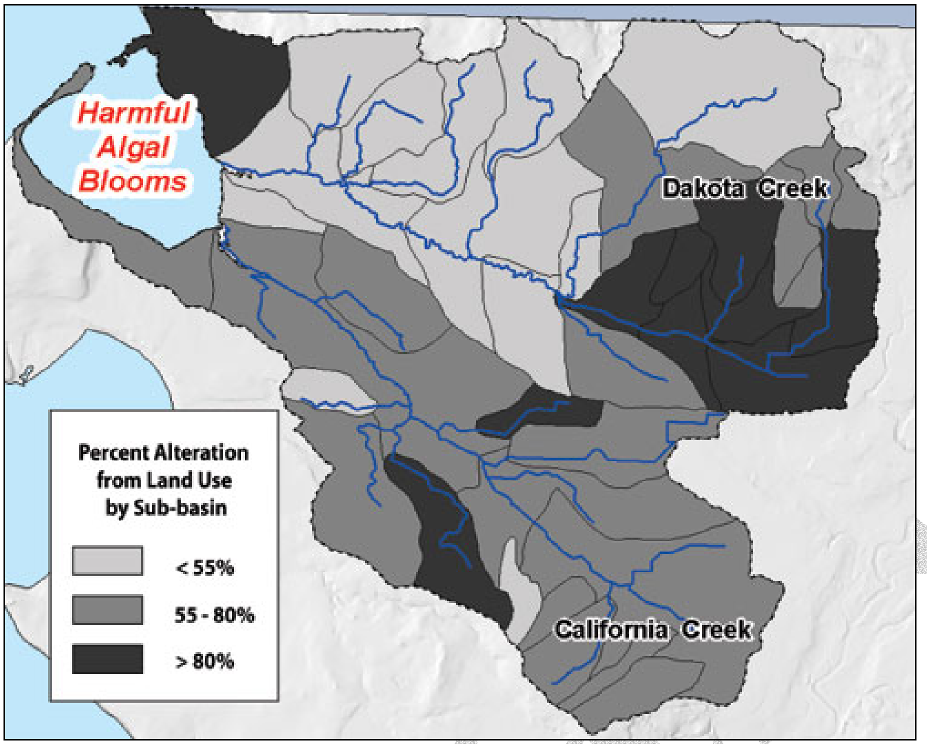


**Figure III-10. Example of Map 5: general alteration map for the contributing area.** This map of Drayton Harbor indicates the percent of each sub-basin that is no longer in forested cover and provides an indication of the degree that landscape processes have been altered in each sub-basin.

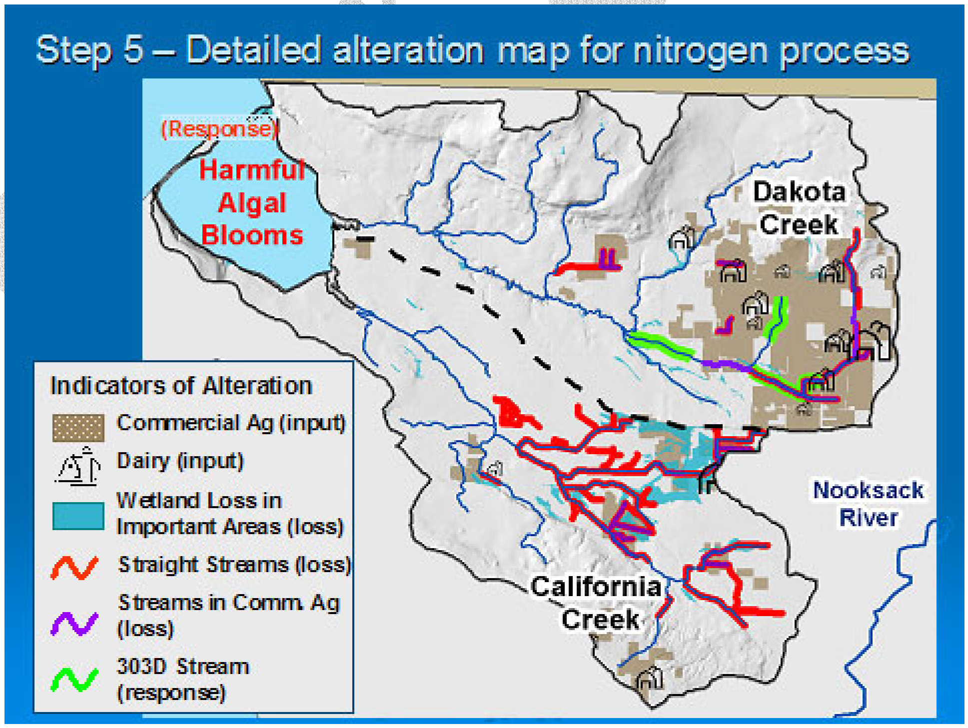


**Figure III-11. Example of Map 6: detailed alteration map** shows the specific locations and types of alteration of the nitrogen delivery and removal process. For the Drayton Harbor watershed, indicators of alteration are shown with different colors and symbols, according to the legend.

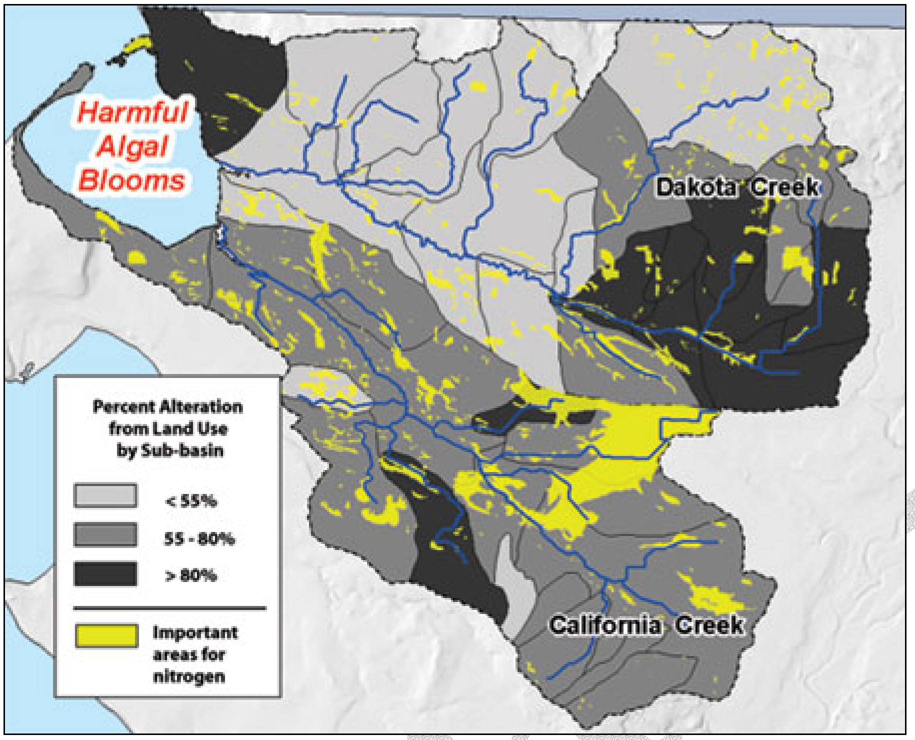


**Figure III-12: General alteration map (Map 5) with important areas (summary Map 3) for nitrogen delivery and removal.** For the Drayton Harbor watershed, this map summarizes the alterations by sub-basin and shows the relationship to the important areas the nitrogen process.

# IV. Application of Results

The products of the steps outlined in Section 3 are most useful when applied within a management planning framework for either a governmental or private entity responsible for land management. They should be used to inform the development of the management plan so that it provides for the long term protection and maintenance of aquatic resources. Examples of possible applications for governmental entities include a comprehensive plan, shoreline management plan, specific plan, or development plan; for private entities this could include habitat management and conservation plans.

The framework itself provides an approach for describing and understanding the landscape processes affecting aquatic resources and the potential ways in which they have been and can be altered. In order for this information to be integrated into existing planning frameworks, it first needs to be synthesized (Figure IV-1). One approach to synthesizing and summarizing the products of this framework is described below. This is followed by a section exploring possible applications of these results to different types of resource plans.

## A. Synthesizing products of the framework-

### i. Introduction:

Upon completing steps 4 and 5, the important areas for each key process and the likely locations of activities that could alter the integrity of these processes have been identified. For each process, four sets of maps have been produced: important areas maps (Map 3) showing the important areas on the landscape for each specific control of a process, multiple processes maps (Map 4) showing the areas that are important to multiple processes, the general alteration map (Map 5) showing the general level of alteration in each sub-basin, and the detailed alteration maps (Map 6) showing the specific location of landuse activities that are likely to be associated with alterations of each process.

This synthesis task involves combining and analyzing the information contained in these maps to highlight areas on the landscape where restoration and planning measures are likely needed and then to identify the types of measures that might be appropriate to support each process (Figure IV-1). The synthesis information can also be organized in a "synthesis table" in order to facilitate analysis (Table C-1, Appendix C). In addition, this synthesis step can put into perspective the relative importance of various areas on the landscape to both individual and multiple processes. These results can be used by planners to develop a management plan that meets the ecological and economic needs of their area by concentrating development in areas that support fewer processes.

Prior to embarking into synthesis, it is important for the planner to become clear about what information would be useful and how it will be used; otherwise, the volume of information produced can be overwhelming. As a general approach, we suggest the following steps:

1. *Identify areas for further analysis and get an overview of the study area*: For each process, overlay the summary map of important areas (Map 3 with important areas all in one color) on the general alteration map (Map 5). This will allow you to get a sense of the relative land cover condition of each sub-basin. Some preliminary conclusions can be drawn from this which can be useful for prioritizing where analysis of the detailed alteration map is pursued. Without this step, the detailed alteration map can be difficult to interpret and synthesize as often much of the area is altered in multiple ways.

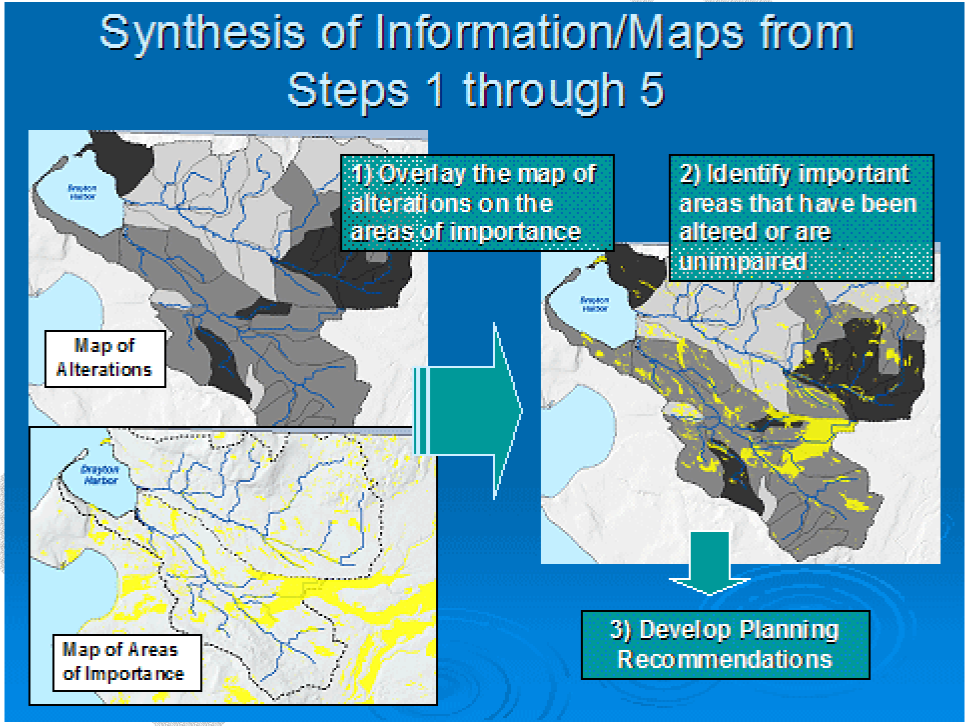
2. *Identify areas important for multiple processes:* Begin to prioritize potential areas for restoration or protection by examining the multiple process map (Map 4). Areas important for many processes could be considered a higher priority for restoration or protection than other areas, depending on the needs and issues of your jurisdiction.

3. *Identify potential protection options*: Based on your findings in the previous steps, choose sub-basins on which to focus identification of potential protection recommendations. Use the summary of important areas map (Map 3 in one color) and the detailed alteration map (Map 6) in these focal areas to identify unimpaired

important areas that might be candidates for protection activities. This should be done for each process.

4. *Identify potential restoration options:* Based on your findings in step 2 above, choose sub-basins on which to focus identification of potential restoration recommendations. Use the important areas map (Map 3 in different colors for different controls), the detailed alteration map (Map 6), and your allocation of the alterations to source, transport, and response categories in these focal areas to identify those important areas that have been impaired, are important to problems in your jurisdiction, and would be good candidates for restoration. This should be done for each process.

Provided below is an example of how the synthesis could be conducted using this approach. This example continues to use the Drayton Harbor area to illustrate how conclusions might be drawn from these analyses.



Synthesis of Information/Maps from Steps 1 through 5

1) Overlay the map of alterations on the areas of importance

2) Identify important areas that have been altered or are unimpaired

3) Develop Planning Recommendations

**Figure IV-1: Synthesis of the products from steps 1-5:** maps are combined for integration into existing planning approaches. (Maps 3 and 5)

### ii. Example of Synthesis:

a. *Identify areas for further analysis and get an overview of the study area*: The objective of this step is to begin to draw some conclusions about the relative condition of each sub-basin and the associated locations of important areas for each process. Overlay the summary map of important areas for a process (Map 3 all in one color) on the general alterations map (Map 5); this will be done for each process.

Figure IV-2 illustrates this for nitrogen removal and delivery in the Drayton Harbor watershed and will serve as an example of how this analysis can be used.

This analysis permits a number of different factors to be evaluated:

1. Which sub-basins have the least degree of alteration and therefore the most intact suite of processes?

   In the Drayton Harbor example (Figure IV-2), the following observations can be made:
   - Dakota Creek to the north has more sub-basins in better condition than California Creek to the south. These least altered areas are generally located in the lower part of the watershed, except for the urban area at the northwest corner of the drainage.
   - The upper portion of Dakota Creek has a large area where processes have been most altered, suggesting that sources of nitrogen may be higher in this area (Table 4).
   - A relatively small area of California Creek has areas where processes are most altered.

2. Which sub-basins have the greatest amount of important area for the process?

   In the Drayton Harbor example:
   - The bulk of the important areas for nitrogen removal and delivery occur in California Creek sub-basins.
   - In Dakota Creek, many important areas for nitrogen removal and delivery occur in the headwaters of sub-basins.

3. What is the relationship between the important areas and the general condition of a sub-basin?
   In the Drayton Harbor example:
   - The headwater important areas for nitrogen delivery and removal in Dakota Creek are generally in sub-basins that are less altered; the exceptions to this are those in the upper sub-basins to the southeast.
   - Sub-basins with important areas for nitrogen delivery and removal along the lower main stem of Dakota Creek are least altered.
   - Most of the important areas for nitrogen removal and delivery in California Creek occur in sub-basins that have a moderate level of alteration.
   - Part of the single largest important area in the northeast portion of California Creek lies in a sub-basin with relatively significant alterations.

4. Are there areas that would appear to be important for developing protection measures?

   The general alteration map does not allow identification of specific important areas that should be considered for protection; however, it does allow for the identification of sub-basins where further evaluation of protection opportunities and need would be warranted using the detailed alteration map (Map 6). The actual conclusions drawn at this stage would depend upon the issues facing the jurisdiction and the specifics of decision making processes but, some possible conclusions are:

- Further evaluation of protection opportunities and options should be conducted in the least altered sub-basins in Dakota Creek that contain important areas for nitrogen delivery and removal. From a land cover perspective, these sub-basins are relatively unaltered so there is a higher likelihood that protection measures can be taken to prevent degradation of the important areas in these sub-basins. It is important to note that "protection opportunities and options" does not just mean the setting aside of important areas. The broadest definition of protection should be used such that it includes siting and designing appropriate development (i.e. development standards) in a manner that would protect and maintain processes.
- One sub-basin in California Creek contains important areas for nitrogen removal and delivery and is has relatively unaltered land cover so perhaps it should be an area for further evaluation of protection options.

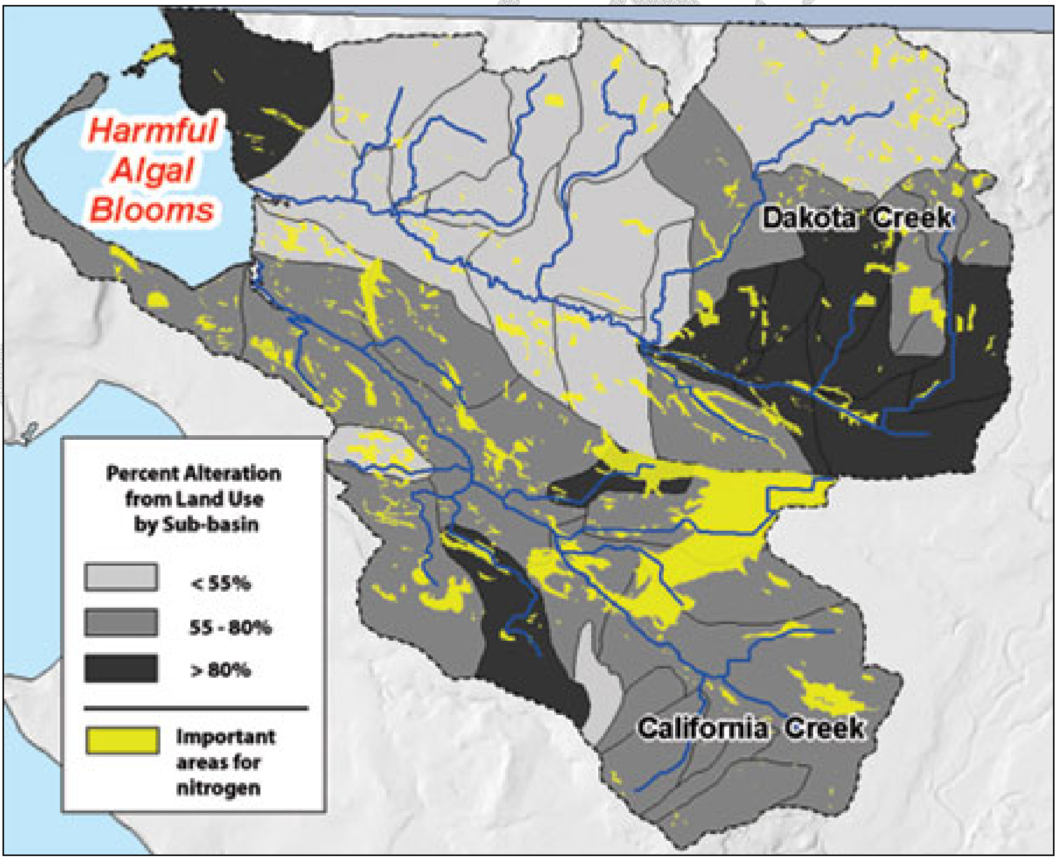


**Figure IV-2. Summary important areas map for nitrogen removal and delivery** (Map 3 in one color) overlaid on general alterations map (Map 5). This map of the Drayton Harbor watershed is used in the first step of synthesis to identify areas for further analysis and get an overview of the condition of sub-basins.

5. Are there areas that would appear to be important for developing restoration measures?

   The general alteration map does not allow identification of specific important areas that should be considered for restoration; however, it does allow for the identification of sub-basins where further evaluation of restoration opportunities and need would be warranted using the detailed alteration map (Map 6). The actual conclusions drawn at this stage would depend upon the issues facing the jurisdiction and the specifics of decision making processes but, some possible conclusions are:
   - Overall, California Creek watershed appears to have a higher degree of alteration (i.e. based on land area ) and larger area of important areas relative to the Dakota Creek watershed. It may, therefore, be a watershed to prioritize restoration efforts since such restoration may have the greatest effect on lowering nitrogen inputs to the Drayton Harbor estuary. Further analysis of the detailed alteration map would be warranted in the California Creek area.
   - The upper portion of Dakota Creek contains numerous important areas for nitrogen removal and delivery that are within sub-basins with moderate to significant level of alteration. These areas, where nitrogen delivery and removal has likely been altered, warrant further assessment of whether this is the case and the options for restoration. An alternative conclusion is that these areas are so altered, restoration is unlikely to be effective (see question 6 below). Further evaluation of the detailed alteration map for this area would help identify a reasonable conclusion.
   - There is one large complex of important area for nitrogen removal and delivery in the upper southeast portion of the California Creek drainage. Given the size of this area, it is likely worth examining further whether and /or how it has been altered so restoration measures can be developed.

6. Are there areas were processes have been significantly altered that cannot be feasibly restored?

   Areas shown with the highest relative level of alteration may not be good candidates for restoration if processes have been significantly altered. For most urban areas this will be the case since the high percentage of paving and buildings and density of roads will have permanently altered processes. Many important areas will have been eliminated or significantly degraded. Restoration will be limited to dealing with specific problems instead of maintaining the full suite of functions for an aquatic resource.

   - For the California Creek watershed, the City of Blaine represents an area of significant alteration that may not be a priority area for restoration.

Restoration of remaining important areas within the City should be carefully evaluated relative to the "problems" (responses) identified for 'downstream' aquatic resources and the likelihood that restoration would abate these problems.

b. *Identify areas important for multiple processes*

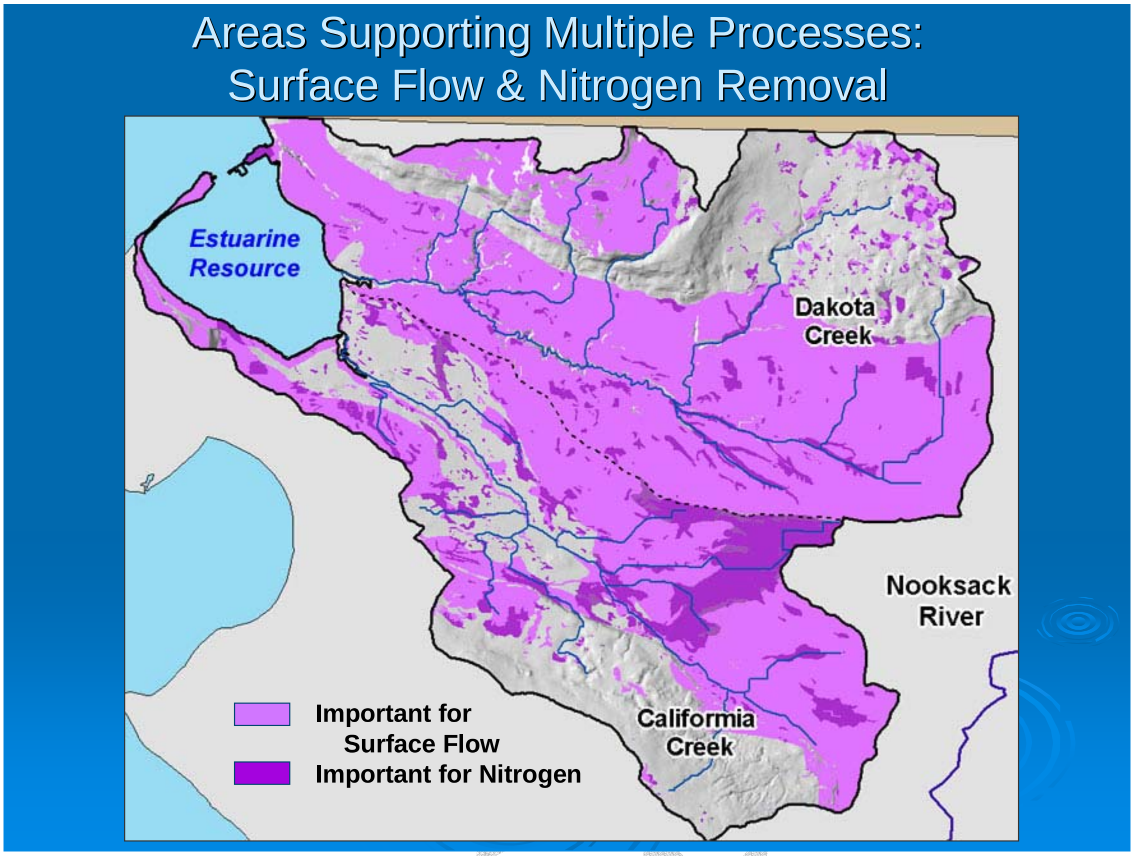
The first step in this synthesis identified some potential areas where further examination of the detailed alteration map would be warranted; this step adds some more information into the mix to help prioritize those areas where further analysis is pursued. This step relies on the multiple process map (Map 4) as this allows for identification of those important areas that support processes in multiple ways (Figure IV-3).

In this example for Drayton Harbor, we have mapped important areas for only two processes – surface water runoff and nitrogen delivery and removal. Even with just this degree of detail, it is possible to draw a few conclusions. The actual conclusions drawn at this stage would depend upon the issues facing the jurisdiction and the specifics of decision making processes. For example, if the focus of planning is on resolving a particular environmental problem, the fact that a particular area supports multiple processes may not be important to integrate into the prioritization of restoration and protection areas. Some possible conclusions are:

- In the upper portion of Dakota Creek, within the sub-basins with altered land cover, some of the important areas for nitrogen removal and delivery are important in multiple ways. This might suggest that further evaluation of the restoration potential of these areas with the detailed alteration map is warranted, despite the fact that the sub-basins are significantly altered.

- The large important area in California Creek is only important in one way for these processes, suggesting that it may not be valuable to consider further analysis of this area.

- The important areas in sub-basins along the mainstem of Dakota Creek are important in multiple ways, unlike those in sub-basins along the south side of California Creek.



Areas Supporting Multiple Processes: Surface Flow & Nitrogen Removal

**Figure IV-3: Multiple process map (Map 4) for surface water runoff and nitrogen delivery and removal.** In this Drayton Harbor map, the darker the purple, the more ways the area is important to the processes.

c. *Identify potential protection options*

As a result of the first two synthesis steps, the planner should have a sense of where further evaluation of potential protection options should occur. Using the Drayton Harbor example and the conclusions proposed in this document, three areas of focus have been identified for further exploration of options for protecting the nitrogen delivery and removal process (Figure IV-4).

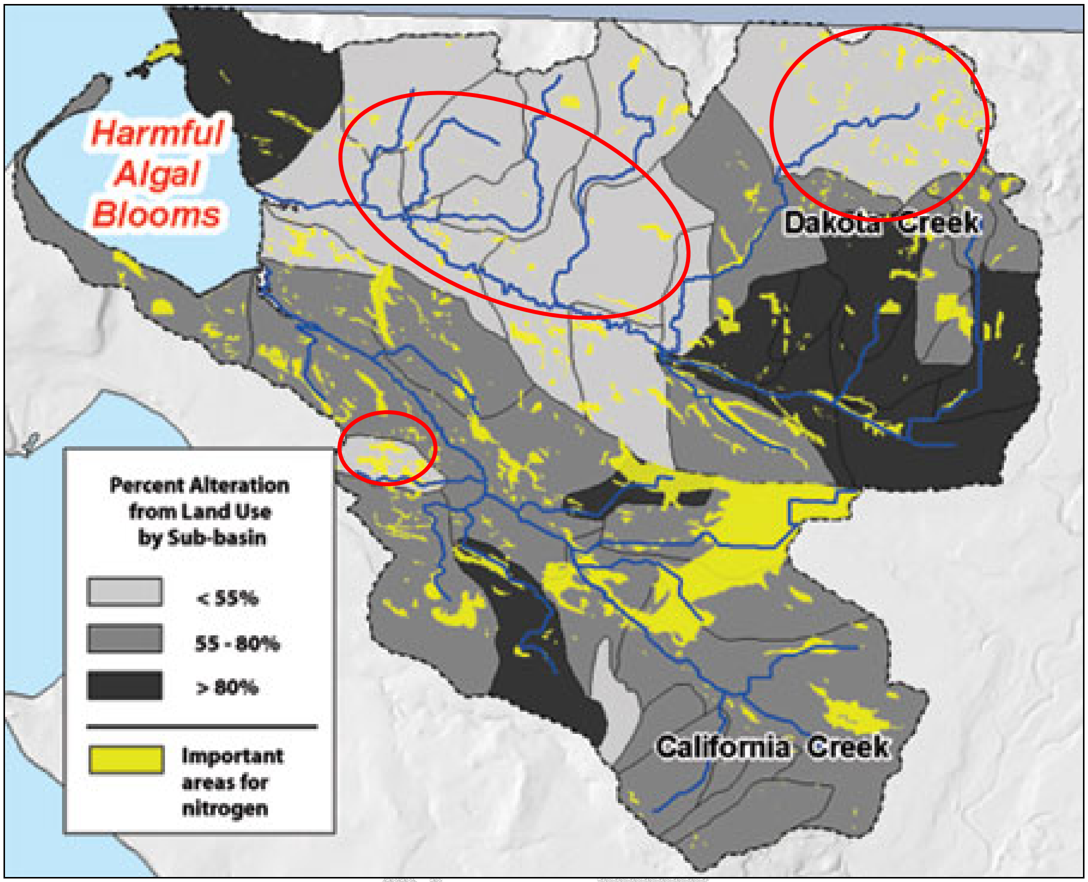


**Figure IV-4: Example of focus areas for protection in Drayton Harbor** selected to explore options for protection of the nitrogen delivery and removal process in subbasins with the least degree of alteration.

These three areas can be further examined to identify important areas for nitrogen delivery and removal that have not been altered. This is best done by examining the important area map (Map 3) in conjunction with the detailed alteration map (Map 6) for each focus area (Figure IV-5). In the Drayton Harbor example, important areas for nitrogen removal and delivery are identified in yellow and alterations to this process are shown as indicated in the legend.

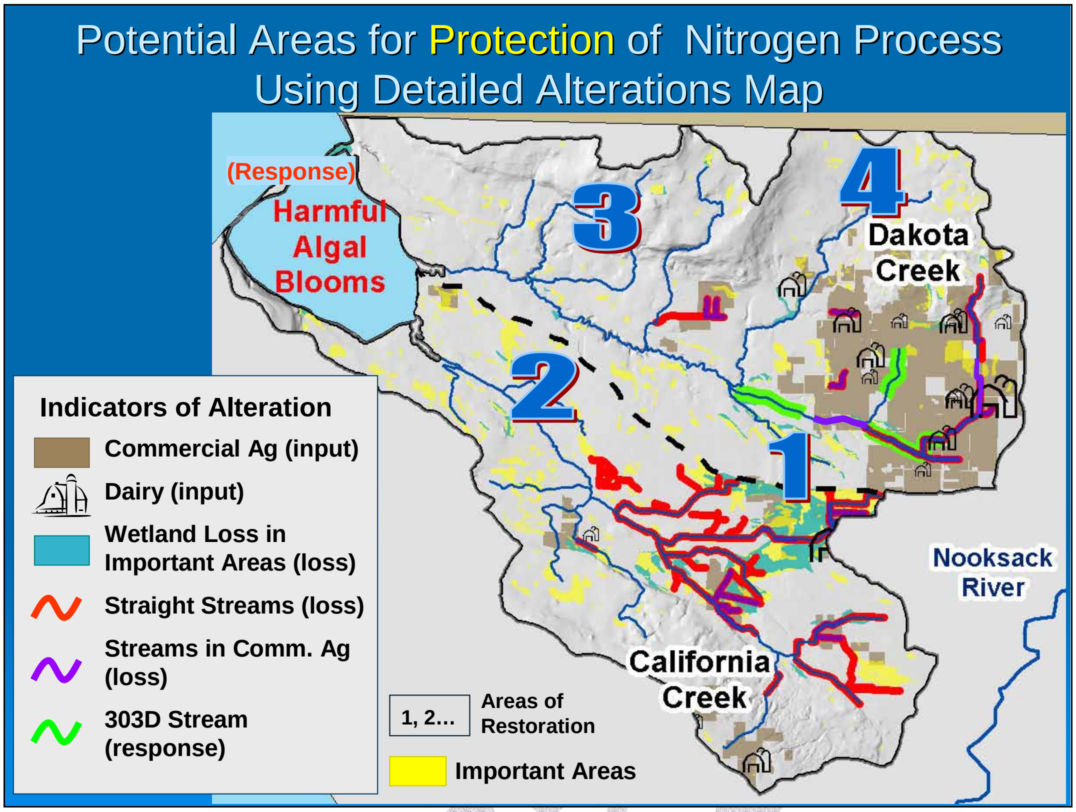


**Figure IV-5: Example of identifying potential areas for protection**, using the important areas map (Map 3) and the detailed alterations map (Map 6) for the nitrogen removal and delivery process. Four potential areas are identified with minimal alteration to important areas. Input, loss and response (i.e. for controls of process) are noted.

In reviewing the detailed alterations map (Figure IV-5), the focus areas selected for protection in figure IV-4 do show the lowest level of alteration for the overall watershed with some important areas not showing any significant alteration (e.g. yellow polygons with areas 2, 3, and 4). Further, the detailed map reveals an additional protection area, (i.e. # 1), in the northeast portion of California Creek that has significant unaltered important areas (i.e. yellow). Given the location of nutrient inputs and downstream alterations this area should receive first consideration for protection.

*d. Identify potential restoration options:*

As a result of the first two synthesis steps, the planner should have a sense of where further evaluation of potential restoration options should occur. Using the Drayton Harbor example and the conclusions proposed in this document, three areas of focus have been identified for further exploration of options for restoring the nitrogen delivery and removal process (Figure IV-6).

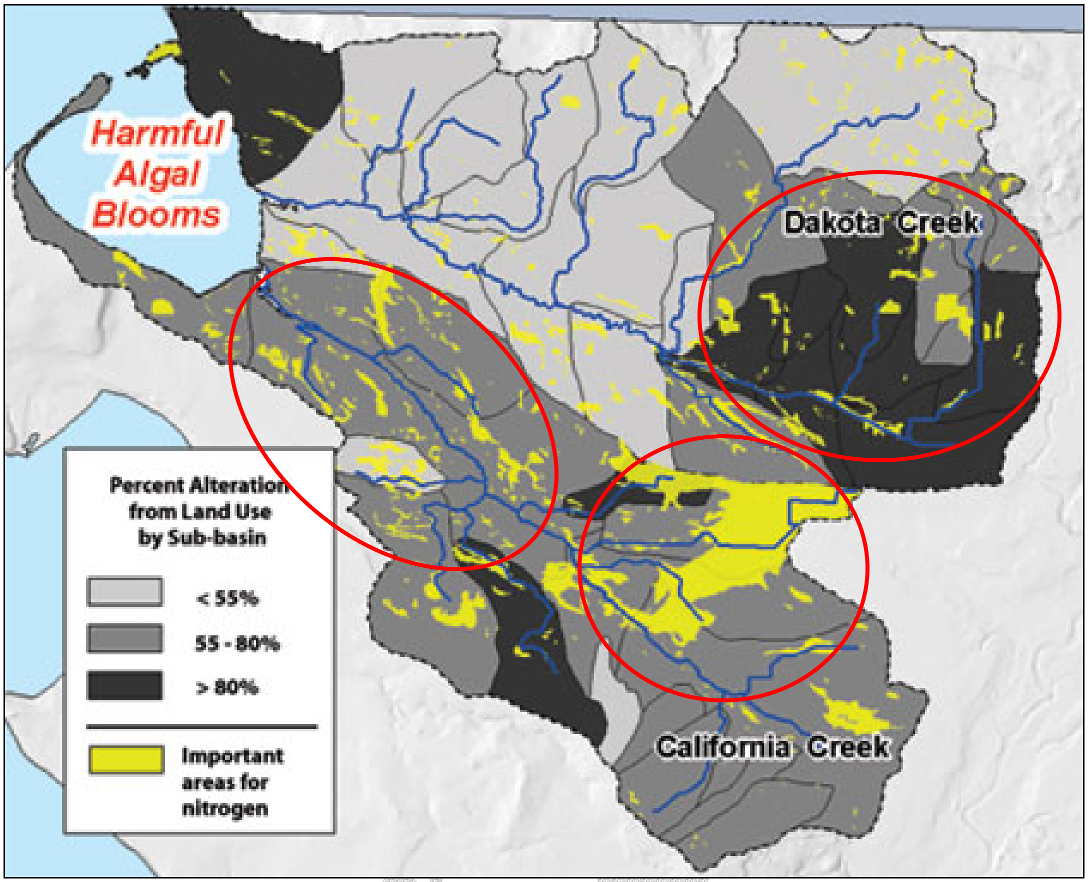


**Figure IV-6: Example of focus areas in Drayton Harbor to explore options for restoration of the nitrogen delivery and removal process.**

These three areas can be further examined to identify are important areas for nitrogen delivery and removal that have been altered. This is best done by examining the important area map (Map 3) in conjunction with the detailed alteration map (Map 6) for each focus area (Figure IV-7). In the Drayton Harbor example, important areas for nitrogen removal and delivery are identified in yellow and alterations to this process are shown as indicated in the legend.

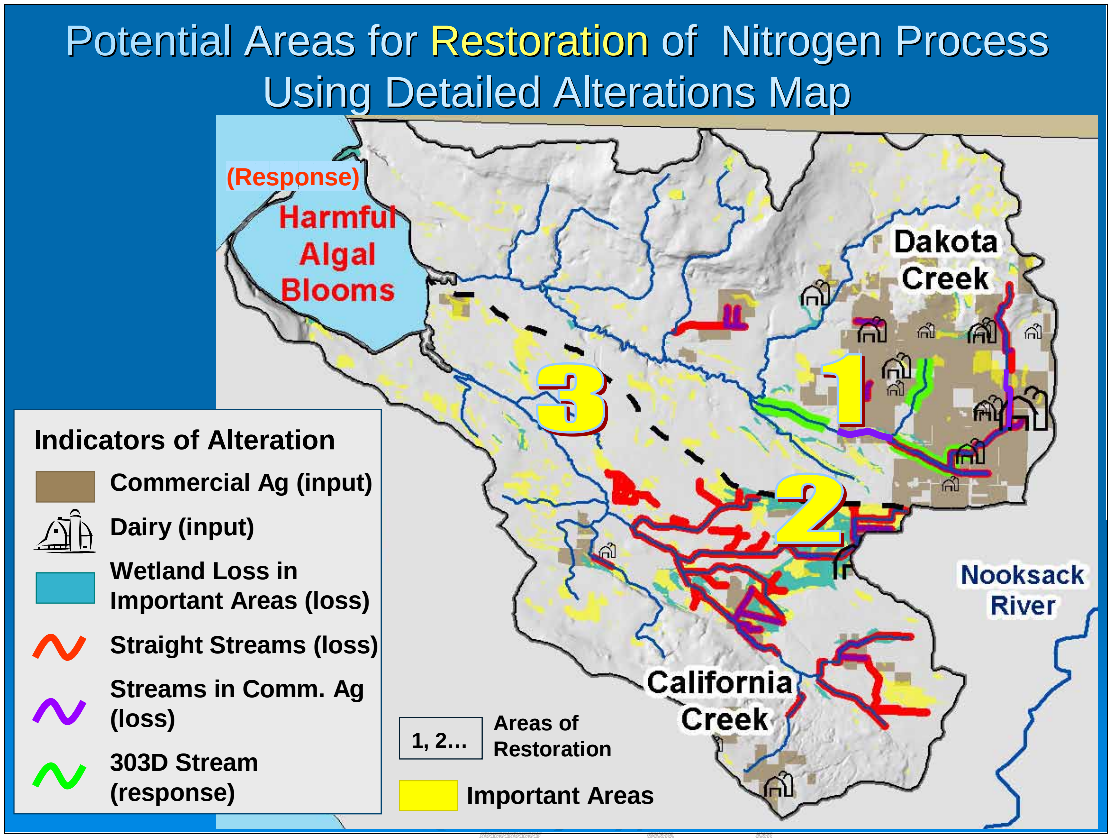


**Figure IV-7 – Example of identifying potential areas for restoration** using detail alterations map for to the nitrogen removal and delivery process. Three potential areas are identified were alteration to important areas is located between input and response (i.e. for estuary).

For the nitrogen delivery and removal process in this example, two of the three focus areas (i.e. # 1 and 2) identified in Figure IV-6 shown a relatively high level of alteration when reviewing the detailed alteration map (Figure IV-7). The area with the largest area of and numbers for indicators for input, located in upper Dakota Creek, was judged to have the greatest priority for restoration. The recommended area of restoration is generally located downstream of these inputs (i.e. #1). The # 2 area for restoration, in upper California Creek, is generally located within the area below the input and within the area of greatest alteration. The # 3 area for restoration is located downstream of the concentrated area of alteration within California creek. Though the #3 area does not show alteration present on the detailed alterations map, it is a relative comparison and some degree of alteration will be present with these areas of importance. All restoration areas are designed to primarily address the "response" problem within the Drayton Harbor estuary.

The alterations identified include numerous <u>inputs</u> of increased nitrogen load, <u>movement</u> alterations (ditches and channelized streams), and resource <u>responses</u> (303d listings for high N loading). In addition, <u>response</u> indicators (i.e. algal blooms) are shown for the Estuarine Resource, indicating that alterations to this process are having significant downstream impacts.

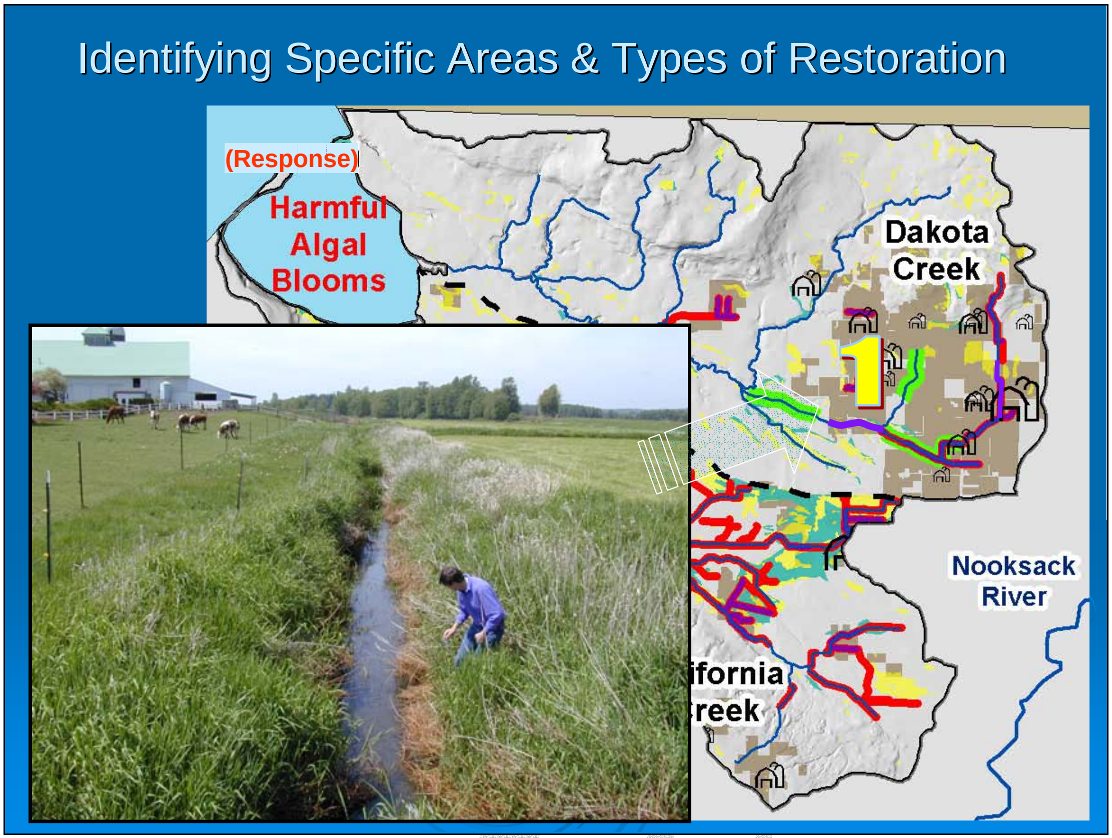

Identifying Specific Areas & Types of Restoration

**Figure IV-8 – Example of identifying one restoration area located between input and response in focus area.** The specific location for a restoration project within priority restoration area #1 is within the altered stream channels (shown in purple and red). The type of restoration would involve eliminating the straightened channels and allowing for overbank flooding and re-establishment of riparian wetlands.

Figure IV-8 provides an example of the specific location and type of restoration in restoration area # 1. The channelized areas located within the areas of "farm plans" could be restored by providing for overbank flooding which would allow for re-establishment of hyporheic and wetland processes for the removal of nitrogen (i.e. denitrification)

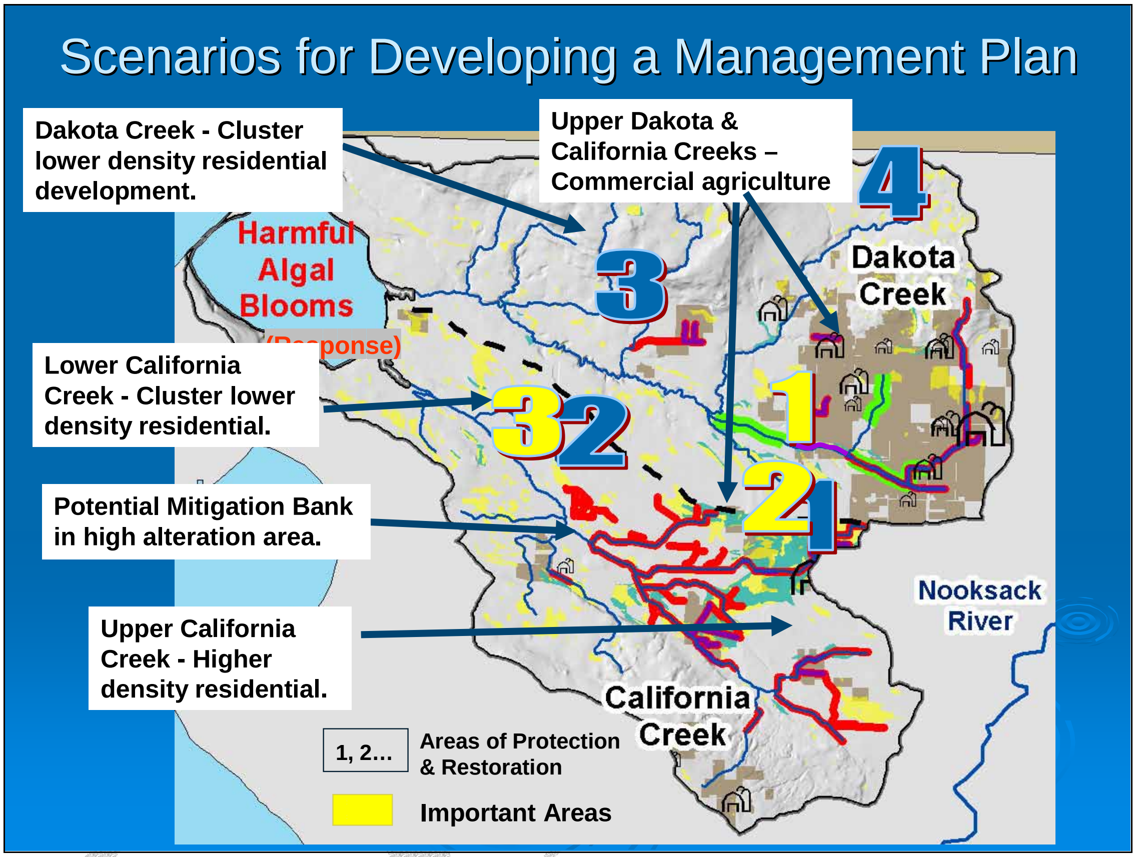
## B. Incorporation of results of synthesis into existing planning efforts

Once the locations of restoration and protection opportunities and accompanying measures have been developed, the user can then incorporate this information into existing frameworks for planning. A broad range of existing frameworks exist to develop plans such as: land use plans, restoration plans for watersheds, or conservation plans. Examples of how the products of synthesis can be integrated into each of these types of plans are given below.

### i. Land Use Plans (Management Plans):

*Example 1: Locating future development:*

Development of land use plans typically involves the application of different development scenarios to determine which development pattern will be most protective of aquatic resources. This can be accomplished by overlaying the proposed development scenarios on the restoration and protection maps and evaluating the potential effect of the scenarios on the aquatic resources (Figure IV-9).



Scenarios for Developing a Management Plan

Dakota Creek - Cluster lower density residential development.

Upper Dakota & California Creeks – Commercial agriculture

Lower California Creek - Cluster lower density residential.

Potential Mitigation Bank in high alteration area.

Upper California Creek - Higher density residential.

1, 2… Areas of Protection & Restoration

🟨 Important Areas

**Figure IV-9 – Example of a management plan**. This shows possible scenarios for commercial, agricultural, and residential land use that will protect and restore the nitrogen delivery and removal process.

For example, in Figure IV-9, development scenario areas are outlined for proposed high density residential and commercial land use in upper California Creek, low density residential in lower California Creek and lower Dakota Creek, and for commercial agriculture in upper Dakota Creek (i.e. continuation of existing use).

These proposed scenarios can be evaluated as follows:

- **Upper Dakota Creek, Area 1 and 4**. As the area for commercial agriculture lies in a proposed priority area for recommended restoration activities in upper Dakota Creek, the management plan should include continued agricultural use of this area but also incorporate the recommended restoration and protection activities. This is also a potential area for siting a mitigation bank.

- **Lower Dakota Creek, Area 3.** Low density residential development is proposed for lower Dakota Creek. As this area contains important areas that are currently not significantly altered, future development would employ green infrastructure measures including clustering to avoid important areas and other measure to prevent addition of new sources of nitrogen to the sub-basin (e.g. well designed storm water and community septic systems that take advantage of nitrogen removal processes in important areas).

☐ **Upper California Creek.** The higher density residential and commercial development is proposed for an area of Upper California Creek that does not contain important areas for the nitrogen removal process. These development activities should be designed to prevent addition new sources of nitrogen to the sub-basin (e.g. well designed storm water and community septic systems that employ green infrastructure measures).

☐ **Upper California Creek, Areas 1 and 2.** As the area for commercial agriculture lies in a proposed priority area for recommended restoration activities in upper Dakota Creek, the management plan should include continued agricultural use of this area but also incorporate the recommended restoration and protection activities. This is also a potential area for siting a mitigation bank.

☐ **Lower California Creek, Areas 3 and 2.** Of particular concern for Lower California Creek is the significant level of alteration that has already occurred throughout its watershed relative to Dakota Creek. Development proposed within these altered areas should employ green infrastructure measures including clustering to avoid important areas and other measure to prevent addition of new sources of nitrogen to the sub-basin (e.g. well designed storm water and community septic systems that take advantage of nitrogen removal processes in important areas). Additionally, consideration should be given to developing a mitigation bank within the area of highest alteration for the watershed (area 1 and 2) to compensate for any impacts to important areas within areas 3 and 2 and elsewhere in the watershed.

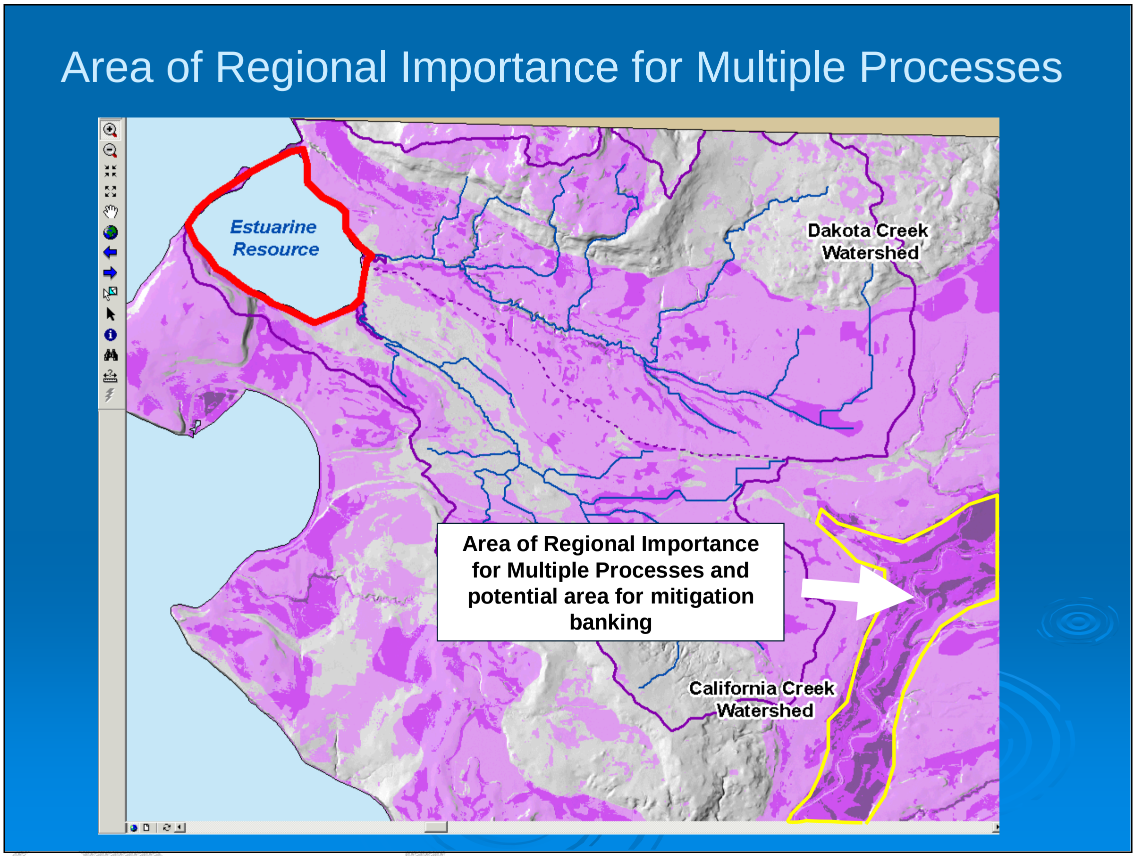
*Example ii: Locating mitigation banks*

Another example of how the results from the landscape characterization can be applied is to identify reasonable locations for mitigation activities such as mitigation banks. Considering the information gathered in the characterization process, mitigation banks could be developed and located to:

- Address specific problems (i.e. responses) occurring within aquatic resources within a watershed and/or
- Restore/protect important areas that are critical to maintaining multiple processes in a watershed and have regional significance

For example, if there was no known “response” problem in the Drayton Harbor watershed (e.g. harmful algal blooms in the estuary), then locating a mitigation bank outside of the watershed could be appropriate. Information from the multiple process map (Map 4) could be used to inform this decision (Figure IV-10) and to suggest that the bank be located in the Nook sack River valley as this area supports multiple processes. In reality there is an identified response problem in the Drayton Harbor estuary; as a result, all mitigation should be located within the watershed in order to address the process alterations.

However, mitigation within a regional mitigation bank may be appropriate for urban areas that have extensively altered processes.



Area of Regional Importance for Multiple Processes

**Figure IV- 10 Example of locating mitigation bank using multiple process map (Map 4).** The area 1 within the Nook sack supports a large area of multiple processes (e.g. surface flow, nitrogen, phosphorous, large woody debris processes) and should be considered a potential area for mitigation banking.

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# Appendices

## Appendix A: Analysis of important areas

## Appendix B: Analysis of alterations

## Appendix C: Alternative methods for small or highly urbanized areas

## Appendix D: Relationship between landscape processes and shoreline functions

## Appendix E: Rationale for linking aquatic resource to key process (Table 2)

## Appendix F: glossary

## Appendix G: GIS Methods

# Appendix A: Important Areas

# Introduction

Step 4 of the characterization of landscape processes involves identifying the geographic areas that are important for each of the key processes. This appendix builds upon Table 3 in the main document by providing a set of GIS-based indicators that can be used in the glaciated portion of Puget Sound to map these important areas (Table A-1) and then by providing a detailed discussion of the technical rationale for the inclusion of each of these indicators. The objective of this step in the analysis is to provide a means of prioritizing the relative importance of different areas to specific processes. Designating an area as important is not meant to imply that other areas have no importance to processes.

Eighteen GIS analyses or mapping procedures are required to complete identification of important areas as outlined in Table A-1; several are used multiple times. For each GIS indicator used, mapping methods are provided.

Several of the processes addressed both in Table A-1 and the discussion have similar important areas; for example, depressional wetlands are important for various controls of surface water storage, sediment removal, phosphorus removal, and toxin removal. Despite this overlap, we have chosen to maintain the redundancy within this document for two reasons:

1. The science underlying the identification of these important areas is always evolving. As a result, it is likely that at some point in the near future, there will be solid evidence that these important areas should be identified differently 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 important areas in an efficient manner. This may involve combining maps for several processes with similar important areas or some other action that results in fewer maps and more efficient display of the findings.

Both Table A-1 and the discussion are organized according to the key processes, in the following order:

1. Surface water runoff
2. Groundwater
3. Sediment
4. Phosphorus
5. Nitrogen
6. Pathogens
7. Toxins
8. Large woody debris

**Table A-1: Geographic areas that are important for each process in the glaciated region of Puget Sound**. For the controls of each process, the types of areas that are more important and the GIS analyses need to identify these areas 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 provided in Appendix XX. * indicates local data needed

| **Key Landscape Process** | | **Controls of Process** | **Relationship of important areas to controls** | **GIS ANALYSIS METHODS** | | |
|---|---|---|---|---|---|---|
| | | | | **Data layers** | **Factor assessed** | **Categories mapped** |
| Surface Water Runoff | *Movement* | Snowmelt/ runoff | Removing vegetative cover in Rain on snow (ROS) zones areas changes quantity and timing of peak flows | Rain on snow zones | Rain on snow zones | Rain on snow zones |
| | | Surface storage | Depressional wetlands store surface water during peak flow events | Soils<br>Slope | Depressional wetlands | • Hydric soils on <2% slope |
| | | | Lakes store surface water during peak flow events | Lakes | Lakes | • Lakes |
| | | | Floodplains store surface water during peak flow events | DEM<br>Hydrography | Large floodplains | Lowland floodplain of Nooksack, Stillaguamish, Skagit, Snohomish/ Snoqualmie, Green/Duwamish, and White/Puyallup Rivers |
| | | | | SSHIAP channel segments | Unconfined streams with floodplains | Unconfined channels |
| | *Loss* | Recharge | Permeable deposits or soils support greater recharge of groundwater than other areas | Surficial geology<br>Soil groups | Permeability of surficial deposits or soils | • Surficial geology of recessional outwash, alluvium, or advanced outwash<br>AND<br>• Soil group of A or B |

**Table A-1** ***continued***

| **Key Landscape Process** | | **Controls of Process** | **Relationship of important areas to controls** | **GIS ANALYSIS METHODS** | | |
|---|---|---|---|---|---|---|
| | | | | **Data layers** | **Factor assessed** | **Categories mapped** |
| Ground-water movement | *Input* | Recharge | Permeable deposits or soils support greater recharge of groundwater than other areas | Surficial geology<br>Soils | Permeability of surficial deposits or soils | • Surficial geology of recessional outwash, alluvium, or advanced outwash<br>AND<br>• Soil group of A or B |
| | | | Areas of higher precipitation have potential for greater recharge | Precipitation isohyetals | Relative amounts of precipitation | Areas of higher precipitation |
| | *Movement* | Storage capacity | Aquifers with greater depth provide greater storage of groundwater | Aquifer * | Depth of aquifer | Aquifers with greater depth |
| | *Loss* | Discharge | *Locally determined* | | | |

**Table A-1** ***continued:***

| **Key Landscape Process** | | **Controls of Process** | **Relationship of important areas to controls** | **GIS ANALYSIS METHODS** | | |
|---|---|---|---|---|---|---|
| | | | | **Data layers** | **Factor assessed** | **Categories mapped** |
| Sediment delivery and removal | *Input* | Soil erosion | Erosion of fine sediments is greater on steeper slopes with highly erodible soils | Slope<br>Soil erodibility index (K)<br>Hydrography | Potential for soil erosion and delivery to stream | Areas, adjacent to streams, with:<br>• >30% slope, K> .25<br>• >65% slope, K<.25<br>• <30% slope, K>.40 |
| | | | Soil disturbance anywhere in the contributing area with delivery to streams can be important | *Do not map – address in alterations* | | |
| | | Mass wasting | Areas adjacent to streams with concave slopes and steep gradients are more prone to mass wasting risk | Shaw Johnson model of risk areas for shallow-rapid landslides<br>Hydrography<br>Slope | Mass wasting risk areas, with a slope steep enough to delivery sediment to the stream, that intersect streams | Areas with high mass wasting risk intersected by streams AND that:<br>• Have a slope >50% across a 250’ buffer from the stream<br>OR<br>• Have a slope >30% across a 150’ buffer from the stream |
| | *Loss* | Water velocity | Areas with longer water retention have greater potential for removal of sediment | Soils<br>Slope | Depressional wetlands | • Hydric soils on <2% slope |
| | | | | SSHIAP channel segments | Unconfined streams with floodplains | Unconfined channels |
| | | | Dams anywhere in the contributing area can be important to the sediment regime | *Do not map – address in alterations* | | |

***Table A-1:** continued*

| **Key Landscape Process** | | **Controls of Process** | **Relationship of important areas to controls** | **GIS ANALYSIS METHODS** | | |
|---|---|---|---|---|---|---|
| | | | | **Data layers** | **Factor assessed** | **Categories mapped** |
| Phosphorus delivery and removal | *Input* | Phosphorus loading | Any excessive phosphorus loads within the contributing area can be important | *Do not map – address in alterations* | | |
| | *Loss* | Water velocity | Areas with longer water retention have greater potential for removal of phosphorus | Soils<br>Slope<br>NWI | Depressional wetlands | • Hydric soils on <2% slope |
| | | Adsorption | Wetlands with organic soils have greater potential for phosphorus removal through adsorption | Surficial geology<br>Soils | Wetlands with organic soils | Soils or surficial geology indicate organic substrate |

***Table A-1:** continued*

| **Key Landscape Process** | | **Controls of Process** | **Relationship of important areas to controls** | **GIS ANALYSIS METHODS** | | |
|---|---|---|---|---|---|---|
| | | | | **Data layers** | **Factor assessed** | **Categories mapped** |
| Nitrogen delivery and removal | *Input* | Nitrogen loading | Any excessive nitrogen loads within the contributing area can be important | *Do not map – address in alterations* | | |
| | *Loss* | Denitrification | Alluvial deposits adjacent to streams are more likely to have more hyporheic area | Surficial geology<br>Hydrography | Alluvial areas adjacent to streams (hyporheic areas) | Areas of alluvium that are associated with streams or their floodplains |
| | | | Seasonal wetlands (alternating oxic/anoxic conditions) increase potential for nitrogen removal | Slope<br>Soils<br>Surficial geology | Seasonal wetlands | Hydric mineral soils on till, glacial marine drift, or lacustrine deposits with <2% slope |
| | | | Wetlands with organic soils have higher potential for nitrogen removal through denitrification | Surficial geology<br>Soils | Wetlands with organic soils | Soils or surficial geology indicate organic substrate |
| | | | Shallow groundwater in riparian area has greater potential to perform denitrification | Surficial geology<br>Hydrography<br>Soils (SSURGO)<br>FEMA floodplain | Areas of shallow groundwater adjacent to streams | Hydric soils on outwash deposits or organic soils on alluvial deposits intersected by stream channels or the FEMA 100 year floodplain |
| | | Assimilation, sorption and denitrification | Small streams in headwater areas have potential to remove nitrogen | Hydrography<br>Shorelines of the State | Presence of small streams | Streams outside of shorelines of the state |

***Table A-1:*** *continued*

| **Key Landscape Process** | | **Controls of Process** | **Relationship of important areas to controls** | **GIS ANALYSIS METHODS** | | |
|---|---|---|---|---|---|---|
| | | | | **Data layers** | **Factor assessed** | **Categories mapped** |
| Mammalian pathogen delivery and removal | *Input* | Pathogen loads | Any excessive pathogen loads within the contributing area can be important | *Do not map – address in alterations* | | |
| | *Loss* | Water velocity | Areas with longer water retention times have greater potential for removal of pathogens; mineral soils reduce potential for pathogen survival | Soils<br>Slope<br>NWI | Depressional wetlands with mineral soils | Hydric mineral soils on <2% slope |
| Toxin delivery and removal | *Input* | Toxin loads | Any input of toxins within the contributing area can be important | *Do not map – address in alterations* | | |
| | *Loss* | Adsorption | Wetlands with organic soils have greater potential for removal of some toxins through adsorption | Surficial geology<br>Soils | Wetlands with organic soils | Soils or surficial geology indicate organic substrate |

***Table A-1** continued:*

| Key Landscape Process | | Controls of Process | Relationship of important areas to controls | GIS ANALYSIS METHODS | | |
|---|---|---|---|---|---|---|
| | | | | **Data layers** | **Factor assessed** | **Categories mapped** |
| Large woody debris (LWD) delivery and removal | *Input* | Streambank erosion | In unconfined channels where mass wasting is unlikely, streambank erosion is a primary woody delivery process | SSHIAP channel segment<br>Mass wasting risk areas<br>Hydrography | Unconfined reaches not within mass wasting risk areas | Unconfined channel reaches not located in a mass wasting risk area |
| | | Mass wasting | In any channel adjacent to a potential mass wasting areas, landslides are the dominant source of LWD, if the debris is likely to reach the stream. | Mass wasting risk areas<br>Hydrography<br>Slope | Mass wasting risk areas, with a slope steep enough to delivery wood to the stream, that intersect streams | All areas with high mass wasting risk intersected by streams except those that:<br>• Have a slope ≥60% that becomes <36% for at least 500' on the downslope OR<br>• Have a slope of 36-60% that becomes <36% for at least 150' on the downslope. |
| | | Windthrow | In channels where mass wasting is unlikely, windthrow is an important woody delivery process | Hydrography<br>Mass wasting risk area<br>DEM | 100 foot buffer width on streams that are not within a mass wasting area | 100' buffer on either side of streams not intersecting mass wasting risk aeas |

# Rationale for Identification of Important Areas

## 1. Surface water runoff:

The types of areas in which the major controls operate to maintain surface water runoff are:

A. Areas where land cover changes are likely to produce changes in snow melt and runoff quantity and timing
B. Areas important for the surface storage of water during high flow events
C. Areas important for recharge

Each of these areas is discussed in detail below. Justification for their importance to this process and a description of the GIS analysis used to identify these areas on the landscape are provided.

### A. Areas with high potential for changing *snowmelt and runoff*:

In the Pacific Northwest runoff from snowmelt is exacerbated during so-called Rain on Snow events. In these warmer storms, rain falls in middle elevations where snow usually accumulates. These warmer conditions cause the snow to melt early and at the same time that runoff from the rain is occurring. Many of the largest flooding events in Western Washington are associated with the larger amount of runoff created during Rain on Snow conditions.

Mapping methods: Use maps of the areas most prone to these rain on snow events, available from the WA DNR

### B. Areas important for *surface storage* of water:

Depressional wetlands, lakes and floodplains are all areas with the potential to store water during high flow events (Sheldon et al, 2003; Hruby et al, 1999).

*Depressional Wetlands:* The cumulative role of depressional wetlands in storing surface water has been demonstrated in numerous locations around the world. Locally in King County, the percentage of a watershed that is in wetland cover has been found to relate to the flashiness or variability of runoff events; Reinelt and Taylor (1997) found that watersheds with less than 4.5% of their area in wetland produced more variable water levels in depressional wetlands than did those with a higher area in wetlands.

However, the effectiveness of specific depressional wetlands in storing surface water depends greatly upon their location within the watershed. Work by Bullock and Acreman (2003) that examined studies from around the world found that headwater depressional wetlands, if directly connected to river systems, played an important role in storing surface water. Depressional wetlands not directly connected to a river or stream were less consistent in their effectiveness in storing surface water.

In Table A-1, depressional wetlands as a whole are identified as important for water storage; this is a coarse indicator of areas important for water storage. Using local data and knowledge of the location of these wetlands and the likely role they play in storing surface water, some of these depressional wetlands may need to be excluded as important areas for this process.

Mapping methods: Potential wetlands, which encompass both existing and historic wetlands, can be located using hydric soils from NRCS soil surveys. Depressional wetlands can be located using the hydrogeomorphic characteristics of the potential wetlands. Depressional wetlands are areas with less than 2% slope that have hydric soils according to the NRCS soil survey

*Lakes:* Lakes can be important for storing surface water.

Mapping methods: Existing GIS data layers can be used to map lakes.

*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 were documented to reduce or delay 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.

Large river valleys: In the glaciated area of the Pacific Northwest, the type of physical process that formed and/or is forming the floodplain determines its capacity to store surface water during flood events. Glacially formed floodplains tend to have a flood storage capacity that exceeds the volume of river-generated floods (Collins et al, 2003).

Mapping methods: No single GIS layer exists that is adequate for delineating the floodplains associated with these large rivers. As a result, this area has to be manually delineated using a topographic map or DEM to identify the large, lowland valleys associated with six major tributaries to Puget Sound – the Nooksack, Skagit, Stillaguamish, Snohomish/Snoqualmie, Green/Duwamish, and White/Puyallup Rivers.

Smaller river valleys: While floodplains of large rivers are clearly most important for moderating major floods, floodplains of smaller streams can, cumulatively, serve an important role in reducing inputs to larger rivers and thus help maintain the size of peak flows within a more natural range.

Mapping methods: 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. Unconfined stream segments in this data layer are used to identify reaches likely to have floodplains and provide surface water storage.

### C. Areas important for *recharge:*

Surficial deposits that support infiltration and percolation of precipitation play an important role in reducing runoff from storm events and snow melt. The infiltration capacity of the soil layer is characterized by the soil hydrologic groups; once water has moved through the soil layer, its likelihood of recharging the groundwater aquifer is controlled by the permeability of the associated geologic deposit. Areas important for recharge are those with soils that allow for the infiltration of water and that lie over geologic deposits that allow water to percolate to depth easily.

In a technical release, the Natural Resources Conservation Service has categorized soils into Hydrologic Soil Groups that are indicative of infiltration capacity and transmissivity. Two of these groups, A and B, have low runoff potential due to relatively high infiltration and transmission rates (NRCS, 1986). Surface water in areas with these types of soils has a higher likelihood of moving to the subsurface, rather than on the surface.

**Table A-2: Generalized relationship between surficial geology and soil permeability in a glaciated landscape**. $^1$=Vaccaro et al, 1998; $^2$ =Jones, 1998

| Surficial Geology | Sediment Size | Permeability | Hydraulic conductivity (ft/d)$^2$ |
|---|---|---|---|
| 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<br>Around .0001 ft/d (p. D29)$^1$ |
| 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 | |

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

Note that on some surficial geology maps the glacial outwash class can include glacial marine drift, which has significantly lower permeability (Table A-2); for this analysis, areas of glacial marine drift should be separated out from outwash deposits due to this difference.

Mapping methods: Areas with soils in hydrologic soil groups A and B (from the NRCS soil survey) that are underlain by recessional outwash, alluvium or advanced outwash (from the surficial geology layer) are identified as those likely to support greater recharge of groundwater.

## 2. Groundwater

### Overview

Groundwater flow paths are usually described hierarchically in three levels, each with slightly longer flow distances and therefore longer residence time: local flow, intermediate flow, and regional flow (Figure A-1). In the Puget Sound region, Morgan and Jones of the USGS (1999) define these flow paths as:

- *Regional* - This is deeper flow paths that are defined by large scale topographic features such as Puget Sound and the Cascade Range. The movement of this groundwater is largely through pre-Quaternary bedrock and deeper unconsolidated sediments.
- *Intermediate* – This is above the bedrock and below the deepest portion of the local flow paths. Groundwater in this flow path can move across basins, moving under major streams.
- *Local* - This is the movement of groundwater in the upper few hundred feet of the Quaternary deposits and is governed largely by local topographic patterns. Recharge occurs largely on the drift plains and discharge is via springs and seepages into streams. Major and even minor stream corridors can be the discharge boundaries of these flows.

This characterization approach is primarily concerned with the local and intermediate flow paths that are largely controlled by topography, the confining units below the aquifer, and the extent of salt water (Vaccaro et al, 1998). Very local groundwater movement patterns, that would be required for a detailed hydrogeologic assessment as part of a restoration or mitigation design, would be addressed at the site level. This finer scale of water movement is not addressed by this approach.

The groundwater flow process is composed of recharge, storage, lateral and vertical movement, and discharge of groundwater. This analysis identifies areas important for recharge of groundwater, areas likely to store larger quantities of water, general lateral gradients of movement due to head gradients, and areas of likely groundwater discharge.

### Mapping general groundwater patterns – a useful exercise:

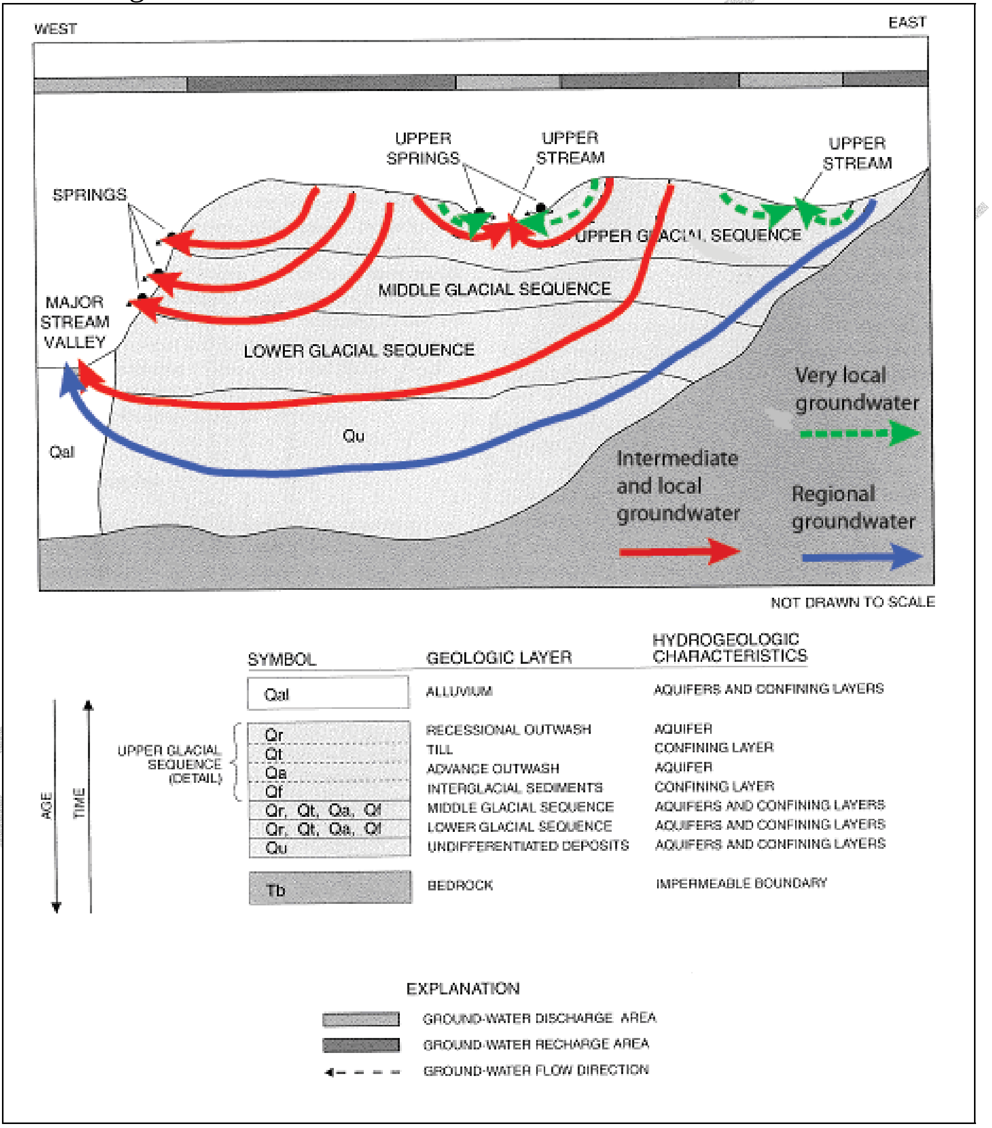
Although not included as a step in the characterization framework, it has proven useful in previous assessments to develop maps of the generalized patterns of groundwater movement in the area of interest. These maps assist in the assessment of the location of likely groundwater discharge points and the development of hypotheses regarding the effect of various human activities on the groundwater system.

Movement of the uppermost layers of groundwater is controlled by topography, the shape of the aquifer system, and the locations and amount of discharge and recharge (Vaccaro et al, 1998). A few assumptions or rules can be used to synthesize this information and hypothesize patterns of groundwater movement:

A. 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 are generally surface water drainages or the Puget Sound itself.

B. Perched groundwater on hillslopes recharges groundwater in more permeable sediments in valley bottoms or other less steep topography as it moves from the steep to less steep topography.

C. Lakes and large wetland areas, if not on perched water tables, and streams are an expression of the water table or the emergence of groundwater at the surface.



| SYMBOL | GEOLOGIC LAYER | HYDROGEOLOGIC CHARACTERISTICS |
|---|---|---|
| Qal | ALLUVIUM | AQUIFERS AND CONFINING LAYERS |
| Qr | RECESSIONAL OUTWASH | AQUIFER |
| Qt | TILL | CONFINING LAYER |
| Qa | ADVANCE OUTWASH | AQUIFER |
| Qf | INTERGLACIAL SEDIMENTS | CONFINING LAYER |
| Qr, Qt, Qa, Qf | MIDDLE GLACIAL SEQUENCE | AQUIFERS AND CONFINING LAYERS |
| Qr, Qt, Qa, Qf | LOWER GLACIAL SEQUENCE | AQUIFERS AND CONFINING LAYERS |
| Qu | UNDIFFERENTIATED DEPOSITS | AQUIFERS AND CONFINING LAYERS |
| Tb | BEDROCK | IMPERMEABLE BOUNDARY |

EXPLANATION

| | |
|---|---|
| ▨ | GROUND-WATER DISCHARGE AREA |
| ▨ | GROUND-WATER RECHARGE AREA |
| ◄– – – – | GROUND-WATER FLOW DIRECTION |

**Figure A-1. Generalized cross section through hypothetical basin typical of the Puget Sound Lowland**, showing recharge and discharge areas and generalized directions of groundwater flow paths in the Puget Sound region (taken from Morgan and Jones, 1999). Blue lines are generalized regional flow lines; red lines are intermediate and local flow lines addressed in this approach; green lines are very local flow lines.

**Characterizing the important areas for groundwater:**

The types of areas in which the major controls operate to maintain surface water runoff are:

A. Areas important for *recharge*
B. Areas important for *storage capacity*
C. Areas important for *discharge*

Each of these areas is discussed in detail below. Justification for their importance to this process and a description of the GIS analysis used to identify these areas on the landscape are provided.

A. **Areas important for *recharge*:**

The amount that groundwater is recharged is controlled by two factors: the ability of surface water to percolate into the aquifer and the relative amount of precipitation in an area.

i. *Areas with greater capacity for percolation:* The justification for this is the same as that described in the previous section on surface water runoff.

ii. Areas with *greater precipitation:* 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; however, 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. As a result, this guidance makes the assumption that higher amounts of precipitation result in greater recharge across areas with coarser surficial deposits.

Mapping methods: Precipitation isohyetals are used to identify any areas that have relatively higher quantities of precipitation.

**B. Areas important for *storage capacity*:**

Permeable surficial deposits or aquifers that are deep provide for greater storage of groundwater.

Mapping methods: There are no region-wide data layers identifying the depth of aquifers or surficial deposits. Instead local data on aquifer depths or the depth of permeable deposits of alluvium and recessional or advance outwash must be used are mapped.

**C. Areas important for *discharge:***

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). For this reason, this aspect of the groundwater flow process is treated differently in this guidance than are the other processes.  Rather than provide some indicators of groundwater discharge that are applicable across the entire Puget Sound region, we suggest some indicators that, with local data and evidence for support, have proven to be useful in specific locales.  In order to apply any of these indicators to highlight likely areas important for groundwater discharge, the planner will need to examine local data sources and determine which of these or other indicators are appropriate for their contributing area.

In the Pacific Northwest, groundwater generally is an important contributor to annual streamflow (Winter et al, 1998). The relevance, and therefore applicability, of these indicators to a given location should be supported with existing local scale data; however, these indicators have been found to be reasonable in some areas of Puget Sound.

i. *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 21)

ii. *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 upwards and emerge at the surface (Winter et al, 1998).

iii. *Areas of organic soils:* Wetlands with soils of high organic content form in places on the landscape that have consistent, continuous inputs of water or waterlogged conditions (Mitsch and Gosselink, 2000). Organic soils form when vegetation is kept wet for long periods of times; the anoxic conditions that form prevent the usual decomposition of vegetative material and allow for the formation of a substrate composed primarily of organic material. In a portion of Whatcom County, organic soils were found to be locations of groundwater discharge (Cox and Kahle, 1999).

**3. Sediment delivery and removal**
Sediment delivery to aquatic ecosystems is a natural phenomenon; however, excessive amounts of sediment, or inadequate removal of sediment from the water column, can undermine the condition of many types of aquatic ecosystems (Edwards, 1998). Like several other analyses of sediment processes in the PNW, the differential abilities of various channel types to transport sediment are not addressed (e.g. Beechie et al, 2003). Instead, it is assumed that the delivery of sediment to the aquatic ecosystems is the proximate issue to be addressed by restoration and protection activities.

Areas important for the delivery and removal of sediment are:

A. Areas important for *soil erosion*
B. Areas important for *mass wasting*
C. Areas important for changing *water velocity*

Each of these types of important areas is discussed in detail below. Justification for their importance to this process and a description of the GIS analysis used to identify these areas on the landscape are provided.

**A. Areas prone to *soil erosion:***

*i. Steep slopes with erodible soils*

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 and 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 A-3, WFPB,1997a**)**.

**Table A-3: Slope and K factor**. Combinations of both slope and K factor that indicate a higher potential for erosion of fine sediments to aquatic resources (WFPB, 1997a)

| **Slope** | **K factor** |
|---|---|
| >30% | >0.25 |
| >65% | <0.25 |
| <30% | >0.40 |

Mapping methods: Using the Statsgo soils data and slope, calculated from a DEM, areas with the combination of slope and K factor shown in Table A-3 are mapped as those prone to surface erosion.

*ii. Soil disturbance in contributing basin*

This is addressed in the alterations section (Appendix B)

**B. Areas prone to *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 made 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. Field verification of this model in the Upper Lewis watershed indicates that the model overpredicts risk of mass wasting in formations with significant deposits of volcanic ash (P. Olson, personal communication, April 2005). 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.

Mapping methods: The output of the Shaw Johnson model is mapped for the Puget Sound region; areas are identified as having low, moderate or high risk of mass wasting events. Areas that this model identifies as being at high risk for mass wasting are mapped as important areas.

**C. Areas important for changing *water velocity*:**

*i. Depressional wetlands*

Depressional wetlands, particularly those without an outlet, are the most effective 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 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 in Sheldon et al, 2003; Adamus et al, 1991).

Mapping methods: These methods are the same as those for identifying depressional wetlands likely to provide surface water storage. Potential wetlands, which encompass both existing and historic wetlands, can be located using hydric soils from NRCS soil surveys. Depressional wetlands can be located using the hydrogeomorphic characteristics of the potential wetlands. Depressional wetlands are areas with less than 2% slope that have hydric soils according to the NRCS soil survey

*ii. Floodplains*

Floodplains, by their very nature slow down water velocity, providing effective areas for removing fine sediments from the water column.

Mapping methods: these methods are the same as those for identifying unconfined streams with floodplains that are likely to provide surface water storage. 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. Unconfined stream segments in this data layer are used to identify reaches likely to have floodplains and provide surface water storage.

*iii. Dam locations in the contributing area*

This is addressed in the alterations section (Appendix B).

## 4. Phosphorus delivery and removal

Areas that are important for the delivery and removal of phosphorus are:

A. Areas important for *phosphorus loading*
B. Areas important for changing *water velocity*
C. Areas important for *adsorption*

Each of these types of important areas is discussed in detail below. Justification for their importance to this process and a description of the GIS analysis used to identify these areas on the landscape are provided.

### A. Areas important for *phosphorus loading*:

Delivery of excessive phosphorus occurs with current land uses; as the addition of this load to aquatic resources is important regardless of where it occurs, no important areas for the delivery of phosphorus have been identified in this analysis. Instead, the excessive delivery of phosphorus is addressed in Appendix B, alterations to the process.

### B. Areas important for reducing *water velocity*:

As phosphorus is often adsorbed to fine sediment particles, removal of phosphorus generally occurs in areas that facilitate sedimentation (Mitsch and Gosselink, 2000). These are places that reduce the velocity of water and increase the residence time of water, thus increasing the likelihood that sediment particles will fall out of the water column. Depressional wetlands, described in the previous section as important for the removal of fine sediment, are also important for the removal of phosphorus that is attached to sediment.

> Mapping methods: These methods are the same as those for identifying depressional wetlands likely to provide surface water storage. Potential wetlands, which encompass both existing and historic wetlands, can be located using hydric soils from NRCS soil surveys. Depressional wetlands can be located using the hydrogeomorphic characteristics of the potential wetlands. Depressional wetlands are areas with less than 2% slope that have hydric soils according to the NRCS soil survey

### C. Areas important for *adsorption*:

As dissolved phosphorus may be removed through adsorption to soils that are high in clay or organic matter (Sheldon et al, 2003 after Mitsch and Gosselink, 2000), wetlands with fine grained (i.e. clay) or organic soils are likely to be effective at removing phosphorus.

> Mapping methods: Areas where either the soils or the surficial geology data layers indicate the substrate is organic are identified as important areas for adsorption of phosphorus

**5. Nitrogen delivery and removal:**
Areas important for the delivery and removal of nitrogen are:

A. Areas important for *nitrogen loading*
B. Areas important for *denitrification*
C. Areas important for *assimilation, sorption and denitrification*

Each of these types of important areas is discussed in detail below. Justification for their importance to this process and a description of the GIS analysis used to identify these areas on the landscape are provided.

### A. Areas important for *nitrogen loading*:

Delivery of excessive nitrogen occurs with current land uses; as the addition of this load to aquatic resources is important regardless of where it occurs, no important areas for the delivery of nitrogen have been identified in this analysis. Instead, the excessive delivery of nitrogen is addressed in Appendix B, alterations to the process.

### B. Areas important for *denitrification*:

i. *Hyporheic areas:* The edges of hyporheic areas have recently been associated with increased potential for performing dentrification (Triska et al, 1993; McClain et al, 1998). The efficiency of this transformation seems to be correlated with the width of the hyporheic areas; rivers with large hyporheic areas retain and process nutrients more efficiently than rivers lacking these areas (Edwards, 1998).

Although many river segments have some hyporheic area, even if it is only immediately below the stream channel (Triska et al, 1989), the importance of hyporheic zones is greatest where "large volumes of porous sediment accumulate" (Edwards, 1998). The extent of the hyporheic zone can be coarsely delineated by the extent of alluvial deposits within which stream channels are located (Edwards, 1998). As this approach identifies the broadest potential extent of hyporheic areas associated with river channels, it is used here to identify areas with a greater potential of performing denitrification through hyporheic processes.

Mapping methods: Areas with surficial deposits of alluvium, associated with streams or their floodplains, are identified as important areas for denitrification through hyporheic processes.

ii. *Seasonal wetlands:* Most of the transformations and processes for removing nitrogen compounds from surface water are biogeochemical in nature. These mechanisms often depend upon the alternating wet and dry conditions (corresponding to anaerobic and aerobic conditions) found in seasonal wetlands (Sheldon et al, 2003; Mitsch and Gosselink, 1993).

Mapping methods: Potential wetlands with a seasonal flooding regime can be identified by locating depressional wetlands with mineral soils underlain by a fairly impermeable geologic deposit. Potential depressional wetlands can be identified areas of hydric soils with less than 2% slope (unpublished analysis). A subset of these wetlands will have mineral soils, an indicator that permanent flooding is absent. This subset of mineral depressional wetlands is then overlaid on surficial geology; those wetlands on an impermeable surficial deposit are assumed to rely primarily on precipitation as a water source and thus are more likely to dry out towards the end of the growing season.

iii. *Wetlands with organic soils*: Wetlands with organic soils tend to have high denitrification rates as they provide the organic carbon required by the denitrifying bacteria (Mitsch et al, 1999).

Mapping methods: These are same methods as used in the phosphorus delivery and removal section to identify areas important for adsorption. Areas where either the soils or the surficial geology data layers indicate the substrate is organic are identified as important areas for denitrification.

iv. *Riparian areas with shallow groundwater:* Recent work in the glaciated portions of the Northeastern US has described an approach to identify riparian areas with a higher likelihood of removing nitrogen from groundwater. Riparian areas with shallow groundwater (i.e. the aquifer is not deep but is underlain by a shallow, relatively impermeable deposit), that are hydric soils in outwash or organic/alluvial deposits, have been found to remove up to 85% of the nitrogen from the groundwater (Rosenblatt et al, 2001; Gold et al, 2001). The mechanism is believed to be shallow water moving through organic soils or other organic matter that allow bacterial denitrification to occur. Rosenblatt et al (2001) examined the relative accuracy of STATSGO and SSURGO soils data for identifying these areas and found SSURGO to be much more appropriate.

Mapping methods: The SSURGO data base is used to identify soils that are hydric and organic. These areas are intersected with the surficial geology datalayer to identify areas of hydric soils underlain by outwash deposits and areas of organic soils underlain by alluvial deposits. In order to identify riparian areas with these geomorphic characteristics, these areas are intersected with the stream hydrography layer; all of these geomorphic areas intersected by a stream are highlighted as important. On larger stream channels, this riparian area can extend a fair distance away from the channel mapped by the hydrography datalayer. The FEMA 100 year floodplain is used as a coarse indicator of this width. All areas of the appropriate geomorphic characteristics that are intersected by the FEMA 100 year floodplain are also highlighted as important areas for denitrification by riparian areas.

**C. Areas important for assimilation, sorption, and denitrification:**

i. *Small headwater streams.* Small headwater streams play a significant role in controlling the export of inorganic nitrogen to rivers, lakes and estuaries. In a study of headwater streams across the U.S., Peterson et al (2001) found that, through assimilation, sorption to sediment and denitrification, small streams can retain and transform more than 50% of the nitrogen inputs from a watershed (Peterson et al 2001). This can be a significant factor in larger watersheds since small streams can constitute up to 85% of the total stream length according to Peterson et al (*Ibid).*

Mapping methods: Of the 15 streams included in this study (Peterson et al, 2001), only two had discharge rates greater than 20 cfs (**http://www.sciencemag.org/cgi/content/full/292/5514/86/DC1)**, the threshold above which streams are mapped as shorelines of the state in Washington. For this reason, all streams not mapped as shorelines of the state are highlighted as having greater potential for removing nitrogen through assimilation, sorption and denitrification processes.

**6. Mammalian pathogen delivery and removal:**
Areas important for the delivery and removal of pathogens are:

A. Areas important for *pathogen loading*
B. Areas important for reducing *water velocity*

Each of these types of important areas is discussed in detail below. Justification for their importance to this process and a description of the GIS analysis used to identify these areas on the landscape are provided.

### A. Areas important for *pathogen loading*:

Because delivery of excessive pathogens, such as fecal coliform, occurs primarily with current land uses which alter processes, it is addressed in Appendix B, Alterations to the Process. Though wildlife play a role in generating pathogen loads (e.g. waterfowl and fecal coliform) human generated pathogen loads were judged, in this guidance, to have a far greater impact to aquatic ecosystems. .

### B. Areas important for changing *water velocity*:

i. *Depressional wetlands with mineral soils:* 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 storm water 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 (Marino and Gannon, 1991) and removal of pathogen-laden sediment through either filtration by vegetation or sedimentation (Borst et al, 2001; Sherer et al, 1992).

Organic soils have been found to increase the longevity of coliform organisms as well as typhoid bacilli and enterococci (Mallman and Litsky, 1951 and Tate, 1978, both cited in Heufelder and Rask). Additionally organic soils in wetlands have been found to interfere with the sorptive capacity of sediment and soils to viruses (Schenerman et al, 1979 cited in Heufelder and Rask.**)**

Mapping methods: Mineral hydric soils, as identified in the NRCS soil surveys, identify wetlands with mineral soils. Those areas with less than 2% slope are identified as depressional wetlands, which are likely to reduce water velocity.

### 7. Toxin delivery and removal

Areas important for the delivery and removal of toxins are:

A. Areas important for *toxin loading*
B. Areas important for *adsorption*

Each of these types of important areas is discussed in detail below. Justification for their importance to this process and a description of the GIS analysis used to identify these areas on the landscape are provided.

#### A. Areas important for *toxin loading*:

Because delivery of toxins, such as heavy metals, pesticides, herbicides, petroleum products and pharmaceuticals, occurs with current land uses which alter processes, it is addressed in Appendix B, Alterations to the Process.

#### B. Areas important for *adsorption:*

i. *Wetlands with organic soils*- In general, wetlands that are effective at removing sediments are important areas for removing those toxins that effectively bind to particles (Sheldon et al, 2003). In particular, wetlands with soils that have a high cation exchange capacity, such as organic soils, are likely to provide adsorption opportunities for various compounds, such as cadmium, copper, iron, lead, manganese, and mercury (Kadlec and Knight, 1996).

Soils with high clay contents may have high cation exchange capacities; however, it is not completely clear whether glacially derived clays have these same conditions as are provided by weathered clays (Sheldon et al, 2003). Locally available data indicating soils with high cation exchange capacities should be used to identify potentially important areas for toxin removal. Additionally, there is some evidence that higher dissolved organic carbon correlate with reduced bioavailability of copper (Johnson, 2005); if data are available indicating these higher levels, this may also be used as an indicator of an important area.

Mapping methods: These are same methods as used in the phosphorus delivery and removal section to identify areas important for adsorption. Areas where either the soils or the surficial geology data layers indicate the substrate is organic are identified as important areas for denitrification.

**8. Large woody debris delivery and delivery**

Three mechanisms are important for the delivery of large woody debris:

A. Areas important for *streambank erosion*:
B. Areas important for *mass wasting*
C. Areas important for *windthrow*:

Each of the important areas is discussed in detail below. Justification for their importance to this process and a description of the GIS analysis used to identify these areas on the landscape are provided.

### A. Areas important for *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). This is a primary source of wood in channels where mass wasting is unlikely.

> Mapping methods: The channel segment database developed by the Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) is used to identify unconfined channels (in the same way it is used to identify areas important for storage of surface water). Areas that have high mass wasting potential, identified in the next section (B), are removed from the set of unconfined channels. Those that remain are unconfined channels with a low to moderate risk of mass wasting and are areas where streambank erosion is an important large woody debris recruitment process.

### B. Areas important for *mass wasting*:

In places where mass wasting or landslide events are likely to occur directly upslope of the stream channel, these events provide a significant amount of wood. In studies of 3 stream systems from California to Washington, Reeves et al (2003) and Benda et al (2002b) found that between 65-80% of instream wood came from upslope areas. A similar result was found for smaller headwater streams in SW Oregon by May and Gresswell (2003).

> Mapping methods: Stream channels that intersect areas of high risk for mass wasting, per the Shaw and Johnson model (evaluated under the sediment process), are identified as important potential sources of wood to streams. Guidelines are applied to these areas, as used by the Washington Department of Natural Resources (WA DNR, 1997), to identify topography that is likely to prevent delivery of wood to streams. High risk areas unlikely to deliver wood to the stream, even if mass wasting events occur, are those with shallow slopes between the mass wasting area and streams:
>
> - High risk areas with a slope ≥60% that change to a slope < 36% for at least 500' or

- High risk areas with a slope between 36 and 60% that changes to <36% for at least 150'

**C. Areas important for *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).

Mapping methods: All streams that do not intersect a mass wasting hazard area are buffered with a 100' width on both sides of the channel to identify the area important for windthrow.

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# Appendix B: Indicators of Altered Processes

# Introduction

Step 5 of the characterization of landscape processes involves determining the likelihood that important areas for each process have been altered through human activities. This Appendix builds upon Table 4 in the main document by providing 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 (Table B-1) and then by providing a detailed discussion of the technical rationale for the use of each of these indicators. 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 for biological components but has adapted some of the physical and chemical indicators (The Heinz Center, 2002). Users of this guidance should ensure that these indicators seem reasonable for their specific planning area and add others that are well justified from local studies or data.

Eighteen GIS analyses or mapping procedures are suggested to complete identification of alterations to the key processes as outlined in Table B-1; several are used multiple times. For each GIS indicator, mapping methods are provided if regional data are available. If local data must be used as an indicator, mapping methods appropriate to that data will need to be developed.

Several of the processes addressed both in Table B-1 and the discussion have similar indicators of alteration; for example, straightline hydrography (indicative of ditches or channelized streams) is an indicator that various controls of 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 these indicators that a process has been altered is always evolving. 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 is 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 important 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.

Both Table B-1 and the discussion are organized according to the key processes, in the following order:

1. Surface water runoff
2. Groundwater
3. Sediment
4. Phosphorus

5. Nitrogen
6. Pathogens
7. Toxins
8. Large woody debris

**Table B-1: Indicators, for the glaciated region of Puget Sound, that key processes have been changed**: For each process, the table ties to Table 4 in the main document by indicating the controls of the process. For each potential change to the process, as a result of changes to the controls, a list is provided of GIS-based indicators that the process is likely changed. *= Local data is needed as statewide or regional data do not exist.

| Key Landscape Process | | Controls of Process | Change to Process | Indicators that process has been changed |
|---|---|---|---|---|
| Surface water runoff | *Movement* | Snowmelt and runoff | Increase in peak flows | Non-forested land cover on Rain on Snow zones |
| | | Surface storage | Decrease storage capacity | Dikes or levees*<br>Straightline hydrography of streams with floodplains that are important for water storage |
| | | | Decrease retention time of water | Straightline hydrography in depressional wetlands<br>Loss of depressional wetlands in the watershed |
| | *Loss* | Recharge | Decrease losses to groundwater<br>Increase surface water runoff | Impervious land cover on areas important for recharge |
| Groundwater movement | *Input* | Recharge | Decrease inputs to groundwater<br>Increase surface water runoff | Impervious land cover on areas important for recharge |
| | *Movement* | Storage capacity | Decrease quantity of water stored in the aquifer | Rural land use – in King and Snohomish Counties<br>Industrial/commercial land use – in Pierce county<br>Row crop agricultural land use – in Whatcom and Skagit counties<br>Well locations*<br>Reduced baseflow* |
| | *Loss* | Discharge | Decrease groundwater supply to aquatic resources | *Determined locally* |

***Table B-1:** continued)* $^{*}$= Local data is needed as statewide or regional data do not exist.

| Key Landscape Process | | Controls of Process | Change to Process | Indicators that process has been changed |
|---|---|---|---|---|
| Sediment delivery and removal | *Input* | Soil erosion | Excessive erosion of fine sediments | Non-forested cover in areas important for erosion<br>Row crop landuse draining to aquatic resource*<br>New construction draining to aquatic resource * |
| | | | Increase delivery of fine sediments to aquatic resources | Roads within 200' of streams<br>High turbidity loads* |
| | | Mass wasting | Increase the likelihood of a mass wasting event and delivery of excessive sediment to aquatic resources | Roads in areas important for mass wasting |
| | *Loss* | Water velocity | Decrease removal of sediment | Straightline hydrography in depressional wetlands and/or streams<br>Loss of area of depressional wetlands<br>Dikes and levees* |
| | | | Increase removal of sediment | Dams |
| Phosphorus delivery and removal | *Input* | Phosphorus loads | Excessive phosphorus loads | High BOD and low DO*<br>Algal blooms*<br>High phosphorus loads* |
| | *Loss* | Water velocity | Decrease removal of phosphorus | Loss of area of depressional wetlands<br>Straightline hydrography in depressional wetlands |
| | | Adsorption | | Loss of area of wetlands with organic soils |

***Table B-1:*** *continued)* *= Local data is needed as statewide or regional data do not exist.

| Key Landscape Process | | Controls of Process | Change to Process | Indicators that process has been changed |
|---|---|---|---|---|
| Nitrogen delivery and removal | *Input* | Nitrogen loads | Excessive nitrogen loads | Agricultural land use<br>Residential land use adjacent to water bodies<br>Disturbed riparian corridors *<br>High nitrate/ammonia loads* |
| | *Loss* | Denitrification | Decrease removal of nitrogen in: | |
| | | | Hyporheic areas | Stream incision*<br>Dikes and /or levees*<br>Straightline hydrography<br>Urban or agricultural landuse adjacent to or in floodplain<br>High fine sediment or turbidity levels* |
| | | | Seasonal wetlands | Loss of area of seasonal wetlands |
| | | | Wetlands with organic soils | Loss of area of wetlands with organic soils |
| | | | Riparian areas with shallow groundwater | Roads or straightline hydrography intercepting shallow groundwater in riparian areas |
| | | Assimilation, sorption, denitrification | Decrease nitrogen removal | Straightline hydrography in small streams |
| Mammalian pathogen delivery and removal | *Input* | Pathogen loads | Excessive pathogen loads | Rural residential land use<br>Impervious land cover of catchment basin<br>Shellfish closures*<br>High fecal coliform loads* |
| | *Loss* | Water velocity | Decrease removal of pathogens | Straightline hydrography in streams or depressional wetlands with mineral soils<br>Loss of area of depressional wetlands with mineral soils |
| Toxin delivery and removal | *Input* | Toxin loads | Addition of toxin loads | Urban land use<br>Agricultural landuse<br>Contamination of fish with PCB's*<br>Contaminant loads* |
| | *Loss* | Adsorption | Decrease removal of | Straightline hydrography in wetlands |

| | | | | |
|---|---|---|---|---|
| | | | certain toxic compounds | with organic soils<br>Loss of area of wetlands with organic soils |
| Large woody debris delivery and removal | *Input* | Stream bank erosion | Decrease large woody debris inputs | Dikes and /or levees*<br>Straightline hydrography<br>Non-forested land use adjacent to streams |
| | | Mass wasting | | Non-forested land cover on mass wasting hazard areas adjacent to streams |
| | | Windthrow | | Non-forested land cover in important areas for windthrow |

# Rationale for Indicators of altered Processes

## 1. Surface water runoff

### A. Snowmelt and runoff:

i. *Non-forested land cover on Rain on snow zone:* Cleared portions of the rain-on-snow zone on the west side of the Cascades can produce 50 to 400% greater outflow from snow packs than forested areas during portions of rain-on-snow events (Coffin and Harr, 1992). The primary causes of increased outflow in cleared areas during rain-on-snow events are both the additional amount of snow on the ground and the increased rate of melting without the vegetation (Brunengo et al, 1992; Coffin and Harr, 1992). Shifts of landuse out of forest cover would produce a permanently higher likelihood of these higher flow situations occurring; clear cut harvest techniques increase the likelihood of this situation occurring until more mature forest vegetation re-establishes.

> Mapping method: Map portions of the rain on snow areas that are not in forested land cover.

### B. 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 resources (Sheldon et al, 2005; Gosselink et al, 1981; Reinelt and Taylor, 1997). The following are indicators that this capacity has been reduced through human activities:

i. *Dikes and levees along rivers:* Dikes and levees directly disconnect the river water from the floodplain, thus removing flood storage capacity at high water levels.

*ii. Straightline hydrography in floodplains or depressional wetlands:* Depending upon their location, straight channels indicate that streams have been disconnected from their floodplains or that wetlands have been drained. These activities reduce the capacity of depressional wetlands and floodplains to store water during high flows (Ziemer and Lisle, 1998; Brown, 1988).

> Mapping methods: Visually examine the hydrograph layer and manually identify those areas that have clearly been straightened. Areas where the water storage capacity has likely been significantly altered are those that overlap with floodplains or depressional wetlands that are important for water storage.

iii. *Loss of area of depressional wetlands in the watershed* –In various parts of the country there is evidence that if the proportion of a watershed that is wetland is reduced, then the runoff to aquatic resources is flashier and quicker. In the glaciated portions of Minnesota and

Wisconsin, streams become much flashier, due to increased run off, as the percentage of the watershed covered by lakes and wetlands drops (Detenbeck et al, 2000). In addition, if less than 10% of the basin was naturally wetlands or lakes, then even small losses in wetland area had a significant effect on flood events (Johnston et al, 1990). In King County, the fluctuation of water levels in response to runoff events increased if the less than 4.5% of the watershed area was wetland (Reinelt and Taylor, 1997).

Mapping methods: 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. These losses are most important if they occur in depressional wetlands that have already been identified as important for their water storage capacity.

To map the loss of wetland area, use the National Wetland Inventory data layer as the current wetland extent and the hydric soils on less than 2% slope data layer (that was created in the important areas analysis) as the potential wetland area. Place the NWI layer on the hydric soil layer; depressional wetlands have likely been lost anywhere the hydric soil layer extends beyond the NWI layer and is visible.

Note that impervious land cover is not included under this control of the process; instead it is included in the next section, under recharge. Much of the work that has been done on urbanization indicates that impervious surfaces increase runoff; however, the proximate cause of this runoff is likely a reduction in the infiltration and percolation of water.

### C. Recharge:

i. *Impervious land cover on areas important for recharge*– Numerous studies now suggest that when more than 10-25% of a watershed area is in effective impervious cover, runoff is increased as the percolation capacity of the land is reduced (Glasoe and Christy, 2004; Paul and Meyer, 2001; Booth and Reinelt, 1993). Studies of the Puget Sound region indicate that recharge in ‘built up areas’ (95% impervious surfaces) is reduced by 75% while that of residential areas (50% impervious surfaces) is reduced by 50% (Vaccaro et al, 1998). Finer scale studies have suggested that the impervious surface of the transportation network (e.g. roads, parking lots and driveways) has a bigger effect on hydrologic processes than does the footprint of buildings (Lee and Heaney, 2003).

Despite many studies indicating a potential threshold between 10 and 25% impervious surface beyond which alterations to hydrologic processes and biota occur, there is a reluctance to apply these thresholds across watersheds for planning purposes or to predict the condition of aquatic resources (Booth et al, 2005). This is due to a growing understanding that a complex interaction of factors affects aquatic resources and that changes to these cannot be consistently predicted by an impervious surface threshold

(Booth et al 2005). A recent study in the Puget Sound area concluded that impervious area alone is not a reliable indicator of biological condition (i.e. IBI scores) at the site level despite a pattern of broad decline with increasing impervious area (Booth et al, 2005).

In addition, there is growing evidence that the spatial arrangement of impervious surfaces may play a major role in determining its impact on hydrologic processes (Alberti, 2003 in review). In this framework, we suggest that impervious surfaces, located in areas of permeable deposits that naturally support larger quantities of percolation and recharge, are likely to produce increases in surface water runoff and decreases in recharge that are larger than if these impervious areas were located on naturally impermeable deposits. As a result, in Table B-1 the presence of impervious surfaces on permeable deposits is used as an indicator of altered infiltration which is likely to affect several watershed processes.

Mapping methods: Alterations to the recharge capacity are mapped if land cover associated with impervious cover (Table B-2) occurs in areas identified as important for the recharge of groundwater.

Although no calculation of the percent effective impervious cover in each watershed is required, it may be useful to map different land uses so that their relative imperviousness can be seen clearly. Table B-2 identifies the percent effective imperviousness associated with common land use categories. By showing each of these categories in different colors (e.g. on a scale from 1 to 5), it may be possible to identify areas in which the recharge process is likely more altered. This table can also be useful for developing future land use designations.

***Table B-2 Land Use Category and Corresponding % Effective Impervious Area*** (from Booth and Jackson, 1997)

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

## 2. Groundwater movement:

**A. Recharge**: The rationale for these indicators is provided in the recharge discussion of the previous section (1C, Surface water runoff process).

**B. Storage capacity**: The amount of water stored in an aquifer, and thus the head gradient that drives groundwater movement, is altered primarily through active removal of groundwater. Below we provide some general indicators of the type of land use associated with significant groundwater use in five of the counties on the East side of Puget Sound. Local data needs to be used to identify more specifically where major groundwater withdrawals are occurring.

i. *Rural land use- in King and Snohomish counties* –In the Puget Sound region, groundwater is the primary source of drinking water for rural areas and this source is increasingly being used by urban areas (Ebbert et al, 2000). In two counties, King and Snohomish, water use data for this region in 2000 (Table B-3; Lane, 2004) suggests that rural land use is a reasonable indicator of areas with higher groundwater extraction.

ii. *Industrial land use – in Pierce county:* While rural and cropland areas use a significant amount of groundwater in Pierce county, the primary use of groundwater in this area is industry (Table B-3; Lane, 2004). As a result, commercial/industrial land use should also be used to indicate significant groundwater extraction.

iii. *Row crop agricultural cropland – in Skagit and Whatcom counties* - In Whatcom county, the largest and most significant user of groundwater is in crop irrigation (Table B-3; Lane, 2004). In Skagit county, crop irrigation uses a bit more than rural areas (Table B-3; Lane, 2004). As a result, commercial row crop land use is used as an indicator of areas with significant groundwater use in these two counties.

**Table B-3: Groundwater extraction for various land uses in five Puget Sound counties in 2000.** Data are from Lane, 2004.

| County | Domestic gw use (Mg/d) | Crop irrigation gw use (Mg/d) | Golf course gw use (Mg/d) | Industrial gw use (Mg/d) | Best indicator of gw extraction |
|---|---|---|---|---|---|
| King | 16 | 2.2 | 1.26 | 3.12 | Rural land use |
| Pierce | 3.06 | 4.4 | 0.79 | 12.9 | Industrial land use |
| Skagit | 4.23 | 6.65 | 0.16 | 0.01 | Agricultural cropland land use |
| Snohomish | 10.6 | 1.84 | 0.35 | 2.33 | Rural land use |
| Whatcom | 3.93 | 18.2 | 0.45 | 0 | Agricultural cropland land use |

Mapping method: For each county, map the landuse that is associated with the most withdrawal of groundwater (Table B-3).

iv. *Well locations:* Wells in the vicinity of streams or other surface water resources can cause a significant reduction in the volume of water available for groundwater discharge (Morgan and Jones, 1999). Local data or knowledge of wells can be used if evidence exists that the amount of water being discharged to the surface has been impaired as a result of groundwater extraction.

v. *Reduced baseflows:* Other than streams that are fed by glaciers or snowfields, streams in the Pacific Northwest generally depend upon groundwater to supply late summer base flow. Given the annual variability in baseflow levels, a long period of record is required to detect a trend of declining baseflow; however, if these data exist locally they may be useful for detecting these trends.

### C. Discharge:

Discharge of groundwater to surface water bodies is important for many reasons including the maintenance of baseflows in streams (Winter et al, 1998; Morgan and Jones, 1999), relatively low stream temperatures in some locations, and specific water chemistry characteristics required by specialized biota (e.g. groundwater maintained wetlands with calcareous water chemistry). These properties may be impaired if the quantity of water discharging to surface water resources is altered. Indicators of this alteration are generally found in local data sources, not in regional datasets; for this reason, no specific guidance is provided for mapping areas of alteration.

i. *Loss of area of discharge wetlands*: Wetlands supported by groundwater discharge can be important to maintaining the flow path of groundwater. Loss of these wetlands can be a good indicator that the flow paths are altered; however, it is difficult to identify, at a regional scale, likely to be maintained by groundwater discharge. Local data and knowledge of where these groundwater discharge wetlands occur and where they have been altered will be needed to use this indicator.

# 3. Sediment delivery and removal

## A. Soil erosion:

### *i. Land use activities that produce soil erosion:*

The input of fine sediment to aquatic resources is likely to occur when vegetation is cleared on areas that are susceptible to surface erosion, due to slope and soil erodibility characteristics. In addition, fine sediment, produced in other areas of the landscape, can be delivered over long distances to aquatic resources (Jones and Gordon, 2000) due to the presence of efficient drainage systems such as agricultural ditches and urban stormwater systems. In most cases, local data will be needed to assess whether delivery of sediment to aquatic resources is occurring. Indicators of these conditions are used to locate activities that have likely increased soil erosion and delivery of fine sediments to aquatic resources.

- <u>Non-forested cover in areas important for surface erosion:</u> The Washington Forest Practices Board (WFPB, 1997a) 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 even more prone to erosion.

  Mapping method: Map those areas prone to surface erosion that are not in forested land cover.

- <u>Row crop land use draining to aquatic resource:</u> Agricultural land use accounts for up to 50% of the total sediment load, generated by human activity, that reaches U.S. surface waters annually (Willett, 1980 cited in Burton and Pitt 2002). Soil disturbance associated with row crop agriculture is likely to produce erosion of fine sediments regardless of where it occurs in a contributing area; however, the significance to aquatic resources will depend upon whether this sediment is delivered to aquatic resources. Local data will need to be evaluated to discern whether agricultural tilling is likely to produce increased sediment delivery to aquatic resources.

- <u>New construction draining to aquatic resources:</u> Soil disturbance from clearing of construction sites can also produce erosion of fine sediments. The EPA estimates that runoff from construction sites is the largest source of sediment in urban areas under development (U.S. Environmental Protection Agency, 1993). Urban lands undergoing construction, without BMP's 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 10% of the sediment loads contributed by row crop agriculture, construction activities occur on only 0.0007% of land area (Willett, 1980 cited in Burton and Pitt, 2002). 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).

Determination of whether this sediment can reach aquatic resources will require local data. In addition, no regionally useful indicators of where new construction is occurring or likely to occur have been developed; local knowledge of development plans will be required to identify areas where soil disturbance may be likely.

**ii.** ***Delivery of sediment to aquatic resources:***

*a.* <u>Roads within 200' of streams:</u> Citing Beschta (1978), the WFPB (1997a) indicates that outside of a buffer of approximately 200' it can be assumed that surface erosion from roads does not reach the stream ecosystem. 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.

Mapping method: Map roads that are within 200' of either side of streams.

***iii. High turbidity loads:*** Turbidity measures the quantity of fine sediment suspended in the water column. While the location of excessive turbidity levels will not necessarily correspond with the source of sediment delivery to an aquatic resource, these data will highlight where problems exist and direct efforts to identify sources. Local data such as the 303d listings or ambient monitoring data are required to locate this alteration.

## B. Mass wasting:

*i.* ***Roads in mass wasting hazard areas*** : The presence of roads through mass wasting hazard areas is a major source of management –induced landslides (Swanson et al, 1987).

Mapping methods: Highlight roads that intersect areas previously identified as having a high potential for mass wasting events.

## C. Water velocity:

Removal of fine sediments and phosphorus 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 and phosphorus removal. Dams, while they act in the opposite manner by increasing the storage of sediments in some portions of the watershed, alter the natural patterns of sediment delivery and removal.

i. ***Straight line hydrography in depressional wetland or streams*****:** Channelization of depressional wetlands increases the rate at which water leaves the wetland, reducing the potential for phosphorus and sediment to be removed. Similarly, 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 or phosphorus, the removal capacity of the wetlands and floodplains have been impaired. As a result, sediment and phosphorus in the system will have the potential to move and impair aquatic resources further downstream.

Mapping methods: This is the same method used to identify areas with reduce capacity to store surface water, earlier in this appendix. Visually examine the hydrography layer and manually identify those areas that have clearly been straightened. Areas where the capacity for removing sediment has been significantly altered are those where the straightlines overlap with depressional wetlands that are important for sediment removal.

*ii.* ***Loss of area of depressional wetlands*** - Numerous research studies have demonstrated the relationship between wetland area in a watershed and the percentage of the water-borne sediment that is removed (Sheldon et al, 2005).

Mapping methods: These are the same methods used to identify the loss of depressional wetlands in the surface water runoff section. To map the loss of depressional wetland area, use the National Wetland Inventory data layer as the current wetland extent and the hydric soils on less than 2% slope data layer (that you created in the important areas analysis) as the potential wetland area. Place the NWI layer on the hydric soil layer; depressional wetlands have likely been lost anywhere the hydric soil layer extends beyond the NWI layer and is visible.

iii. ***Dikes and levees****:* 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.

iv. ***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).

Mapping methods: Map presence of dams in the contributing area.

## 4. Phosphorus delivery and removal

### A. Phosphorus loading:

Agricultural land use contributes phosphorus in the form of fertilizer for row crops and nutrient supplementation for dairy cattle. Phosphorous levels in streams is five to 10 times higher in developed areas relative to forested areas (Welch 1998 citing Reckhow and Chapra 1983) and total phosphorus (TP) in Puget Sound lowland streams is correlated to the percent impervious area (Welch citing Bryant 1995). The source of phosphorus enrichment in these developed areas appears to be from fertilizers, detergents and wastewater (Welch 1998). However, in a study of Puget Sound, no particular land use or cover could be strongly correlated with high total phosphorus concentrations (Ebbert et al, 2000); it appears that both urban and agricultural land uses are associated with substantial increases in phosphorus loads.

Northwest aquatic systems (lakes, streams and wetlands) are naturally low in phosphorus (N:P ratio typically 20:1 by weight) since regional bedrock supplies low levels of this nutrient (Welch 1998; Horner et al, 1997). Because phosphorous is a limiting nutrient, phosphorus enrichment can significantly effect aquatic ecosystems. Though phosphorous is biologically available in the form of orthophosphate (i.e. ionic form, also known as "soluble reactive phosphorous") it remains at low "dissolved" levels in aquatic waters due to adsorptive reactions (i.e. binds to iron, aluminum and clay minerals), coprecipitation reactions and assimilation (McClain 1998, Murphy 1998). Therefore, assessing alteration to phosphorus processes should be based on both phosphorus levels and other factors such as algal/plankton biomass and water quality (e.g. dissolved oxygen, biological oxygen demand, benthic species richness).

i. ***High biological oxygen demand (BOD) or low dissolved oxygen (DO) levels:*** Wetlands, with open water areas, can become eutrophic if they receive excessive amounts of phosphorus (Sheldon et al 2005). Excessive levels of phosphorus can lead to algal blooms and a reduction in available oxygen. Impaired levels of DO are often identified through local monitoring efforts and can be recorded on the 303d list of impaired waters; high levels of BOD are usually identified only through local studies or monitoring.

ii. ***Algal blooms:*** Phosphorous enrichment in streams causes growth of nuisance algae, blooms of microbial communities and water quality problems (Welch 1998, McClain 1998). Lakes biomass will increase until the nutrient is exhausted (Murphy 1998). Evidence of harmful algal blooms will come from local studies or monitoring data.

iii. ***Phosphorus loads****:* High phosphorus loads will be indicated by data from local studies and monitoring projects such as the 303(d) list of impaired waters.

**B. Water velocity**: Areas that are effective at trapping sediment are also effective at removing phosphorus; as a result, alterations to the capacity of depressional wetlands to remove sediment also impair the capacity of depressional wetlands to remove phosphorus. See the previous section on sediment delivery and removal for indicators that this process has been altered.

## C. Adsorption:

i. ***Loss of area of wetlands with organic soils**:* As area of wetlands effective at removing phosphorus is reduced, the process of phosphorus removal is impaired.

Mapping methods: Use the data layer showing wetlands with organic soils, that you developed when identifying important areas for the removal of phosphorus, as the full extent of wetlands with a capacity for removing phosphorus through adsorption. Use those wetlands in NWI that have organic soils (soil modifier g) as the current extent of wetlands with organic soils. Place the NWI layer on the organic soil layer; wetlands with organic soils have likely been lost anywhere the organic soil layer extends beyond the NWI layer and is visible.

## 5. Nitrogen delivery and removal

### A. Nitrogen loads:

Nitrogen pollution is now being 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 largely results from the production of fertilizers and the burning of fossil fuels (Giles, 2005). Indicators in the Puget Sound region of high nitrogen loads are:

i.***Agricultural landuse:*** 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 results in low 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 and others (2000) found that areas with agricultural land use designations 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 be much greater as current methods for estimating emissions of nitrous oxide from fertilizer use maybe 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, using local data, to separate agricultural land uses into commercial enterprises and rural agriculture then the areas in commercial production should be highlighted.

Mapping methods: Map all areas with agricultural land use. If possible, commercial agricultural areas, including crop production, dairy farms, feed lots should be mapped separately from lower intensity agriculture (e.g. rural agriculture involving pastureland).

ii. ***Residential landuse adjacent to water bodies****:* Residential land use adjacent to water bodies is used as an indicator of likely locations of leaky septic systems. This is a surrogate for having actual data on the location and condition or age of septic systems.

Mapping methods: Map all areas with residential land use adjacent to water bodies.

iii. ***Disturbed riparian corridors:*** Disturbed riparian corridors often have more herbaceous vegetation than intact corridors; when litter from vegetation falls into the stream, the herbaceous litter produces a more labile source of nutrients than the coniferous vegetation that would dominate intact corridors (McClain et al, 1998). In the fall, herbaceous vegetation produces large releases of nitrogen, phosphorus and sulfur. This increased nutrient flux can impair other hyporheic nutrient transformations. Local data can be used to identify riparian corridors where non-coniferous vegetation is present.

iv. ***High nitrate and ammonia load data:*** Actual locations of excessive nitrate and ammonia loading are available from local studies and from the 303d list.

## B. Denitrification:

Nitrogen removal occurs in several important areas, each of which can be altered by various human activities. Below, indicators that each of these areas has been altered are organized by the type of important area:

*i.* ***Degradation of hyporheic areas****:*

a. Stream incision: Disconnecting the floodplain from the stream/river channel through channel incisement reduces the opportunity for hyporheic processes to remove nitrogen from the system (Dahm et al, 1998). Local data on stream incision will be required for this analysis.

b. Dikes and levees. Highly modified stream/river corridors, including those that have been channelized, diked, and straightened, speed the flow of surface waters, reduce the connection between the active channel and riparian subsystems, and restrict the extent of surface water and groundwater interactions (Dahm et al 1998). These alterations can impair the regulation of nutrient cycling and transport (*ibid*). Local data of diking and levees will be required.

c. Straight line hydrography*:* See above.

Mapping methods: This is the same method used to identify areas with reduce capacity to store surface water, earlier in this appendix. Visually examine the hydrography layer and manually identify those streams with hyporheic areas that have clearly been straightened.

d. Agricultural, urban, and suburban land use in floodplain: Conversion of forested areas to agricultural, urban or suburban landuse can significantly impact natural nutrient cycles in riverine ecosystems (McClain et al 1998). Urbanization increases fine sediment inputs which clogs alluvial sediments and reduces hyporheic exchange (Edwards 1998). Clearing of forest for agricultural land can increase “hill slope slumping” and clogging of stream gravel bars and alteration of hyporheic chemical processes ( Boulton et al, 1997). Logging can increase sediment input to streams and rivers by two orders of magnitude (Fredriksen et al. 1975); this can change nutrient fluxes (Edwards, 1998). In addition, agricultural, urban and suburban land uses are often associated with the straightening and confinement of stream channels.

Mapping methods: Map agricultural, urban and suburban land use that occurs within the FEMA 100 year floodplain. The FEMA boundary is used as a coarse estimation of the floodplain boundary; identifying the actual floodplain would require further site level analyses to assess changes in topography that are not detectable at a large scale.

e. <u>High fine sediment or turbidity loads:</u> Actual locations of excessive sediment or turbidity loads are available from local studies and from the 303d list.

*i.* ***Loss of area of seasonal wetlands***:

Mapping methods: Use the map of seasonal wetlands produced for areas important for denitrification (See Methods in Appendix A) as the potential extent of seasonal wetlands. Identify existing seasonal wetlands from wetlands inventory maps such as NWI and/or local wetland inventory maps; palustrine wetlands with a water regime modifier of C, D, or E on less than 2% slope are likely to be seasonal wetlands. Overlay the existing seasonal wetlands on the potential seasonal wetlands; seasonal wetlands have likely been lost anywhere the extent of potential seasonal wetlands extends beyond the existing seasonal wetland layer and is visible.

*ii.* ***Loss of area of wetlands with organic soils***

Mapping methods: These are the same methods used to identify loss of wetlands with organic soils in the phosphorus removal section of this Appendix. Use the data layer showing wetlands with organic soils, that you developed when identifying important areas for the removal of nitrogen, as the full extent of wetlands with a capacity for removing nitrogen through denitrification. Use those wetlands in NWI that have organic soils (soil modifier g) as the current extent of wetlands with organic soils. Place the NWI layer on the organic soil layer; wetlands with organic soils have likely been lost anywhere the organic soil layer extends beyond the NWI layer and is visible.

iii. ***Roads or ditches intercepting shallow groundwater in riparian zones***: It is important that the retention time of groundwater remains in tact in these 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 this critical organic zone where biological activity transforms nitrogen (Gold et al, 2001).

Mapping methods: Overlay the hydrography layer and roads layer with the riparian areas with shallow groundwater identified through methods in Appendix A. Identify all roads and straight sections of stream that intersect these riparian areas; these are the roads and ditches that are likely interfering with the movement of shallow groundwater through riparian areas.

## C. Assimilation, sorption and denitrification:

i. ***Straightline hydrography on small streams:*** Channelization of small streams removes their capacity to remove nitrogen from aquatic ecosystems (Peterson et al, 2001).

Mapping methods: This is the same method used to identify areas with reduce capacity to store surface water, earlier in this appendix. Visually examine the hydrography layer and manually identify those small streams that have clearly been straightened.

## 6. Mammalian pathogen delivery and removal

### A. Pathogen loads:

Mammalian pathogens includes bacteria and viruses which contaminate waters from both human and animal fecal matter.

i. ***Rural residential land use*** **–** This is an indicator of septic systems which have been associated with high levels of pathogen contamination (Lipp et al, 2001; Glasoe and Christy, 2004)

Mapping methods: Map rural residential areas.

ii. ***Impervious cover of catchment basin****:* Numerous studies have examined the relationship between urbanization and the contamination of shellfish harvest areas by fecal coliform and other pathogens, including viruses. The percentage of the catchment area that drains into the nearshore waters and is in impervious cover seems to offer a good correlation with the integrity of this marine habitat and the healthiness of shellfish beds (Glasoe and Christy, 2004 citing numerous other studies). The Center for Watershed Protection (cited in Glasoe and Christy, 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 in impervious cover then significant, degrading changes will occur to the amount of stormwater runoff, the proportion of the stream network that remains, the proportion of the riparian buffer that remains and the contamination of water with bacteria. 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.

Mapping methods: This uses the same methods described in the groundwater recharge section. Areas where pathogen loading has likely been increased are mapped as those where land cover is associated with impervious cover (Table B-2).

Although no calculation of the percent effective impervious cover in each watershed is required, it may be useful to map different land uses so that their relative imperviousness can be seen clearly. Table B-2 identifies the different percent effective imperviousness associated with common land use categories. By showing each of these categories in different colors (e.g. on a scale from 1 to 5), it may be possible to identify areas in which the recharge process is likely more altered. This table can also be useful for developing future land use designations.

***Table B-2 Land Use Category and Corresponding % Effective Impervious Area*** (from Booth and Jackson, 1997)

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

iii. ***Shellfish closures**: Local data will be needed to identify shellfish beds that have been contaminated by pathogens.*

iv. ***High fecal coliform loads:*** Actual locations of excessive fecal coliform loads are available from local studies and from the 303d list

## B. Water velocity:

i. ***Straightline hydrography in streams or depressional wetlands with mineral soils**:* 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, that speed up the movement of water contaminated with pathogens to estuarine waters can be equally culpable in the contamination of shellfish beds. White et al (2000; cited by Glasoe and Christy, 2004) found even low levels of impervious cover could contaminate aquatic resources with fecal coliform loads if there was a high hydrologic connectivity between sources and the aquatic resources. This connectivity could be created by ditching or even bank hardening. Similarly, straightline hydrography leaving depressional wetlands with mineral soils indicates that the pathogen removal capacity of these wetlands has been degraded.

Mapping method: This is the same method used to identify areas with reduce capacity to store surface water, earlier in this appendix. Visually examine the hydrograph layer and manually identify those streams and depressional wetlands with mineral soils that have clearly been straightened.

ii. ***Loss of area of depressional wetlands with mineral soils:***

Mapping methods: Identify existing depressional wetlands with mineral soils by using the palustrine wetlands from NWI that are on less than 2% slope and that do not have a soil modifier ‘g’, indicating organic soils. Overlay this data layer on the map of potential depressional wetland with mineral soils developed in Appendix A for the important areas for pathogens. Those potential wetlands visible beyond the NWI layer are the wetland areas that have been lost.

## 7. Toxin delivery and removal

### A. Toxin loads:

The primary toxins that this guidance addresses are heavy metals and pesticide/herbicides. Tetra Tech (1988, cited in Staubitz et al, 1997) 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 the Puget Sound itself, half of the contaminants are from industrial or point source discharges directly into the marine waters (Staubitz et al, 1997, citing Puget Sound Water Quality Authority, 1992); these inputs by pass freshwater systems entirely. The remaining half is from nonpoint sources that are mediated by freshwater ecosystems. Urban land use is associated with increased loads of many of these nonpoint sources of toxins.

i. ***Urban landuse:*** Urban land use is good indicator for pesticides and herbicides (Ebbert et al 2000) as these areas had highest samples violating organochlorine, semivolativle organics and most herbicides and pesticides. Many of the contaminants in the urban areas are from pesticides, wood preservatives (pentachlorophenol), and petroleum based products that leak or drip from vehicles (polycyclic aromatic hydrocarbons) (Galvin and Moore, 1982, cited in Staubitz et al, 1997). Furthermore, work by Black et al (2000) in the Pacific Northwest indicates that if more than 40% of the upstream area is in urban land use, the chance of having a fish contaminated by PCB's is greater than 20%.

Mapping method: Map urban land cover

ii. ***Row crop land use:*** While, in Puget Sound, most herbicides and pesticides were worse in areas of urban land cover than in any other landuses, atrazine and deethylatrizine were also high in agricultural areas (Staubitz et al, 1997).

Mapping methods: Map agricultural land use.

iii. ***Contamination of fish with PCB's:*** Local data required

iv. ***Contaminant loads:*** Local data required.

### B. Adsorption:

*i.* ***Straightline hydrography in depressional wetlands with organic soils:***

Mapping method: Overlay the hydrography data layer with the full extent of depressional wetlands with organic soils. Visually examine the hydrograph layer and manually identify those reaches within depressional wetlands with organic soils that have clearly been straightened.

*ii.* ***Loss of area of depressional wetlands with organic soils****:*

Mapping methods: These are same methods used for 'adsorption' in the delivery and removal of phosphorus discussion. Use the data layer showing wetlands with organic soils, that you developed when identifying important areas for the removal of phosphorus, as the full extent of wetlands with a capacity for removing phosphorus through adsorption. Use those wetlands in NWI that have organic soils (soil modifier g) as the current extent of wetlands with organic soils. Place the NWI layer on the organic soil layer; wetlands with organic soils have likely been lost anywhere the organic soil layer extends beyond the NWI layer and is visible.

## 8. Large woody debris delivery

Delivery of large woody debris to aquatic resources can be altered by degrading three mechanisms:

**A. Stream bank erosion:** LWD delivery to low gradient channels is impaired when there is either an inadequate cover of 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:

i. ***Dikes and levees****:* local data required

ii. ***Straightline hydrography***: The delivery of wood, if it is available, 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. Straightline hydrography can be used to identify streams that have likely had banks hardened.

> Mapping method: This is the same method used to identify areas with reduce capacity to store surface water, earlier in this appendix. Visually examine the hydrography layer and manually identify those unconfined streams that have clearly been straightened.

iii. ***Non-forested land use adjacent to unconfined streams****:* In the 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, inadequate LWD recruitment was associated with urban, agricultural and rural zoning; 77, 85, and 60%, respectively, of these streamside areas lacked adequate vegetation support LWD recruitment to the channel. Beechie et al (2003) found similar results in the Skagit River watershed; agricultural, urban/industrial, and rural land use was associated with less than half of the riparian areas being fully functioning.

> Mapping method: Map urban, agricultural or rural zoning or land use that occurs adjacent to or within the FEMA floodplain that was used to identify areas where streambank erosion is important for the large woody debris delivery process.

**B. Mass wasting:**

i. ***Non-forested land cover on areas important for mass wasting****:* The wood recruitment process is altered when forested cover is removed from potential landslide areas.

Mapping method: These areas can be identified by intersecting the areas of mass wasting hazard with any land cover that is non-forested (e.g. urban, suburban, agricultural, commercial, or rural).

## C. Windthrow:

i. ***Non-forested land cover in areas important for windthrow***: Recruitment of LWD 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 LWD for the stream channel.

Mapping method: Identify areas with non-forested land cover (e.g. urban, suburban, agricultural, commercial, or rural) within a 100' buffer on either side of streams.

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# Appendix C – Alternate Option

In some jurisdictions or planning areas, there are often few opportunities for protecting or restoring key landscape processes. In these instances, it may be more efficient to apply the landscape approach in an alternative manner. Instead of mapping the important areas for each process, the alternate option focuses on identifying the land use changes that have likely produced environmental problems or issues of concern that are associated with the aquatic resources. This option is most suitable for smaller jurisdictions or areas where urban development has significantly altered landscape processes, where there are limited opportunities to protect and restore these processes. It should be noted that the products of this application are more generalized since they do not identify specific areas of importance for each process. As a result, less mapping and analysis is required. However, because the selection of restoration activities is without consideration of important areas, the restoration sites and measures identified may be potentially less specific and possibly less effective than those identified by the methods in the main guidance. This in turn could hamper the ranking and prioritization of these areas for development alternatives, including protection and restoration measures.

As presented in Figure C-1, the order of applying these steps is different from that presented in the main guidance, and Step 4 is optional. All of the steps can be applied by integrating existing studies into a “synthesis” table (Table C-1) and producing either hand-drawn or GIS maps.

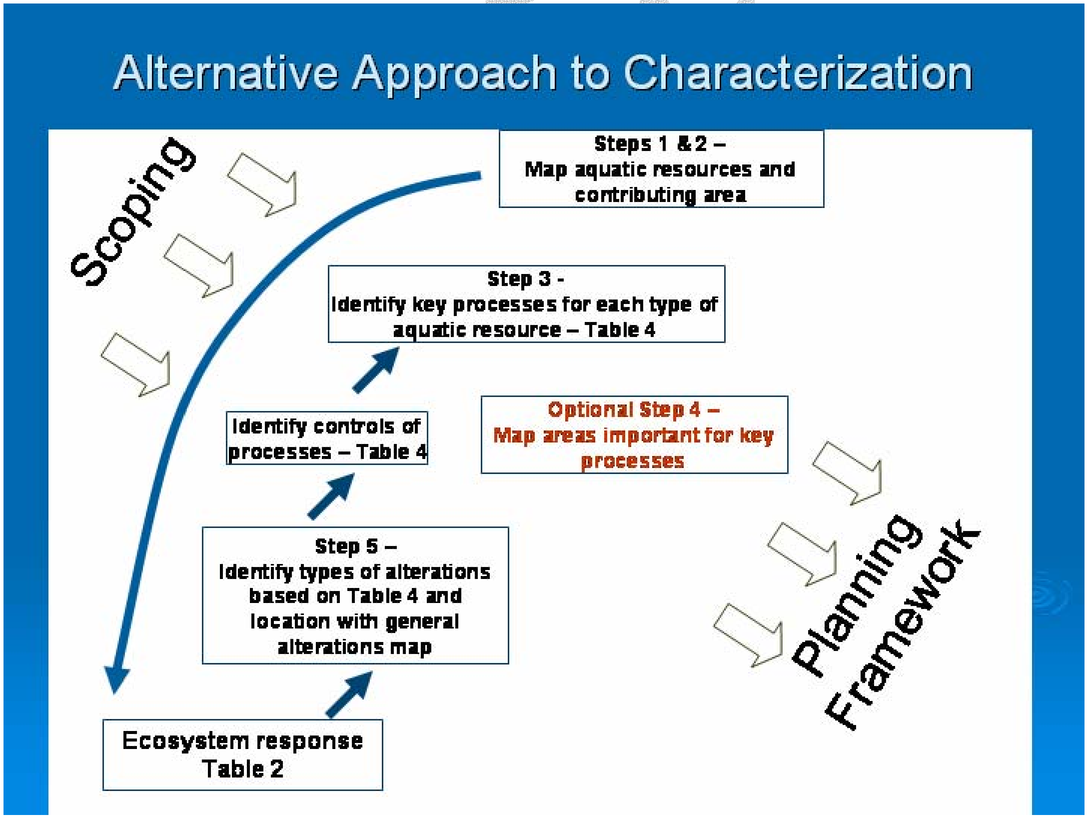

**Figure C-1: Summary of steps for an alternate option** in areas with few protection and restoration opportunities or without GIS capacity.

Following the identification of the aquatic resources of concern within the jurisdiction and the associated contributing area, this application follows the solid blue lines in Figure C-1. It begins with identification of known problems within the aquatic ecosystems, termed 'ecosystem response' within Table E in Appendix E and Table D in Appendix D.. These ecosystem responses or "problems" can be identified or documented from existing studies and/or data. Using Table E and Table 4 the ecosystem responses can then be linked initially to the type of human activity that likely produces this response and ultimately to the key process that has been altered.

As an alternative to producing map as a summary of the findings, a synthesis table can be developed to (Table C-1). In this the sources and rationale for identifying particular issues and also relating those issues to particular human activities can be included. Finally, the suggested planning measures to abate these problems can also be added to the table. This approach makes the linkages between the problems, the human activities, the key processes, and the solutions transparent and well supported while reducing the amount of mapping and GIS analysis required.

**Table C-1. Example of "Synthesis" Table Adapted from Table 2 and 4 For Nitrogen Delivery and Removal Process.**
Entries in "*red italics*" represent information/measures entered by planner

| Ecosystem Response (Table 2) | Process | Major controls of process | Important areas where process is controlled | Human alteration of process | Indicators of process alteration | Proposed Planning Measures |
|---|---|---|---|---|---|---|
| Increased algal blooms<br>*Reported algal blooms in Drayton Harbor estuary by Puget Sound Action Team Report "Olvoid Blooms"* | *Input* | Natural sources:<br>Nitrogen fixing by vegetation<br>Lightning<br>Decomposition of organic matter | Contributing area | Application of fertilizers and livestock manure<br>Leaky septic systems<br>Shifting riparian vegetation from conifers to deciduous and herbaceous species | Agricultural land use (+)<br>*Yes in upper watershed*<br>Residential land use adjacent to water bodies (+)<br>*Yes in lower watershed (Blaine)*<br>Disturbed riparian corridors* (+)<br>*Yes, in upper watershed, T. Coe study of riparian conditions, 2001*<br>High nitrate/ammonia loads*$^{@}$(+)<br>*Yes, High N loads (DOE, NWIC). Also low DO for Dakota Ck. – 303D listing –WRIA 1  Basin Plan* | *Replant and restore riparian corridors in areas that have highest level of alteration as shown in figure C-2* |
|  | *Loss* | Denitrification | Hyporheic areas | Hyporheic zones degraded:<br>• Disconnection of stream waters from floodplain | Stream incision* (-)<br>Dikes and levees* (-)<br>Straightline hydrography in streams (-)<br>*Yes in upper Dakota and California Creeks*<br>Urban or agricultural | *Restore hyporheic zone in areas of highest level of alteration* |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Seasonal wetlands<br>Wetlands with organic soils<br>Riparian areas with shallow groundwater | • Filling of hyporheic area with sediment<br>Seasonal wetlands filled or drained<br>Wetlands with organic soils filled or drained<br>Shallow groundwater bypasses riparian zones | land cover adjacent to or in floodplain (-)<br>*Yes, in upper Dakota and California Creeks*<br>High fine sediment or turbidity loads * (-)<br>Loss of seasonal wetland area (-)<br>*Yes, Gersib report (1999) indicates and maps loss of wetlands throughout basin*<br>Loss of area of wetlands with organic soils (-)<br>*Yes, Gersib report shows loss of large area of wetlands with organic soils in upper California Creek basin.* | *Restore seasonal wetlands in areas of highest level of alteration*<br>*Restore wetlands with organic soils in upper California Creek Basin.* |
| | | Assimilation, sorption, denitrification | Small streams | Channelization<br>Diverting of small streams | Straightline hydrography (-) | *Restore small streams in areas of highest alteration* |

# Appendix D

***Table D:*** Relationship of Shoreline Functions (per Shoreline Management Rule) to ecosystem processes and ecosystem response

| **Aquatic Ecosystem Type** | **Key Processes Ecosystem** | **Ecosystem Response to Alteration** | **Function in Shoreline Rule** |
|---|---|---|---|
| Estuarine ecosystem | Nitrogen delivery and removal | • Increased algal blooms<br>• Contamination of shellfish<br>• Potentially reduced species richness | Vegetation<br>Habitat<br>Habitat |
| | Mammalian pathogen delivery and removal | | |
| | Toxin delivery and removal | • Lethal and sublethal effects on aquatic biota | Habitat |
| Riverine ecosystem | Surface water runoff | • Channel incision<br>• Excessive peak flows<br>• Reduced flood storage<br>• Reduced habitat complexity & availability to instream organisms | Hydrologic<br>Hydrologic<br>Hydrologic<br>Habitat |
| | Groundwater movement | • Reduced baseflow<br>• Increase temperature<br>• Reduced species diversity | Hyporheic & Hydrologic<br>Vegetation & Hyporheic<br>Habitat |
| | Sediment delivery and removal | • Channel morphology changes<br>• Loss of habitat<br>• Homogenization of habitat<br>• Lethal and sublethal effects on stream biota<br>• Reduction of exchange with hyporheic waters and overall reduction of hyporheic processes | Hydrologic, Hyporheic<br>Habitat<br>Habitat<br>Habitat<br>Hyporheic |
| | Phosphorous delivery and removal | • Blooms of nuisance algae<br>• Reduced nutrient cycling<br>• Reduced invertebrate abundance and richness<br>• Decreased food source for fish<br>• Reduced denitrification<br>• Higher C:N ratio, lower invert diversity | Hyporheic & Vegetation<br>Hyporheic & Vegetation<br>Habitat & Hyporheic<br>Habitat<br>Vegetation<br>Hyporheic, Vegetation, Habitat |
| | Nitrogen delivery and removal | | |
| | Toxin delivery and removal | • Lethal and sublethal effects on aquatic biota | Habitat |
| | Large woody debris delivery and removal | • Simplification of habitat structure<br>• Reduced species diversity | Vegetation, Habitat<br>Habitat |

***Table D continued)***

| **Aquatic Ecosystem Type** | **Key Processes Ecosystem** | **Ecosystem Response to Alteration** | **Function in Shoreline Rule** |
|---|---|---|---|
| Lacustrine ecosystems | Phosphorous delivery and removal | • Eutrophication<br>• Reduced species diversity<br>• Reduced GW discharge | Hydrologic, Hyporheic, Vegetation<br>Habitat<br>Hydrologic, |
| | Nitrogen delivery and removal | | |
| | Toxin delivery and removal | • Lethal and sublethal effects on aquatic biota | Habitat |
| Depressional wetland ecosystems | Groundwater movement | • Reduced GW discharge<br>• Increase temperature<br>• Reduced species diversity | Hyporheic, Hydrologic<br>Hyporheic, Hydrologic<br>Habitat |
| | Phosphorus delivery and removal | • Increased algal blooms<br>• Increased BOD<br>• Decreased DO<br>• Reduced species diversity (e..g as seen in wetlands dominated by *Phalaris arundinaceae*) | Hyporheic, Hydrologic, Vegetation<br>Hyporheic, Hydrologic, Vegetation<br>Hyporheic, Hydrologic, Vegetation<br>Habitat |
| | Nitrogen delivery and removal | | |
| | Toxin delivery and removal | • Lethal and sublethal effects on aquatic biota | Habitat |
| Slope wetland ecosystems | Groundwater movement | • Reduced GW discharge<br>• Increase temperature<br>• Reduced species diversity | Hyporheic<br>Hyporheic<br>Habitat |
| | Toxin delivery and removal | • Lethal and sublethal effects on aquatic biota | Habitat |

# Appendix E:  Rationale for linking type of aquatic resource to key processes

Each type of aquatic resource is dependent upon a suite of key processes.  **<u>Key</u>** processes are not a complete list of all processes underlying a particular ecosystem; instead they are those that are:

1. essential to the integrity of an aquatic resource
2. likely to be altered by human activities and
3. if altered, would impair that aquatic resource.

Below, each type of aquatic resource is discussed and the rationale for the selection of the key processes (Table 2) is provided.  These processes were selected because their importance to a type of aquatic resource is supportable in a broad, general manner throughout Puget Sound.  Site or region-specific information may support the identification of additional processes.  If these are added, documentation of the rationale should be provided and a modification should be made to Table E-1.

**Table E-1: Key landscape processes that maintain aquatic resources in the Puget Sound Lowlands.** Processes in bold are those that are both critical to sustaining aquatic resources and are also likely to be altered by human activities. These are the processes addressed by this characterization. Climate is assumed to be a driver for all resources and therefore affects all processes, especially surface water runoff and groundwater movement.

| Aquatic Resource | Key Landscape Process | Importance of Process to Aquatic Resource |
|---|---|---|
| Riverine | **Surface water runoff** | **Importance:** Surface water runoff is a key component in driving stream/river hydrology.<br>Scouring by fall and winter flood flows appears to play a significant role in reducing nuisance periphyton mats when they accumulate during low flow periods (Welch 1998).<br>**Response to alteration:** Simplified habitat |
| | **Groundwater movement** | **Importance:** In the Pacific Northwest, groundwater generally is an important contributor to annual streamflow (Winter et al, 1998; Harr 1977). In streams that do not drain permanent snow fields or glaciers, groundwater inputs are an important source of late season baseflow. Groundwater inputs also have a high influence on maintaining water temperature in smaller (1-2nd order) streams and a moderate influence on 3-4 order streams (Poole et al 2001).<br>**Response to alteration:** Reduced species diversity ; increased temperature; reduced baseflow |
| | **Sediment delivery and removal** | **Importance:** Sediment delivery and transport plays an important role in maintaining habitat structure in riverine ecosystems; when sediment quantity overwhelms local transport capacity channel structure alters (Montgomery and Buffington 1998). The delivery of sediment plays a major role in the structure and function of riverine habitat and directly affects the water quality and quantity processes. Significant impacts to stream water quality can occur when sediment delivery exceeds stream/river transport capacity (Madej 1978).<br>**Response to alteration:** High rates of sedimentation can reduce and even eliminate hyporheic exchange which can result in increased stream temperature, reduced dissolved oxygen and decreased richness in bacteria and invertebrate populations (Boulton et al 1997). High total suspended solid levels in the water column can reduce invertebrate biomass and taxa richness in addition to reducing the survival of salmon eggs and alevins (Welch, 1998). |

*Table E-1 continued…*

| Aquatic Resource | Key Landscape Process | Importance of Process to Aquatic Resource |
|---|---|---|
| Riverine continued | **Phosphorus delivery and removal**<br>**Nitrogen delivery and removal** | **Importance:** Research has shown that coastal rivers of the Pacific Northwest link the temperate forests with the adjacent marine ecosystems and serve as transport pathways for nutrients (McClain et al, 1998). Nutrients from forested areas are transferred into streams and rivers where they accumulate and as they move downstream undergo nutrient spiraling, a process of repeated cycling between organic and inorganic forms that results from numerous chemical and biological interactions (Webster and Patten 1979). The three nutrients of key importance to river biota are nitrogen (N), phosphorus (P), and sulfur (S) (McClain et al,1998), although analysis of sulfur in Pacific rivers is limited.<br>**Response to alteration:** Increased nutrient loading and biological oxygen demand can impact hyporheic solute retention and transformation efficiency due to changes in the redox environment (Edwards, 1998). Nutrient enrichment, particularly by inorganic P, results in significant increase of the biomass and composition of periphyton communities (Welch, 1998). Phosphorus is found naturally at low levels relative to nitrogen (i.e. 20:1 by weight) in Pacific NW coastal streams; as a result, these ecosystems are considered oligotrophic and very sensitive to enrichment (Welch 1998; Staubitz et al, 1997). |
| | *Mammalian pathogen delivery and removal* | Not addressed -see estuarine resources. Pathogen delivery and removal is addressed for estuarine resources as impacts to shellfish beds from fecal coliform have been clearly documented. Streams and rivers play an important role in the transport of pathogens to estuarine and marine resources. |
| | **Toxin delivery and removal** | **Importance:** Toxins are naturally not a component of aquatic resources. As the presence of toxins alters natural conditions, this process is important for all aquatic resources.<br>**Response to alteration:** Toxic compounds have sublethal and lethal effects on riverine organisms. |
| | **Large woody debris delivery and removal** | **Importance:** Large woody debris determines channel form, controls storage and movement of organic matter and sediment, influences movement and transformation of nutrients, and has a significant effect on the biological community of riverine ecosystems (Bisson et al, 1987; Gurnell et al, 2002). Cedarholm et al (1989) reported that 60% of coho salmon (*Oncorhynchus Kisutch*) that had spawned, which are an important source of particulate organic matter, were retained by LWD.<br>**Response to alteration:** Simplified habitat (Maser and Sedell, 1994); loss of species richness and abundance (Bisson et al, 1987); reduction in pool frequency and depth and an increase in fast water habitats (Bilby and Bisson 1998); more rapid transport of particulate organic matter from terrestrial sources (Naiman and Sedell 1980); alteration of nutrient spiraling processes and reduction food resources (i.e. salmon carcasses) for wildlife (Cedarholm et al. 1989). |

*Table E-1 continued…*

| Aquatic Resource | Key Landscape Process | Importance of Process to Aquatic Resource |
|---|---|---|
| Estuarine | *Tidal range* | Not addressed. Tidal patterns affect many physical, chemical and biological processes in estuarine ecosystems (Mitsch and Gosselink 2000). These patterns are primarily driven by factors which occur at a scale larger than that addressed by this method (e.g. global climate patterns, gravitation forces, etc…) . |
| | *Salinity gradient* | Not addressed. Salinity is a major control of estuarine productivity and species type and distribution (Mitsch and Gosselink 2000). A number of factors affect salinity including precipitation and freshwater inflow (Mitsch and Gosselink 2000), most of which occur at a scale larger than that addressed by this method. |
| | *Sediment delivery and removal* | Not addressed. Sediment processes (i.e. source, type, rate) are not as important to the productivity of estuarine ecosytems as local hydrologic factors such as marsh elevation, drainage and organic content (Mitsch and Gosselink 2000) |
| | *Phosphorus delivery and removal* | Not addressed. Phosphorus is not a limiting nutrient in marine systems; it accumulates in high concentrations and does appear to limit salt marsh productivity (Pomeroy et al, 1972 cited in Mitsch and Gosselink 2000) |
| | **Nitrogen delivery and removal** | **Importance:** Nitrogen is the "limited" nutrient for salt marsh vegetation and can therefore affect the productivity of estuarine ecosystems (Webster et al, Valiela and Teal, 1974; Smart and Barko, 1980).<br>**Response to alteration:** High inputs result in eutrophic conditions and blooms of toxic dinoflagellates (Mallin et al 2000); loss of diversity in sea floor communities (Vitousek et al, 1997) |
| | **Mammalian pathogen delivery and removal** | **Importance:** Waterborne pathogens accumulate in shellfish (Glasoe and Christy 2004).<br>**Response to alteration:** Shellfish bed closures; Because waterborne pathogens accumulate in shellfish, consumption of shellfish has become a major transmission route for a variety of human bacterial and viral diseases (Glasoe and Christy 2004). |
| | **Toxin delivery and removal** | **Importance:** Toxins are naturally not a component of aquatic resources. As the presence of toxins alters natural conditions, this process is important for all aquatic resources.<br>**Response to alteration:** Toxic compounds have adverse effects on marine/estuarine ecosystems in limited areas around population centers; this includes effects on reproductive, immune, or endocrine systems of marine organisms at low concentrations, and possible subtle effects on marine organisms and populations over a larger area. (Pew Oceans Commission 2003). |
| | *Large woody debris delivery and removal* | Not addressed here – see riverine resources. This process is addressed for riverine resources where delivery of large woody debris to estuarine resources is largely controlled. |

***Table E-1 continued…***

| Aquatic Resource | Key Landscape Process | Importance of Process to Aquatic Resource |
|---|---|---|
| Marine | Not yet developed | |
| Lacustrine | *Surface water runoff and groundwater movement* | Not addressed. While surface water runoff and groundwater movement drive the hydrology in lakes, degradation of lake ecosystems is usually due to alteration of other processes (e.g. nutrient delivery and removal). |
| | *Sediment delivery and removal* | Not addressed here – see phosphorous process for lakes. Sediment delivery is addressed under the phosphorous delivery process (which was judged to be a more critical process to lakes) since phosphorus adsorbs to sediment. |
| | **Phosphorus delivery and removal** | **Importance:** As phosphorus is a limiting nutrient in lakes, excessive levels can result in eutrophication (Sheldon et al, 2005, Horner et al, 1997, Welch 1998, McClain 1998, Murphy 1998).<br>**Response to alteration:** Eutrophication contributes to fish kills and causes shifts in species abundance and richness (The Heinz Center 2002). |
| | **Nitrogen delivery and removal** | **Importance:** Nitrogen, along with phosphorous and sulfur, is key to the biological and physiological requirements of aquatic biota (McClain 1998).<br>**Response to alteration:** loss of species diversity (Giles, 2005) |
| | *Mammalian pathogen delivery and removal* | Not addressed here – see estuarine resources. This process is addressed for estuarine resources which identifies important areas (such as depressional wetlands) which also benefit lakes. |
| | **Toxin delivery and removal** | **Importance:** Toxins are naturally not a component of aquatic resources. As the presence of toxins alters natural conditions, this process is important for all aquatic resources.<br>**Response to alteration:** Toxic compounds have adverse effects on lake ecosystems. Through bioamplication toxic compounds can be concentrated in fish which can affect the health of other organisms. |
| | *Large woody debris delivery and removal* | Not addressed |

***Table E-1 continued…***

| Aquatic Resource | Key Landscape Process | Importance of Process to Aquatic Resource |
|---|---|---|
| De-pressional wetland | *Surface water runoff* | Not addressed. |
| | **Groundwater movement** | **Importance:** Many depressional wetlands in Puget Lowlands are groundwater driven.<br>**Response to alteration:** Reduced groundwater discharge, increased water temperature, reduced species diversity. |
| | *Sediment delivery and removal* | Not addressed. |
| | **Phosphorus delivery and removal**<br>**Nitrogen delivery and removal** | **Importance:** Nitrogen, along with phosphorous and sulfur are key to the biological and physiological requirements of aquatic biota (McClain 1998).<br>**Response to alteration:** High nutrients have negative impacts on wetland plant, invertebrate, and amphibian communities (Sheldon et al 2005). |
| | *Mammalian pathogen delivery and removal* | Not addressed here. |
| | **Toxin delivery and removal** | **Importance:** Toxins are naturally not a component of aquatic resources. As the presence of toxins alters natural conditions, this process is important for all aquatic resources.<br>**Response to alteration:**Toxic compounds effect wetland plant growth, decline in invertebrate species richness and negatively impacted amphibian embryos and tadpoles (Sheldon et al, 2005). |
| | *Large woody debris delivery and removal* | Not addressed. Not a critical process for depressional wetlands. |

***Table E-1 continued…***

| **Aquatic Resource** | **Key Landscape Process** | **Importance of Process to Aquatic Resource** |
|---|---|---|
| Slope wetland | *Surface water runoff* | Not addressed |
| | **Ground water movement** | **Importance:** Slope wetlands are primarily driven by groundwater discharge.<br>**Response to alteration:** Reduced groundwater discharge, increased water temperature, reduced species diversity |
| | *Sediment delivery and removal* | Not addressed |
| | *Phosphorus delivery and removal* | Not addressed |
| | *Nitrogen delivery and removal* | Not addressed |
| | *Mammalian pathogen delivery and removal* | Not addressed |
| | *Toxin delivery and removal* | Not addressed |
| | *Large woody debris delivery and removal* | Not addressed |

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