THURSTON COUNTY
SHORELINE MASTER PROGRAM UPDATE

Inventory and Characterization Report

Final Draft – June 30, 2013

APPENDIX F:
ECOSYSTEM-WIDE PROCESS CHARACTERIZATION METHODS

OVERVIEW

This appendix provides a description of the methods used to map and characterize freshwater and marine ecosystem-wide processes. A description of marine ecosystem-wide processes is provided as well as general mapping and assessment methods.

FRESHWATER ECOSYSTEM-WIDE PROCESSES CHARACTERIZATION METHODS

The characterization of ecosystem-wide processes approach used for non-marine shorelines (freshwater rivers, streams, and lakes) is based in part on an adaptation of the document Protecting Aquatic Ecosystems by Understanding Watershed Processes: A Guide for Planners, by Stephen Stanley, Jenny Brown, Susan Grigsby, and Tom Hruby (2008) (Ecology Publication #05-06-027).

The analysis based on Stanley et al., 2008 (Ecology Publication #05-06-027) uses Geographic Information Systems (GIS) data to examine specific processes including the movement of water, sediment, nutrients, pathogens, toxins, and wood as they enter, pass through, and leave the watershed (Stanley et al, 2005). These processes are primarily governed by precipitation,, geology, topography, soils, land cover and land uses including major vegetation types and predominant land use (residential, commercial, forestry, etc) – collectively called process controls. These processes form and maintain the landscape over large geographic scales and interact with landscape features to create the structure and function of aquatic resources (Ecology 2008). In general, human activities impair watershed processes by changing the dynamic physical and chemical interactions that form and maintain the landscape.

The purposes of the analysis are to highlight the relationship between key processes and aquatic resource function and to describe the effects of land use on those key processes. This approach is not intended to quantify landscape processes and function. Rather, the goal is to: 1) identify and map areas on the landscape important to processes that sustain shoreline resources; and 2) determine their degree of alteration; and 3) identify the potential for protecting or restoring these areas.

Ecosystems are natural systems consisting of all plants, animals and microorganisms (biotic factors) in an area functioning together with all the non-living physical (abiotic) factors of the environment. Ecosystem-wide processes refer to the dynamic physical and chemical interactions that form and maintain the landscape and ecosystems on a geographic scale of basins to watersheds (100's to 1000's of square miles). In Washington State, the most important ecosystem-wide processes include the movement of water, sediment, nutrients, pathogens, toxic compounds, and wood as they enter, pass through, and eventually leave the watershed (Stanley et al, 2008). Ecosystem-wide processes determine both the type and level of performance of shoreline functions.

Shoreline ecological functions include the service performed by physical, chemical, and biological processes that occur at the shoreline. Shoreline ecological functions may be generally grouped into water quality, water quantity, and habitat functions. Water quality functions may involve the removal of sediment, toxics, and nutrients. The storage of flood waters in a floodplain is an example of a water quantity function. Habitat functions include the physical, chemical, and biological structure necessary to support the life cycle needs of aquatic invertebrates, amphibians, birds, mammals, and native fish. For example, natural erosion and the transport of sediment within a river basin or along a marine shoreline form habitat such as side channels or coastal lagoons.

Characterization Steps

The approach to characterizing watershed-scale processes acting on freshwater systems consisted of several steps, which are described below (see also Stanley et al., 2008 for a complete description of the background and methods for this approach).

Step 1 – Identify Aquatic Resources and their Contributing Areas

Project analysts identified and mapped aquatic resources including rivers, lakes, estuaries, and wetlands (existing and historic wetlands) using available GIS data from various sources. Mapped areas include aquatic resources that are subject to shoreline jurisdiction (e.g., large rivers and lakes) and resources outside of shoreline jurisdiction (e.g., small streams, depressional wetlands outside floodplains, etc.). Contributing areas are defined as the surface water drainage boundaries defined by the WRIAs within Thurston County. WRIAs were used as the hydrologic unit for the general descriptions of watershed processes in this report.

Step 2- Map Process 'Important Areas'

Processes occurring at the landscape scale maintain aquatic resources to varying degrees. This analysis focuses on key processes that are fundamental to the integrity of the ecosystem and can be managed within the context of the available land use plans and regulations:

- Hydrology
- Sediment
- Water Quality
- Woody debris

This analysis identifies the areas important to maintaining each watershed process in the absence of human impairment, as well as where these areas are located and their relative importance to each process.

For this step, analysts used available GIS data to identify and map areas within the County that support ecosystem-wide processes. These "important areas" are those areas which, when maintained in an unaltered condition, help maintain a watershed process. The use of the term "important areas" is used as a means of distinguishing, on a relative scale, areas that play a key role in how ecosystem processes operate within a watershed. This does not imply that other areas are not important for ecological functioning, land use management or other purposes.

Table 1. Data sources for identifying process important areas in Thurston County using methods from Stanley et al., 2008

Key Process	Components of Process / Mechanism	Important Areas	Thurston SMP Update Data Layer Name	Data Sources for Mapping Important Areas
Water	Surface runoff and peak flows	Areas with higher amounts of precipitation	mean_annual	maprecip (Mean Annual Precipitation). Precipitation Intensities for Western WA. DOT.
		Rain-on-snow zones	Thurston_ROS	State_ROS. DNR.
		Snow-dominated zones	N/A. No snow dominated zones in TC	State_ROS. DNR.
	Surface Water Storage	Depressional wetlands	dep_wet. Depressional Wetlands = hydric soils on < 2% slopes	soils. Thurston County GeoData. 25-foot DEM. Thurston County GeoData.
		100-year flood plain	floodzoneA	floodzoneA. Thurston County GeoData.
		Wetlands	wetlands	wetlands. Thurston County Geodata.
		Lakes	hydro	hydro. Thurston County Geodata.
		Unconfined and moderately confined stream channels	segments_spft_CountyClip	segments_spft (stream attributes). SSHIAP, WDFW.
	Shallow subsurface flow	Areas on geologic deposits with low permeability	Low_Permeability	Geologic Units 100k. DNR.
	Recharge	Areas on geologic deposits with high permeability	High_Permeability	Geologic Units 100k. DNR.
Sediment	Surface erosion	Steep slopes with erodible soils	erod_slopes	25-foot DEM. Thurston County GeoData. K factor. SSURGO NRCS Soil Data, USDA. k(w) value for surface layer, aggregated by dominant condition
	Mass wasting	Hazard areas for shallow rapid landslides	high_risk	Slope Stability. DNR.
		Landslide/steep slope hazard	recl_25ft_cnt	25-foot DEM. Thurston County GeoData.
		Past landslides	Landslide24k_Thurston	landslides_24k. DNR.
	In channel erosion	Unconfined and moderately confined stream channels	segments_spft_CountyClip	segments_spft (stream attributes). SSHIAP, WDFW.

		Channels with <4% gradient	segments_spft_CountyClip	segments_spft (stream attributes). SSHIAP, WDFW.
	Storage	Depressional wetlands	dep_wet. Depressional Wetlands = hydric soils on < 2% slopes	soils. Thurston County GeoData.
				25-foot DEM. Thurston County GeoData.
		100-year floodplain	floodzoneA	floodzoneA. Thurston County GeoData.
		Lakes	hydro	hydro. Thurston County Geodata.
Water Quality (including heat/light inputs)	Sources of Nitrogen, Phosphorus, Toxins, or Pathogens	No important historic areas are identified (see impairments)	N/A	N/A
	Nitrification	Depressional wetlands	dep_wet. Depressional Wetlands = hydric soils on < 2% slopes	soils. Thurston County GeoData.
				25-foot DEM. Thurston County GeoData.
		Lakes	hydro	hydro. Thurston County Geodata.
	Denitrification	Depressional wetlands	dep_wet. Depressional Wetlands = hydric soils on < 2% slopes	soils. Thurston County GeoData.
				25-foot DEM. Thurston County GeoData.
		Lakes	hydro	hydro. Thurston County Geodata.
	Transport of pathogens via Surface flows	Streams	hydro	hydro. Thurston County Geodata.
			streams	streams. Thurston County Geodata.
		Connected wetlands	wetlands	wetlands. Thurston County Geodata.
	Pathogen movement through Shallow subsurface flows & recharge	Areas of low permeability	soils	soils. Thurston County Geodata. Low permeability = CARA Categories Low and Moderate
		Areas of high permeability	soils	soils. Thurston County Geodata. High permeability = CARA Categories High and Extreme
	Pathogen removal via Adsorption and Sedimentation	Depressional wetlands	dep_wet. Depressional Wetlands = hydric soils on < 2% slopes	soils. Thurston County GeoData.
				25-foot DEM. Thurston County GeoData.
		100-year floodplain	floodzoneA	floodzoneA. Thurston County GeoData.
	Pathogen loss via Mortality	Depressional wetlands	dep_wet. Depressional	soils. Thurston County GeoData.

			Wetlands = hydric soils on < 2% slopes	25-foot DEM. Thurston County GeoData.
	Phosphorus and Toxins Input via Surface erosion	Steep slopes with erodible soils (addressed in sediment section)	erod_slopes	25-foot DEM. Thurston County GeoData.
				K factor. SSURGO NRCS Soil Data, USDA. k(w) value for surface layer, aggregated by dominant condition
	Movement via Adsorption (P)	Depressional wetlands with mineral soils	dep_wet* * Soil type not used per S. Stanley (pers comm, 2010)	soils. Thurston County GeoData.
				25-foot DEM. Thurston County GeoData.
		Upland areas with clay soils adjacent to aquatic ecosystems	Not analyzed. Soil type not used per S. Stanley (pers comm, 2010)	
	Movement via Adsorption (T)	Depressional wetlands with organic or clay soils	dep_wet*. Soil type not used per S. Stanley (pers comm, 2010)	soils. Thurston County GeoData.
				25-foot DEM. Thurston County GeoData.
	Movement via Sedimentation of Phosphorus and Toxins	Depressional wetlands	dep_wet. Depressional Wetlands = hydric soils on < 2% slopes	soils. Thurston County GeoData.
				25-foot DEM. Thurston County GeoData.
		100-year floodplain	floodzoneA	floodzoneA. Thurston County GeoData.
		Lakes	hydro	hydro. Thurston County Geodata.
		Depositional stream channels (addressed in Sediment section)	segments_spft_CountyClip	segments_spft (stream attributes). SSHIAP, WDFW.
	Riparian canopy cover	Forest within 100' of streams	forest_rip	Streams_100ft. Thurston County Planning Dept.
				landcover2006. DOE.
Wood	Stream erosion	Unconfined and moderately confined stream channels	segments_spft_CountyClip	segments_spft (stream attributes). SSHIAP, WDFW.
		Channels with <4% gradient	segments_spft_CountyClip	segments_spft (stream attributes). SSHIAP, WDFW.
	Mass wasting	Mass wasting areas that are likely to deliver debris to the stream	high_risk	Slope Stability. DNR.
	Windthrow	Forest within 100' of streams	forest_rip	Streams_100ft. Thurston County Planning Dept.

				landcover2006. DOE.
	Storage	Unconfined and moderately confined stream channels	segments_spft_CountyClip	segments_spft (stream attributes). SSHIAP, WDFW.
		Channels with <4% gradient	segments_spft_CountyClip	segments_spft (stream attributes). SSHIAP, WDFW.

The geographic location of these specific features (e.g., depressional wetlands, permeable surficial deposits, or steep gradients) is used to identify process important areas. Because of their inherent characteristics, areas that are identified as process important areas have a greater influence on aquatic resource structure and function than other areas and therefore may be more important for protection and/or restoration. However, the designated process-intensive areas are not the only areas where process mechanisms occur.

Process important areas are the focus of this analysis because they control how key processes operate. In some cases, the process important areas are areas where inputs to the processes occur (e.g., the steep slopes that generate sediment supply as a result of erosion). For other processes, inputs occur so broadly across the landscape that specific process-intensive input areas are difficult to identify. In those cases, the important process areas are areas that facilitate movement or storage of materials such as water, sediment, or pathogens.

Commonly, multiple processes are present in a single area, sometimes due to feedback relationships among processes. Storage areas such as depressional wetlands are a good example because they store surface water, which traps sediment and facilitates phosphorus removal and contaminant adsorption, uptake and storage. The mapping exercise allowed us to identify areas where each process occurs as well as areas that support multiple processes and therefore may provide valuable protection and/or restoration opportunities.

Freshwater process-intensive areas for hydrologic, sediment, water quality, and wood processes in Thurston County often coincide (Table 2.1).

Table 2. Process Important Areas for Hydrologic, Sediment, Water Quality, and Vegetation Processes

Process Important Area	Processes
Rain-on-snow and snow- dominated zones	Surface runoff and peak flows
Channel migration zones	Surface runoff and peak flows Groundwater flow/discharge Surface erosion Sediment storage
Floodplains	Surface water storage Surface runoff and peak flows Groundwater flow/discharge Nutrient cycling

Process Important Area	Processes
	Sediment storage
Lakes	Surface water storage Sediment storage Nutrient retention/cycling
Wetlands and infiltrative soils	Surface water storage Nutrient sink Sediment storage Pathogen removal Toxins/metals removal
High groundwater areas	Groundwater flow/discharge Surface water storage
Bare ground/early seral stage vegetation cover	Surface runoff and peak flows Surface erosion
Landslide-prone areas/ steep slopes with erodible soils/areas of mass wasting	Organic debris input Sediment delivery
Riparian areas	Nutrient sink Toxins/metals removal Heat/light control
Aquifer recharge areas	Infiltration/recharge Groundwater flow/discharge Nutrient cycling Pathogen removal
Stream banks	Organic debris input Sediment delivery

Water Process Important Areas

In this section, important areas for the delivery, movement, and loss of water in a basin are discussed.

Surface Runoff and Peak Flows

Surface runoff in Thurston County is derived from snowmelt, glacial melt, and rainfall. Important areas for precipitation are areas in a watershed that have relatively larger rates of precipitation. The amount of water available to supply surface water and groundwater will be greater in areas with higher precipitation. Variation in rainfall can have a significant effect on both surface flows and groundwater recharge. For example, the estimated rates of mean annual groundwater recharge in Whatcom County range from 11- 50 inches which corresponds to the rainfall gradient. In models of groundwater recharge in the Puget Sound region, Vaccaro et al. (1998) estimated the recharge of the groundwater aquifer by first examining the geologic deposit and then overlaying precipitation patterns. In coarse-grained deposits, recharge related linearly to precipitation. In finer-grained deposits, recharge was initially a linear response to precipitation but eventually leveled off indicating that even increased precipitation did not produce greater recharge or groundwater flow. This pattern occurs as finer-grained materials and the overlying deposits become saturated, preventing water from moving downward to support groundwater recharge.

Process important areas for snowmelt are zones mapped as Rain-on-snow and snow-dominated by the Washington State Department of Natural Resources. Thurston County does not have any snow-dominated zones so only rain-on-snow zones will be discussed here. Snowmelt provides an important source of water that can support groundwater recharge and baseflow, depending upon the hydrogeologic setting of a watershed. For rain-on-snow zones, major changes to the timing of snow melt results when warm rains occur. These warmer conditions cause the snow to melt at a faster rate at the same time that runoff from the rain is occurring (Brunengo et al. 1992). This can increase the amount of surface water flowing in the watershed to the extent that many of the largest flooding events in Western Washington are associated with these rain-on-snow storms.

Surface Water Storage

Depressional wetlands, lakes, and floodplains are process important areas for surface water storage and contain the highest potential to store water during high-flow events.

(a) Depressional Wetlands: The cumulative role of depressional wetlands in storing surface water has been demonstrated in numerous locations around the world. By storing water, depressional wetlands delay the release of surface waters during storms, thereby reducing downstream peak flows in rivers and streams (Adamus et al. 1991). Studies of depressional wetlands in other parts of the world also conclude that they can reduce or delay peak downstream flows (Bullock and Acreman 2003). In King County the percentage of a watershed that contains wetlands has been found to relate to the flashiness or variability of runoff events. For example, Reinelt and Taylor (1997) found that watersheds with less than 4.5% of their area in wetlands produced a greater range of surface water level fluctuations in depressional wetlands than did those with a higher percentage of area in wetlands.

(b) Lakes: Lakes are important for storing surface water because of the large volumes of water they can hold. For example, Lake Washington holds 2,350,000 acre feet of water about half of which is flushed out every year (DNR King County, July 29, 2008). Thus, the annual storage in Lake Washington is equivalent to every drop of rain that falls on about 400 square miles of the region in a year (assuming an average rainfall of 48”/yr).

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

Recharge

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

Groundwater Flow

This analysis focuses on process important areas for shallow subsurface flow which are areas with surface deposits of low permeability. Under natural conditions, after infiltrating the soil column, some water is likely to move down slope as subsurface flow, particularly in areas with underlying geologic deposits with low permeability (Booth et al. 2003).

Sediment Process Important Areas

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

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

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

Surface Erosion

Process important areas for surface erosion are areas with steep slopes and erodible soils (gray areas in Table X). 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 with intact vegetation, this analysis follows the example of the Washington Forest Practices Board (WFPB). It combines the erodibility of soils, indicated by the K factor, with the gradient of the slope adjacent to aquatic ecosystems to predict areas at risk for sediment delivery (Table X, WFPB 1997).

Table 3. Combinations of both slope and K factor that indicate a moderate to high potential for soil erosion (gray boxes)

Slope/K factor	<0.25	0.26-0.4	>0.4
<30%			
30-65%			
>65%			

Mass Wasting

Process Important areas for mass wasting are high mass wasting hazard areas identified by the Shaw Johnson model. In some parts of the landscape, mass wasting events dominate the delivery of sediment to aquatic ecosystems (Gomi et al. 2002). Areas at higher risk for mass wasting throughout the Puget Sound region can be identified using the Shaw Johnson model for slope stability (Shaw and Johnson 1995). This model predicts the potential for landslides based upon two factors: the slope gradient and the form (or curvature) of the slope. 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. Field verification of this model in the Upper Lewis watershed indicates that the model over predicts risk of mass wasting in formations with significant deposits of volcanic ash (P. Olson, personal communication, April 2005).

In-channel Erosion

In-channel erosion process important areas for are unconfined channels or those with gradients less than 4%. Stream channels that are low-gradient and unconfined (i.e., pool riffle and dune ripple channel types) (Buffington et al. 2003) have greater potential for bank erosion, depending upon the discharge levels and condition of the riparian vegetation (Montgomery and Buffington 1993).

Sediment Storage

Depressional wetlands, floodplains, depositional stream channels, and lakes are process important areas for sediment storage. Depressional wetlands, particularly those without an outlet, are the most effective wetland areas for removing fine sediments (Hruby et al. 1999 and 2000). Even though conclusive studies have yet to be completed in Washington, depressional wetlands in a floodplain setting are also believed to be effective in removing sediment as they slow the velocity of water flow during high flow events (Hruby et al. 1999, Adamus et al. 1991).

In floodplains and depositional stream channels, channels with slopes less than 4% (i.e., pool riffle and dune ripple channel types, Buffington et al. 2003) also provide a greater opportunity for sediment storage than do other channel types (Montgomery and Buffington 1993). During high flows, floodplains associated with these channels can also provide storage of sediment (Buffington et al. 2003). Lakes are also areas where sediment can be stored, due to the low transport capacity of water (i.e. low water velocity).

Water Quality Process Important Areas

Nutrients (nitrogen and phosphorus)

Process important areas for nitrification and denitrification are depressional wetlands on <2% slopes and lakes. The seasonal edges of depressional wetlands provide the aerobic conditions necessary for nitrification to occur (Sheldon et al., 2005). Nitrification transforms ammonium to nitrate. This is important because nitrate can be permanently removed from a watershed through denitrification. Wetlands are the primary source of denitrification in a watershed because they are the one feature in the landscape where anaerobic soils near the surface are found (Arheimer and Wittgren 1994). The saturated areas within depressional wetlands provide the anaerobic conditions necessary for denitrification to occur (Sheldon et al. 2005, Mitsch and Gosselink 2000). The other major location for denitrification in a watershed is the anaerobic bottoms of lakes (Arheimer and Wittgren 1994). These usually occur below the thermocline in the summer months.

Depressional wetlands are also important areas for phosphorus adsorption and sedimentation because the lower water velocity results in the removal and storage of phosphorous and toxins. The 100-year floodplain, lakes, and depositional stream channels are also important areas for phosphorous sedimentation because of lowered water velocity (addressed in sediment section).

Important areas for surface erosion of particles to which phosphorus or toxins may be attached are steep slopes with erodible soils (addressed in sediment section).

Pathogens

This characterization focuses on fecal coliform as an indicator of pathogens because it is the most commonly occurring pathogen and because it has serious water quality implications for both aquatic fauna and humans. Fecal coliform is the primary pathogen monitored in Ecology water quality studies and is also the parameter used by the Department of Health for classifying shellfish growing areas.

Important areas for water quality processes involving pathogens include areas where pathogens are stored or removed. Adsorption and sedimentation play an important role in temporarily removing sediment and pathogens from the water column and storing them within the aquatic ecosystem. Natural events, such as high flood flows, can re-suspend sediments and pathogens and transport them downstream into other aquatic ecosystems. Depressional wetlands are important areas for removing sediments and pathogens due to low water velocities, high residence times, filtering vegetation, and soils suitable for adsorption.

Important areas for pathogen transport via surface flow are streams, rivers and wetlands (with surface water connection). Streams, rivers and wetlands directly connected to streams and rivers form the surface water network for transport of pathogens.

Important areas for pathogen transport through shallow subsurface flow and recharge are areas of low and high permeability (Described in the water processes section). Shallow sub-surface flow and recharge: Areas with shallow sub-surface flows are located on geologic deposits with low permeability. Areas that provide recharge are located on geologic deposits with high permeability. Both of these areas in their unaltered state (native vegetation and no surface hydrologic modification) route pathogens through a longer flow path relative to overland and surface flow.

Important areas for pathogen adsorption and sedimentation are depressional wetlands and 100-year floodplains. Depressional wetlands contain mineral and organic hydric soils that have high adsorptive capacity. Therefore, these soils can remove pathogens from surface waters.

Depressional wetlands can also remove pathogen bearing sediment in surface waters through the mechanisms of filtration and sedimentation (Borst et al. 2001, Sherer et al. 1992). There is some indication that fecal pathogens survive for considerably longer periods of time in water with sediment than without (Sherer et al. 1992). In sediment laden waters, fecal coliform had a half-life of 11-30 days while fecal streptococci had a half life of 9-17 days (Sherer et al. 1992).

Therefore, the mechanisms that remove sediment from the water column play an important role in the temporary storage of pathogens in aquatic ecosystems. These mechanisms would include filtration by vegetation and velocity reduction. Velocity reduction causes sediment to “settle out” of the water column and occurs predominantly in depressional wetlands (Sheldon et al. 2005). Velocity reduction also occurs in low gradient, unconfined floodplains as does filtration by vegetation.

Depressional wetlands are also important areas for pathogen removal via mortality. Pathogens are removed from the watershed via mortality. The primary factors causing death of these organisms are UV radiation, temperature, pH, salinity, predation, and starvation (Roszak and Colwell 1987). Marino and Gannon (1991) report that bacterial and protozoan predation are major factors determining fecal coliform and fecal streptococci survival. Tate (1978) demonstrated that protozoans played a significant role in reducing E. coli populations in muck soils over a 10-day period. In an experiment simulating normal stream flows (no re-suspension of sediment occurring) Cox et al. (2005) reported a 99.8 percent die off of E. coli bacteria during first 65 days in 8 liters of stream sediment supplemented with 3 liters of dairy barnyard manure.

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 and fecal streptococci (Marino and Gannon 1991). Cox et al. (2005) reported a 99.8 percent die off of E. coli bacteria during first 65 days in 8 liters of stream sediment supplemented with 3 liters of dairy barnyard manure. Hemond and Benoit (1988) reported that detention time and predation by micro-organism in wetlands results in the loss of pathogens. This suggests that aquatic ecosystems that allow predation of pathogens to occur over a longer period of time play an important role in eliminating pathogens. Due to their ability to hold water back, depressional wetlands can provide longer residence time for surface waters relative to streams and rivers.

Toxins/Metals

Toxins input via surface erosion – steep slopes with erodible soils (addressed in sediment section)

Depressional wetlands are important areas for toxics adsorption. Adsorption of toxins is most likely to occur in depressional wetland areas with soils of high cation exchange capacity (Kadlec and Knight 1996). These are usually soils with high organic or clay content (Sheldon et al. 2005). Depressional wetlands, as well as the 100-year floodplain, lakes, depositional stream channels are important areas for toxin sedimentation (addressed in sediment section).

Large Woody Debris Process Important Areas

Woody debris enters streams primarily via streambank erosion, mass wasting, and windthrow. Therefore, important areas for woody debris input and movement generally include areas of eroding stream banks in unconfined channels, mass wasting areas, and riparian areas 100’ from all water bodies and streams. In unconfined channels, the amount of wood recruited through stream bank erosion increases as channels actively migrate in areas of erodible soils (any substrate other than bedrock, cobbles, or boulders) (May and Gresswell 2003). Where mass wasting or landslides occur directly upslope of the stream channel, these events can provide a significant amount of wood. In studies of three stream systems from California to Washington, between 65-80% of instream wood came from upslope areas (Reeves et al. 2003, Benda et al. 2002b). A similar result was found for smaller headwater streams in southwest Oregon by May and Gresswell (2003). 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).

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

Step 3 – Map Process Alterations

This step determines where land uses and/or actions associated with land use have altered naturally occurring watershed processes. Knowing where and how processes have been altered provides insight into the various management approaches that may be appropriate for each geographic region. Altered areas may provide opportunities for restoration, while unaltered areas may have potential for conservation or similar protection. In some cases it is not possible to map the activities that impair the processes. In such cases, indicators were used that strongly correspond to these activities and are easier to map.

Lowland areas of Puget Sound are altered by varying degrees from natural conditions by human activity. However, the intensity of impairment varies significantly. Where impairment is minimal, processes are likely still primarily intact and functioning. Where impairments are significant, processes are no longer functioning. The current condition of important areas can be assessed by evaluating the locations and impacts of various activities.

Table 4. Data sources mapped by Thurston County for Identifying Process Impairments using methods from Stanley et al. 2008

Process	Mechanism	Change to process	Alteration	Indicators of alteration	Thurston SMP Update Data Layer Name	Data Sources for Mapping Impaired Areas
Water	Delivery	Increased streamflow	Removal of forest vegetation	Reduction of forest cover in rain-on-snow and snow dominated zones	Thurston_ROS	State_ROS. DNR.
					landcover06	landcover2006. Ecology.
	Overland flow	Change in timing of surface runoff, Decreased infiltration	Impervious areas	Watershed imperviousness	landcover06	landcover2006. Ecology.
	Surface Storage	Increased streamflow; Decreased storage capacity; Increased velocity of surface flows	Drainage or filling of depressional wetlands	Rural and urban land use adjacent to depressional wetlands	dep_wet	dep_wet. Thurston County Planning Dept.
					zoning	zoning. Thurston County GeoData.
					parcels	parcels. Assessor's land use code. Thurston County GeoData.
				Loss of depressional wetlands	lost_wet	dep_wet. Thurston County Planning Dept.
						landcover2006. Ecology.
			Channelization of streams and disconnection from floodplain	Miles of stream through urban areas	SMA_Streams_Shoreline	SMA_Streams_Shoreline. Thurston County Planning Dept.
					cities	cities. Thurston County GeoData.
		Increase water storage capacity; Decrease downstream flow	Dam operation	Dams	Dams	Facility/Site (Ecology permitted sites). Ecology.
	Shallow subsurface flow	Reduce recharge and increase surface	Impervious surfaces	Land uses with impervious cover on geologic deposits of low	built_lo_perm	landcover2006. Ecology.
						Geologic Units 100k. DNR.

		runoff		permeability		
			Loss of forest cover	Non-forested vegetation on geologic deposits of low permeability	nonfor_loperm	landcover2006. Ecology.
						Geologic Units 100k. DNR.
	Recharge	Reduce recharge and increase surface runoff	Loss of forest cover	Non-forested vegetation on geologic deposits of high permeability	nonfor_hiperm	landcover2006. Ecology.
						Geologic Units 100k. DNR.
		Reduce groundwater recharge	Impervious surfaces	Land uses with impervious cover on geologic deposits of high permeability	built_hi_perm	landcover2006. Ecology.
						Geologic Units 100k. DNR.
		Shift location of groundwater recharge. Losses from water supply pipes or sewer lines, or septic drainfield discharges	Leaky pipes or irrigation canals; Water suppy and wastewater management	Septic systems	septic_parcels	parcels. Thurston County GeoData.
	Subsurface flow	Change location of groundwater discharge	Interception of subsurface flow by ditches and roads	Roads	roads	roads. Thurston County GeoData.
	Discharge	Decrease groundwater inputs to aquatic resources	Loss of groundwater discharge areas and upland areas recharging discharge areas	Loss of forest on areas recharging discharge areas	landcover06	landcover2006. Ecology.
					soils	soils. CARA Category. Thurston County GeoData.

	Transpiration	Alter evapotranspiration rates	Clearing vegetation; Shifting vegetation composition	Land cover	landcover06	landcover2006. Ecology.
	Streamflow out of basin	Change streamflow direction	Diversions; Interbasin transfers	Diversion Structures	hydro	hydro. Thurston County GeoData.
Sediment	Surface erosion	Increase delivery of fine sediment to aquatic resources	Removal of vegetation	Non-forested land cover on highly erodible slopes adjacent to aquatic resources	nonforest_hir	landcover2006. Ecology. Slope Stability. DNR.
			Soil disturbance and clearing	Row crop agriculture draining directly to aquatic resources	landcover06	Cultivated land classificaton. landcover2006. Ecology.
			Roads increasing stream network	Roads within 200' of aquatic resources	Roads_Aquatic_200ft	Roads_Aquatic_200ft. Thurston County Planning Dept.
	Mass wasting	Increase delivery of fine sediment to aquatic resources	Roads triggering landslides	Roads in high mass wasting hazard areas	Roads_Hi_Mass Wast	roads. Thurston County GeoData. Slope Stability. DNR.
			Removal of vegetation	Non-forested land cover on high mass wasting hazard areas	nonforest_hir	landcover2006. Ecology. Slope Stability. DNR.
	In channel erosion	Alter fine sediment delivery to streams	Increase in stream discharge	Urban land cover	landcover06	landcover2006. Ecology.
	Storage/ Sedimentation	Decrease sediment storage	Drainage or filling of depressional wetlands	Loss of depressional wetlands	lost_wet	dep_wet. Thurston County Planning Dept. landcover2006. Ecology.
			Increase in stream flow	Addressed in hydrology section		

		Increase sediment storage	Dams	Dams	Dams	Facility/Site (Ecology permitted sites). Ecology.
	Loss	Decrease in sediment storage	Drainage or filling of depressional wetlands	Loss of depressional wetlands	lost_wet	dep_wet. Thurston County Planning Dept.
						landcover2006. Ecology.
			Increase in stream flow	Addressed in hydrology section		
		Increase in sediment storage	Dams	Dams	Dams	Facility/Site (Ecology permitted sites). Ecology.
Water Quality (includes Nitrogen, Pathogens, Phosphorus, Toxins, and Heat and Light)	Nitrogen sources	Additional sources	Application of fertilizer and manure	Agricultural land use and urban land use	parcels	parcels. Thurston County GeoData.
			Septic systems	Rural Residential land use	zoning	zoning. Thurston County GeoData.
					parcels	parcels. Thurston County GeoData.
	Nitrification	Reduced areas with seasonal flooding	Draining or filling of depressional wetlands	Rural and urban land use	parcels	parcels. Thurston County GeoData.
				Loss of depressional wetlands	lost_wet	dep_wet. Thurston County Planning Dept.
						landcover2006. Ecology.
	Denitrification	Reduced area for denitrification	Draining or filling of depressional wetlands	Rural and urban land use	parcels	parcels. Thurston County GeoData.
				Loss of depressional wetlands	lost_wet	dep_wet. Thurston County Planning Dept.
						landcover2006. Ecology.
		Loss of hydrologic connectivity between upland and riparian area	Interception of shallow groundwater flow into riparian areas	Construction of roads and drainage systems	roads	roads. Thurston County GeoData.

	Fecal inputs	Additional fecal inputs	Failed septic systems	Rural Residential land use (lot density) adjacent to streams	septic_parcels	parcels. Thurston County GeoData.
			Discharge of untreated human and animal waste	Rural and Commercial agriculture (dairy farms, feedlots, livestock)	dairy_county	dairy. Ecology.
	Surface flows	Increased velocity and erosion of streambed	Channelization of streams	Urban and agricultural land uses	landcover06	landcover2006. Ecology.
	Infiltration/ recharge & subsurface flows	Conversion to surface flows	Impervious cover	Urban land cover and/or impervious cover of greater than 10%	imp_2006	wa_2006_impervious. Ecology.
	Adsorption and Sedimentation	Reduced storage of pathogens	Ditching, draining, or filling depressional wetlands with mineral and organic soils	Rural and urban land use	landcover06	landcover2006. Ecology.
				Loss of depressional wetlands	lost_wet	dep_wet. Thurston County Planning Dept.
						landcover2006. Ecology.
	Mortality	Reduced residence time	Draining or filling of depressional wetlands with mineral and/or organic soils	Rural and urban land use	landcover06	landcover2006. Ecology.
				Loss of depressional wetlands	lost_wet	dep_wet. Thurston County Planning Dept.
						landcover2006. Ecology.
	Phosphorus sources	Additional sources	Application of fertilizer	Urban and Agricultural land use	landcover06	landcover2006. Ecology.
			Application of manure	Agricultural land use adjacent to	dairy_county	dairy. Ecology.
					landcover06	landcover2006. Ecology.

				dairies		
	Toxin sources	Additional sources; New toxins	Use of pesticides, herbicides, and other chemicals	Urban land use; Row crop land use	landcover06	landcover2006. Ecology.
	Surface erosion			Addressed in sediment section		
	Adsorption (P)	Reduced phosphorus adsorption	Draining or filling of depressional wetlands	Loss of depressional wetlands	lost_wet*.	dep_wet. Thurston County Planning Dept.
						landcover2006. Ecology.
			Loss of upland areas with clay soils	Urban land cover in areas of clay soils adjacent to aquatic ecosystems	landcover06	landcover2006. Ecology.
	Adsorption (T)	Reduced toxin adsorption	Draining or filling of depressional wetlands	Loss of depressional wetlands	lost_wet	dep_wet. Thurston County Planning Dept.
						landcover2006. Ecology.
	Sedimentation	Reduced storage of phosphorus and toxins	Draining or filling of depressional wetlands	Loss of depressional wetlands	lost_wet	dep_wet. Thurston County Planning Dept.
						landcover2006. Ecology.
			Increase in stream flow	Addressed in hydrology section		
	Riparian canopy cover	Loss of vegetation	Remove riparian vegetation	Non-forested land cover within 100' of streams	nonfor_lwdrz	landcover2006. Ecology.
						Streams_100ft. Thurston County Planning Dept.
Wood	Stream erosion	Reduce LWD available to reach stream	Remove riparian vegeation	Non-forested land cover within 100' of stream in a floodplain	nonfor_lwdfza	landcover2006. Ecology.
						Streams_100ft. Thurston County Planning Dept.
						floodzoneA. Thurston County GeoData.
	Mass wasting		Remove forest	Non-forested land cover on	nonforest_hir	landcover2006. Ecology.

			vegetation on high mass wasting hazard areas	high mass wasting hazard areas		Slope Stability. DNR.
	Windthrow		Removal of vegetation adjacent to stream	Non-forested land cover within 100' of streams	nonfor_lwdrz	landcover2006. Ecology.
						Streams_100ft. Thurston County Planning Dept.
	Storage	Reduce capacity of stream to store wood	Increased streamflow	Addressed in hydrology section		

Water Process Alterations

Human activity has impaired the natural condition of the lowland areas of Puget Sound. However, the intensity of impairments varies significantly. Where impairment is minimal, processes are still primarily intact and functioning. Where impairments have been significant, processes are no longer providing the functions on which we rely. We can characterize the current condition of the important areas identified in the previous section by mapping the locations and impacts of various activities. This section describes the relationships between a suite of human activities and the delivery, movement and loss of water in Thurston County.

Table 5. Alterations Associated with Key Processes

Process	Mechanism	Important Areas	Alterations
Water	Surface runoff and peak flows	High precipitation areas	Roads
		Rain-on-snow zones; Snow-dominated zones	Removal of forest vegetation
	Recharge	Areas on geologic deposits with high permeability	Loss of forest cover
			Impervious surfaces
			Leaky pipes or irrigation canals; Water supply and wastewater management
	Shallow subsurface flow	Areas on geologic deposits with low permeability	Removal or compaction of soil
			Impervious surfaces
			Loss of forest cover
	Surface Storage	Depressional wetlands; Floodplains; and Lakes	Drainage or filling of depressional wetlands
			Channelization of streams
			Disconnection of stream from floodplain
			Dam operation
	Stream flow out of basin	Rivers	Diversions; Interbasin transfers

Sediment	Surface erosion	Steep slopes with erodible soils	Removal of vegetation
			Soil disturbance and clearing
			Roads near streams increasing stream network
	Mass wasting	Hazard areas for shallow rapid landslides	Roads triggering landslides
			Removal of vegetation
	In channel erosion	Unconfined channels or with <4% gradient	Channelization of streams
			Increase in stream discharge
	Storage/ Sedimentation	Depressional wetlands; Floodplains; Lakes	Drainage or filling of depressional wetlands
			Channelization of floodplains
			Disconnection of stream from floodplain
			Dams
Water Quality (includes Nitrogen, Pathogens, Phosphorus, Toxins, and Heat and Light)	Nutrient sources (Nitrogen and Phosphorus)	No important historic areas are identified	Application of fertilizer and manure
			Septic systems
			Frequent clearing of forest
	Pathogen Sources		Failed septic systems
			Discharge of untreated fecal matter
	Toxin sources		Use of pesticides, herbicides, chemicals
	Storage/ Transformation/ Loss	Depressional wetlands; Lakes; Floodplains; streams	Draining or filling of depressional wetlands; channelization of streams; Reduction of recharge and groundwater flow to riparian areas; impervious cover; ditching
	Riparian canopy cover	Forest cover within 100' from aquatic resources	Loss of riparian vegetation
Wood	Stream erosion/ Storage	Unconfined channels or with <4% gradient	Channelization of unconfined streams
			Armoring of streams
			Removal of riparian vegetation
	Windthrow	Forest within 100' from aquatic resources	Removal of vegetation adjacent to stream
	Mass wasting	Mass wasting hazard areas	Removal of forest vegetation on high mass wasting hazard areas

Surface Runoff and Peak Flows

Areas of process alteration for snow melt are non-forested land cover in rain-on-snow zones. During rain-on-snow events, areas in the rain-on-snow zone that have been cleared can produce 50 to 400% greater outflow from snow packs than do similar areas that are still forested (Coffin and Harr 1992). The absence of vegetation during rain-on-snow events results in more snow accumulation due to reduced interception and a higher rate of snowmelt (Brunengo et al. 1992, Coffin and Harr 1992). Both of these factors result in increased peak outflow from snow packs. In rain-on-snow zones that are cleared of vegetation but are still in forestry land use, the increased flow will occur in response to rain-on-snow events until more mature forest vegetation re-establishes. However, if land cover is permanently shifted out of forest cover (i.e., through conversion to agriculture or impervious surfaces) increased outflow is a permanent response to rain-on-snow events.

Areas of alteration for impaired timing of runoff are non-forested land cover in “rain-dominated” zones. Removal of forest in “rain-dominated” zones (outside the snow zones) also alters runoff patterns by decreasing recharge and increasing surface flow (Booth et al. 2002).

Areas of alteration for impaired overland flow are found by the percent impervious cover within a watershed. Impervious cover within a watershed decreases infiltration and increases overland flow. Seasonally saturated areas are impaired by increased surface flows from upland development and by filling or drainage activities within their boundaries. Upland development decreases infiltration and increases surface flows which is usually routed into seasonally saturated areas. As a result seasonally saturated areas can expand in size. Draining and filling activities are common within these impaired seasonally saturated areas. Determining impairment within saturated areas requires local data and was not analyzed for this characterization.

Surface Water Storage

Floodplains and depressional wetlands can be important areas for the storage of surface water runoff. Activities that reduce the spatial extent or storage capacity of these areas during peak flow events can increase the volume of water and the rate at which it reaches aquatic ecosystems (Sheldon et al. 2005, Gosselink et al. 1981, Reinelt and Taylor 1997). Areas of alteration for impaired surface storage through loss of depressional wetlands are rural and urban land use adjacent to depressional wetland areas. Land use types associated with depressional wetlands can provide a general but consistent assessment of the potential degree of impairment to wetlands.

In various parts of the country there is evidence reducing the amount of wetlands in a watershed results in a larger quantity of water being delivered to down-gradient aquatic ecosystems in a shorter period of time. As a result, water level fluctuations in aquatic ecosystems are greater. In King County, the fluctuation of surface water levels in response to runoff events was statistically greater where less than 4.5% of the watershed area was wetland (Reinelt and Taylor 1997). Straight channels associated with depressional wetlands or historic depressional wetlands can indicate drainage of these aquatic resources. Also, the type of land use associated with these wetlands can indicate the degree of impairment to wetland water regime.

Surface storage may be altered through channelization of streams. Areas of alteration for impaired surface storage through stream channelization are streams with adjacent urban land cover. These streams will have a greater relative degree of impairment than streams with rural land cover. The capacity of streams to store water within the channel is reduced when streams are channelized or straightened. This can also result in disconnection of a stream from its floodplain. Areas of alteration for impaired surface storage through disconnection from floodplain are streams within unconfined floodplains with adjacent urban land cover which will have a greater relative degree of impairment than streams within unconfined floodplains with rural land cover. Dikes and levees directly disconnect the river water from the floodplain, thus removing flood storage capacity at high water levels (Sheldon et al. 2005). No regionally available data layer exists showing the locations of dikes or levees. However, by intersecting land use with degree of floodplain confinement (SSHIAP data) a relative rating of impairment to floodplain storage can be attained.

The presence of dams indication areas of alterations for impaired surface storage due to dams. The presence of dams that form reservoirs increases the surface storage of water above the dam but reduces the surface flow downstream of the dam.

Recharge

Areas of altered recharge are non-forested vegetation on areas with geologic deposits of high permeability. Although the Q 2 developed can be maintained at less than the Q10 forested on impermeable deposits if less than 35% of the forested cover in a watershed has been removed, this relationship cannot be maintained with any forest clearing on permeable deposits because so little surface runoff occurred naturally. As a result, the threshold of forest clearing at which aquatic resources are impaired is likely much lower for the permeable deposits than impermeable. The modeling also demonstrated that the conversion of forest to suburban development (primarily lawns) affected peak discharges more significantly than small increases in impermeable cover associated with low density rural development (i.e., 4% EIA) (Booth et al. 2002).

Areas of altered recharge are land uses with impervious cover on areas with geologic deposits of high permeability. The construction of impervious surfaces on areas that are important for recharge can reduce the quantity of recharge as well as increase surface runoff (Table X). Studies of Western Washington indicate that recharge in "built-up areas" (appx. 95% impervious surfaces) is reduced by 75% while that of residential areas (appx. 50% impervious surfaces) is reduced by 50% (Vaccaro et al. 1998). A given amount of impervious cover can produce a greater percentage increase in runoff if it is located on permeable surface deposits than if it is on impermeable surface deposits (Booth et al. 2002). However, in such areas with permeable deposits, development designs that include measures to increase infiltration are also most effective at reducing the amount of surface runoff (U.S. EPA 1999, Washington State Department of Ecology 2005).

Groundwater Flow

Three factors are likely to alter the quantity of water that flows subsurface on less permeable deposits: removal of soils, construction of impervious surfaces, and removal of forest vegetation. Each of these activities will prevent water from infiltrating into the soil and produce surface runoff instead. In order to map the removal of soil, local data are needed. Local data were not available so the removal of soil was not mapped.

Areas of alteration for impaired shallow sub-surface flows are land cover with impervious surfaces on areas with geologic deposits of low permeability. Impairment of aquatic ecosystems has been documented to occur with virtually any level of impervious cover in a watershed. Furthermore, this decline progresses as the portion of the watershed with impervious cover increases (Booth et al. 2002). In the Puget Lowland, readily observable damage to stream resources (i.e., unstable channels) occurs if the effective impervious area (EIA) of a watershed is greater than 10% (Booth et al. 2002) (Table 6).

Table 6. Summary of thresholds associated with visible degradation of stream channels in the Western Washington.

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

Areas of alteration for impaired shallow sub-surface flows are non-forested vegetation on areas with geologic deposits of low permeability. There is growing evidence that simply clearing forest vegetation, even in rural areas that have little impervious cover, can produce increased streamflow as subsurface flow is converted to surface runoff (Booth et al. 2002). In Western Washington, visibly impaired (or unstable) stream channels are associated with watersheds in which the 2-year peak flow that occurs under current conditions (Q_2 developed) is greater than the 10-year peak flow (Q_{10} forested) that occurs under natural conditions (Booth et al. 2002). While the precise reason for this equivalency is not yet understood, the relationship has been confirmed in numerous watersheds in King County.

Modeling efforts have found that on the most common, impermeable deposits (i.e. glacial till), the Q 2 developed discharge can be maintained at less than the Q10 forested discharge if less than 35% of the forested cover in a watershed has been removed (Booth et al. 2002). The modeling also demonstrated that the conversion of forest to suburban development (primarily lawns) affected peak discharges more significantly than small increases in impermeable cover associated with low-density rural development (i.e., 4% EIA).

Areas of altered vertical and lateral flows are roads and their associated drainage system (ditches and culverts) which intercept sub-surface flow and convert it to surface flow. Research suggests that forest roads may intercept subsurface flows, alter the timing of runoff, and increase peak flows within those basins (Luce et al. 2001). This interception can convert water to surface runoff and alter the location at which it discharges into aquatic ecosystems. Correlations between road densities and hydrologic changes at the sub-watershed scale were observed in several studies in the Puget Lowlands. Road densities exceeding 3 miles/mile^2 in the Skagit watershed were found to correlate with changes to the hydrologic regime (Beamer et al. 2002). For Snohomish County, sub-units in the Stillaguamish watershed with peak flow problems had road densities exceeding 3 km/km2 and vegetative cover consisting of >50% immature vegetation (Beamer 2000).

Areas of altered groundwater discharge are areas with loss of forest on permeable deposits that intersect floodplains. Alteration of groundwater discharge areas, such as diking or ditching in floodplains, has the potential to cause two major changes. First, it can change the way water from groundwater discharge areas moves to other aquatic ecosystems, potentially altering such water quality characteristics as temperature. Second, it can alter the amount of groundwater that discharges at a particular location as the water table is lowered and the piezometric gradient is shifted. Removal of forest on permeable deposits adjacent to and/or intersecting floodplains also reduces discharge to floodplains. Land cover data including percent forest loss on permeable deposits and land use (urban vs rural) adjacent to streams with unconfined floodplains can be used.

Loss of Water

Areas of altered evaporation and transpiration are areas with impervious surface cover within a watershed. Evaporation and transpiration are impaired by human activities. While it is difficult to quantify the exact change to evaporation and transpiration, impervious cover is an acceptable indicator of elimination of this water flow component.

Natural patterns of water loss from a watershed can be impaired with inter-basin transfers or diversions that transfer water to a different watershed. Local data is needed to identify these activities.

Sediment Process Alterations

Surface Erosion

Surface erosion may be altered by removal of vegetation, soil disturbance and clearing, or roads increasing the stream network. Non-forested land cover on highly erodible slopes adjacent to streams are areas of altered surface erosion. The Washington Forest Practices Board (WFPB 1997) identifies gradient, erodibility of soils (K factor), and vegetative cover as the three factors governing surface erosion. The gradient and erodibility of soils are used to identify areas with a high likelihood of delivering fine sediment. If the vegetative cover of these areas has been cleared, they are more prone to erosion.

Others areas indicating altered surface erosion are areas containing row crop agriculture and clearing for construction sites which can produce increased fine sediment loads with the potential to reach aquatic resources. Agricultural land use accounts for up to 50% of the total sediment load, generated by human activity, which reaches U.S. surface waters annually (Willett 1980). Depending upon the use and effectiveness of best management practices, soil disturbance associated with row crop agriculture is likely to produce erosion of fine sediments. Thurston County used the cultivated land classification from the 2006 classified landcover data from Ecology adjacent to aquatic resources to identify areas of alteration due to row crop agriculture. Soil disturbance from clearing of construction sites was not analyzed due to lack of data.

Roads within 200’ of aquatic ecosystems or road crossings indicate areas of altered surface erosion. The Washington Forest Practices Board (WFPB 1997) indicates that roads further than 200’ from a water body are unlikely to contribute surface erosion directly into aquatic ecosystems. Within that buffer, the presence of ditches and culverts and the relative absence of places to remove the sediment increase the likelihood that sediment will be delivered from the roads to the streams.

Mass Wasting

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

Others indicators of altered mass wasting are non-forested land cover in high mass wasting hazard areas. Altering the vegetative composition of unstable slopes can further destabilize conditions. Roots of trees can serve to anchor thin, overlying layers of soil to bedrock or to create a membrane of intertwined roots that provides lateral stability to soil (Sidle 1985, Chatwin et al. 1994).

In-channel Erosion

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

Sediment Storage

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

Areas of altered sediment storage are 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).

Water Quality Process Alterations

Many alterations to water quality processes have occurred in Thurston County, including point sources (e.g., focused discharge from a wastewater treatment plant), and non-point sources (e.g., diffuse discharge from agricultural fields). The construction of impervious surfaces and stormwater conveyance infrastructure has altered water quality processes by bypassing natural hydrologic pathways such as soil infiltration and percolation. Toxic, nutrients, and pathogens that can negatively impact water quality can build up on impervious surfaces, and be washed into aquatic ecosystems during storm events.

Water quality alterations can be assessed by comparing state water quality standards to local water quality in streams and lakes. The Department of Ecology maintains a database, known generally as the 303(d) list, of water bodies where water quality issues are known to exist. Waters that are known to exceed State water quality standards are Category 5. Water bodies rated as category 4, indicate that a clean-up plan has been developed (also known as a Total Maximum Daily Load [TMDL]) and is being implemented.

Nutrients (nitrogen and phosphorus)

Indicators of additional sources of nitrogen are areas containing the application of fertilizer and manure, and septic systems. Areas of impaired sources of nitrogen are areas containing agricultural land use that supply additional nitrogen sources such as application and manure, and septic systems. Application of fertilizers and livestock manure has resulted in significant changes to terrestrial nitrogen dynamics resulting in increased levels of dissolved inorganic nitrogen in streams (Webster et al. 2003). Excessive nitrogen inputs from agricultural runoff can result in lower water quality in adjacent streams (Edwards 1998). Agriculture is also the leading source for nutrient loading in U.S. lakes (Burton and Pitt 2002). In a Puget Sound region study, Ebbert et al. (2000) found that areas with agricultural land use produced 40 times the nitrogen concentrations than did forested areas and twice the concentrations of urban areas. The significance of agricultural use of fertilizers as a source of nitrogen pollution may actually be much greater since current methods for estimating emissions of nitrous oxide from fertilizer use may be underestimating actual emissions by as much as 50% (Giles 2005b). Commercial agriculture operations (such as row crop production, feedlots, rangeland, or dairies) are the leading source of pollution, including nutrients, in surveyed streams across the country (U.S. EPA 2000). If it is possible, use local data to separate agricultural land uses into commercial production and rural agriculture.

Indicators of impaired sources of nitrogen via septic systems are areas with rural residential land use adjacent to water bodies. Rural residential land use adjacent to water bodies is used as an indicator of likely locations of nitrogen inputs. Nitrogen is a compound that is not removed by septic systems. All the nitrogen discharged by a household into its septic system will end up in the groundwater. Organic nitrogen will get broken down to ammonium or nitrates in a septic system, but no further. These inorganic forms of nitrogen are soluble and flow into the groundwater. If septic systems are close to the areas where groundwater is discharged the nitrogen will have a short path to aquatic ecosystems and this can cause eutrophication. The USGS has concluded that septic effluent from rural residences close to the Hood Canal shoreline flows laterally into Hood Canal (Paulson et al. 2007). Such a setting allows little opportunity for denitrification to occur or for vertical movement of effluent into the regional ground-water flow system. Because most rural areas are not connected to sewer systems and each residence requires a septic system, rural residential land use is used as an indicator of the presence of septic systems. This is a surrogate for having actual data on the location and condition or age of septic systems. Nitrogen from septic systems as far away as 3-4 miles has also been implicated in the eutrophication of Waquoit Bay on Cape Cod (Valiela et al. 1992).

Indicators of impaired nitrification and denitrification are rural and urban land use adjacent to depressional wetlands. Reducing the area of depressional wetlands through draining or filling reduces the potential area that is seasonally wet, thus providing aerobic conditions needed for nitrification to occur (Hruby 2004). Reducing the area of depressional wetlands through draining or filling also reduces the potential area of anaerobic conditions needed for denitrification to occur (Hruby 2004).

Indicators of impaired denitrification are areas where there has been interception of shallow groundwater flow into riparian areas through loss of forest cover on high and low permeability deposits adjacent to or intersecting the floodplains of streams and rivers or through road density which is an indicator of the degree of interception of shallow subsurface flows. Land cover changes such as clearing of forest can reduce recharge and the movement of water to riparian areas and reduce the level of denitrification that occurs there. It is important that the retention time of groundwater remains intact in areas with either high organic content or other electron donors that support denitrification (Tesoriero et al. 2000). In addition, drainage activities generally lower the water table below the critical organic zone where biological activity transforms nitrogen (Gold et al. 2001).

Indicators of altered phosphorus inputs are areas of urban and agricultural land use where fertilizers and manure (from dairies) are applied. In a study of Puget Sound, no single land use could be strongly correlated with high total phosphorus concentrations (Ebbert et al. 2000). It appears that both urban and agricultural land uses can be associated with substantial increases in phosphorus loads. In agricultural areas this input is largely from the use of fertilizers (Sheldon et al. 2005). The application of manure to fields results in a buildup of phosphorous levels in soils and a subsequent increase of phosphorous in storm runoff (Carpenter et al. 1998). Application of manure can also increase the result of phosphorous from soil in sub-surface flows (Kleinman et al. 2005). Manure application is usually associated with dairy operations in the Puget lowlands. In developed areas of Washington, phosphorus levels in streams are five to ten times higher than in forested areas (Reckhow and Chapra 1983). Additionally, total phosphorus (both dissolved and particulate phosphorus) in Puget Sound lowland streams is correlated to the percent of the basin in impervious cover (Bryant 1995). The source of phosphorus enrichment in these developed areas appears to be from fertilizers, detergents and wastewater (Welch 1998). Indicators of altered phosphorous adsorption are areas with straight-line hydrography in and loss of area of depressional wetlands with mineral soils. Adsorption of phosphorus is facilitated in depressional wetlands with mineral soils as water velocity slows. This capability is impaired when impairments prevent water velocity from slowing or reduce the area of wetland available for phosphorus adsorption.

Pathogens

Fecal coliform was used as an indicator of pathogens in this report because Ecology monitors it in water quality studies and it occurs most commonly. Natural concentrations of pathogens in water are very low, and pathogen inputs are chiefly associated with human disturbance. Sources of fecal matter and related pathogens resulting from humans include animal operations such as dairies and hobby farms and onsite septic systems.

Indicators of impaired fecal inputs are areas of rural residential land cover (lot density) adjacent to streams. Fecal inputs may be impaired by failed septic systems, or discharge of untreated human and animal waste. Septic systems have been associated with high levels of pathogen contamination (Lipp and Rose 2001, Lipp et al. 2001, Glasoe and Christy 2004). The U.S. EPA estimates that 10 to 30% of these systems are not functioning properly (U.S. EPA 2001). Septic systems installed on poorly draining soils (low permeability deposits) are often ditched and drained to tidal creeks increasing transport of pathogens (Duda and Cromartic 1982). Duda and Cromartic also determined that septic system densities of greater than one system per seven acres resulted in closure of shellfish beds in a coastal North Carolina watershed.

Indicators of impaired pathogen inputs are areas with commercial agricultural land cover (i.e. dairy farms/feedlots) and livestock density. Animal waste from concentrated animal feeding operations contains pathogens such as cryptosporidium and campylobacter (Cole et al. 1999). Transport, adsorption, and sedimentation of pathogens are primarily altered by ditching, channelization, impervious cover, and filling of wetlands within a watershed. Impairments to the movement of pathogens (Glasoe and Christy 2004) indicate that, while impervious cover is highly correlated with shellfish contamination, even areas of little development can impair shellfish integrity if the watershed hydrologic processes have been significantly altered. In particular, land use activities such as ditching and draining can be responsible for contaminating shellfish beds. Agricultural and roadside ditches by-pass the pathogen removal processes of wetlands and speed up the movement of water contaminated with pathogens to estuarine waters. White et al. (2000) found even low levels of impervious cover could contaminate aquatic ecosystems with fecal coliform if there was a high degree of hydrologic connectivity between sources and the aquatic ecosystems. Mallin (2001, 2000) found that watersheds with extensive wetland cover, relative to those with reduced/altered wetland cover, did not exhibit fecal coliform counts and turbidity during rainfall events. Indicators of impairment to the transport of pathogens via subsurface flows and recharge are impervious land cover of greater than 10% and ditching on low permeability geologic deposits.

Numerous studies have examined the relationship between urbanization and the contamination of shellfish harvest areas by fecal coliform bacteria and other pathogens, including viruses. The percentage of the catchment area that is impervious and that drains into the nearshore waters seems to offer a good correlation with the integrity of the marine habitat and the health of shellfish beds (Glasoe and Christy 2004). The Center for Watershed Protection (2003, 2004) modeled the relationship between impervious cover and shellfish habitat degradation. Supported by numerous other studies, they indicate that if more than 10- 25% of the watershed is impervious, then bacterial standards will be frequently, if not continuously, exceeded during wet weather conditions. The primary effect of impervious surfaces appears to be increased stormwater runoff and movement of water from source areas (e.g., pets, livestock, septic systems, waste water treatment plants, combined sewer overflow facilities) to critical habitat areas (Glasoe and Christy 2004).

Hydrologic impairments (i.e., ditching, impervious cover) on permeable geologic deposits may have a significant effect on the transport of pathogens. Unaltered flows within these deposits are typically deeper and have a longer flow path than in geologic deposits of low permeability. The longer flow path may reduce pathogen levels through adsorption. Based on research in the

Buttermilk Bay watershed of Massachusetts, Weiskel et al. (1996) recommended that stormwater runoff be routed to a groundwater pathway in order to reduce bacterial levels. Impairments on these deposits, especially impervious surface, significantly reduce recharge and the longer flow path afforded by them.

Low permeability deposits have shallow sub-surface flows which have a shorter flow path than provided by permeable geologic deposits. Hydrologic impairments on low permeability deposits also reduce the flow path length. These areas may be even more susceptible to accelerated transport of pathogens. Lipp et al. (2001) reported that sub-surface flow was the principle mechanism for transporting pathogens to Sarasota Bay from residential septic systems. Indicators of impaired adsorption, sedimentation, and loss of pathogens are urban and rural land use adjacent to depressional wetlands Depressional wetlands are important areas for removing sediments and pathogens via adsorption and sedimentation from surface water due to low water velocities, high residence times, filtering vegetation, and soils suitable for adsorption. Impairment to depressional wetlands, such as ditching and draining, reduces the residence time of water. This reduces the effectiveness of sedimentation and filtration mechanisms within the wetland. Filling of depressional wetlands eliminates contact of surface waters with soils that have a capacity for high adsorption.

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

Toxins/Metals

Indicators of impairment to the input of toxins/metals are urban land use and row crop land use. The primary toxins addressed by this document are heavy metals and pesticides/herbicides. Tetra Tech (1988) identified a suite of pesticides of concern that can be transported to riverine and marine waters: 2-4D, dicamba, alachlor, tributyltin, bromacil, atrazine, triclopyr, carbaryl, and diazinon. In Puget Sound, most herbicide and pesticide levels in streams were higher in urban areas than in any other land use area; however, atrazine and diethylatrizine levels were also high in agricultural areas (Staubitz et al. 1997). Urban areas most commonly violate standards for organochlorines, semi-volatile organics and most herbicides and pesticides (Ebbert et al. 2000). Many of the contaminants in the urban areas are from the use of pesticides, wood preservatives (pentachlorophenol), and petroleum-based products that leak or drip from vehicles (polycyclic aromatic hydrocarbons) (Galvin and Moore 1982).

Indicators of impairment of the adsorption of toxins/metals are straight-line hydrography in and loss of area of depressional wetlands with organic or clay soils. Adsorption of toxins is facilitated in depressional wetlands with clay or an organic soil as water velocity slows. This capability is impaired when impairments prevent water velocity from slowing or reduce the area of wetland available for toxin adsorption.

Indicators of impairment to the sedimentation of nutrients, pathogens, and toxics are straight-line hydrography in and loss of area of depressional wetland, straight-line hydrography in unconfined stream reaches, and the presence of dams. The rationale for these indicators is discussed in the sediment section.

Heat/Light

Indicators of alteration for riparian canopy cover are loss of forest cover within 100 feet of streams. Thirty meters is the recommended minimum riparian width required to maintain natural function of heat/light inputs in Puget Sound (Castelle et al. 1994; May 2000). The loss of forest cover within 100 feet of the streams reduces the ability of the riparian canopy cover to moderate the heat and light reaching the stream.

Large Woody Debris Process Alterations

Delivery of large woody debris to low-gradient channels through in-channel erosion is impaired when there is either inadequate 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 are altered are: channelization of streams on unconfined channels, armoring of streams, and removal of riparian vegetation (indicated by non-native land cover adjacent to stream). The delivery of available wood to a stream is increased by the erosion of banks as channels migrate. Channelization, ditching, and diking are all factors that prevent the bank erosion process and remove the associated delivery of wood. Straight-line hydrography can identify streams that likely have hardened banks. Armoring a stream channel also reduces the delivery of wood to the stream by preventing its migration. In unconfined channels, impairment of the wood recruitment process can occur when the availability is decreased within 100’ of the stream channel. Coe (2001) and Hyatt et al. (2004) found that in unconfined channels of the Nooksack River, inadequate large woody debris recruitment was associated with urban (77%), agricultural (85%), and rural (60%) zoning. Beechie et al. (2003) found similar results in the Skagit River watershed. Agricultural, urban/industrial, and rural land uses were associated with less than half of the riparian areas being fully functioning.

The wood recruitment process is altered when forest is removed from potential landslide areas. Indicators of impaired wood recruitment via mass wasting are areas of non-forested land cover on high mass wasting hazard areas. Recruitment of large woody debris by windthrow depends upon the availability of standing trees within one tree length of the stream channel. Any cover other than forested land cover within 100’ of the stream is unlikely to ensure availability of future large woody debris for the stream channel. Indicators of impairment to wood recruitment via windthrow are areas of non-forested land cover within 100’ of streams.

Table 7. Key Processes and Responses to Alterations

Key Process	Mechanism	Change to process / Structural Response	Functional response to Alteration
Water	Surface runoff and peak flows	Increased stream flow and overland flow; Increased velocity of surface flows; Altered timing of spring/summer runoff; Reduced infiltration and recharge; shifted location of groundwater recharge; Decreased surface water storage capacity	Channel incision; increased sediment transport; loss of habitat complexity; Decreased flow attenuation; Decreased removal of nutrients and toxic compounds; Decreased sediment removal and stabilization; decreased maintenance of base flows; decreased habitat for native aquatic and shoreline-dependent species
	Infiltration/ Recharge		
	Shallow subsurface flow		
	Surface Storage		
		Dams result in increased water storage capacity; Decreased downstream flow	Reduced transport of water and sediment across the natural range of flow variability; Increased water and sediment storage
	Stream flow out of basin	Changed stream flow direction	Decreased habitat availability; Migratory barriers
Sediment	Inputs	Increase delivery of fine sediment to aquatic resources	Increased turbidity; Increased coarse sediment supply; Interstitial infill; Reduced hyporheic connection and volume; aggrading channels
	Storage/ Sedimentation	Decreased sediment storage	Increased channel instability; decreased removal of excess nutrients and toxic compounds; decreased water storage; decreased habitat complexity
		Increased sediment storage above dam	Sediment removed from water column above dam; decreased sediment below dam; altered substrate size distribution above and below dam; decreased habitat structure and complexity
Water Quality (includes Nitrogen, Pathogens, Phosphorus, Toxins, and Heat and Light)	Inputs of Nitrogen, Phosphorus, Toxins, Pathogens	Increased concentrations (303(d) listings)	Increased mortality; Reduced species richness; Drinking water contamination; Increased eutrophication; Increased shellfish contamination; Sub-lethal effects like reduced growth or reproductive success
	Riparian canopy cover	Loss of vegetation	Decreased temperature maintenance resulting in decreased shading and increased temperature extremes (303(d) listings); Reduced LWD and other organic material available to reach stream; Decreased habitat complexity; Increased primary productivity; Reduced Dissolved Oxygen; Migration barriers; Reduced species richness; Reduced growth; Increased disease susceptibility; Decreased aquatic egg viability

Wood	Inputs	Reduced bank undercutting	Decreased LWD density; Reduced habitat complexity (pool density and quality); Decreased sediment and organic matter storage and sorting; Decreased biodiversity and productivity
		Reduced LWD available to reach stream	
	Storage	Reduced capacity of stream to store wood	

Step 4 – Identify Restoration and Protection Opportunities

This step involves synthesizing the results of steps 2 and 3 identifying process important areas and alterations to identify general management recommendations for shoreline restoration and/or protection. In the Stanley et al., 2008 methods, this synthesis step was conducted qualitatively. In subsequent years, an update to the Stanley et al., 2008 methods has been completed for water flow: Puget Sound Characterization Volume 1: The Water Resource Assessments (Water Flow and Water Quality) (Stanley, et al. 2012. Ecology Publication #11-06-016).

This updated method uses an ArcGIS model to relatively quantify the most important basins for supporting water flow processes, the locations of impairments to water flow, and provides general management recommendations. Thurston County used the Stanley et al., 2012 results to identify restoration and protection opportunities for WRIA's 11, 13, and 14. WRIA 23's water flow processes were assessed separately for Thurston County's SMP update (because WRIA 23 was not included in the Puget Sound Water Flow Assessment) by the Washington Department of Ecology in December, 2010 using the technical document Puget Sound Watershed Characterization Project: Description of Methods, Models and Analysis (Draft for Peer Review, March 2010, Version 2) (Stanley et al., 2010. Ecology Publication #10-06-05).

The management recommendations in Stanley et al. (2012) are based on a water flow management matrix (Figure 1). Areas that are important and relatively unimpaired become candidates for protection, while those that are important to the process but more impaired become candidates for restoration. Areas that are both relatively less important for a process and in which severe changes have already occurred will result in the least impact to watershed processes if further development occurs.

IMPORTANCE			
	HIGH	Highest Protection	Highest Restoration
	MED-HIGH	Protection	Restoration
	MEDIUM	Protection/Restoration	Restoration/Development
	LOW	Conservation	Development/Restoration
		LOW / MEDIUM	MED-HIGH / HIGH
		DEGRADATION	

Figure 1. Watershed Management Matrix. The importance rating is on the vertical axes, and the impairment rating is along the horizontal axes. The combination of these two indicates suitability of the sub-unit for protection, restoration, conservation, or development. Figure modified from Stanley et al., 2012.

This information should be used in conjunction with the shoreline inventory to identify reach-scale opportunities for restoration/ protection. For each waterbody, readers should look at the general management recommendation outcome from the Puget Sound Water Flow Characterization (Stanley et al., 2010 and 2012) studies. Each general management recommendation has numerous potential management options listed in Chapter 9. If a general recommendation from these studies lists two categories of general recommendations (such as protection/restoration), readers should consider the management options for both recommendation categories. The management options listed for each general recommendation may or may not apply, depending on the specifics of each waterbody.

MARINE NEARSHORE ECOSYSTEM-WIDE PROCESSES CHARACTERIZATION METHODS

The marine nearshore environment encompasses the interface between subtidal marine habitats and the adjacent uplands, or more specifically, "the estuarine/delta, marine shoreline and areas of shallow water from the top of the coastal bank or bluffs to the water at a depth of about 10 meters relative to Mean Lower Low Water (the average depth limit of light penetration.) This zone incorporates those geological and ecological processes, such as sediment movement, freshwater inputs, and subtidal light penetration, which are key to determining the distribution and condition of aquatic habitats. By this definition, the nearshore extends landward into the tidally influenced freshwater heads of estuaries and coastal streams" (Puget Sound Nearshore Ecosystem Restoration Project (PSNERP), 2003).

Marine nearshore environments are formed and maintained by landscape-level ecosystem processes such as net shore-drift (Williams et al., 2004). These landscape processes must function properly across various spatial scales in order to maintain nearshore habitats and the species that occupy and depend on them (including juvenile salmonid species and many species of commercially/recreationally harvestable shellfish) (Williams and Thom 2001; Ruckleshaus and McClure, 2007). The health of nearshore environments is linked to physical processes at the landscape-scale (Williams et al. 2004, Diefenderfer et al., 2006). Physical processes form habitat structure, which influences habitat-related processes, which in turn shape ecological functions and values. Nearshore environments are also affected by chemical and biological processes.

This section discusses key ecosystem-wide processes in the marine nearshore in Thurston County involving the delivery, movement, and loss, of water, sediment, nutrients, pathogens, toxins, and wood:

- Process controls: geology, topography, climate, and land use/land cover;
- Hydrology: circulation, tides/currents, streams, tidal wetlands
- Sediment processes: beach processes and coastal erosion; net shore-drift; coastal bluff landslides; and fluvial influences;
- Water quality processes: nitrogen, phosphorus, pathogens, toxics, and heat/light;
- Riparian vegetation processes: large woody debris, organic matter.

Marine Nearshore Ecosystem-wide Processes

Water Processes

Circulation

South Puget Sound oceanographic circulation processes are typical of a fjordal estuary, with landward flow at depth and seaward flow at the surface. The Nisqually and Deschutes Rivers deliver freshwater which usually flows seaward on the surface. This occurs because freshwater has lower salinity and is warmer than incoming Pacific Ocean water, which makes it less dense). The incoming water from the Pacific Ocean is colder and more saline than the freshwater, causing it to be more dense and flow landward along the bottom (Nightengale, 2000). These layers are mixed by a combination of wind, bathymetry, and lunar influence. The influx of saltier water and seawater intrusions to Puget Sound are greatest when the tidal range is smallest, due to neap tides (when the moon is in the first and last quarters), The mixing of fresh and salt water occurs most during spring tides when the moon is full or new as a result of higher velocity tidal currents (Nightengale, 2000). The difference in temperature, salinity, and density between the freshwater and saltier ocean water, as well as the level of wind on the water surface, determines the degree of mixing (Nightengale, 2000).

Tides and Currents

Salt water in the Puget Sound enters from the Pacific Ocean through the Strait of Juan de Fuca then diverges south into Puget Sound. Tides in the Puget Sound are semi-diurnal, with two unequal high tides and two unequal low tides daily. As the distance from the Pacific Ocean increases, mean tidal range in the Sound also increases. Thurston County contains some of the largest tidal ranges in Puget Sound (greater than 4 meters between MLLW and MHHW) (Finlayson, 2006). Budd Inlet has the largest tide range (4.4 meters with spring maximum tides of over 5 meters).

Tidal currents are muted within South Puget Sound, particularly within protected Henderson, Budd, and Eld Inlets (Albertson et al., 2002). The edge of the Nisqually estuary touching Puget Sound is the most exposed portion of the marine shoreline and tidal currents here are typically stronger and directed to the northwest. More information on tidal currents in Thurston County can be found in the results of hydrodynamic models produced by hydraulic and water quality process investigations within the South Sound (Albertson et al., 2002). Tidal currents have been measured for the Environmental Fluid Dynamics Code (EFDC) model created for the Budd Inlet Scientific Study Report (Aura Nova et al., 1998). Budd Inlet has a flushing rate of between 8 to 12 days with established circulation patterns (Aura Nova et al., 1998).

Sediment Processes

Beach Processes and Coastal Erosion

Thurston County beaches exhibit a common characteristic of Puget Sound beaches, frequently having two distinct foreshore components: a high-tide beach and a low-tide terrace (Downing, 1982). The high-tide beach is a comparatively steep beach face composed of coarse sediment with an abrupt slope break at its water ward extent. In a mixed sand and gravel beach, sand is typically winnowed out of the high-tide beach by wave action (Chu, 1985 in Herrera 2005) and deposited on the low-tide terrace. The low-tide terrace extends seaward from the break in slope at the toe of the high-tide beach. The low-tide terrace is typically a gently sloping accumulation of poorly-sorted fine-grained sediment (Komar, 1976). The low-tide terrace also contains the lag deposits derived from bluff recession (larger rocks, cobbles, and boulders).

The composition of Thurston County beaches is primarily determined by three main influences: wave energy, sediment sources, and relative position of the beach within a littoral cell. Wave energy is controlled by fetch (the open water over which winds blow without any interference from land). In Puget Sound, winds and waves originating from the south are the most frequent (prevailing) and strongest (predominant) wind direction. Waves generated by wind sporadically erode beaches and the toe of coastal bluffs, helping initiate bluff landslides. Coastal bluffs (referred to as feeder bluffs or contributing bluffs) provide the primary source of sediment for most Puget Sound Beaches (Downing, 1983). Beach sediment composition is influenced by bluff composition and wave energy. Waves act to sort coarse and fine sediment. Larger, higher energy waves can move larger rocks when smaller waves are unable. Bluffs composed of coarse gravel will provide different sediment to a beach than a bluff containing sandy material. Sand, gravel, and silt dominate the bluffs in Thurston County. Sand and gravel are the primary beach sediments, because the silt is winnowed away from the beach face to deeper water. Coastal erosion in Puget Sound occurs most when high-wind events overlap with high tides and the waves directly hit the backshore and bluffs (Downing, 1983). Also, the majority of coastal landsliding in the region occurs during and following prolonged high precipitation periods in the winter (Gerstel et al., 1997; Shipman 2004)

Thurston County's beaches are composed primarily of sand and pea gravel overlying cobblewhich is glacially derived sediment delivered to the beaches by bluff erosion or landslides. Forage fish, including sand lance and surf smelt, spawn preferentially on beaches of mixed sand and pea gravel (Penttila, 2000). Eelgrass beds rely on sediment with high proportions of sand and pea gravel and are not able to flourish in sediment-deprived systems dominated by cobble (Hirschi, 1999). Salmon rely on the nearshore sand and pea gravel beaches in several ways such as for gently sloping beaches as safe havens from predators during migration, on forage fish for nourishment, and on eelgrass beds for cover and foraging habitat (Groot and Margolis, 1991).

Net Shore-drift

Beach sediment is moved along the shoreline through the process of littoral drift (shore drift). Littoral drift is the product of wind-generated waves approaching the shore from an oblique angle. Since it is caused by wind-generated waves, littoral drift can change in response to short-term shifts in wind direction including daily, weekly, and seasonally. Over longer periods of time, many shorelines demonstrate a single direction of *net shore-drift*. The direction of net shore-drift is ascertained through geomorphologic analysis of coastal landforms and beach sediment patterns. Most shorelines can be divided into distinct littoral, or drift, cells. These cells act independently of each other and each have discrete sources and sinks of sediment. Each drift cell is a system with three elements: a sediment source which is the erosional feature that originates the drift cell; the transport zone where waves move the sediment alongshore with minimal sediment input; and a deposition zone where the sediment finally comes to rest, often creating spits or barrier beaches. The sediment deposition area is the end of the drift cell and it occurs when wave energy is no longer strong enough to transport sediment in the drift cell (Ecology Coastal Atlas, 2009).

Net shore-drift creates unique drift cells through the process of transporting sediment over time from a feeder bluff to a depositional shoreform. This process creates stretches of shoreline where sediment flow is effectively isolated from adjacent shoreline stretches. Correctly functioning drift cells are critical for creating and maintaining nearshore habitats for nearshore dependent species such as salmon and shellfish. Due to their importance as an ecosystem process and unique nature, drift cells are useful elements for planners to use to delineate the shoreline into reaches for characterization and management (Map 14).

Coastal Bluff Landslides

Along the shores of much of Thurston County, erosion of sedimentary deposits has created high-elevation, often unstable coastal bluffs. Coastal landslides are the primary contributor of sediment to beaches and net shore-drift systems. Coastal landslides typically occur on bluffs where a combination of characteristics makes the bluff vulnerable to slope failure, and during and following periods of prolonged high precipitation in the winter (Tubbs, 1974; Gerstel et al., 1997; Shipman, 2004). Characteristics that make the bluff vulnerable to slope failure include the underlying geology of the bluff, its level of wind-exposure, the local hydrology (groundwater and surface water), and the extent of development impacts (Hampton et al., 2004) (Map 14). The long-term cause of bluff recession is usually undercutting of the toe of the bluff. Significant waves caused by windstorms attacking the toe of the bluff can directly activate bluff failures. Bluffs exposed to greater wind energy (fetch) receive higher wave energy during storms, causing greater toe erosion and bluff undercutting, and subsequently more frequent landslides (Shipman, 2004). More often, toe erosion leads bluff landslides by a period of years, and bluff instability increasingly progresses up the slopes. Bulkheads can reduce wave attack to bluff toes causing undercutting, but bulkheads can accelerate erosion of the beach.

Bluff landslides are more likely to occur in locations where there is a history of landslides, and/or where the bluff strata consist of an unconsolidated, permeable layer (sand), on top of a comparatively impermeable layer (dense silt or clay) (Gerstel et al., 1997). Water is able to percolate through the permeable layer, but then collects above the impermeable layer, creating a “slip-plane”, or zone of weakness. Mass wasting (landslides and larger deep-seated failures) is typically caused by this stratigraphic pattern.

Periods of high rainfall intensity and duration (particularly during times of saturated soil conditions) are the most common trigger of coastal landslides such as those observed at New Years 1996-1997 (Gerstel et al., 1997)

Development of housing and roads often increase and concentrate surface water volumes. This is true due to decreased infiltration and interception of the water. Concentrated surface water can locally erode bluff crests while also saturating soils, which exacerbates “natural” slope stability problems along coastal bluffs and can trigger landslides (Shipman 2004). As an example, a broken drainage pipeline on a bluff face is a form of development that triggers slides. Another example is runoff flowing down a driveway and across a lawn as sheet flow to the bluff face. Removing or failing to plant bluff vegetation, especially conifers, can lead to low root strength and increased likelihood of future landslides. Bluffs with significant modifications to both the natural drainage regime and vegetation are particularly susceptible to landsliding.

Reestablishment and maintenance of native vegetation cover or installation of a fibrous-rooted vegetation cover along with some type of drainage control can reduce the likelihood of bank failures (Menashe 2001; Roering et al., 2003)

Fluvial Influences on the Nearshore

Fluvial systems (rivers and streams) shape nearshore character and can cause change in the marine landscape. Most river sediment delivered to the coast is initially deposited in deltas. Subsequently, since fluvial sediment is often too fine to remain in the nearshore due to prevailing wave regimes, the majority of river-borne sediment is transported further waterward than beaches and deposited on delta fronts and in deeper water (Downing, 1983). The coarse grain portion of the river and stream sediment is typically transported in net shore-drift cells. However, it makes up only a small portion of the total beach sediment as the majority is derived from the erosion and landsliding of unconsolidated bluffs.

How much and what type of fluvial sediment is delivered to the nearshore is dependent on the qualities of the upland: the rocks and soils found there, the amount and type of vegetation, the climate, and the elevation (Komar, 1976). The more fluvial sediment delivered to the coast, the greater its influence on nearshore processes. Fluvial systems influence the nearshore in numerous ways including salinity changes, sediment supply, altered littoral drift, and habitat formation. Fluvial systems locally decrease the salinity of the marine water. Fluvial sediment transport provides sediment to local beaches, which can assist in the establishment of ecologically valuable habitats including marshes, shallow water deltaic habitats, sand and mudflats, and distributary channels. The abundance and density of aquatic flora (e.g., eelgrass) and fauna can be affected by fluvial influences. River or stream discharge into the nearshore can alter littoral drift patterns, commonly leading to the formation of alongshore bars or shoals and creating increased shoreline complexity. Depending on river discharge and wave conditions, these features can display seasonal dynamics, be ephemeral or permanent.

Sediment from the Nisqually river influences marine habitat well over a mile into the Nisqually Reach from the delta. The Deschutes River has been dammed and the sediment is deposited into Capitol Lake resulting in a reduction of historic sediment source to Budd Inlet. Several shoreline creeks, located within Thurston County also contribute freshwater and sediment to the nearshore. These include, but are not limited to: Perry Creek, McLane Creek, Green Cove Creek, Woodard Creek, Woodland Creek, and McAllister Creek (Map 10).

Water Quality Processes

Puget Sound marine nearshore water quality is the result of many complex interactions between physical and biological processes. In the continental United States, Puget Sound is the largest fjord-type estuary. Puget Sound's main basin is over 900 feet deep; however, the South Sound basin is much shallower. Many factors combine to influence South Puget Sound water quality by delivering nutrients, organic matter, pathogens, and inorganic compounds, including, but not limited to: salty, cold water from the Pacific Ocean, terrestrial watersheds that contribute freshwater runoff to the Sound through surface and groundwater discharge, and atmospheric inputs of water, nutrients, and pollutants. Materials that influence water quality (e.g., nutrients, organic matter, etc.) are also stored and released from the bottom sediment of Puget Sound.
The physical structure of the nearshore determines the extent of mixing of the inputs. In general, as the distance south from the Strait of Juan de Fuca increases, the influence of the deeper marine waters is also reduced, while the influence of terrestrial inputs increases. Nutrients, organic matter, pathogens, and inorganic compounds influence and provide important feedback loops for water quality as well as form the basis for biological processes (e.g., primary production of algae and other plankton).

Nutrients (Nitrogen and Phosphorus)

Thurston County's nearshore and marine waters receive inputs of nutrients and organic matter from nearshore bottom sediments mixing with deeper ocean waters via upwelling and estuarine circulation as well as from adjacent uplands, streams, rivers, and groundwater seeps. Typically, nitrogen and phosphorus inputs from natural sources are much greater than anthropogenic sources in Puget Sound (Harrison et al., 1994). However, South Puget Sound has a number of characteristics which lead to a greater contribution of nitrogen and phosphorus inputs from terrestrial and anthropogenic sources than oceanic influences (Albertson et al., 2002). The South Sound is characterized by a high shoreline to water surface-area ratio with relatively shallow depths, stratification of the water column, slow flushing times, protected bays and narrow inlets (Albertson et al., 2001; Herrera, 2005). These conditions make it difficult to dilute nutrients entering the nearshore from adjacent uplands, rivers, and streams by mixing or flushing. Due to these physical characteristics, the South Sound is vulnerable to the effects of excess nutrients which can lead to water quality problems associated with eutrophication (algal blooms) and low levels of dissolved oxygen (hypoxia).

Eutrophication and decreased dissolved oxygen (hypoxia) levels can be detrimental to marine organisms. Excess nutrients stimulate greater phytoplankton growth or algal blooms which in turn reduce light levels reaching the sea bottom, which then reduces the growth and vigor of other plants such as eelgrass and kelp (Williams and Thom, 2001). Excess nutrients can also contribute to contamination of shellfish beds with the harmful bacteria associated with some nutrient sources (i.e., fecal coliform) and through and from harmful algal blooms (eutrophication), which are thought to contribute to Paralytic Shellfish Poisoning (PSP) and Amnesiac Shellfish Poisoning (ASP) (WDOH, 2005). Excess nutrients can also affect phytoplankton community composition, resulting in an indirect affect on marine food webs that rely on phytoplankton. Eutrophication and low dissolved oxygen resulting from increased anthropogenic nutrient inputs or from stratification that can locally concentrate nutrients also have negative impacts on other marine species, including: critical salmonids; forage fish spawning; riparian buffers; shorebird and seabird nesting and foraging; and marine mammal foraging, migration, and haulout habitats. Already, South Puget Sound experiences periods with dissolved oxygen levels low enough to kill marine organisms more frequently than other areas of Puget Sound.

Many human land uses in the upland watersheds draining to Puget Sound contribute to excess nutrients, toxins, and pathogens, for example: failing septic systems, use of fertilizers and pesticides, agricultural operations (animal manure, fertilizers), contaminated sediments, wastewater treatment plants, and stormwater runoff from impervious surfaces (Embrey and Inkpen, 1998).

The processes that control nutrient inputs, dispersion, and areas of concentration also influence inputs and concentrations of pathogens, pollutants, and toxins in Thurston County nearshore waters. Specific water quality impairments are described in the reach analyses.

Pathogens

Fecal coliform was used as an indicator of overall pathogens because it is monitored in Ecology water quality studies and it is the most commonly occurring pathogen. The presence of fecal coliform bacteria indicates the possibility that feces and pathogenic organisms are also present. However, fecal coliform bacteria may not reliably predict pathogens and enteric viruses in the marine environment (Glasoe and Christy, 2004). Humans may introduce fecal matter and associated pathogens to water bodies in many ways which include but are not limited to septic systems built on or near marine and estuarine shorelines, marina and boating activities, and pet waste.

Toxins/Metals

The State of Washington and the Puget Sound Partnership have declared an objective for the recovery of Puget Sound, to significantly improve water quality by reducing toxics and pollutants entering Puget Sound. To date, toxic contaminants in Puget Sound have threatened water quality, reduced marine habitat, and resulted in shellfish closures. Toxic contaminants in the marine nearshore have been documented as a continually increasing problem in the South Sound area. The Department of Ecology and other state agencies are currently studying toxic contaminant loading to Puget Sound in an effort to identify toxic input sources. Preliminary study results indicate that surface water runoff and stormwater may be the largest contributing factors to pollutant loading in Puget Sound (Hart Crowser et al., 2007). Toxics contaminants include metals such as lead, copper, zinc, mercury, and other persistent chemicals including PCBs, flame retardants, and phthalates. These toxics are concentrated in the food chain and have detrimental effects to marine organisms including, but not limited to fish and shellfish. Southern resident Puget Sound orcas have been found to have some of the highest concentrations of fire retardants and PCBs found in the world in marine mammals (Ross, 2005).

Heat/Light

Shaded shorelines will receive lower levels of solar radiation than exposed shorelines. Higher levels of solar radiation can support higher levels of primary productivity, which influences water quality.

Vegetation Processes

Riparian vegetation processes affect delivery of large wood and organic matter to the shorelines, wildlife habitat and migration corridors, shade, habitat structure, microclimate regulation, and nutrient levels (Brennan and Culverwell, 2004).

Organic Matter, Large Wood, and Habitat

Bluff-top and shoreline vegetation is a source of organic matter and large woody debris to the nearshore in bluff landslides as well as serving habitat functions for many species. Large woody debris from riparian vegetation areas provide multiple habitat functions such as: potential nesting, roosting, refuge and foraging opportunities for wildlife; foraging, refuge, and spawning substrate for fishes; and foraging, refuge, spawning, and attachment substrate for aquatic invertebrates and algae. For example, bluff trees are favorite spots for nesting and perching by bald eagles as well as other bird species. Vegetation overhanging from the bluff supplies terrestrial insects for marine fish consumption, provides shade for surf smelt and sand lance eggs, and provides cover at high tide (Brennan and Culverwell, 2004).

Water Quality

Riparian buffers provide measurable water quality protection from nearshore nutrient sources. The value of riparian buffers for protecting water quality depends on a number of factors, including: type and level of pollution, surrounding land uses, vegetation type, soil type, slope, annual rainfall, and adequate buffer width and integrity. The amount of impervious surface and vegetated cover is directly related to soil stability and sediment control. In developed areas where riparian vegetation has been removed and soils have been compacted, soil quality is typically degraded (May, 2000). Water that is not absorbed or intercepted by vegetation creates surface runoff over the surface that can increase the potential for landslides, lead to erosion, siltation, burial of aquatic environs, and introduction of contaminants into water. Stormwater and agricultural runoff commonly contain pollutants such as excess nutrients, metals, and organic chemicals, typically in particulate form. Therefore, controlling waterborne sediments with riparian buffers often also removes a large percentage of the pollutant load to water bodies (May, 2000).

Nearshore Process Important Areas

Nearshore process-important areas for water quality, coastal erosion, and beach processes in Thurston County often coincide. In general, process-important areas include feeder bluffs, stream/river deltas, marine riparian areas, accretionary landforms, estuaries, and tidal inlets. These process important areas play key roles in maintaining and shaping critical nearshore habitat including eelgrass meadows, kelp forests, beaches and backshore, banks and bluffs, mudflats, tidal marshes, sand spits, and marine riparian areas. The habitats supported by process-important areas provide critical ecosystem functions such as providing areas for primary production, providing foraging and refuge opportunities for birds and other wildlife, supporting invertebrates and juvenile and adult fish (including salmonids). In order to support and maintain all of the above habitats, bluff sediment input and net shore-drift system processes must continue to function properly (Johannessen, 1999).

Feeder Bluffs

Feeder bluffs are process important areas for coastal erosion and beach processes. Feeder bluffs are the sediment source for drift cells. They provide the beach sediment essential to maintain critical habitats throughout the drift cell including: forage fish spawning areas; eelgrass beds; and accretionary landforms such as spits and pocket estuaries at the end of a drift cell. Sediment can also be contributed to the nearshore through landslides or surface runoff, which can lead to surficial erosion, siltation, contamination of water, and burial of aquatic environs. Pocket estuaries and spits often protect valuable salt marsh habitat. Salt marshes provide habitat for primary productivity, and shelter and forage for many species including juvenile salmonids.

Tidal inlets maintain water quality and nutrient dynamics for spit/marsh complex by maintaining circulation processes important for flushing these critical habitats.

Estuaries, tidal inlets, tidal marshes, and lagoons

Estuaries, tidal inlets, tidal marshes, and lagoons are process important areas for circulation and beach processes. Highly productive habitats, estuaries provide flood attenuation, nutrient retention and cycling, erosion/shoreline protection, habitat structure/connectivity functions, and food web support. Water circulation within an estuary fundamentally influences the estuary habitat functions. Water movement from rivers, waves, and tides erodes and deposits sediments, carries organic material and nutrients, and transports fish and prey items. Water movement also affects the complexity and physical form of the estuary (e.g., depth, slope, size of the system, connections to other habitats, landform, and channel network) which also affects habitat for shellfish, salmonids and other species. Circulation processes also create habitat features within the estuary, such as pockets and bars (Redman et al., 2005). Estuaries are critical nurseries for out-migrating salmonid fry; allowing the fry time to adjust to changing salinity levels.

Additionally, estuaries serve as nurseries for other aquatic species that are a primary source of food for salmon. These shallow water habitats provide a refuge from predators for juvenile salmonids and other species while migrating. Estuaries are significant shellfish production areas because the shellfish depend on good water quality and well-functioning circulation patterns. Pocket estuaries are non-natal lagoons with coastal stream mouths and freshwater input. Salt marshes, lagoons, and brackish marshes occur in areas with tidal inundation and flushing. The vegetation in salt marshes traps and stabilizes sediments. Salt marsh habitat supplies complex, branching, tidal channel networks where juvenile salmonids forage and hide from predators. Salt marshes also form migratory linkages between marine and riverine environments (Brewer et al., 2005). In Thurston County, major estuaries include the Nisqually Delta/estuary, Henderson, Eld and Totten estuaries. Marine riparian and critical saltwater habitat areas are described in detail in the basin analysis and in the individual reach sections.

Deltas

Deltas are process important areas for beach processes and fluvial processes. Deltas are formed at river and stream mouths where the freshwater enters the nearshore. The velocity of stream flow decreases when the river or stream water enters the larger marine water body. When the water slows down, the stream loses energy to carry most of the sediments and nutrients being transported, and deposits the sediments on the delta. Not only do deltas provide a source of sediment, organics, and LWD to the nearshore, but they also typically provide important habitat functions for salmonids including foraging, physiological transition from fresh to salt water, predator avoidance, and migratory corridors to marine feeding grounds (Simenstad et al., 1982). The habitat functions of deltas also benefit other nearshore-dependent species. In Thurston County, the major river delta is the Nisqually Delta.

Riparian vegetation

Riparian vegetation areas are process important areas for coastal erosion, water quality, and organic debris, playing a part in nutrient cycling, sediment control, heat/light inputs, and habitat.

Riparian vegetation areas processes affect wildlife habitat, shade, habitat structure, microclimate, and nutrient levels (Brennan and Culverwell, 2004).

Mapping Nearshore Process Important Areas and Alterations

Thurston County mapped process important areas and alterations for the nearshore using available GIS data sets. The data sets and maps are described in the following tables. The maps provide approximate locations of process important areas and alterations. These maps were used to describe the conditions of the nearshore in each WRIA chapter.

Process important areas and alterations within the marine nearshore focus on:

- Freshwater inputs to saltwater (streams)
- Sources and sinks of sediment (e.g., feeder bluffs)
- Presence of forested marine riparian area
- Presence of artificial structures along the shoreline (e.g., bulkheads, seawalls, buildings, docks)
- Known areas with water quality degradation (e.g., Category 5 303(d) listings, WDOH Shellfish closures)

Step 1 – Map Nearshore Process Important Areas

Table 7. Data used to map nearshore process important areas (Map 14)

Dataset	Name in SMP File Geodatabase	Original File Name	Source
Drift Cells	Drift_Cells	driftcell.shp	Ecology
Pocket Estuaries	Pocket_Estuaries	pocketestuaries.shp	Ecology
Estuarine Emergent Wetlands	DOE_NOAA_CCAP_Landcover_06	landcover06	NOAA via Ecology
Unstable Slopes	Slope_Stability	slopestab.shp	Ecology
Past Landslides	Coastal_Landslides	landslides.shp	DNR
Streams	streams.shp	streams.shp	Thurston County GeoData
Riparian Vegetation – is mapped on the LWD Process Important Areas (Map 22) (shown on only one map to avoid duplication).			

Step 2 - Map Coastal Process Alterations (Map 15 and 15b)

Thurston County used two methods to assess and describe coastal process alterations. First, the County mapped coastal process alterations using the data sets described below and shown on Map 15. The County used this map to describe the general locations of alterations. For the second method, the County used the GIS model results of the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) Strategic Needs Assessment (2011) (Schlenger et al., 2011) to identify relative shoreline process degradation (Map 15a).

Table 8. Data used to map nearshore process alterations (Map 15)

Dataset	Name in SMP File Geodatabase	Original File Name	Source
Boat Ramps	Boat_Ramps	launches.shp	Thurston County GeoData (WDFW)
Docks	Docks_Marine_2006	n/a	Thurston County Planning Department
Dams	Dams	FacilitySiteInteraction	Ecology (partial data extract from Facilty/ Site data)
Marinas	Shoreline_Public_Acce ss	shore_pub_ac	Ecology
Bulkheads	Bulkheads	bulkheads.shp	Thurston County GeoData (TRPC)
Coastal Fill Areas	Coastal_Fill_Areas	Bulkhead_areas.shp	Thurston County GeoData (Herrera Environmental Consultants)
Roads	roads.shp	roads.shp	Thurston County GeoData
Railroads	railroads.shp	railroads.shp	Thurston County GeoData
Streams	streams.shp	streams.shp	Thurston County GeoData
Riparian Vegetation Clearing – is mapped on the LWD Process Alterations Areas (Map 23) (shown on only one map to avoid duplication).			
Water Quality Alterations – is mapped on the Water Quality Process Alterations (Map 21) (shown on only one map to avoid duplication).			

The PSNERP Strategic Needs Assessment (2011) evaluated the implications of extensive anthropogenic alterations (caused or produced by humans) on the nearshore ecosystem processes that create and sustain the nearshore ecosystems of Puget Sound. The assessment identified how the changes to the Puget Sound nearshore have impacted nearshore processes and the main problems caused by the changes.

The following list of stressors impacting nearshore processes was developed from Strategic Needs Assessment: Analysis of Nearshore Process Degradation in Puget Sound (Schlenger et al., 2011). Please see the Schlenger et al., 2011 report for a detailed description of how these items alter nearshore processes.

- Tidal Barriers
- Nearshore Fill
- Shoreline Armoring
- Railroads
- Nearshore Roads
- Marinas
- Breakwaters and Jetties
- Overwater Structures
- Dams
- Stream Crossings
- Impervious Surfaces
- Land Cover Change

The evaluation resulted in numeric outputs for each nearshore process in each process unit. These outputs were combined to estimate the degradation of the individual nearshore processes separately. Overall degradation categories were then assigned to process units to reflect geographic differences in terms of where higher degradation occurs compared to lesser degradation. The degradation categories are relative to degradation conditions in other process units, rather than absolute based on impact thresholds. Overall degradation categories include Most Degraded, More Degraded, Moderately Degraded, Less Degraded, Least Degraded, and Not Degraded. The process degradation categories for marine waterbodies were reported for each waterbody within the WRIA chapters of this report (Map 15a).

Assessing landscape degradation helps identify locations where future restoration and protection efforts will be most successful. When a restoration site is located within a degraded environment, the function and resilience of the restoration project is reduced. Protection efforts should be targeted in large patches of shoreline with the least process degradation. A natural starting point for protection strategies is to conserve those processes and shoreforms identified that are relatively intact (i.e., conserve healthy deltas, shorelines with intact sediment movement processes, and embayments).

Step 3 – Identify Restoration and Protection Opportunities

To identify management recommendations for the nearshore, Thurston County used Strategies for Nearshore Protection and Restoration in Puget Sound (Cereghino, et al. 2012. Technical Report No. 2012-01. Prepared in support of the Puget Sound Nearshore Ecosystem Restoration Project). The report identifies management strategies for all river deltas, barrier embayments, beaches, and coastal inlets in Puget Sound. Management measures are the types of actions that can protect and restore nearshore Puget Sound (Figure 2-2). The report organizes the landscape into four different kinds of places that describe four different ways that ecosystem processes structure the shoreline to sustain a unique set of ecosystem services. Each landform provides a discrete set of services, not replaceable by another landform. Therefore the strategies do not attempt to compare deltas to beaches or beaches to inlets. For all marine waterbodies, these management strategies were reported (Maps 45-48). Each nearshore management strategy has numerous potential management options listed under marine shorelines in Chapter 9.

PROTECT HIGH High potential sites that are minimally degraded and indicate substantial opportunities to protect large complex systems.	RESTORE HIGH High potential sites with moderate degradation, where there may be opportunity to substantially increase ecosystem services.	ENHANCE HIGH High potential sites that have been highly modified, and where strategic actions may enhance ecosystem services.	Increasing Potential
PROTECT Sites that are minimally degraded and indicate opportunities to protect systems.	RESTORE Sites with moderate degradation, where there may be an opportunity to increase ecosystem services.	ENHANCE Sites that have been highly modified and where strategic actions may enhance ecosystem services.	
Increasing Degradation			

Figure Error! No text of specified style in document.**-2. Management Strategies for Nearshore Protection and Restoration in Puget Sound. Figure adapted from Cereghino et al. (2012).**