# Wahkiakum County and Town of Cathlamet Shoreline Master Program Update

# Inventory and Characterization Report

Local Adoption Draft

# APPENDIX D 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. The purpose is to consider landscape-scale influences on shoreline functions and to identify potential areas for protection and restoration based on the relative degrees of ecological importance and impairment. 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 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). Additionally, relevant descriptions of processes and alterations associated with Wahkiakum County and the Town of Cathlamet below are derived from the 2013 Thurston County Shoreline Master Program Update, Inventory and Characterization Report: Appendix F.

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 goals are to: 1) identify and map areas of the landscape that are important to the processes that sustain shoreline resources; and 2) determine the degree of alteration in those important areas; 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 such as water, temperature, light, humidity, soil, and atmosphere. 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 respectively). 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 a watershed (Stanley et al, 2008). Ecosystem-wide processes determine both the type and the quality or 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 the watershed-scale processes that are 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., medium to 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 Wahkiakum 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 they help maintain.

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 2 below summarizes the data sources for mapping important areas, the layer name (for documentation purposes), what the important areas are, components of the process and associated key processes mentioned above.

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 (See Figure 1). 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 (Maps 63-65 in the Mapfolio) 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.

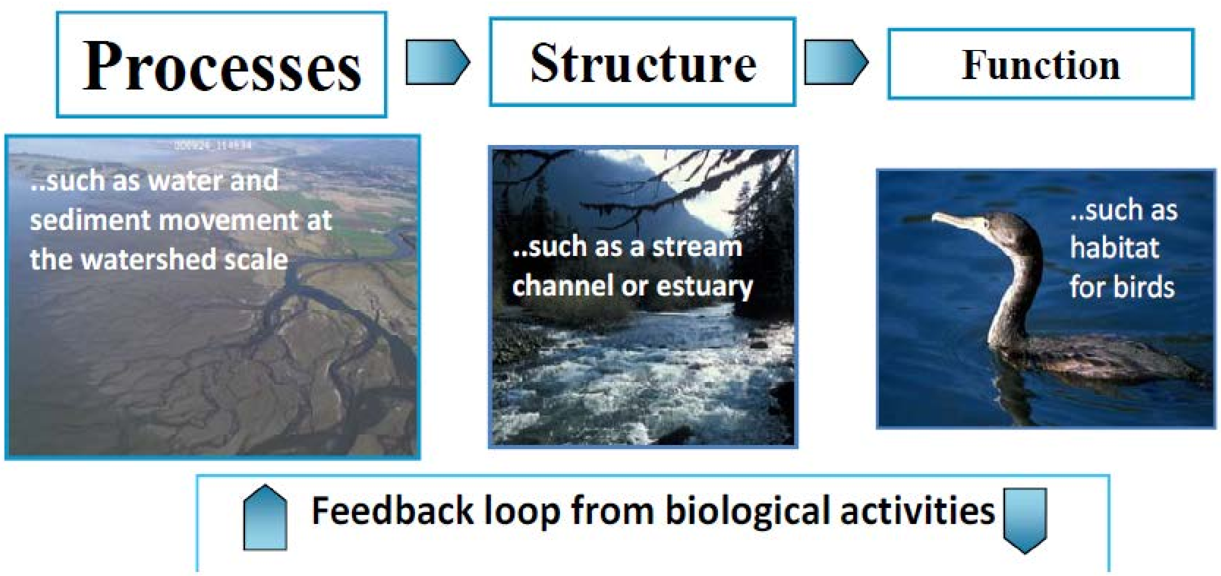


Figure 1 Relationships between Watershed Processes. Source: Ecology Handbook 2010

**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 Wahkiakum 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. 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. Wahkiakum 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. 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 (WFPB 1997).

### *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 3 below summarizes Alterations associated with key processes and the data used to identify these alterations.

## Water Process Alterations

Human activity has impaired the natural condition of the lower Columbia River. 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 Wahkiakum County.  Table 1 (below) summarizes alterations and their effect on key processes.

### *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 **s**treams 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 1). 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).

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 (Q10 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/mile2 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. Wahkiakum 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 Wahkiakum 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). Total phosphorus (both dissolved and particulate phosphorus) is correlated with the amount of impervious surface in the watershed (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). 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.

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. 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 and in the lower Columbia River Estuary (Castelle et al. 1994; May 2000 and LCRSRB 2004). 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 functional.

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 1** Key processes and responses to alterations. Table 1 is a list of ecosystem processes, the mechanisms that influence these process, a descriptions of how these mechanisms affect the function, and how these mechanisms, if impaired affect the ecosystem process.

| 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).

An updated method was adapted for Wahkiakum County, who does not have any WRIA's in and around the Puget Sound. A suitability analysis was performed by scoring all process and impairment data into relative 'high-medium-low' categories. Individual datasets were weighted based on their relative importance (how many times individual datasets represented more than one process or impairment. A weighted sum was calculated combining all important area datasets and all impairments separately. 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. Wahkiakum County used the Stanley et al., 2012 results to identify restoration and protection opportunities for WRIA's 24 and 25.

Several underlying assumptions were made during the analysis such as using abiotic factors as sub as mechanisms that characterize important areas for biotic organisms, habitats, etc. The exception to this was that National Wetland Inventory data was used in the analysis to capture wetland habitat and other chemical and physical characteristics. Given the data available and the scale at which the available data was able to assess site specific locations. As a result, some areas identified as priorities for "protection" may actually be sites that have a high importance but is in some way degraded and better suited for restoration. Many times this occurs as a result of the scale by which a particular impairment and/or mechanism being limited the resolution of the data provided. The resolution of this data may not pick up fine scale changes to the landscape/shoreline. As a result, field verification of this data is necessary to refine the accuracy and ultimately, the utility of the data. An example of this is the culverts just south of the Elochoman River under SR 4. The project was identified as a "protection priority", but on the ground, was identified for restoration. Again, this is due to the resolution of the available data not being able to pick up smaller impairments/intact mechanisms across the Town/County. However, this mapping exercise is a useful primer for identifying important areas to conserve, protect, and restore.

The management recommendations in Stanley et al. (2012) are based on a water flow management matrix similar to the one in Figure 2 below. The matrix in Figure 2 uses the same concepts as Stanley et al (2012) with some adaptations that were relevant to Wahkiakum County such as?. 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 (shaded green, blue, red, brown, pink, and orange below). Areas that are both relatively less important for a process and in which severe impairment has already occurred (will result in the least impact to watershed processes if further development occurs. Generally, the eight colors in Figure 1 represent the level of priority assigned to each category. "High and Highest Importance' areas should be viewed as a priority for protection or restoration. The colors change (less of a priority) as the level of importance of an area decreases. Restoration is recommended for areas in the "medium" to the "highest" level of degradation in an attempt to recommend project sites with degraded ecological function, particularly in areas rated as having a "high" and/or "highest" importance rating.

Four terms were used to characterize the type of action under various levels of important and degraded areas. These terms include: protection, conservation, restoration and development. Protection is a management action meant to fully protect important ecosystem processes that are intact and of high value to the landscape, communities and organisms. Conservation is generally reserved to the lowest area of importance that has the lowest level of degradation. The lowest areas of important, the conservation management recommendation is intended to allow low impact development in areas have the lowest contributor to larger scale ecosystem processes. Restoration a management action recommendation intended to reestablish the mechanisms that in areas that contribute to areas that have varying levels of ecological process importance with a priority being on the "High" or "Highest Importance".

| | | | | | | |
|---|---|---|---|---|---|---|
| Importance | Highest | Highest Protection | Highest Protection | Highest Restoration | Highest Restoration | Highest Restoration |
| | High | Protection | Protection | Highest Restoration | Highest Restoration | Highest Restoration |
| | Medium | Protection | Protection | Restoration | Restoration | Restoration |
| | Low | Protection/Restoration | Protection/Restoration | Restoration/Development | Restoration/Development | Restoration/Development |
| | Lowest | Conservation | Conservation | Development/Restoration | Development/Restoration | Development/Restoration |
| | | Lowest | Low | Medium | High | Highest |
| | | **Degradation** | | | | |

**Figure 2** Watershed Management Matrix. The importance rating is on the vertical Y-axis, and the impairment rating is along the horizontal X-axis. The combination of these two ratings indicates suitability of the sub-unit for protection, restoration, conservation, or development management strategies. Figure modified from Stanley et al., 2012. See also Map at the end of this section

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 recommendations described in Chapter four, five, and seven in the Wahkiakum County and Town of Cathlamet SMP Update: Inventory and Characterization Report (2015)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.

**Table 2** Data sources for identifying process Important Areas in Wahkiakum County using methods from Stanley et al., 2008

| Key Process | Components of Process/Mechanism | Important Areas | Wahkiakum SMP Update Data Layer Name | Data Source(s) for Mapping Important Areas |
|---|---|---|---|---|
| Water | Surface runnoff and Peak Flows | Areas with higher amounts of precipitation | Precip1981_2010_a_wa | Mean annual precipitation for Washington State 1981-2010. OSU |
| | | Rain-on-snow Zones | Rain_On_Snow_Wahkiakum_DNR | State ROS DNR |
| | Surface water storage | Depressional Wetlands | Dep_Wetlands_Wahkiakum Depressional Wetlands = hydric soils on <2% slopes | SSURGO Soils. NRCS 2014 |
| | | | | 10 meter DEM. National Elevation Dataset. |
| | | 100-Year Floodplain | Flood_100yr_FEMA | Floodzones. FEMA-Wahkiakum County |
| | | Wetlands | Wetlands_NWI_Wahkiakum_County_Jan2014 | Wetlands. NWI 2014 |
| | Recharge | Areas on geologic deposits with high permeability | High_Permeability_GeoUnits_Wahkiakum_DNR | Geologic Units 100K. DNR |
| | Shallow subsurface flow | Areas on geologic deposits with low permeability | Low_Permeability_GeoUnits_Wahkiakum_DNR | |
| Sediment | Surface erosion | Steep slopes with | Slopes_Erodable_Wahkiakum | 10 meter DEM. National Elevation Dataset. |

| | | | | |
|---|---|---|---|---|
| | | erodable soils | | K Factor. SSURGO NRCS Soil Data, USDA. K(w) value for surface layer aggregated by dominant condition |
| | Mass Wasting | Hazard areas for shallow | Slope_stabrsk | Slope stability. DNR |
| | | Landslide steep slope hazard | LandslideHazardZones_moderaterisk | Landslide Hazards. Wahkiakum County |
| | | Landslide steep slope hazard | LandslideHazardZones_highrisk | Landslide Hazards. Wahkiakum County |
| | In-Channel Erosion | Past landslides | Landslide | Landslides_24k. DNR |
| | Storage | Unconfined and moderately confined stream channels | strms_con&un | WDFW has discontinued the use of SSHIAP where previous jurisdictions have used the data. New data may become available in the future. |
| | | Depressional Wetlands | dep_wet Depressional Wetlands = hydric soils on < 2% slopes | Soils. USDA SSURGO<br>10 meter DEM. National Elevation Dataset. |
| | | 100 yr Floodplain | Flood_100yr_FEMA | Floodzones. FEMA-Wahkiakum County |
| Water Quality including Temperature and light inputs | Sources of Nitrogen, Phosphorus, Toxins, or Pathogens | Lakes | Lakes_Wahkiakum_NWI_2014 | NWI. USFWS |
| | Nitrification | No important historic areas are identified (See impairments) | | N/A |

| | | | | |
|---|---|---|---|---|
| | | Depressional Wetlands | dep_wet Depressional Wetlands = hydric soils on < 2% slopes | Soils. USDA SSURGO |
| | | | | 10 meter DEM. National Elevation Dataset. |
| | Denitrification | Lakes | Lakes_Wahkiakum_NWI_2014 | NWI. USFWS |
| | | Depressional Wetlands | dep_wet Depressional Wetlands = hydric soils on < 2% slopes | Soils. USDA SSURGO |
| | | | | 10 meter DEM. National Elevation Dataset. |
| | Transport of pathogens via surface flows | Lakes | Lakes_Wahkiakum_NWI_2014 | NWI. USFWS |
| | | Streams | Streams_NHD_Wahkiakum_2014 | NHD Streams |
| | Pathogen movement through shallow subsurface flows and recharge | Wetlands | Wetlands_NWI_Wahkiakum_County_Jan2014 | NWI. USFWS |
| | | Areas of high permeability | Soils_PermHigh_Wahkiakum_2014. CARA categories "high" and "extreme" | Soils. USDA SSURGO. Ksat_r = 28 and 92 |
| | Pathogen removal via adsorption and sedimentation | Areas of low permeability | Soils_PermLow_Wahkiakum_2014. CARA categories "Low" and "Moderate" | Soils. USDA SSURGO. Ksat_r = 3 and 9 |
| | | Depressional Wetlands | dep_wet Depressional Wetlands = hydric soils on < 2% slopes | Soils. USDA SSURGO |
| | | | | 10 meter DEM. National Elevation Dataset. |
| | Pathogen loss via mortality | 100 yr Floodplain | Flood_100yr_FEMA | Floodzones. FEMA-Wahkiakum County |
| | | Depressional Wetlands | dep_wet Depressional Wetlands = hydric soils on < 2% slopes | Soils. USDA SSURGO |
| | Phosphorus and Toxins Input via surface erosion | | | 10 meter DEM. National Elevation Dataset. |
| | | Steep slopes with | Slopes_Erodable_Wahkiakum | 10 meter DEM. National Elevation Dataset. |

| | | | | |
|---|---|---|---|---|
| | Movement via adsorption (P) | erodable soils | | K Factor. SSURGO NRCS Soil Data, USDA. K(w) value for surface layer aggregated by dominant condition |
| | | Depressional Wetlands | dep_wet Depressional Wetlands = hydric soils on < 2% slopes | Soils. USDA SSURGO. |
| | | | | 10 meter DEM. National Elevation Dataset. |
| | Movement via adsorption (T) | Upland areas with clay soils adjacent to aquatic ecosystems | Not analyzed. Soil type not used per S. Stanley (2008). (Thurston County Characterization Report) | N/A |
| | | Depressional Wetlands with organic or clay soils | dep_wet Depressional Wetlands. Not used per S. Stanley (2008) (Thurston County). | Soils. USDA SSURGO |
| | | | | 10 meter DEM. National Elevation Dataset. |
| | Movement via sedimentation of phosphorus and toxins | Depressional Wetlands | dep_wet Depressional Wetlands = hydric soils on < 2% slopes | Soils. USDA SSURGO |
| | | | | 10 meter DEM. National Elevation Dataset. |
| | | 100 yr Floodplain | Flood_100yr_FEMA | Floodzones. FEMA-Wahkiakum County |
| | | Lakes | Lakes_Wahkiakum_NWI_2014 | NWI. USFWS |
| | Riparian Canopy Cover | Depositional stream channels | | SSHIAP data no longer available from WDFW |
| | | Forest within 100' of streams | forest_rip | Streams_NHD_Buffer_100ft_Wahk_2014 |
| | | | | Landcover2011. NOAA |
| | Temperature Moderation | Depressional Wetlands | dep_wet Depressional Wetlands = hydric soils on < 2% slopes | Soils. USDA SSURGO |
| | | | | 10 meter DEM. National Elevation Dataset. |

| | | | | |
|---|---|---|---|---|
| | | Lakes | Lakes_Wahkiakum_NWI_2014 | NWI. USFWS |
| | | Depressional Wetlands | dep_wet Depressional Wetlands = hydric soils on < 2% slopes | Soils. USDA SSURGO |
| | | | | 10 meter DEM. National Elevation Dataset. |
| | | Areas on geologic deposits with high permeability | High_Permeability_GeoUnits_Wahkiakum_DNR | Geologic Units 100K. DNR |
| Wood | Stream erosion | Unconfined and moderately confined stream channels | strms_con&un | SSHIAP data no longer available from WDFW. Data created from LiDAR, DEM and Aerial photography |
| | Mass wasting | Channels with 4% gradient | | SSHIAP data no longer available from WDFW. N/A |
| | Windthrow | Mass wastin areas that are likely to deliver debris to the stream | Slope_stabrsk | Slope stability. DNR |
| | | Forest within 100' of streams | forest_rip | Streams_NHD_Buffer_100ft_Wahk_2014 |
| | | | | Landcover2011. NOAA |
| | Storage | Unconfined and moderately confined stream channels | strms_con&un | SSHIAP data no longer available from WDFW. Data created from LiDAR, DEM and Aerial photography |

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|---|---|---|---|---|
| Wetland refugia | wetland habitat | Wetlands | Wetlands_NWI_Wahkiakum_County_Jan2014 | NWI. USFWS |
| | | 100 yr Floodplain | Flood_100yr_FEMA | Floodzones. FEMA-Wahkiakum County |
| Instream habitat creation | Bank erosion/in-stream erosion | Past landslides | Landslide | Landslides_24k. DNR |
| | | Channel Migration Zones | CMZ_Ecology_2015 | CMZ_Ecology |
| | Windthrow | Mass wastin areas that are likely to deliver debris to the stream | Slope_stabrsk | Slope stability. DNR |
| | | Forest within 100' of streams | forest_rip | Streams_NHD_Buffer_100ft_Wahk_2014<br>Landcover2011. NOAA |
| | Storage | Unconfined and moderately confined stream channels | strms_con&un | SSHIAP data no longer available from WDFW. Data created from LiDAR, DEM and Aerial photography |
| | | Channels with 4% gradient | | SSHIAP data no longer available from WDFW. N/A |

**Table 3** Data sources mapped by Wahkiakum County and the Town of Cathlamet for Identifying Process Impairments using methods from Stanley et al., 2008

| Key Process | Mechanism | Change to Process | Alteration | Indicators of Alteration | Final Data Layer Name | Wahkiakum Data Layer Name | Data Source for Mapping Impaired Areas |
|---|---|---|---|---|---|---|---|
| Water | Delivery | Increased Streamflow | Removal of forest vegetation | Reduction of forest cover in rain-on-snow and snow dominated zones | ROS_Lndcvr | Rain_on_Snow_Wahkiakum | State_ROS. DNR |
| | | | | | | wa_2011_ccap_Land_Cover | LandCover 20011. NOAA CCAP |
| | Overland flow | Change in timing of surface runoff, decreased infiltration | Impervious areas | Watershed imperviousness | imperv_wahk | imperv_wahk | wa_2006_impervious. NOAA |
| | 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 | dvlpmt_wet | Wetlands_Depressional_Wahk_2014 | Wetlands_Depressional_Buffer_Wahk_2014 |
| | | | | | | Zoning_Cathlamet | Zoning_Cathlamet |
| | | | | | | TaxMaps | Taxmap (parcels) |
| | | | | Loss of Depressional Wetlands | | ROS_lndcvr | ROS_lndcvr |
| | | | | | | Wetlands_Depressional_Wahk_2013 | Wetlands_Depressional_Wahk_2014 |
| | | | disconnected floodplain | Miles of stream disconnected from floodplain | Streams_SMA_DisconnectedFldpln | | Shoreline_OHWM_200ft |
| | | | | | | | Levees |
| | | | Channelization of streams | Miles of stream channelized | Streams_Channelized_Wahkiakum_2014 | | Streams_Channelized_Wahkiakum_2014 |

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|---|---|---|---|---|---|---|---|
| | | Increase water storage capacity; decrease downstream flow | Dam Operation | Dams | Dams_Wahkiakum | Dams_Wahkiakum | Fish_Barriers_WDFW |
| | Recharge | Reduce recharge and increase surface runoff | Impervious surfaces | Land uses with impervious cover on geologic deposits of low permeability | Imperv_loperm | imperv_wahk | imperv_wahk. 2006 from NOAA CCAP |
| | | | | | | Permeability_Low_GeoUnits_DNR | Geologic Units 100k. DNR |
| | | | loss of forest cover | Non-forest vegetation on geologic deposits of low permeability | nofrst_loperm | nofrstveg_wahk | LandCover 2011. NOAA CCAP |
| | | | | | | Permeability_Low_GeoUnits_DNR | Geologic Units 100k. DNR |
| | | Reduce groundwater recharge | loss of forest cover | Non-forest vegetation on geologic deposits of high permeability | nofrst_hiperm | nofrstveg_wahk | LandCover 2011. NOAA CCAP |
| | | | | | | Permeability_High_GeoUnits_DNR | Geologic Units 100k. DNR |
| | | | Impervious surfaces | Land uses with impervious cover on geologic deposits of high permeability | imperv_hiperm | Permeability_High_GeoUnits_DNR | Geologic Units 100k. DNR |
| | | | | | | imperv_wahk | imperv_wahk. 2006 from NOAA CCAP |
| | | Shift location of groundwater recharge. Losses from water supply pipes or sewer lines or septic drainfield discharges | Leaky pipes or irrigation canals; water supply and wastewater management | Septic systems | septic_parcels | septic_parcels | residential_sf_wahkiakum_septic_2010 |
| | Subsurface flow | Change location of groundwater discharge | Interception of subsurface flow by ditches and roads | Roads | Roads | Roads | Roads. Wahkiakum County |
| | Discharge | Decrease | Loss of | Loss of forest | nofrstsoilprm | Nofrst_All | landcover2011. NOAA |

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| | | grounwater inputes to aquatic resources | groundwater discharge areas and upland areas recharging discharge areas | on areas recharging discharge areas | | Soil_High_Perm_SSURGO_Wahk | Soils. SSURGO USDA |
| | Transpiration | Alter evaportranspirati on rates | Clearing vegetation; shifting vegetation composition | Land Cover Change | Nofrst_All | Nofrst_All | landcvr2011. NOAA |
| | Streamflow out of basin | Change streamflow direction | Diversion; Interbasin transfers | Diversion Structures | ArtificialFlows_NHD_Wahkiakum | NHDFlowline_Wahkiakum | NHDFlowline. NHD |
| Sediment | Surface erosion | Increase delivery of fine sediment to aquatic resources | Removal of forest vegetation | Non forested land cover on highly erodible slopes adjacent to aquatic resources | NoFrst_HiErod | nonfrst_All | landcvr2011. NOAA |
| | | | | | | SlpStab_Hi | Slope Stability. DNR |
| | | | soil disturbance and clearing | Row crop agriculture draining directly to aquatic resources | cult_landcvr | landcvr2011 | Cultivated land classification. Landcvr2011. NOAA |
| | | | roads increasing stream network | Roads within 200ft of aquatic resources | roads_aquatic_buff200ft_Wahk_2014 | roads_aquatic_buff200ft_Wahk_2014 | roads_aquatic_buff200ft_Wahk_2014. Wahkiakum County |
| | Mass wasting | Increase delivery of fine sediment to aqaquatic resources | Roads triggering landslides | Roads in high mass wasting hazard areas | Roads_High_Masswasting_Wahk | Roads | Roads. Wahkiakum County |
| | | | | | | Slopes_HighErode_DNR_Wahk | Slope Stability. DNR |
| | | | Removal of vegetation | Non forested land cover on high mass wasting hazard areas | NoFrst_HiErod | nonfrst_All | landcvr2011. NOAA |
| | | | | | | SlpStab_Hi | Slope Stability. DNR |
| | In channel erosion | Alter fine sediment deliver to streams | Increase in stream discharge | Urban land cover | urbn_lndcvr | urbn_lndcvr | landcvr2011. NOAA |

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|---|---|---|---|---|---|---|---|
| | Storage/Sedimentation | Decrease sediment storage | Drainage or filling of depressional wetlands | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr | landcvr2011. NOAA |
| | | | | | | Wetlands_Depressional_Wahk_2014 | NWI. USFWS |
| | | | Increase in stream flow | Addressed in hydrology section | Dams_Wahkiakum | Dams_Wahkiakum | Facility/site (Ecology permitted sites). Ecology |
| | Loss | Decrease in sediment storage | Drainage or filling of depressional wetlands | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr | landcvr2011. NOAA |
| | | | Increase in stream flow | Addressed in hydrology section | | Wetlands_Depressional_Wahk_2014 | NWI. USFWS |
| | | Increase in sediment storage | Dams | Dams | Dams_Wahkiakum | Dams_Wahkiakum | Facility/site (Ecology permitted sites). Ecology |
| Water Quality | Nitrogen Sources | Additional Sources | Application of fertilizer and Manure | Urban and agricultural land use | ROS_Lndcvr | ROS_lndcvr | landcvr2011. NOAA |
| | | | | | | | landcvr2011. NOAA |
| | Nitrification | Reduced areas with seasonal flooding | Drainage or filling of depressional wetlands | Rural and urban land use adjacent to depressional wetlands | Land_use_County_Wahkiakum | Land_use_County_Wahkiakum | Landuse (based on parcels). Ecology 2010 |
| | | | | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr | landcvr2011. NOAA |
| | | | | | | Wetlands_Depressional_Wahk_2014 | NWI. USFWS |
| | Denitrification | Reduced area for denitrification | Drainage or filling of depressional wetlands | Rural and urban land use adjacent to depressional wetlands | Land_use_County_Wahkiakum | Land_use_County_Wahkiakum | Landuse (based on parcels). Ecology 2010 |
| | | | | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr | landcvr2011. NOAA |
| | | | | | | Wetlands_Depressional_Wahk_2014 | NWI. USFWS |

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|---|---|---|---|---|---|---|---|
| | | 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 | Roads. Wahkiakum County |
| | Fecal inputs | additional fecal inputs | Failed septic systems | Rural residential land use (lot density adjacent to streams | residential_sf_wahkiakum_septic_2010 | residential_sf_wahkiakum_septic_2010 | Land use. Ecology 2010 |
| | | | Discharge of untreated human and animal waste | Rural an commercial agriculture (dairy farms feedlots, livestock) | Dairy_Wahkiakum_2012 | Dairy_Wahkiakum_2012 | Dairy. Ecology |
| | Surface flows | Increased velocity and erosion of streambed | Channelization of streams | Urban and Agricultural land uses | Urb&Ag_lndcvr | Urb&Ag_lndcvr | landcvr2011. NOAA |
| | Infiltration/recharge and subsurface flows | Conversion to surface flows | Impervious areas | Watershed imperviousness | imperv_wahk | imperv_wahk | wa_2006_impervious. NOAA |
| | Adsorption and Sedimentation | Reduced storage of pathogens | Ditching, draining or filling depressional wetlands with mineral and organic soils | Urban and Agricultural land uses | Urb&Ag_lndcvr | Urb&Ag_lndcvr | landcvr2011. NOAA |
| | | | | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr | landcvr2011. NOAA |
| | | | | | | Wetlands_Depressional_Wahk_2014 | NWI. USFWS |
| | Mortality | Reduced residence time | Draining or filling of depressional wetlands with mineral and/or organic soils | Urban and Agricultural land uses | Urb&Ag_lndcvr | Urb&Ag_lndcvr | landcvr2011. NOAA |
| | | | | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr | landcvr2011. NOAA |
| | | | | | | Wetlands_Depressional_Wahk_2014 | NWI. USFWS |
| | Phosphorus sources | Additional Sources | Application of fertilizer | Urban and Agricultural land uses | Urb&Ag_lndcvr | Urb&Ag_lndcvr | landcvr2011. NOAA |

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|---|---|---|---|---|---|---|---|
| | | | Application of Manure | Agricultural land use adjacent to dairies | Aginpts_man | Dairy_buff1mi_Ecology_2010 | Dairy. Ecology |
| | | | | | | Ag_landcrv | landcvr2011. NOAA |
| | Toxin Sources | Additional sources; new toxins | Use of pesticides and herbicides and other chemicals | Urban land use; row crop land use | Urb&Ag_lndcvr | Urb&Ag_lndcvr | landcvr2011. NOAA |
| | Surface erosion | | | Addresed in sediment section | | | |
| | Adsorption (P) | Reduced phosphorus adsorption | Draining or filling of depressional wetlands | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr | landcvr2011. NOAA |
| | | | | | | Wetlands_Depressional_Wahk_2014 | NWI. USFWS |
| | | | Loss of upland areas with clay soils | Urban land cover in areas of clay soils adjacent to aquatic ecosystems | dvlpmt_lndcvr | dvlpmt_lndcvr | landcvr2011. NOAA |
| | Adsorption (T) | Reduced toxin adsorption | Draining or filling of depressional wetlands | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr | landcvr2011. NOAA |
| | | | | | | Wetlands_Depressional_Wahk_2014 | NWI. USFWS |
| | Sedimentation | Reduced storage of phosphorus and toxins | Draining or filling of depressional wetlands | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr | landcvr2011. NOAA |
| | | | | | | Wetlands_Depressional_Wahk_2014 | NWI. USFWS |
| | | | 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_rip | Nofrst_All | landcvr2011. NOAA |
| | | | | | | Streams_NHD_Buffer_100ft_Wahk_2014 | Streams. NHD |
| | Temperature moderation | | | | | | |
| Wood | Stream Erosion | Reduction of LWD available to reach stream | Remove riparian vegetation | Non forested land cover within 100' of streams in a floodplain | nonfor_fldstr | Nofrst_All | Landcvr2011. NOAA |
| | | | | | | Streams_100yrflood_buff100ft_wahk | NHD Streams |
| | | | | | | Floodplain_100yr_Wahk | FEMA Flood data |

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|---|---|---|---|---|---|---|---|
| | Mass wasting | | Remove forest vegetation on high mass wasting hazard areas | Non forested land cover on high mass wasting hazard areas | nofrst_HiErod | nofrst_HiErod | Landcvr2011. NOAA |
| | Windthrow | | Remove riparian vegetation adjacent to a stream | Non forested land cover within 100' of streams | Nonfor_rip | Nofrst_All | landcvr2011. NOAA |
| | | | | | | Streams_NHD_Buffer_100ft_Wahk_2014 | Streams. NHD |
| | Storage | Reduced capacity of stream to store wood | Increased streamflow | Addressed in hydrology section | | | N/A |
| Wetland refugia | wetland habitat | Reduction in available/quality wetland habitat | Reduced available wetland habitat | Ditching, draining or filling depressional wetlands with mineral and organic soils | Urban and Agricultural land uses | Urb&Ag_lndcvr | Urb&Ag_lndcvr |
| | | | | | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr |
| | | | | | | | Wetlands_Depressional_Wahk_2014 |
| | | | Reduced habtat quality | Draining or filling of depressional wetlands with mineral and/or organic soils | Urban and Agricultural land uses | Urb&Ag_lndcvr | Urb&Ag_lndcvr |
| | | | | | Loss of depressional wetlands | dvlpmt_wet | dvlpmt_lndcvr |
| | | | | | | | Wetlands_Depressional_Wahk_2014 |
| Instream habitat creation | Bank erosion/in-stream erosion | Alter fine sediment deliver to streams | Increase in stream discharge | Urban land cover | urbn_lndcvr | urbn_lndcvr | landcvr2011. NOAA |
| | | Surface flows | Increased velocity and erosion of streambed | Channelization of streams | Urban and Agricultural land uses | Urb&Ag_lndcvr | Urb&Ag_lndcvr |
| | Windthrow | Reduction of LWD available to reach stream | Removed riparian vegetation adjacent to a stream | Non forested land cover within 100' of streams | Nonfor_rip | Nofrst_All | landcvr2011. NOAA |
| | | | | | | Streams_NHD_Buffer_100ft_Wahk_2014 | Streams. NHD |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Storage | Reduced capacity of stream to store wood | Increased streamflow | Addressed in hydrology section | | | N/A |