Section 2. CHARACTERIZATION OF ECOLOGICAL PROCESSES

This section describes the overall King County approach to shoreline characterization. It details the concepts, criteria, limitations, and results of the shoreline alterations analysis; describes the methods for putting the results into basin-wide context and associated results; provides an overview of available biological resources data; and outlines an initial framework for discussion of projected impacts of future climate change, as well as large-scale geomorphic events, on the management of shorelines of the state in King County.

A. Purpose and Uses of Shoreline Characterization

A characterization (in this case synonymous with the terms assessment or classification) is a systematic description of the condition and value of an object or area of interest (Forman 1986). Characterizations are done in resource management projects to help explain the spatial and temporal variability in the condition of a resource, as well as to explore the possible causes for that variability (Beechie et al. 2003; Pess et al. 2003).

To conduct a characterization, an area of common interest (e.g., a watershed or marine nearshore drift cell) is delineated, and the attributes that affect key natural and human processes, structures, and functions are mapped by type, location, condition, and degree of influence. The condition or value of an area can be determined by estimating the degree to which a function is intact (or impaired). This can be done either quantitatively (measuring a number or amount) or qualitatively (ranking from low to high using a variety of measurements or estimates, including the best professional judgment of the person doing the ranking).

In recent years, characterizations have been conducted more frequently in order to identify in a systematic way the effects of development on natural systems and to increase understanding of the complex ecological relationships between people and natural resources. For example, Beechie et al. (2003) and Pess et al. (2003) summarize and describe river and watershed assessments for the purposes of guiding river and watershed restoration projects.

Characterizations have been done along the shorelines of Puget Sound in an effort to document conditions and the effects of human activities (Johannessen et al, 2005; Anchor Environmental, 2006). A recent, local example of a characterization is King County's Critical Areas Ordinance Basin Conditions Map (King County, 2004C) in which over 500 catchments and marine shoreline drift cells were characterized for level of development and general ecological condition. This map has been used as a reference for implementation of critical areas stewardship planning.

Foundation and General Approach

Forman (1986) defines ecology as the study of how organisms and their environment interrelate. Processes are important in ecological interactions because they control the abundance, movement, routing, timing, and energy of ecosystem materials such as water, wind, light, sediment, nutrients, pathogens, toxins, and large woody debris. As a result, these processes affect where and how plants, animals, and people use and are distributed along shoreline habitats. A characterization framework that incorporates and properly applies current knowledge of ecological processes can help to identify how and the extent to which an area is functioning at its natural capacity or is impaired, as well as to assess risks and opportunities for protection and restoration.

There are a variety of definitions for ecological process. For example, WAC 173-26-020 provides a legal definition (see Section 1.A in this document). A theoretical definition for process is “an expenditure of energy (kinetic, biochemical, etc.) that results in a change in state” (Forman 1986). A working definition might be the creation, modification, recruitment, mobilization or deposition of ecosystem materials, such as water, soil, nutrients and organisms (plants and animals).

Processes occur over a wide range of physical and time scales, and in large part are defined by those scales (Naiman et al. 1992; Bauer and Ralph 1999). As an example, for the purpose of salmon recovery planning, Redman et al. (2005, citing unpublished work by Simenstad, Univ. of Washington) identified three scales of processes affecting salmon habitat in Puget Sound:

- Regional or large-scale processes – These processes occur at the scale of hundreds of miles or more and influence multiple ecosystems. They may periodically reshape whole or major landscape areas and set the context for local ecosystem processes. Regional processes include plate tectonics, post-glacial changes such as isostatic rebound, climate (including temperature, precipitation, wind, cloudiness, etc), solar inputs that control precipitation, temperature, wind, major earth movements (earthquakes, volcanoes), glaciations, tides, and sea level rise.

- Local or landscape-scale processes – These processes occur at the scale of miles or less in the context of regional processes and create the localized patterns of shoreline conditions and processes. Examples of local processes include beach and bluff erosion, landslides, sediment drift and routing in a drift cell or catchment, and local water circulation patterns.

- Finite or small-scale processes – these occur at the scale of yards or less. They include biogeochemical process such as nutrient uptake, transformation and movement by plants and animals, and behavioral interactions among individuals such as competition and predation.

For shoreline characterization, all three scales are relevant. Even though they cannot be controlled by man, regional processes are important to consider because they have significant effects. The manner in which an area is managed can affect the extent and costs of damages that regional processes cause, as well as the ability for habitats and people to recover from an event (Adger 2005; Lindenmeyer and Tambiah 2005).

A subset of processes or components of processes, such as windstorms, fire, floods, earthquakes, tsunamis, and landslides, occur at regional or local scales, and can have great effects on shaping landscapes (Forman and Godron 1986). While often damaging to both people and development in hazardous areas, the timing, rates and magnitudes (i.e., regimes) of these events are also important ecologically because they help to create and sustain the uneven distribution or “patchiness” of habitats in a landscape, i.e., they promote structural variability, which contributes to healthy, biologically diverse ecosystems (Naiman et al. 1992; Dale et al. 1998).

As an example, if floods never occurred or occurred with only small effects, side channels along rivers would never or only rarely form and there would be less diversity of riparian vegetation and floodplain habitats. In such a situation, the structural and biological diversity of floodplain and shoreline habitats would be reduced over time. This has been shown resulting from dams, which tend to stop or reduce flooding and the flow of sediment and woody debris (Ward and

Stanford 1979; Ligon et al. 1995; Poff et al. 1997). A local example of the effect of altered flood disturbance regime is the conditions along the lower Cedar River, where dams and bank armoring have reduced flooding and channel migration since the mid-1800s, i.e., before a water supply dam was constructed and prior to modern development (King County 1993). The construction and operation of water supply dams are estimated to have reduced the Cedar River's peak 100-year flood event by one-third from 18,000 cfs to 12,000 cfs. Bank armoring is common along the Cedar as well, with almost 50% of the river armored along both banks. The combined effect of these actions has been a 56% reduction in area of the active channel and a loss or disconnection of many historic side channels on the Cedar River (Perkins 1994).

As implied above, there are numerous processes -- large and small, fast and slow -- operating in an ecosystem. Some are more relevant than others for assessing and managing shorelines. Naiman et al. (1992) identified "the delivery and routing of water, sediment, and woody debris as the key processes regulating the vitality of watersheds and their drainage networks in the Pacific Northwest coastal ecoregion." More recently, for the purpose of characterizing shorelines in the context of their respective watersheds, Stanley et al. (2005) described key watershed processes as "the delivery, movement, and loss of water, sediment, nutrients, toxins, pathogens and large woody debris." For the purposes of this characterization analysis, King County has applied the Stanley et al. (2005) concept of process components as a guide, and expanded the analysis to include other ecosystem scales, materials and processes as deemed important and as data were available.

Processes are typically thought of in the context of the structure and function they create and sustain. These variables interact and modify each other via feedback loops. Thus the "Process-Structure-Function" (PSF) relationship is shown as being circular (see Figure 1). In many instances, processes can be difficult to measure directly, thus measures of structure and function are used as surrogates for assessing process. For example, a lack of sediment or woody debris in an area where they would be normally expected may indicate that the processes for supplying them are impaired in some fashion. Impairment could occur by loss of riparian forest or by the presence of artificial structures such as levees or bulkheads that limit channel migration and bank erosion, or both.

Processes are important because they result in the structures, functions and, ultimately, the values of shorelines (see Figure 1). Structure refers to how materials assort themselves in time and space and is typically measured in terms of location, orientation, number and/or area. A function is how a given structure is used ecologically, such as for spawning, rearing, migration, refuge by fish or wildlife, or by people for commercial, residential, agricultural, recreational or cultural purposes (see also the legal definition for function provided in Section 1.A. of this document). Value is the magnitude of a given function, typically expressed as worth to society or to a species' survival; the higher the magnitude of its value, the more valuable is a given function.

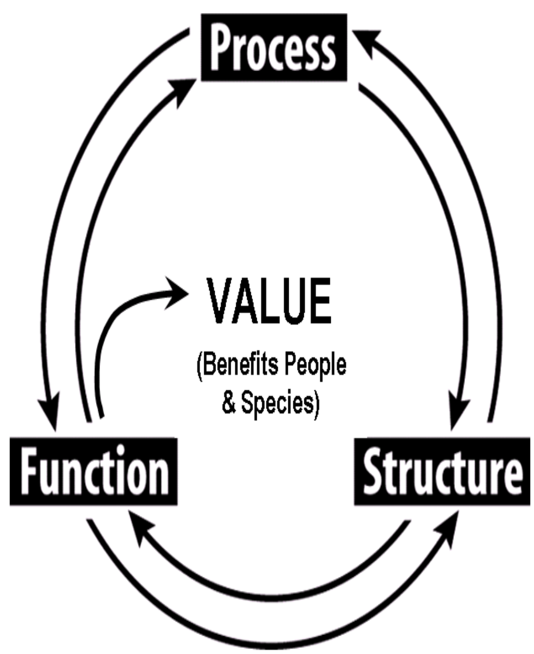

Figure 1. Process-Structure-Function

A practical example of how the PSF relationship results in value is the process of erosion (expenditure of potential and kinetic energy) of a beach or bluff, and the subsequent routing and deposition of sediment and large woody debris. Sediment and woody debris are structural materials that help to create, modify or stabilize a shoreline structure (cobble beaches, sand spits, mud-bottomed lagoons). The structure in turn dictates how a shoreline functions as habitat for fish and wildlife spawning, rearing, migration, refuge, or as a protective (or risky) area for development. In this example, value for a given species occurs when PSF creates the right conditions to sustain a habitat for a particular use by a species over time. In turn, if people value that species or an area has some other societal value (economic, aesthetic, and intrinsic), its protection or restoration would likely be prioritized. Ultimately, variation in value results from the interactions of PSF to cause some areas to have higher function, and potentially more value, than others.

Additional factors to consider when characterizing an area's PSF are its size and position. The size of a given landscape area in general affects the nature and influence of processes proportionately (Forman and Godron 1986). However, in some cases small areas can have disproportionately greater influences on adjacent larger areas. An example of this is the likely effect of Cold Creek on salmon productivity in the Bear Creek system in King County. Cold Creek is a relatively small and short stream fed by a cold spring emanating from recessional outwash sediments laid down during the last glaciation. It flows into Cottage Lake Creek (Bear Creek's main tributary) a short distance downstream from Cottage Lake. Normally, Cottage Lake Creek would be expected to be as warm as streams with headwater lakes and approximately as warm as the main branch of Bear Creek during late summer when Chinook are migrating into the system to spawn. In fact, its water temperature is slightly cooler, apparently due to inflow from Cold Creek and associated cold springs. Since 1999, approximately 75% of the returning Chinook in the Bear Creek Basin spawn in Cottage Lake Creek, and it is hypothesized that the reason is related to the difference in temperature between Bear and Cottage Lake creeks (WRIA 8 2005).

Position refers to location and orientation of a given area (site, reach, etc) in relation to a larger reference area, such as a watershed or marine shoreline drift cell. Information about position helps in understanding how a site is potentially affected by various processes, and in turn how it may affect and modify processes and influence adjacent, down-slope, or down-stream locations. For example, whether a site or reach is up or downstream relative to other areas will affect its role and influence in a given area. Vannote et al. (1980) described a continuum of stream processes depending on position in a watershed. Gomi et al. (2002) noted the strong role small headwater streams play in watershed processes due to their uppermost position in a watershed and their close coupling with uplands.

A complicating factor in the characterization of shoreline ecosystems is that they are highly complex, and detailed knowledge is generally limited. In part, the complexity arises from the many and diverse variables and pathways for interaction within an ecosystem. Adding to this complexity is the fact that ecosystems are "open systems", meaning they are subject to external, across-ecosystem exchanges of energy and materials (Meyer 1997). Variability resulting from the complexity of interactions and incomplete understanding of them creates management uncertainty (Wissmar and Bisson 2003).

King County Approach to Ecosystem Process Analysis

Stanley et al. (2005) – Ecology publication #05-06-027 – developed a streamlined approach for characterizing watershed processes (this publication is provided as Attachment G to this document). King County has conducted a shoreline alterations analysis that relies on Stanley et al. (2005), the Puget Sound Nearshore Ecosystem Restoration (PSNER) Science Team (Simenstad et al. 2005), and Battelle Marine Sciences Laboratory (Williams et al. 2003; Williams et al. 2004).

Stanley et al. (2005) described six watershed processes that play key roles in Pacific Northwest riverine systems in terms of how they deliver, move, store, remove, or lose materials within ecosystems. The materials addressed by the six processes are: water (via the hydrologic cycle), large woody debris, sediment, phosphorus/toxins, nitrogen, and pathogens. A short-coming of their work for the King County effort is that it was focused primarily on freshwater stream environments. As a result, there are several key processes such as tidal effects and wave action left out that are either unique to marine shorelines or common to lacustrine and marine systems, but not to rivers. King County also separated toxins and phosphorus since delivery, movement, and loss of the two materials were not always similar between the three different environments.

For marine processes, the list of processes described in Simenstad et al. (2005) includes those identified in Stanley et al. (2005), as well as wave energy and tidal regime (or tidal interactions). Two groups of "biological response processes" were included as well: food web (primary production, primary consumption, excretion and respiration, etc) and ecology (recruitment, predation, behavior, etc).

Both wave energy and tidal regimes are important processes in shaping shorelines. Humans modify how wave energy interacts with shorelines by building breakwaters or armoring and by creating waves through boat wakes (Williams et al. 2003). Tidal regimes on shorelines are modified by altering timing frequency, and magnitude of the freshwater flow of rivers and streams (Williams et al. 2003), through water diversions, dams, and increasing impervious surfaces. They can also be modified by filling intertidal areas, causing the ordinary high water mark of the marine shoreline to be moved seaward. This change can create the phenomenon in which it appears that the tide doesn't go out anymore (Douglas and Pickel 1999).

The shoreline characterization work by Battelle for Bainbridge Island (Williams et al. 2003) includes a list of physical components of an ecosystem labeled "controlling factors." Again, most of the processes overlap with both the work by Stanley et al. (2005) and Simenstad et al. (2005). However, they also included a process not covered in the other two bodies of work: how light energy reaches the shoreline. This process is not only an important control on the growth of eelgrass in the marine shorelines (Williams et al. 2003), but it is also important for juvenile salmonid migration in both freshwater (Tabor et al. 2004) and saltwater (Nightingale and Simenstad 2001).

The processes listed and described from these three bodies of work make up the key list used for the comprehensive analysis of ecosystem processes. Although the biological response processes are important for understanding how ecosystems work, especially how habitat functions for various animals, it proved difficult to use available biological data for this analysis. The reasons include: the lack of comprehensive data sets across the entire county (the species may well exist in many places not investigated); data sets are not current or have not been kept up to date or re-evaluated; the nature of the data collected does not lend itself to habitat evaluation (i.e., presence/absence based on one-time observations); lack of reported methodology; and general lack of precision or replicability. Because of these factors and others, the two groups of biological response processes described by Simenstad et al. (2005) were not included. However, some of the physical processes are closely related to biological processes and might be considered as including a small amount of biological process in the assessment. An example of this is natural light energy, which is necessary for photosynthesis, thus may be a limiting factor for primary production, although certainly not the only one to act upon the system.

There are other processes that could be included, but for a variety of reasons were not considered. For example, wind energy could be viewed as its own process because it also causes change by contributing to wave-driven erosion and causing wind-fallen trees, thus mobilizing soils and contributing to LWD. However, wind energy is already incorporated in other processes, such as wave energy and LWD, so there is a risk of overlap and double-counting if included as a separate process.

In summary, King County's alternations analysis looks at 10 key landscape processes that deliver, move, store, remove or diminish (see Attachment E):

- water
- large woody debris
- sediment
- phosphorus
- nitrogen
- toxins
- pathogens
- light energy
- wave energy
- tidal influences

The last three processes, which were not included in Stanley et al. (2005), were adapted to the Stanley et al. (2005) methodology. In addition, certain aspects of the analytical framework were modified in order to streamline the analysis and tailor it to the shoreline alterations analysis. As an example, Stanley et al. (2005) evaluated entire watersheds, whereas this analysis was mostly limited to areas that are located within the Shoreline Management Act jurisdiction. "Key areas" and "alterations" mapping described by Stanley et al. (2005) as separate steps were combined into one. Further details on the specific analytical methodology are discussed in the concept and criteria for the shoreline alterations analysis (Section 2.B).

In applying the analytical framework developed by Stanley et al. (2005), King County focused on the publication appendices B through G, which explain why each component of the process is important and which alterations are the most critical. These appendices also describe the supporting scientific rational/reference showing why the specific components or alterations are important. Though each process is summarized below, the description is not as detailed as that found in Stanley et al. (2005), which has been included in this document as Attachment G for ease of reference and in order to avoid repeating its content.

The format of the descriptions of all included processes follows a regular progression. All the processes are described in a series of tables (Attachment E) and scoring flow charts (Attachment F), as well as summarized in the text of the following section. The tables describe each process in terms of expected delivery, movement and loss to the ecosystem for both unaltered and altered conditions. Each aspect of the process is further broken up into components. For example, overland flow, shallow subsurface flow, and discharge are all different components of movement within the hydrologic cycle and are treated separately.

King County Approach to Ecosystem Function Analysis

As discussed previously, ecosystem processes and structure interact to create function, which can provide feedback to both the process and the structure. For example, sediment erosion processes along a feeder bluff on a marine shoreline provide a mixture of sediments that are sorted by tidal regimes and wave energy. As a result, certain areas have the right combination of salinity, wave and light energy, and substrate to allow eelgrass to grow. Over time, the eelgrass bed expands and thereby decreases the wave energy that reaches the shoreline, thus reducing the process of sediment erosion.

WAC 173-26-201(3)(d)(i) states that four groups of ecological functions are present on shorelines. These include: hydrologic, shoreline vegetation, hyporheic, and habitat for fish and wildlife. King County's analysis addresses these four groups of functions indirectly by addressing the alterations in the processes that produce them, since the processes are the controlling factors of concern. A weighted or additive analysis would be difficult to score appropriately and consistently if measures of both functions and processes are included together. By focusing on processes, the analysis is cleaner and more transparent to critique. However, the analysis of ecological processes does indirectly include some measures of ecological functions. For example, at least three processes from the analysis correspond with the hydrologic functions listed in the guidelines (Table 4). Given the overlap between functions and processes, the plan of characterizing the ecosystem processes that create and maintain the structure and function of the shorelines should be adequate for the shoreline management designation work.

Table 4. Comparison of Functions in WAC 173-26-201 (3)(d)(i)(c) to the Processes in King County's Shoreline Alterations Analysis

Shoreline Function		Primarily corresponding process in King County's ecological characterization
Group	Subgroup	
Hyrdologic	Transport of sediment and water	Hydrologic cycle Sediment Large woody debris
	Flow/wave energy	Hydrologic cycle Sediment Large woody debris Tidal regime Wave energy
	Large Woody Debris	Hydrologic cycle Sediment Large woody debris Tidal regime Wave energy
	Nutrients/toxins	Nitrogen Phosphorous/toxins Pathogens
	Pools/Riffles (habitat)	Hydrologic cycle Sediment Large woody debris Tidal regime Wave energy

B. Shoreline Alterations Analysis: Concept, Criteria and Results

Overview

As discussed in Section 2.A, the shoreline alterations analysis is based on the approach from Stanley et al. (2005), with some modifications to fit King County's available data sets, specific goals, and computer programming capabilities. An analytical tool was developed using Model Builder in ArcGIS 9 to overlay selected geographic information system data layers pertaining to each process and then evaluate that information using a decision tree (i.e., a series of questions and criteria for scoring) to produce a score within the jurisdictional area. The number of decisions that went into scoring varied, depending on the shoreline type (marine, lacustrine, riverine) and the geomorphic context, e.g., depositional versus erosion zones.

The goal of the analysis was to evaluate the extent to which key physiochemical conditions and vegetation have been altered at the site scale from their pre-development condition. The extent to which these conditions have been altered is assumed to indicate the relative condition of the physiochemical processes they affect and by extension the integrity of biological and ecological processes they create and sustain.

A series of relatively small (25 X 25 ft, or 625 ft^2) pixels covering the landward area of shoreline jurisdiction were created to serve as the base unit for analysis. Within each pixel, the condition of a process was assessed and scored using indicators of the degree and effect of change from an ideal or undisturbed condition in selected physiochemical conditions (see below for more detail on pixel-scale analysis and scoring). At this stage of the analysis, each pixel was rated independently. Ultimately, individual pixel scores for each process indicator were averaged within a reach defined by geomorphic similarity. For this analysis, reaches in the marine shoreline were defined as contiguous segments of sediment sources, accretion areas, and transport zones; in rivers reaches were defined by SSHIAP segments; and in lake shorelines reaches were defined as geomorphically similar areas based on slopes and water flow criteria.

Analysis Structure and Scoring

The first step of the analysis was to define the geographic area to be covered. The study area boundaries were defined as those shoreline areas under Shoreline Management Act jurisdiction, including associated wetlands and floodplains. Then, as noted earlier, a grid of equal-sized pixels covering the area of jurisdiction was created. Conditions in each pixel were then assessed and scored for 7 to 10 separate processes, depending on whether the pixel was along a river, lake or marine shoreline. This resulted in a total of 27 separate analyses (10 marine, 9 lacustrine, and 8 riverine).

The geographic information system data layers used in the shoreline alterations analysis are available in a variety of formats, with the bulk of the data occurring in vector format (polygons, points and lines). All of the data was converted to raster (grid) format to allow for the analyses to function properly. This conversion causes data that was graphically represented by a line to look like a series of blocks (pixels or rasters) in the graphical representation (Figure 2).

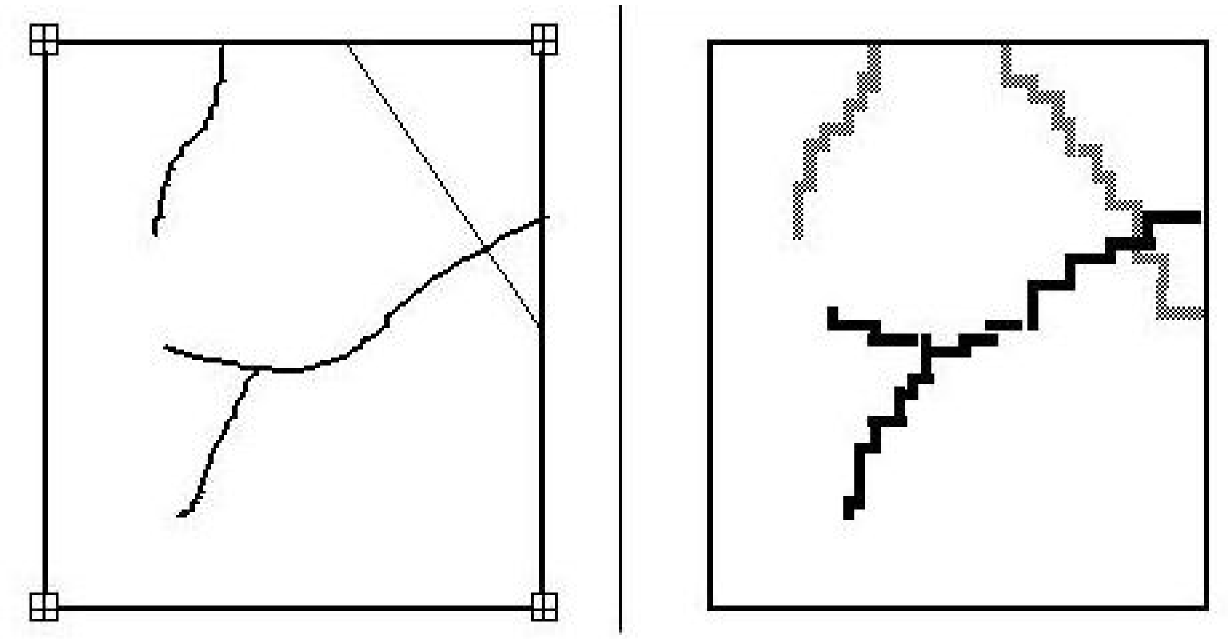

Figure 2. Conversion of a Shoreline Represented as Vector Line (Left) Data to Raster Data (Right)

The raster cell size (pixel) used for the analysis was 25 feet by 25 feet (625 ft^2). This size appeared to represent more accurately the shoreline edges and buffer area compared to larger cell sizes. For example, using a 100 feet by 100 feet (10,000 ft^2) cell size would allow for only two cells landward from the water's edge within the jurisdiction, thus potentially losing much detail through averaging of information within each large cell. In addition, resolution of the chosen data sources varied from 4 feet for impervious surface to 100 feet for land cover data. Thus, while land cover data produced only mean data across several smaller cells at 25-foot resolution, the alternative of using the 100-foot cells as the chosen pixel size would have meant that important detail from the 4 foot impervious surface data would be lost in the analysis. As a result, the 25-foot pixel size was considered the best compromise to accommodate the varying data scales.

Following the approach of Stanley et al. (2005), each pixel was scored for conditions related to the three elements (delivery, movement and loss) of a process, with each element separated into multiple components. Figure 3 shows an example of how this analysis was framed for LWD. For example, the delivery portion of the LWD process is divided into three components considered most critical for providing LWD to shorelines: shoreline erosion, mass wasting, and windthrow.

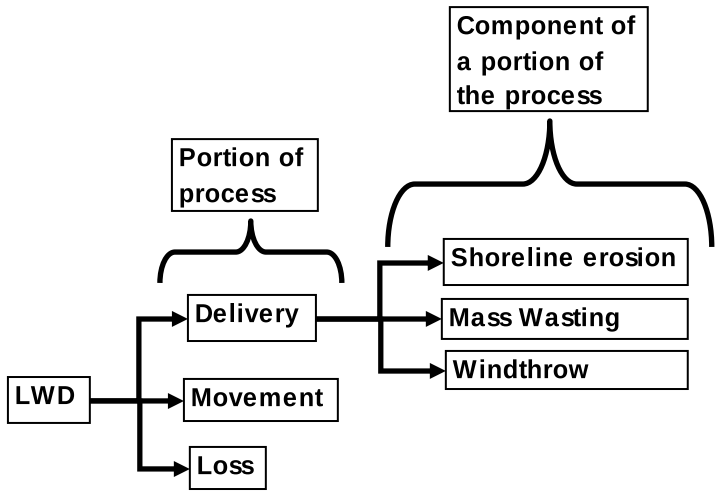

Figure 3. Example of the LWD Process Separated into Portions of the Process and Components of Each Portion

The scoring system was five-tiered: values ranged from 0 to 4, with 0 equaling the poorest (i.e., most highly altered) conditions and 4 representing the best (least altered) conditions. Each pixel received a single score representing the average score of the components. This scoring was done in one of two ways (Figure 4): One was to score each component of a portion of the process from 0-4 and then average the scores (the process shown is from the toxin decision tree). The second method was to utilize a more complex decision tree that resulted in a single non-averaged final score.

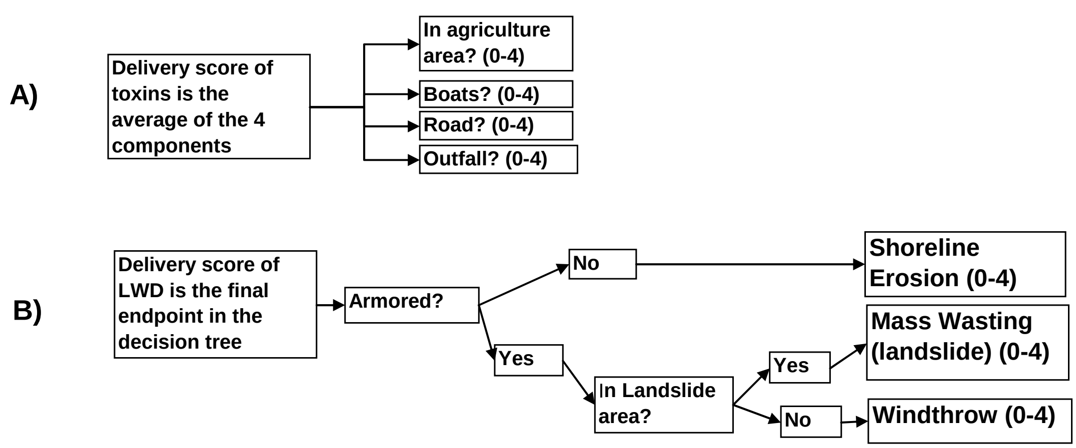

Figure 4. Two Scoring Methods, Examples: (A) Marine Scoring for the Delivery Components of Toxins Are Averaged Resulting in a Single Score; (B) Marine Scoring for the Delivery Components Of LWD Follows a Decision Tree Resulting in a Single Non-Averaged Score

Once each component was scored, the scores for each portion of the process were then averaged together to provide a single score for the process for that pixel (Figure 5). Note that while most analyses scored every pixel within shoreline jurisdiction, some processes or portions of processes, such as wave energy, evaluated only the first pixel directly abutting a shoreline because the process or the alteration’s impact is limited to that extent of effect.

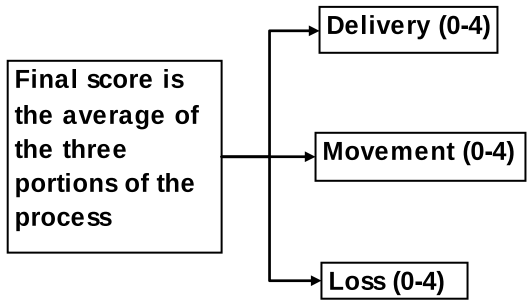

Figure 5. Final Score Assigned to Each Pixel for Each Process Is the Average of the Elements of the Process

Output from the analysis included scores for each of the 10 marine processes, 9 lacustrine processes and 8 riverine processes. The scores for each process were then summed to produce a single score for each pixel, which was then expressed as a percentage of the total points possible. In this way, higher percentages indicate a less altered condition, while lower percentages indicate a more altered condition (Figure 6).

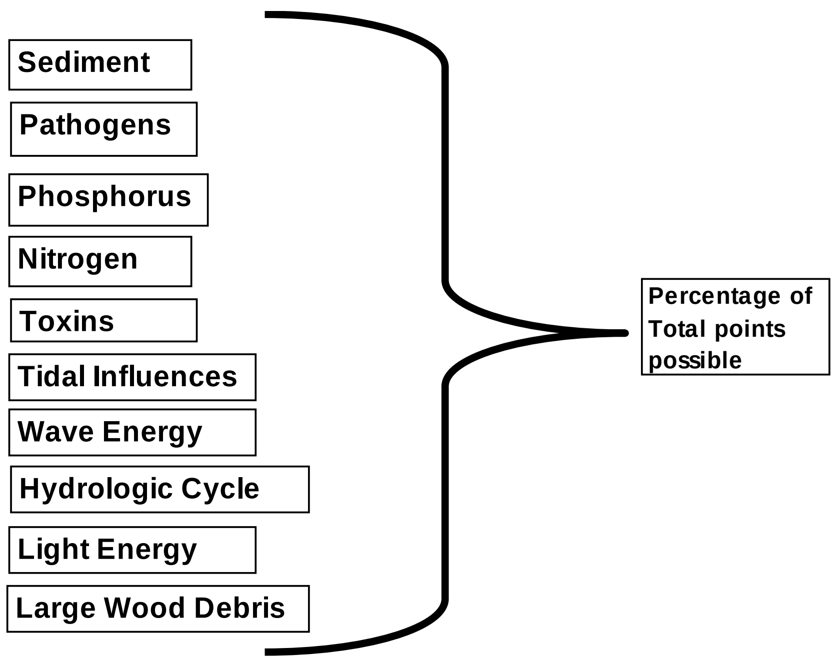

Figure 6. Final overall score for all processes combined is the percentage of the total points possible for each pixel.

Because the decision trees used for each shoreline type are slightly different, it would be inappropriate to compare direct scores between shoreline types. It should also be noted that the same data (such as land cover and shoreline armoring) were used to score the effect of alterations on different processes to account for various impacts of a particular alteration on different processes. Although this gives the appearance of counting a particular alteration twice, it is actually accounting for the multiple and different effects that a specific alteration can have on a variety of processes.

Scoring varied depending on the nature of the alteration and the condition. Some scores were based on the simple presence or absence of a feature. For example, for delivery of toxins, a pixel with an outfall was given a 0, while an area with no outfalls was assigned a 4. Other scores were assessed on the degree, or location of an alteration. For example, when marine shoreline armoring is closer to the water, LWD is less likely to accumulate on the shore than if armoring is away from the shore's edge. Therefore, the absence of shoreline armoring gets 4 points and shoreline armoring placed landward from the ordinary high water mark gets a 3. Conversely, shoreline armoring at or below the ordinary high water mark receives a 0.

When initial analysis and scoring was complete, a ground-truthing exercise was conducted by reviewing scores with King County staff having detailed local knowledge of conditions for select areas on all types of shoreline assessed by the analysis. Scoring criteria were sometimes modified where the scores were inconsistent with known conditions on the landscape and logical reasons could be found to explain the discrepancies. The scoring criteria were further modified after comparison to city characterization results (where available) and external peer review.

Assumptions and Limitations of the Analysis

The alterations analysis attempts to capture the interaction between environmental and human factors that can alter the ten different ecological processes along shorelines of the state: sediment, large woody debris, wave energy, light energy (including both solar and artificial), nutrients (phosphorus and nitrogen), pathogens, tidal influences, hydrologic cycle and toxins. Detailed knowledge of precisely how these processes and interactions occur in this region is currently limited. As a result, the analysis is largely based on literature-derived relationships and empirical observations, although local information was incorporated when possible.

Some processes which operate along shorelines were not addressed, such as temperature. This was due to the limitations of the available data sets as well as information in the literature, as far as scoring of particular pixels for the process. This is not an assertion that temperature is not important, but rather that a method for assessing it could not be set up within the confines of the existing data and level of understanding for this area.

The analysis relies most heavily on geographic data and, in some cases satellite imagery, for an accurate representation of conditions on the ground. Of course satellite images have some inherent inaccuracies due to limitations of technology and variation in atmospheric conditions at the time the images were taken. In addition, the images are often converted into useful information (e.g., land use or land cover) using human-guided decisions on how to interpret the imagery, introducing some further potential sources of error and variability. For example, in the landcover data, both steep slopes and land surface in shadow could not be accurately evaluated, which meant that in the alpine areas of the County, large portions of land were classified as "steep slopes" or "no data," thus limiting the ability to score those sections. Use of this data could have resulted in some inaccuracy in the characterization of lakes in the alpine regions.

From necessity, the analysis also incorporates a number of assumptions about conditions, interactions, and accuracy across the landscape of shoreline jurisdiction. While detailed, discrete assessment of the intrinsic or inherent capability of a given area to produce or modify natural materials was not routinely included in the analysis, it was taken into account wherever some information made that possible. There were some cases where information was available for one type of shoreline, but not the others. For example, the likelihood of bluffs delivering sediment to the marine shoreline could be broken out into a variety of classes, but similar data were not available for lakes and streams. Thus for freshwater shorelines, the likelihood of a landslide occurring was assumed to be similar to the marine shores (based on maps of hazard areas, vegetation and soil types) and was treated in the same fashion.

Another cautionary note concerns the precision of the analytical tool with reference to its intended use versus any other possible uses in the future. In order to undertake a more precise analysis or even a predictive model, more accurate data would needed. Given the time and financial constraints on this project, it was not possible to collect new data to augment the analysis. The results were intended to estimate current physiochemical conditions at an appropriate level for the planning analyses related to shoreline management. It was not intended to be an exact predictor of particular shoreline conditions at any given time, but rather to indicate where alterations are minimal and where they are extensive. For this purpose, it provides a useful and reproducible way to describe general shoreline conditions at a site and the effects of natural-human interactions on the processes used to characterize overall conditions.

There are also a variety of limitations related to the particular data sets used to evaluate each process, and these are discussed in the sections that follow at the appropriate points in the text.

Data Sets Used Frequently in the Alterations Analysis

Several data sets were used repeatedly in the analysis in various decision trees. Given their overall importance, they are described here in detail rather than repeating the discussion for each process description.

<u>Shoreline Armoring</u>

For river shorelines, three data sets covering different shoreline armoring were combined into one. This included a GIS file of the levees and revetments maintained by King County, data collected by King County and Washington Trout on all shoreline armoring in the Snoqualmie River below the Falls, and data collected by Anchor Environmental Ltd on the Green River from the mouth to river mile 32. These data are field verified, and the extent of shoreline armoring for these rivers was considered to be well represented in these data sets. However, it is likely that shoreline armoring was under-represented in other areas where there were no data sets of privately maintained bank armoring.

Data for marine shoreline armoring on Vashon were collected in 2004 by Anchor Environmental Ltd. The data were collected through a combination of photograph interpretation and field verification. Because of the time spent and detail used in compiling this data set, there is a high degree of confidence that it comprehensively and accurately captures the location and tidal height of marine shoreline armoring.

Little or no information has been collected on the occurrence of bulkheads or armoring for the shorelines of most lakes in King County, and yet bank armoring and bulkheads are frequently used techniques to protect properties developed along lake shorelines. King County DNRP recently created a geographic information system file indicating the location of docks on all lakes within King County in 2002. Since docks are usually set firmly into the land somewhere above the ordinary high water mark, the foundation for the dock attachment often acts as an armoring structure itself. In addition, docks are commonly accompanied by other shoreline development and landscaping that can include bulkheading or bank stabilization. Thus, the presence of a dock is often indicative of other development-related alterations such as bank armoring, bulkheading and artificial beaches and landscaping. Given the lack of specific bank armoring data and their frequent co-occurrence, docks were used as an indicator of a degree of shoreline armoring and artificial protection.

Land Cover and Impervious Surface

The characterization analysis made extensive use of the regional land cover analysis carried out at the University of Washington using multiple 2002 Landsat images (Alberti et al. 2004). The land cover is raster-based, characterizing 100 X 100 foot pixels. Each pixel was assessed for degree of urbanization, dominant plant type, or geomorphic features and ultimately classified as one of 15 different categories (Table 5). Steep slopes could not be interpreted from land cover, nor could areas covered by clouds or shadows during flyovers.

Table 5. Land Cover Categories Used in the 2002 University of Washington Land Cover Analysis

Category	Land cover classification
1	Dense Urban (>75%)
2	Light-medium development (<75%)
3	Bare ground
4	Dry ground
5	Native grass
6	Grass/crops/shrubs
7	Mixed deciduous forest
8	Conifer forest
9	Re-growning vegetation
10	Clear-cut forest
11	Snow/rock/ice
13	Wetlands
14	Shoreline
15	Water
17	Steep slopes/no data

There were some challenges in using this data as a basis for evaluating process integrity along the shorelines of King County. Because the pixels were 100 feet on a side, shoreline positions and extent were not as precise as desired for the analyses. Additionally, land cover was occasionally misclassified. For example, in some cases, land was classified as “water,” whereas in others, riparian areas and gravel bars were classified as urban/light-medium development. Similarly, some areas of light development were classified as trees.

In order to reduce the effect of these errors, where ever land was classified as water, shorelines were redrawn. The original water classification was then reclassified based on the surrounding land cover and aerial photographs. While fixing the misclassified water pixels, any obvious errors related to gravel bars and riparian being classified as urban development were also corrected. The reclassified results were converted to 25 ft^2 rasters.

Recognizing that the large pixel size of the Alberti et al. (2004) dataset could misclassify land cover, especially missing light development, the land cover data were overlain with impervious surface data (4 foot scale) in order to refine the land cover classifications (Figure 7). Cells of

625ft^2 were then categorized according to whether they contained 0 to 12.5%, 12.5% to 50% and greater than 50% impervious surfaces. This modification resulted in a more accurate representation of land cover, especially for recognizing development in many areas.

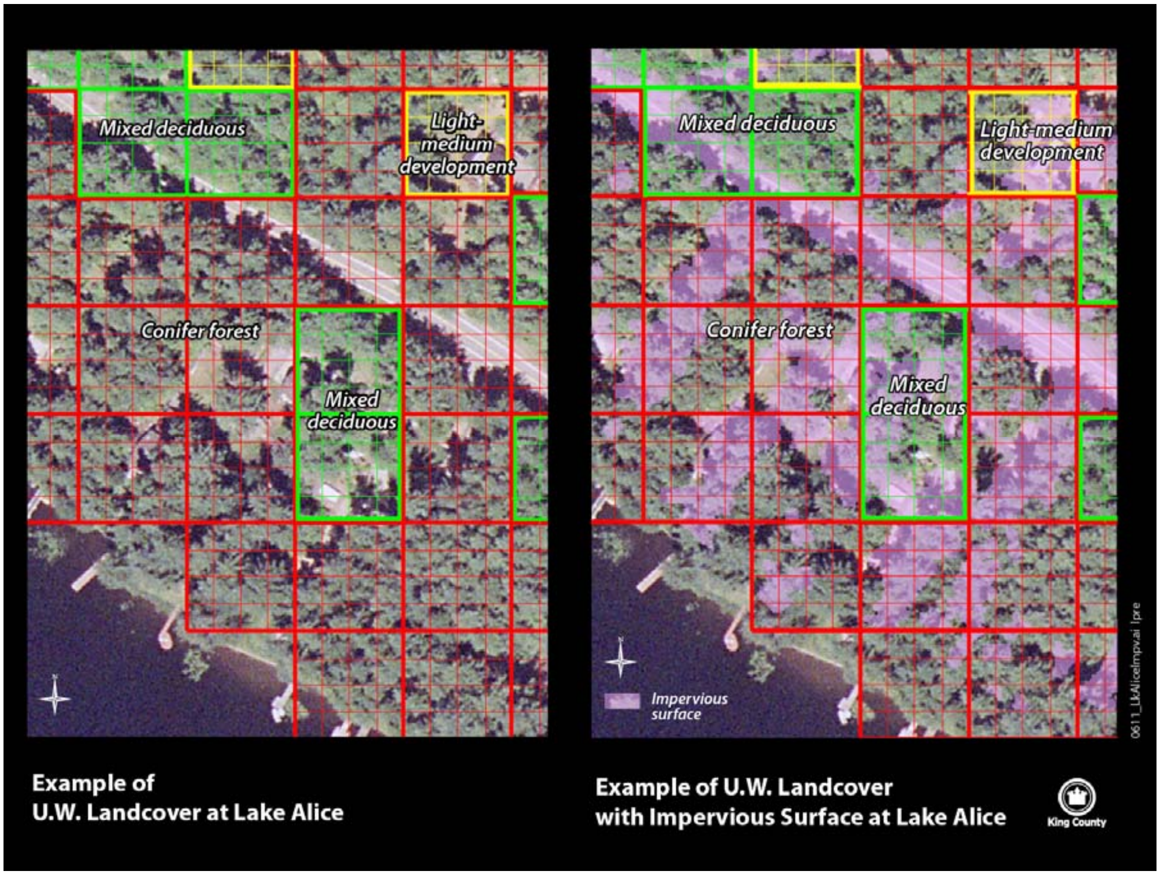

Figure 7. Land Cover Categories at Lake Alice, with and without Impervious Surface Data (Impervious surface data is shown in purple in picture on the right). The larger bold squares are 100 feet by 100 feet. The smaller squares are 25 feet by 25 feet. Red squares represent conifer forest. Green Squares represent mixed/deciduous forest. Yellow squares represent light/medium development.

Along with using impervious surface data to correct some of the land cover misclassifications, several other limitations were found in the data. One example was that scrub/shrub class was combined with crops and grass, thus losing the opportunity to use shrubs, lawns, or agricultural crops as separate classes. The classifications of vegetation re-growth areas and clear-cut forest allowed for shrub or immature vegetation to be used in some of the analyses, but these classifications generally occurred in heavily forested areas and did not occur in areas with development, making usefulness limited.

To simplify the analyses, mixed/deciduous forest and coniferous forest were combined into a single category designated “trees.” Also, for “natural” conditions, deciduous trees, coniferous trees, rock, snow, ice, wetland, water and steep slopes were frequently lumped together because each condition generally represented an unaltered state and so denoted degree of alteration in similar fashion. A quick analysis of steep slopes showed that the vast majority of steep slope classifications occurred in steep mountainous areas that, when compared to aerial photographs, showed primarily rock, snow or ice. Thus, it was appropriate to include as a natural condition.

Marine Riparian Areas

Much of the marine shoreline was simply classified as "shoreline" in the UW landcover data, due to large areas of gravel beaches that the computer program was unable to interpret properly, which made it of little use for the marine analyses. Instead, marine riparian vegetation data collected by Anchor Environmental in 2004 and a qualitative imperviousness data set were substituted for landcover in the marine process analyses. Imperviousness was classified as low, medium and high for the area within 200 feet from the ordinary high water mark by Anchor Environmental (Anchor 2004). This data was used as a proxy for the level of development in marine shoreline areas.

These data, characterizing vegetation on the upland areas adjacent to the shoreline for land cover, were based on aerial photos and were field verified. They were used because much of the land cover characterization for marine shorelines was classified simply as "shoreline". Vegetation was classified by Anchor Environmental as trees, shrubs, grass (landscaped areas), and no vegetation. They further classified vegetation into continuous (more than 75% of the shoreline was vegetated) or patchy (less than 75% of the shoreline was vegetated), as well as whether it was adjacent to the shoreline or separated from it by another feature, such as a road or structure.

Docks/Over-Water Structures

As noted earlier, data on dock locations along lacustrine and riverine shorelines of King County were generated using low-elevation ortho-photographs from 2002. For marine shorelines, data were generated using a combination of ortho-photograph analysis and field verification by Anchor Environmental (Anchor 2004).

Agricultural Use

This dataset was generated in 2001 by King County's agricultural program staff (R. Reinlasoder, pers. comm.) using aerial photos and field verification. This was done for areas both inside and outside the Agricultural Production Districts. The data were broken into 13 categories within the Agricultural Production Districts (APDs) and into 5 categories outside the districts, based on dairy, livestock, horticultural operations, and mixed agricultural uses. For consistency across all agricultural areas, the simpler 5-category data set was used throughout the analysis.

Sewered Areas

This dataset was generated by King County Wastewater Treatment Division. It delineates areas of King County that are served by sewer systems. It should be noted, however, that being connected to a sewer line is not mandatory, and therefore it is likely that some parcels may be on septic systems instead and that the data set most likely overestimates the total number of parcels that are actually sewered. King County Public Health is currently undertaking an analysis to verify which parcels are connected to sewers and which are on onsite sewage systems (septic); however, their work will not be completed in time to use for this analysis.

Inside/Outside Quartermaster Harbor

Because of differences in flow circulation patterns within Quartermaster Harbor compared to the rest of the marine shorelines, water quality impacts within and outside of Quartermaster Harbor were assessed differently. As a result, alterations affecting water quality within the harbor received lower scores than the areas outside the harbor.

Soils Data

Analyses of wetland loss, erodability of soils, and upland areas with clay soils used data from the National Resources Conservation Service soil survey. This data set does not cover the highly urbanized area of western King County. For unincorporated King County, the lack of coverage was limited to two relatively small potential annexation areas along the Duwamish River and the western shores of Lake Washington. For those particular areas, minor changes needed to be made in the toxins and phosphorus process assessments in order to account for the lack of data.

Wetland Loss

King County has lost many wetlands due to changes in land use over the past 150 years. Some specific areas of the county have had the loss of wetlands mapped based on historic General Land Office maps (Collins and Sheikh 2005a, 2005b, Collins and Sheikh 2004a, 2004b). While these mapping efforts provided valuable data, the analyses were generally limited to the major floodplain areas and based primarily on historic maps (versus soils data). Due to the limitation of the geographic extent of the previous analyses, this analysis followed the guidance in Stanley et al. (2005), and wetland loss was estimated by comparing the estimated prehistoric extent of depressional wetlands to existing wetlands data. The prehistoric extent of depressional wetlands was calculated by combining the area of mapped hydric soils with slopes of less than 2%. The resulting areas were then compared to the existing King County wetland coverage, which is a combination of wetland information from the National Wetland Inventory (NWI) of 1973 and the King County wetland folio, last updated in 1980. Areas had to meet both the soils and slope criteria or else were excluded from the analysis.

Wetland loss was defined as the sum of areas that had hydric soils, and with slopes less than 2%, but with no currently existing wetland mapped in county coverage. This analysis may overestimate the loss of wetland area, both because the original extent of wetlands across the county cannot be verified and because the current wetland maps are not complete or always accurate. As a result, some currently existing wetlands may not be included, and some areas that never were wetlands might be considered. This means that the estimate of loss is useful only as a general indicator rather than as a highly accurate estimate of area of actual wetland loss.

Description of the Analysis by Each Process

Each of the ten processes that are evaluated in the GIS-based analyses are discussed below, but much of the basic logic and methodology for the choice of processes and scoring logic follows Stanley et al. (2005), which has been included in this document as Attachment G. Six processes discussed in that document are laid out in the appendices of that document, including background information, reasoning, and analysis of impacts.

In the following sections, each process is first described using the approach of Stanley et al. (2005) followed by a description of the scoring. Where relevant, the same processes are considered jointly for each of the riverine, lacustrine and marine shorelines. Exceptions, such as for tidal influences which are not relevant for lakes, are noted. Attachment E of this document contains charts that lay out key elements and considerations for each process, while Attachment F contains charts of the decision trees and scoring.

Wave Energy

A good description of wave energy can be found in Williams et al. (2003). They state: "Waves are characterized by length, period, and height, and are the physical representation of energy moving through water. The short-period waves generated by local winds and vessel wakes are superimposed on the water elevation that varies with tide, season, and longer-term influences. In addition to winds and vessels, waves may be generated by geologic sources (i.e., large-scale bluff collapse, seismic forces)…The wave energy is translated across the water and is ultimately expended on the shoreline, working to erode, transport, and deposit beach sediment (U.S. Army Corps of Engineers 2002; Terich 1987). Compared with other locations in the U.S., Puget Sound is considered to be a moderate wave-energy environment, even in the most exposed locations (McDonald and Witek 1994)."

Wave energy is relevant in marine and lacustrine shoreline types. There are sections of some rivers within King County that experience significant boat traffic, but these particular river segments are not in King County's jurisdiction, so it was not addressed in the river shoreline analysis. Since the impacts of altered wave energy occur primarily on the shoreline edge, the wave energy analysis only evaluates the shoreline pixel closest to the water's edge. The importance of wave energy and how it operates in the ecosystem is described below through the three components of processes: delivery, movement and loss. Alterations and scoring for the two analyses are described below. Diagrammatic descriptions are located in Attachment F.2.

Delivery

Under natural conditions, wave energy is primarily generated by localized wind patterns and can be increased greatly during high-wind events. It also can be increased through boat traffic (Anchor Environmental 2000). This impact is focused on areas of high boat traffic, where wave energy is increased on a regular basis, not everywhere boats might cause a wake to occur infrequently. The amount of wave energy reaching the shoreline can also be decreased by submerged aquatic vegetation, which can act to moderate wave energy (Williams et al. 2003).

Since larger wind patterns along marine shorelines are not readily altered by human activities, it is not included in this analysis. For lacustrine shorelines, changes in shoreline vegetation (i.e. height) can impact how winds interact to create wave energy. Thus, changes in land cover from forested or a natural state to some form of developed state were given zero points, while natural land cover types received four points. A major human alteration of the delivery of wave energy is through motorized boat traffic. Alterations to wave energy along marine shoreline were assessed based on proximity to shipping lanes and ferry traffic and whether the shoreline is in an area with high recreational boating use. Quartermaster Harbor was identified as an area with high potential wave energy alteration due to high levels of recreational boating, as evidenced by availability of protected moorage and the location of several marinas. There is also one major commercial shipping lane in this portion of Puget Sound, running from southern Maury Island to the northern tip of Vashon Island along Vashon's eastern shore.

Lakes that permit motorized boat use or that do not have an ordinance prohibiting internal combustion engines on the lake were considered to have shorelines with increased wave energy. Some river segments also experience an increased amount of boat traffic, particularly during recreational fishing seasons.

Movement

The movement of wave energy translates to the transfer of the wave energy from the water to the shoreline, or the energy being dissipated on the shoreline. The natural transfer of energy onto the shoreline is altered by shoreline armoring, which tends to dissipate and deflect energy differently than natural banks. The type of natural shoreline (rocky or sandy) and artificial armoring (hard rock vs. vegetative, bio-engineered banks) and location of the armoring relative to the tidal elevation (well above the high tide line versus below tide line) play a strong role in the effect of the alteration. Williams et al. (2004) state, "Wave reflection forces generally increase as armoring methods intensify, with higher impacts to beach processes in areas with solid vertical or recurved seawalls, and lower impacts in areas using graded or porous structures (e.g., revetments and riprap) or dynamic "soft" solutions (Macdonald et al. 1994; Williams and Thom 2001).

Hardened armoring approaches, such as bulkheads and revetments, represent the types of shoreline modifications most likely to affect wave-energy regimes. Encroachment of the structure into the intertidal zone, measured as the vertical distance of the mean high-water line from the toe of the structure, also may increase the reflective energy of waves." King County data on marine shoreline armoring is limited to presence/absence and encroachment. It does not include data on type of armoring (i.e. recurved seawall, rip-rap, wood piling). There are no comprehensive data sets of lake shoreline bulkheading for most lakes within King County, although such a data set does exist for Lake Washington, which is mostly out of King County jurisdiction.

Alterations to the interaction of wave energy with shorelines were assessed through evaluation of the location and extent of shoreline armoring. If the marine shoreline was not armored, it received the maximum four points. If the shoreline was armored, points were based on where it was armored in relation to the ordinary high water mark. Fewer points were given for armoring in the intertidal zone.

Armoring on lake shorelines was assessed using the presence of docks as an estimator for the presence of shoreline armoring. If a pixel contained a dock it got zero points. Since shoreline armoring may extend beyond the shoreline footprint of the dock, the pixels immediately adjacent to the dock also received zero points. As pixels got further away from a dock, they received more points because they were considered less likely to be armored. Thus, pixels greater than 25 feet but less than 75 feet away from a dock received 1 point. Pixels with no dock and not located within 75 feet of a dock received the maximum of four points.

Loss

Loss or reduction of wave energy under natural conditions is classified by the level of beach exposure to waves. For example, due to surrounding land masses, shorelines in Quartermaster Harbor are relatively well-protected from wave energy compared to the outer south shoreline of Maury Island. While shoreline armoring can also be considered an endpoint or loss of wave energy, the effect of shoreline armoring is considered under the movement component of wave energy. Other structures such as jetties, docks, piers and breakwaters decrease wave energy through intervention of wave motion before it reaches the shorelines. Thus, when the wave energy reaches the shoreline, the actual amount of energy being expended has been greatly reduced.

The loss of wave energy was captured by the presence of structures such as docks and piers in both lacustrine and marine shorelines. Breakwaters were not considered because there are no known breakwaters in King County's shoreline jurisdiction.

Modifications from Stanley et al. (2005)
This process was not included in the analysis by Stanley et al. (2005).

Tidal Influences

Tides along King County's marine, and estuarine shorelines are mixed semi-diurnal, resulting in two high tides and two low tides of unequal height every day. Generally, the tidal regime is affected at a regional scale and not controllable at the local level. However, there have been some large scale changes to hydrology within basins (e.g. diverting the White and the Cedar Rivers away from the Duwamish River) that have had a significant impact on the extent of the local tidal regime. Tidal influence can also be affected by changes in sea level over the long term by tectonic subsidence and global warming, and over the short term by storm surges and El Nino events (Williams et al. 2003). Because the impact of tidal influence is concentrated along the shoreline edge, only the shoreline pixel closest to the water's edge was evaluated. A diagrammatic description of the tidal influence alterations analysis is located in Attachment F.9.

Due to the modified river flow described above, tidal influences are less variable in the Duwamish now than historically, particularly during winter when rivers run high. Another potential impact is on the degree and timing of the interaction of tidal movement with river flow, which will change with varying levels of river discharge through the seasons. Similarly, alterations occur at a smaller scale for many of the streams entering Puget Sound because of diversions of freshwater for human consumption or through increased levels of impervious surfaces in the basin, which increase the peak flows for storm events.

The extent of tidal influence can be altered (truncated or lost) through alterations in beach profiles and elevations by shoreline armoring, and by artificial tidal restrictions at stream outlets caused by culverts, tide gates, and weirs. Shoreline armoring at or below ordinary high water levels shifts tidal influence to offshore areas which in turn can preclude the growth of important marine vegetation, such as eelgrass, and the existence of spawning habitat for certain fish species (Williams et al. 2004). Tide gates and weirs on streams can limit or prevent salinity gradients and backwatering effects that can create highly productive fresh- to-saltwater transition areas for vegetation and fish and wildlife. For example on Vashon Island, Rabb's Lagoon, which was originally formed by a natural sand spit constriction that allowed for free exchange of freshwater and saltwater, currently is constrained by a weir (which is old and failing) and a bulkhead across its mouth. These structures cause freshwater to back up like a lake during low tides, while simultaneously reducing the duration that salt water has access to the lagoon during high tides. Thus, the flushing and inundation rates, or tidal movement, within the lagoon have been altered.

Delivery

Changes in the delivery of the tidal energy are addressed under movement.

Movement

Three different components of movement were analyzed: tidal constrictions, tidal encroachments, and total imperviousness of the basin. A tidal constriction was classified as artificial feature that could restrict the degree of tidal influences. The data to evaluate tidal constrictions were compiled from several sources. This data included man-made outfalls along the marine shoreline, culverts within 100 feet of the shoreline, bulkheads at the shoreline that constitute barriers to fish (and therefore also tidal influence), and one tidal weir. Tide gates would also be a constriction; however, current data for the marine shorelines does not indicate the presence of any tidal gates in King County's area of jurisdiction. Any pixel with one of these constrictions was scored zero, while all other pixels received a four.

Tidal encroachment was evaluated based on how far shoreline armoring extended into the intertidal zone. The farther or deeper the armoring extended into the intertidal, the greater the impact and the lower the pixel score. Pixels having no shoreline armoring or having armoring above the ordinary high water mark were given four points. Shoreline armoring at the ordinary high water mark was given one point. Any shoreline armoring below ordinary high water mark was given a zero.

Total impervious area (TIA) of a sub-basin was used to indicate the level to which overland flow had been modified through various development activities. As noted earlier, changing flow patterns can impact how tidal movements interact with streams. If the TIA of a basin was less than 10% it was given a four. If the TIA of the basin was between 10 and 25% the pixel was given a one, while any level of TIA over 25% was given a zero.

Loss

Alterations in the loss of tidal influences are addressed under movement.

Modifications from Stanley et al. (2005)

This process was not included in the analysis by Stanley et al. (2005).

<u>Large Woody Debris</u>

Large woody debris (LWD) is an important form of organic input to aquatic ecosystems and is a principal factor in structuring habitat characteristics in ecosystems around Puget Sound (Naiman et al. 1992). The importance of LWD and how it operates in the ecosystem is described below through the three components of the process: delivery, movement and loss. Puget Sound lowland areas, including King County, have been altered to varying degrees by human activity (Stanley 2005). In areas where riparian forests, floodplains, steep forested slopes with landslide potential and channel and beach migration areas are not heavily altered, LWD processes are likely intact. Conversely, areas where alterations of riparian conditions have been extensive the likelihood of the LWD process functioning naturally is very low (Stanley 2005). The alterations to LWD processes are described below in the three subheadings. The complete LWD analysis is located in Attachment F.3.

Delivery

Large woody debris is delivered to aquatic ecosystems via three main mechanisms: windthrow, shoreline bank erosion, and mass wasting (Stanley et al. 2005). Key areas for delivery of LWD include stream riparian areas, especially along unconfined meandering channels (May and Gresswell 2003), non-accretion shoreforms in the marine environment (Shipman 2004), and steep, landslide prone forested areas adjacent to aquatic areas (Reeves et al. 2003). The delivery of LWD is primarily altered/reduced by shoreline armoring, stream/flow reductions through diversions or withdrawals, removal of shoreline forest vegetation, especially on unstable slopes and removal for safety, recreation and shipping. Furthermore, as the channel size increases, LWD delivery from off site (upstream) increases (Fox 2003). This aspect of delivery was not addressed.

Lake:
Along lake shorelines LWD is mainly delivered through mass wasting and windthrow. Shoreline erosion is not a major concern in lake systems due to the low water velocity found in lakes. Coe (2001) and Hyatt et al. (2005) discovered that in unconfined channels of the Nooksack River, poor LWD recruitment was associated with urban, agricultural and rural zoning. Based on their findings, the analysis used land cover to assess presence and extent of trees and percent impervious surface to assess effects of local development intensity to capture the ability of a pixel to deliver LWD. Windthrow and mass wasting were initially separated and scored independently, but because they received identical scores, they were combined into a single analysis and score.

To score delivery for lakes, pixels with trees and less than 12.5% imperviousness were considered as the highest condition to deliver LWD either through windthrow or mass wasting and received four points. If a pixel was classified as trees but had between 12.5% and 50% imperviousness it was given two points, with the reasoning that windthrow would still be able to deliver LWD to the system. Pixels that were considered trees in the landcover data but had greater than 50% imperviousness were given zero points. Areas with light or medium development and less than 12.5% imperviousness were able to deliver LWD through windthrow and received two points, areas classified as light or medium development with between 12.5% and 50% imperviousness were given 1 point and areas with greater than 50% imperviousness was given zero points All other land cover types or areas with over 50% impervious surface were given zero points.

River:
Along river shorelines, armoring prevents stream migration, which in turn prevents bank erosion and limits the possibility for LWD to be captured by channel processes (Stanley et al. 2005). If the bank was armored, LWD could still be delivered through mass wasting and windthrow. If the shoreline was armored and covered by trees, rock, snow, ice or water and had less than 12.5% impervious surface coverage, the pixel was given three points; if it had between 12.5% and 50% the pixel was given two points, and if it had greater than 50% impervious surface is was given one point. If the pixel was armored and had light/medium development on it and less than 12.5% impervious surface the pixel was given 2 points, if it had between 12.5% and 50% impervious surface it was given one point and if it had greater than 50% it was given zero points. All other land cover types were given zero points.

However, where a river shoreline was not armored, shoreline erosion was analyzed by using natural channel confinement, land use and impervious surface data layers. Stanley et al. (2005) stated, “Channelization, ditching and diking are all factors that prevent the bank erosion process and remove the associated delivery of wood.” Unconfined channels allow rivers to migrate in a more natural pattern, and an unconfined channel with tree coverage on the banks would be the ideal condition for shoreline erosion and LWD recruitment to occur. Unconfined or moderately confined channels with landcover classified as trees, rock, snow, ice and water with between 0 - 12.5% imperviousness were given four points. Unconfined shorelines with the same landcover but with between 12.5% and 50% imperviousness were given two points, and the same areas with greater than 50% imperviousness the shoreline was given one point. An unconfined channel with light/medium development along the shoreline and less than 12.5% impervious surface received one point and, if the areas had greater than 12.5% imperviousness, the channel shoreline received zero points. All other land covers received zero points.

If the river was confined, the channel would not naturally migrate as much, so it would not bring in as much LWD through shoreline erosion. Confined river channels with trees and less than

12.5% impervious surface were given three points, and if between 12.5% and 50% impervious surface was present, two points were given; if the channel had greater than 50% impervious surface zero points were given. The only point given for light/medium development was if the amount of impervious surface was less than 12.5% of the pixel. All other landcover types were given zero points.

Marine:
As with river shorelines, marine shoreline armoring affects the delivery of LWD. If the shoreline was not armored, the proximity and density of trees and shrubs to the shoreline greatly affected the score. If the trees were continuous and adjacent to the shoreline four points were given to the pixel. If the trees were patchy, but adjacent to the shoreline, three points were given. If the shrubs and trees were present, but not adjacent to the shoreline, only one point was awarded. If only shrubs were adjacent, one point was given, because of the future recruitment potential versus the ability to produce LWD at this time. All other combinations of vegetation density and proximity were given zero points.

If the marine shoreline was armored, it was analyzed for landslide potential. Since the shoreline is armored, one of the three main mechanisms for LWD recruitment has been stopped and none of the pixels could score 4 points. If the pixel was in a landslide area, the density and proximity of trees and other vegetation to the shoreline became the indicators of alteration. Shoreline areas that were not in a landslide area were evaluated for windthrow based on the density of trees and proximity to the shoreline. Because patchy trees are more susceptible to windthrow, three points were given to the pixel for that condition. Dense trees adjacent to the shoreline were given two points, and all other vegetation combinations were given zero points. The movement of LWD for this analysis was related to an area's ability to store wood, generally temporarily, rather than the actual movement of a piece of wood from one place to another. Low gradient river channels, confinement, gradient, bridges/culverts and bank armoring are important along river shorelines. Accretion shoreforms in the marine environment are key areas for LWD storage. Given the lower wave energy of most lake shorelines, LWD storage occurs throughout the shoreline, versus at specific types of habitats, although there may be greater accumulation of LWD along the shorelines at the receiving end of a long fetch in the direction of a prevailing wind (Marburg 2006). Typical alterations to the storage capacity of a shoreline are associated with the armoring of the shoreline and to streams that have been channelized, disconnecting them from their floodplains.

For this portion of the analysis, each shoreline type was analyzed differently as described below:

Lake:
Docks are expected to hinder the movement of LWD along a lake shoreline, and property owners may remove LWD that moves into a dock. Thus, pixels with docks received zero points, and those without were given a full four points. The presence of bridges or culverts can impede the flow of LWD to the lake shoreline. Therefore, pixels with either a bridge or culvert through which a stream or river flowed under/through were given zero points, while those without were given four points.

There is currently no way to evaluate the effects of wind and fetch for most King County lakes via GIS, other than for wave action. Therefore this analysis did not score how shoreline alterations would affect the wind movement process for LWD.

River:
In general, lower gradient channels are more likely to trap and retain LWD in large jams than steeper channels. Stanley et al. (2005) states, "Channels with less then 4% slope are more responsive to wood within the channel because wood is more likely to be stored in these areas…" Also, unconfined large channels with lower gradients are key areas that allow more and bigger LWD to accumulate in jams (Fox 2001). To account for channel size – as large channels are more capable of moving LWD than small channels – channel size was broken into small and large categories based on the Salmon and Steelhead Habitat Inventory Assessment Program (SSHIAP) geomorphic river classification. If channel gradient was less than 4% in the small channels the shoreline was given four points. If the channel gradient was greater than 4% and unconfined or moderately confined, three points were given to the pixel, while pixels along confined channels received two points. Large channels that were unconfined received four points. Large channels that were identified by SSHIAP as being moderately confined or unconfined were evaluated based on presence or absence of shoreline armoring, where shorelines with armoring were given 0 points and those without armoring were given four points.

The presence of bridges or culverts can impede the flow of LWD either to the river system from smaller tributaries or within the river itself. Therefore, pixels with either a bridge or culvert through which a stream or river flowed under/through were given zero points, while those without were given four points. Similarly, dams can impede the flow of LWD to downstream areas. While some dams likely have a greater impact than others, they were all treated the same for this analysis, with river reaches downstream of dams receiving no points.

Marine:
In the marine system shoreline armoring was used to evaluate the ability for LWD to settle out on beaches. If the armoring occurred at or below ordinary high water mark, LWD was considered unlikely to settle on the beach and was given a score of zero. If the armor was above the OWHM then it was considered more likely than a beach with armor below ordinary high water mark to accumulate LWD and it was given a three. Shorelines with no armoring were given a score of four. If a dock was present in any pixel a point was subtracted because docks will inhibit LWD movement along shore and often trap LWD on one side of the dock. As with lakes and rivers, the presence of bridges or culverts can impede the flow of LWD to the marine shoreline. Therefore, pixels with either a bridge or culvert through which a stream or river flowed under/through were given zero points, while those without were given four points.

Loss

Loss of LWD was considered by Stanley et al. (2005) to be through its eventual decomposition. However, loss through removal by people for safety, aesthetics or other reasons is also known to occur. Thus, loss was evaluated based on the likelihood that people would remove LWD from shoreline areas, using the concentration of residences adjacent to the shoreline as an indicator.

Rivers and Lakes:
In the lacustrine and riverine systems, loss of LWD was assessed using the land cover data. If light/medium development was present, the pixel received two points. Urban density development received zero points and all other land covers received four points.

Marine:
In the marine system, LWD loss was measured using qualitative impervious surface data from Anchor Environmental Ltd. to indicate level of development. The data are broken into three categories of high, medium and low density, with low representing roughly less than 10% of the

area being impervious surface and high being greater than 75% of the area being impervious surface. High received a zero, while medium received a two and low received a four.

For all shorelines, boat launches and docks were also incorporated into loss on the rationale that LWD would be removed to keep the property open and clear for safety, recreational traffic, or aesthetics. Pixels that included boat launches were given zero points for the high probability that LWD would be cleared from them. Pixels within 200 feet of a boat launch had one point subtracted from their previous land cover classification score.

Modifications from Stanley et al. (2005)
King County made several changes to the Stanley approach for analyzing LWD. First, the natural control of tidal height for marine/estuarine shorelines was added. For marine shorelines, the tidal height is extremely important in defining where LWD can be deposited. Accretion shoreforms (movement) and non accretion shoreforms (delivery) were added to the key areas where the process of LWD is important for marine shorelines. Several other alterations were also added, which are important in reducing delivery, like the reduction of LWD to the system by people pulling it out either for safety or easier recreational access. The rate of loss of LWD due to removal without permits, presumably for recreation or aesthetics, is not well documented in the scientific literature. However, several King County ecologists have seen evidence of LWD removal or modifications on a regular basis over the past 10 years (personal communication: Gino Lucchetti, Sally Abella, Kollin Higgins, March 2006) and believe it may be a significant reduction of LWD available to the system. For more details see Attachment G (Stanley et al. 2005, Appendix G).

<u>Sediment</u>

Sediment processes are an extremely important part of many ecosystems, as well as of primary importance to particular species, including some on the endangered species list. For example, various organisms in both marine and freshwater systems rely on specific substrate particle sizes for appropriate reproductive habitat. Changes to sediment delivery or movement (either too much or too little) can bury these substrates or cause sediment to not to be deposited in amounts and locations consistent with being good habitat for high priority organisms, such as ESA-listed chinook salmon and bull trout. The importance and elements of sediment delivery, storage and loss are described below. While there are important impacts of sediment delivery on water clarity or turbidity, it is not treated directly in this analysis, but is partly captured through alterations to surface erosion in the delivery component. Alterations and scoring for the analysis are described below. Diagrammatic descriptions are located in Attachment F.10.

Delivery

Sediment is delivered to aquatic areas in three main ways: surface erosion, mass wasting events, and through shoreline erosion. While natural rates of sediment delivery are highly variable over time, alterations causing excessive amounts of sediment can be detrimental to an ecosystem (Edwards 1998), just as alterations causing major reductions in sediment delivery can be detrimental in different ways (MacDonald et al. 1994). Key areas for delivery of sediment are steep slopes with erodable soils, landslide hazard areas, and unconfined channels. The primary alterations affecting delivery rates include the removal of vegetation on erodable soils (Washington Forest Practices Board 1997), soil disturbance and clearings adjacent to the shoreline (Nelson and Booth 2002), roads within 200 feet of the shoreline (Washington Forest Practices Board 1997a), shoreline armoring (Williams et al. 2001), and channelization of streams, and increases in stream flows (Nelson and Booth 2002).

The three mechanisms of sediment delivery evaluated in this analysis were shoreline or bank erosion, landslides, and erosion of fine sediments contained in the topsoil. Surface erosion was evaluated by looking at agricultural land use and an analysis of erodable soils recommended in Stanley et al. (2005). Several methods were considered to evaluate the landslide delivery mechanism in lacustrine and riverine shoreline areas. Current King County landslide hazard data does not include approximately the eastern third of the county. This data was compiled through a variety of methods, which meant that similarly collected data for the coverage gap could not be created without a substantial time commitment.

The Shaw-Johnson model (Shaw and Johnson 1995) of landslide hazard analysis was also looked at to supply the primary landslide data. However, it was noted that to use that model appropriately, King County should calibrate it based on local data. Also, the Shaw-Johnson model only evaluates shallow landslide hazards and is intended for use in undisturbed forested areas. Given that several different types of landslides occur in King County, and much of the western half of King County landscape has been highly altered, it was chosen not to use this method. Therefore, a more simplified approach was used to look at landslide hazard risk, by using percent slope to evaluate landslide hazard areas. Percent slope was broken into three categories, less than 25%, from 25% to 40%, and greater than 40%. For marine shorelines, an assessment by Johannessen et al. (2005) of the likelihood of sediment delivery to the shoreline was used for the marine shorelines in place of percent slope.

For surface erosion, in the lacustrine and riverine analyses, if the pixel was in an agricultural area most use types were given zero points. For agricultural land uses, only dairy use received some points, since many of the areas classified as dairy are covered in grassy fields. For those areas not in agricultural land use, if the slope of the pixel was less than 25%, the area was evaluated for erodable soils. Pixels with erodible soils and trees received four points, areas with erodable soils and medium development, grasses, or crops received three points, while areas with erodable soils but having bare ground, clear cuts, or urban development received zero points.

The steeper slope categories were analyzed for landslide hazards by using percent impervious surface within the pixel to improve the land cover data. For the 25% to 40% slope category, pixels with less than 12.5% impervious surface received four points for natural land cover types, while pixels with development or clearing received two to zero points. For pixels with greater than 12.5% impervious surface natural land cover types received three points, while areas with development or clearing impacts received one to zero points.

For the greater than 40% slope category, pixels with less than 12.5% impervious surface received four points for natural land cover types such as trees, rock, snow, ice, wetland, and water, while areas with development or clearing impacts such as urban or residential development and clear cut areas received one to zero points. For pixels with greater than 12.5% impervious surface natural land cover types received two points, while areas with any development or clearing impacts received zero points. The scoring for the three slope categories and the agricultural land use was augmented by subtracting a point from the previous score if a road was present within the first 200 feet of the shoreline.

Shoreline erosion in the lacustrine analysis was evaluated by using the presence of docks as a proxy for shoreline erosion. If the pixel contained a dock it got zero points. Pixels adjacent to docks also received zero points because County staff observations of lake shorelines suggest that armoring typically extends at least 25 feet along a shoreline, and in many cases, along the entire parcel in question. As pixels got further away from a dock they were considered less likely to be armored and received more points. Pixels greater than 25 feet but less than 75 feet away from a dock received 1 point. Pixels with no dock and not located within 75 feet of a dock received four points.

Shoreline erosion in the riverine sediment delivery analysis was evaluated by assessing shoreline armoring, changes to the flow regime caused by dams and loss of forest cover (as indicated by imperviousness of the basin). There are four major dams on King County's rivers (Howard Hansen, Masonry, SF Tolt and Mud Mountain Dams on the Green, Cedar, Tolt and White Rivers, respectively). Each dam has differing levels of impacts on the flow regime, with the Howard Hansen Dam having much larger relative influence than the any of the others. However, for this level of analysis no distinction in relative effect was made, and dams were evaluated equally for impact on the flow regime and consequently on channel sediment dynamics.

Scoring was first separated by shoreline armoring. If a pixel was not armored, and not in one of the four river reaches with a major dam, it was scored based on the % TIA of the basin, with the higher the percentage the lower the score. Areas where the %TIA of the basin was less than 10% received four points, while areas with greater than 25% received one point. Areas that were not armored but located within a dam reach, received two points for less than 10% basin TIA, basins with between 10% and 25% received one point and basins with TIA greater than 25% received zero points. Reaches that were armored and were located below a dam received one point for basins with less than 10% TIA, while any TIA greater than 10% received zero points. Reaches that were armored but below a dam received two points for basins with less than 10% TIA, basins with between 10% and 25% TIA received one point and basins with greater than 25% TIA received zero points.

In the marine analysis, surface erosion was scored based on if the pixel was in an agricultural area. Most agricultural land use types were given zero points. As in the other two analyses, only dairy use received two points, since many of the areas classified as dairy are covered in grassy fields. If the pixel was in a nonagricultural area, it was evaluated for landslide potential based on presence/absence of "feeder bluffs" (bluffs prone to sliding). Intact (i.e., unarmored) feeder bluffs scored four points. Areas with shoreline armoring were classified based on their historic (predevelopment) potential to deliver sediment. While the armoring can decrease the size or frequency of landslides, it does not stop them altogether. Therefore, areas with armored bluffs were given one point. Accretion areas (where sediment builds up) were given zero points since they are generally located a sink for sediment, rather than being a source. Sediment delivery from shoreline erosion was assessed based primarily on shoreline armoring. Areas with no armoring received four points, while areas with armoring received zero to two points, depending on its level of intrusion into the intertidal. Both the agricultural and landslide scores were changed by subtracting one point if there was a road present within the 200 foot jurisdiction.

Movement

Like LWD, movement of sediment primarily involves the temporary storage of sediment. The key areas of sediment storage are depressional wetlands, floodplains, depositional stream reaches, lakes, and the banks of the shorelines (especially accretion shoreforms in the marine shoreline). These areas are primarily altered by draining or filling of depressional wetlands (Kadlec and Knight 1996), loss of channel roughness (e.g. LWD removal or loss), channelization of streams, armored shorelines (Macdonald et al. 1994), dams (Dube 2003), and structures like boat ramps and groins which are oriented perpendicular to the shore in the intertidal zone and which tend to cause sediment to accumulate on one side of the structure (Williams et al. 2004).

For lacustrine and riverine shorelines, movement was evaluated through the loss of wetland areas and the presence of bridges or culverts. Pixels with no estimated wetland loss received four points, while a pixel with any estimated wetland loss was given a zero. Pixels with no culverts or bridges received four points, while pixels with culverts or bridges received no points. The riverine analysis also incorporated shoreline armoring and channelization for its impact on floodplain and in-channel deposition. For floodplain deposition, if the shoreline had a levee present or was channelized, it received zero points. If it did not have either structure, it received four points. For in-channel impacts, if the shoreline pixel was armored (all types, not just levees) it received zero points, while no armoring received 4 points. Originally, evaluating the impact of dams on sediment was expected. However, while some dams can limit sediment downstream, not all dams have the same type or degree of impact, nor is it clear how far downstream impacts should be considered, and it will likely vary between individual dams as well. Therefore, the analysis does not address the impact of dams on the movement of sediment.

On the marine shoreline, shoreline armoring and the presence of docks and groins were the alterations to sediment movement along shore that were analyzed. If a shoreline was armored it was evaluated by its location relative to the intertidal zone. Armoring above ordinary high water mark received three points, while armoring at ordinary high water mark received one point. If a groin or dock was present along with it being armored, two points were subtracted from the armoring score. The sole purpose of a groin is to interrupt the movement of sediment along the shore. Thus, for unarmored shorelines, if a groin was present the pixel received two points. If the unarmored shoreline did not have a groin, but did have a dock it was given three points. Unarmored shorelines without a dock or a groin received four points.

Loss

Sediment loss was not directly addressed in Stanley et al. (2005) because sediment is not “lost” under natural conditions at the watershed scale; it merely moves from one area to another (e.g. from a stream to estuarine/marine waters). While, shoreline armoring could be considered to cause a loss of sediment, in fact the sediment is still present but its delivery has been constrained or altered. Therefore, it was treated under the delivery portion of the process instead of under loss.

King County originally added dredged shorelines as an indicator of loss of sediment to the system. A variety of rivers, lakes and marine shorelines have been dredged over the years to address both perceived and real flooding problems or to increase capacity for boat traffic, etc. The data does not exist to use this as an indicator of change, but because it is a significant loss of sediment from some aquatic areas within King County, it should be noted, even if it cannot be directly assessed in this analysis.

Sub-basin Context

Sub-basin context was added to the sediment analyses by summarizing percent slope, forest cover, road density, and the percent agriculture in the immediate basin draining to the pixel (sub-basin). The scoring for the sub-basin context was treated as a separate scoring branch in the analysis, versus part of the delivery component. This causes the sub-basin context scoring to get equal weighting to the delivery, movement, and loss components of the analysis when the scores are averaged to produce a final score for that process.

The Critical Area Ordinance (CAO) sub-basin layer was used as the base layer for the sub-basin analysis. The sub-basin was first broken out by percentage of total steepness of slope within the basin and then analyzed for percent coverage of trees, rock, snow, ice, wetland, or water. If less than 25% of the basin had steep slopes and less than 20% of the basin was covered by unaltered land cover, zero points were given. If it was between 21% and 40% of the pixel was covered by unaltered land cover, two points were given. If the pixel had between 41% and 80%, three points were given, and if greater than 81% unaltered land cover, it was given four points. If the basin had between 26% and 50% steep slopes and less than 20% of the pixel was covered in unaltered land cover, zero points were given; between 21% to 40% received one point, 41% to 60% received two points; coverage between 61% and 80% received three points; and coverage greater than 80% received four points. If greater than 50% of the basin contained steep slopes and less than 40% of the pixel is covered in unaltered landcover, the pixel received zero points. If unaltered landcover accounted for 41% to 60% of the pixel, one point was given. Unaltered landcover of 61% to 80% received two points and coverage greater than 80% received four points.

The same steep slope classifications were used for analyzing road density (measured in km/km^2). If the basin had less than 25% of steep slopes and the total basin road density was greater than six km/km^2 the pixel received zero points, if the road density was between three km/km^2 and six km/km^2 the pixel received two points; between one km/km^2 and three km/km^2 it received three point and less than one km/km^2 it received four points. In basins where the total slope percentage was between 25% and 50% if road density was greater than six km/km^2 it received zero points, between three km/km^2 and six km/km^2 it received one point, between one and three it received two km/km^2 points and less than one km/km^2 it received four points. In basin with greater than 50% of the basin containing steep slopes and the sub-basin road density was greater than three km/km^2 the pixel received zero points, if road density was between one km/km^2 and three km/km^2 the pixel received two points and less than one km/km^2 the pixel received four points.

Percent of agriculture in the basin was also accounted for in the analysis. If the basin had less than 5% dedicated to agriculture the basin received four points, agriculture density between 6% and 20% received three points, 20% to 50% received two points and greater than 50% received zero points.

Modifications from Stanley et al. (2005)
King County made several changes to Stanley et al's (2005) approach. First, shoreline erosion was added to address lacustrine and marine shorelines in a similar manner as Stanley et al's (2005) in-channel erosion for stream shorelines. In addition, for lacustrine and marine shorelines, wave energy was added to the natural controls of shoreline erosion. Feeder bluffs were added to the key areas for the marine environment. In marine shorelines, a primary concern is the reduction of sediment sources due to the disconnecting of the sources by bulkheading. A recent study of sediment sources/transport in the marine shoreline of King County found large reductions in the sediment sources available to the marine nearshore (Johannessen et al. 2005). Therefore, King County expanded the analysis to look at the reduction of sediment sources as well as increases. Since King County's analysis includes marine shorelines, groins and bulkheading were added at or below ordinary high water as indicators of alterations to the movement of sediment. For more details see Attachment G (Stanley et al. 2005, Appendix C).

Light Energy

Light energy plays an important role in biological processes such as reproduction, growth and predator-prey relationships. Light energy also plays an important role in controlling water temperatures, but that aspect of light energy is not analyzed here due to a lack of appropriate data sets. Alterations to both natural light patterns and artificial light at nighttime were seen as two differing components of evaluating changes to how light energy reaches the shoreline. Alterations to light energy can happen by removing vegetation, increasing artificial light or shading out natural light through overwater structures. Diagrammatic descriptions of the analysis are located in Attachment F4.

Delivery

Under natural conditions the delivery of light to the shoreline is controlled by topography, cloudiness, degree vegetative canopy closure, and seasonal day length. The primary alteration to the delivery of light during the daytime is the removal of shoreline vegetation. One example of an impact due to marine shoreline vegetation removal is the decrease in survival of surf smelt eggs, due to loss of shade and subsequent dessication along marine shorelines (Rice 2006). In addition, it can affect the predator/prey relationships in aquatic ecosystems, by giving an adaptive advantage to visual predators over longer periods of time (i.e, no refuge at night for animals that must rise to the surface to feed).

During night time, the delivery of light can be increased by artificial lighting (sometimes called “light pollution”), which can have unintended consequences on the migration, predation and feeding of various animals. For a detailed discussion of some of the documented impacts, see the review by Rich and Longcore (2005). The primary indicators used for increased night time lighting were the density of streets or houses along the shoreline, and the presence of docks and piers. Larger sports complexes and industrial areas could also be considered indicators of a larger impact than residential development, but there is no specific data on their locations.

To assess vegetation loss in freshwater systems, the land cover data was used to assess natural light delivery. Pixels with trees were given four points whereas the smaller vegetation types (grasses, shrubs) were given one. Areas that are naturally devoid of tall vegetation, such as shorelines in the alpine region, were given four points. Developed shoreline pixels were given zero points because development generally implies vegetation removal.

In the marine shoreline, marine riparian vegetation data (Anchor Environmental 2004) was used to evaluate natural light delivery. Delivery was dependent on trees and whether they were overhanging and adjacent to the shoreline. Trees that were adjacent and overhanging received four points whereas adjacent trees with no overhang received three points. All other combinations of vegetation and shoreline proximity were given zero points because they would provide little or no natural shade to the shoreline.

Artificial light is delivered at night in areas that are highly developed. In the freshwater systems, impervious surface and land cover were used to estimate artificial light delivery. Pixels where impervious surface was less than 50% with light/medium development received two points, and urban development received zero. All other land cover types received four points because few artificial structures would be present to provide light. In areas where impervious surface was more than 50%, light/medium development was given one point and urban development was again given zero points. All other land cover types received two points because the high level of impervious surface indicated some form of infrastructure that would be likely to be associated with lighting at night.

In the marine system a pixel with a ferry terminal or marina was given zero points due to the large amount of light given off by those structures. The rest of the scoring was broken down similarly to freshwater, but using marine riparian data instead of land cover. Pixels where impervious surface was less than 50% with continuous (dense) and adjacent trees or shrubs received four points. Those with patchy trees or shrubs received two points, while other combinations of vegetation received zero points as they indicate some form of development along the shoreline. For pixels where impervious surface was greater than 50%, pixels with adjacent and continuous trees or shrubs received two points. All other vegetation combinations received zero points.

Movement

The movement of light energy is included within delivery and loss.

Loss

Loss of light energy naturally occurs as it is absorbed or reflected by vegetation, the ground, or water surfaces. The depth at which light energy can penetrate is dependent on water clarity or turbidity, which is highly variable under natural conditions. While humans can and often do impact water clarity in various ways, the impacts generally cannot be mapped, are ephemeral in nature, and can change in magnitude over time, so turbidity is not included in this analysis. These natural aspects of “loss” are not included in this analysis.

Tall buildings can also cause light energy to be lost to the shoreline through shading. Given the general lack of very tall buildings in unincorporated King County and the lack of specific data on building heights, this alteration is not included in this analysis. The primary alteration that decreases light’s ability to penetrate the water along the shoreline is the presence of overwater structures like docks, piers, and marinas, and ferry terminals. This type of alteration has been associated with changes to the migration of fish and the ability of eelgrass to grow. While new or rebuilt docks are currently required to have 50% light passage under KC Administrative Rule 25-16-20, it was assumed for this analysis that most existing docks have not been constructed in this fashion and are completely or mostly blocking light from penetrating the water.

Lakes and rivers:
In freshwater, if a pixel contained a dock it was given zero points, while if no dock was present four points were given.

Marine:
In the marine system, areas with marinas or ferry terminals were given zero points, and a single dock, common for single family residences, were given one point as their impact is not as great as the other structures. If no docks were present, the pixel received four points.

Modifications from Stanley et al. (2005)
This process was not included in the analysis by Stanley et al. (2005).

<u>Hydrologic Cycle</u>

Water has a profound effect on many of the other processes analyzed in this analysis. It is the primary driver for delivery and routing of chemical, physical and biological processes in an ecosystem. The hydrologic cycle is described below through its three process components:

delivery, movement, and loss. Alterations and scoring for all three analyses are described below. Diagrammatic descriptions of the analysis are located in Attachment F1.

Delivery

Water is delivered to the landscape in the form of rain and snowmelt. Delivery is controlled primarily by precipitation patterns and the timing of snowmelt. The key areas for the delivery of water in King County are in areas with highly permeable soils and, in higher elevation, rain on snow zones. The key causes of change to the delivery of water are through climate change -- wetter and warmer winters are predicted for the Pacific Northwest (U.S. Global Change Research Program 2000) -- and the removal of forest vegetation in the rain on snow zones (Brunengo et al. 1992, Coffin and Harr 1992).

The analysis does not incorporate climate change at this time, due to the lack of predictability or data in a compatible format for these analyses. It is understood that climate change will cause alterations to the hydrologic cycle, and some estimate of changes should be included in the future.

Due to the lack of local information and reliability of forecast models, the analysis was also unable to incorporate geographical variation in precipitation patterns. However, data does exist to asses impacts of alterations to snowmelt in rain-on-snow zones. The analysis assessed delivery at the pixel scale for lacustrine and riverine shorelines by identifying areas that are in rain-on-snow zones. This method of delivery is not applicable to marine shorelines, due to the absence of rain-on-snow areas in the King County marine shorelines. The analysis used the rain-on-snow zones and land cover to score the areas of water delivery. If a pixel was in a rain-on-snow zone and was forested, had ice or snow as the land cover, or was identified as a shoreline area, the pixel received four points. If it is any other type of land cover, the pixel received zero points due to the alteration of water delivery to the system. If the pixel was not in a rain on snow area it was not scored or averaged info the final pixel score for the hydrologic process. For example, for all of the marine shoreline pixels, delivery was not scored or averaged into total score for the pixel. So, the score was comprised of only the movement and loss components of the process.

Movement

Once water falls on the ground (either as rain or snow) it starts moving across the landscape, either as above ground (surface flow) or below ground (groundwater). The key areas for movement of water are primarily related to the permeability of soils or the lack thereof. The key causes of change to the movement of water are related to changing the ability of the soil to accept water through increases of impervious surface and removal of forest cover (Booth et al. 2002), water withdrawals or impoundments, filling or altering of depressional wetlands (Reinelt and Taylor 1997) and streams. Also note that the movement of water is critical to many other processes such as the movement of nutrients, pathogens, toxins, and sediment in aquatic ecosystems.

The analysis breaks movement of water into surface and below ground components. The surface component is broken into two main pathways for water movement at the surface: through overland flow and as surface storage. For all three shoreline types, overland flow was evaluated using the percent impervious per pixel and then analyzing the percent of total impervious area (%TIA) in the sub-basin. Water flow will increase in areas with impervious surface cover and the % TIA of the sub-basin helps put any particular pixel into a larger landscape context. Pixels with greater than 50% impervious surface received zero, whereas pixels with between 12.5% and 50% impervious surface received 2 points and pixels with less than 12.5% imperviousness received four points. If the sub-basin %TIA was great than 10% an extra point was taken off the total overland flow score.

All three shoreline analyses evaluate the loss of storage at the surface through a wetland analysis that assesses the loss of depressional wetlands at the site and sub-basin scales. At the site scale, if a wetland was not altered or had never been present, the pixel was given four points. If the wetland was altered in some way (not present in current geographic information system data) the pixel received zero points. At the sub-basin scale, the relative percent of altered wetlands in the sub-basin was evaluated. Sub-basins with 0 to 5% change in wetlands received four points. The rest of the scores were derived by dividing the range of wetland loss in all sub-basins into three equal sets and assigning a score of 3 to 0, respectively, for increasing level of lost (filled) wetlands.

The riverine analysis included alterations to the floodplain and the presence of dams as further alterations to surface storage. To capture the alterations in the floodplain, the presence of levees were taken into account. Levees disconnect the river from the natural floodplain, thereby reducing the flood storage capacity at high water flows. If a levee was present, the pixel received a zero score, whereas if no levee was present, the pixel received four points. Note that the scoring does not include all shoreline armoring, only those structures intended to keep water out of the floodplain. Dams also alter the timing and magnitude of water movement in a riverine system, and these alterations often create artificial lakes and impede the flow of water downstream. Reaches above dams or reaches that have no dams receive four points, whereas reaches downstream of dams received zero points because the dam interrupts the natural flow of the water to downstream reaches.

There are also two components for the movement of water below ground (groundwater), shallow sub-surface flow and recharge, and vertical/lateral subsurface flow and sub-surface storage. Groundwater recharge and sub-surface flow are important components to the movement of water through the landscape. The analysis addressed the alterations to this process by evaluating impervious surface and land cover in the same way. The percent of impervious surface is important because it has been documented that alterations to aquatic ecosystems occur with any level of impervious cover in the watershed (Stanley et al. 2005). Pixels with vegetation, rock, snow and ice with less than 12.5% impervious surface coverage received higher scores than developed land uses, with the highest scores going to tree, rock, snow, ice, wetland and water coverage. Pixels that were unaltered with little impervious surface were felt to be able to recharge groundwater and not hinder subsurface flow. Pixels that were considered light to medium development, but did not have greater than 12.5% impervious surface coverage received a point for the potential to allow groundwater recharge and subsurface flow. Pixels with over 12.5% impervious surface scored lower. The amount of impervious surface by sub-basin was also used to account for basin wide impacts of impervious surfaces. Sub-basins with impervious surface from zero to 1% received 4 points. Increasing level of sub-basin imperviousness decreased the number of points received, with greater than 10% receiving one point.

Another major component of water movement is the ability for the landscape to recharge the groundwater, as well as the ability to store groundwater. There are two major causes of alterations to groundwater recharge and storage in the freshwater systems, namely groundwater pumping and roads (Stanley et al. 2005). Groundwater pumping can significantly alter the groundwater flow pattern, and road side ditches often capture the water that would normally become subsurface flow and cause it to become surface water. To capture these alterations, wells and road coverage data were used. In the freshwater systems, where no roads and wells were present, the pixel received four points, while when both were present the pixel received zero points. In the marine shoreline jurisdiction there are no known wells so they were not incorporated into the analysis. Also, shoreline armoring was used in the marine analysis because, like road side ditches, the armoring blocks the subsurface flow and is often converted into surface flow via a pipe and discharged into one spot as opposed to being discharged throughout the reach.

Discharge was not addressed because of a lack of information regarding alterations in groundwater discharge to wetlands.

Loss

Water is lost from an ecosystem in two ways evaporation/transpiration to the atmosphere and through surface or subsurface outflows. It is important to note that when water flows out of one ecosystem, it usually becomes part of another ecosystem downstream, like an estuary. The key causes of change to the rate of water loss from an ecosystem are changes in land cover from vegetated to non-vegetated, stream diversions, and groundwater pumping.

The alterations to the natural loss of water to aquatic ecosystems can occur through evaporation, transpiration, streamflow out of the area, and groundwater flow out of the basin. For all three aquatic shoreline analyses, the process of evaporation and transpiration were captured through alterations to the historic land cover. Pixels in areas classified as vegetation, received higher points than those classified as light or medium development and urban density. In freshwater systems, wells were used to indicate the loss of groundwater to aquatic systems. A special case with riverine shorelines involved assessing the loss of streamflow from the basin. Riverine reaches downstream of water diversion/supply dams were given zero points whereas reaches with no dams or above dams were given the full four points.

Sub-basin Context

The analysis also looked at the delivery of water at the sub-basin scale by summarizing forest cover, wetland loss and total impervious area (TIA) by sub-basin for the lacustrine and riverine shorelines. Scoring for the sub-basin context was treated as a separate scoring branch in the analysis, rather than as part of the delivery component. This causes the sub-basin context scoring to get equal weighting to the delivery, movement, and loss components of the analysis when the scores are averaged to produce a final score for that process.

The Critical Area Ordinance (CAO) sub-basin layer was used as the base layer for the sub-basin analysis. Sub-basins with a high percentage of forest cover received four points. In sub-basins where there is a decreased percentage of forest coverage fewer points were given. Based on peer review input, the levels of TIA by basin were scored by sub-basins with almost no TIA (less than 1%) receiving 4 points; sub-basins with 1 to 3% TIA received 3 points; sub-basins with 3 to 10% TIA received 2 points; sub-basins with 10 to 25% TIA received 1 point, and sub-basins with greater than 25% TIA received 0 points. Basin wide wetland loss was treated in a similar manner. The wetland loss for all sub-basins; was calculated. The scores were then split into four equally apportioned categories. The quarter with the lowest wetland loss received four points, while the category with the greatest loss received only 1 point.

Modifications from Stanley et al. (2005)

This process was originally listed as just “water”; however, because it is really describing various aspects of the hydrologic cycle, it was renamed as such. For more details see Attachment G (Stanley et al. 2005, Appendix B).

<u>Phosphorus</u>

Phosphorus is a naturally occurring nutrient, and under unaltered conditions it enters watercourses through the weathering of rocks and dustfall from the atmosphere. Phosphorus is a limiting nutrient for primary production in the freshwater systems of the Puget lowlands, though generally not limiting in marine systems. Increases in phosphorus input can lead to changes in freshwater ecosystems, such as eutrophication marked by more frequent algal blooms (Stanley 2005). Human activities have altered the landscape and caused increases in phosphorus reaching lacustrine, riverine and marine systems. Phosphorus concentrations in water are often increased through agriculture, flow from septic systems and increases in impervious surface. The process and analysis of phosphorus are described below through the three components of the process: delivery, movement and loss. See Attachment F.5 for the full flow chart.

Delivery

The major natural controls for phosphorus are the surficial geology present, hydrologic processes, and soil erodability, which occur across the landscape. This makes it hard to identify and map “key areas” for phosphorus delivery under unaltered conditions. The primary alterations to the input of phosphorus are increases through the application of fertilizers, pet waste and manure, wastewater, and urban development.

All agriculture practices can add phosphorus to the system, either through fertilizer applications or the stockpiling of manure from livestock. For this reason, all agricultural uses received zero points in all three shoreline analyses. Septic system leakage may also contribute to increased phosphorus in many aquatic areas. For the lake and river analyses, areas that were not located in an area served by sewer systems received fewer points than those areas that were sewered. Sewered areas with light/medium density were given one point and urban density was given zero points, while all other land cover types received four points. This scoring also captured the likelihood of parcels with developed lawns and gardens to contribute phosphorus through the use of fertilizers.

The marine system was evaluated much the same way, except that for areas where land cover was used to identify degrees of development, the marine riparian vegetation data was used instead. Sewered areas where trees and shrubs were continuously adjacent to the shoreline were given four points; patchy trees and shrubs adjacent to the shoreline were given three points; and trees separated from the shoreline were given one point. All other vegetation combinations were given zero points.

Areas not on sewers were evaluated based on whether the pixel was located within Quartermaster Harbor and the marine riparian area. As noted earlier, Quartermaster Harbor has a relatively low flushing rate compared to the rest of the marine shorelines in King County. Thus water quality alterations have a greater impact within the harbor.

Continuous trees and shrubs adjacent to the shoreline were given four points regardless of being in Quartermaster Harbor or not, as that indicated little or no development. Patchy trees and shrubs adjacent to the shoreline were given one point in Quartermaster Harbor and two points elsewhere. All other vegetation types were given zero points in Quartermaster Harbor.

Patchy continuous trees separated from the shoreline outside Quarter Master Harbor were given one point, while other vegetation combinations were given zero points.

For the river and lake shoreline types, the percent TIA in the basin was also included as a separate component of delivery in this analysis. This component was added due to the results of a study that was unable to link any single land use to increased levels of phosphorus (Ebbert, et al. 2000). It was felt that using the impervious surface amounts of the basin would help to supplement the components of delivery. Pixels within basins that were less than 10% TIA received four points, pixels within basins with between 10 and 25% TIA received one point and pixels within basins that have more than 25% TIA received zero points.

Movement

The movement of phosphorus is greatly dependent on the movement of water. See Appendix B for related impacts due to alterations in the movement of water. Phosphorus moves through the system in two forms, either dissolved or particulate. Dissolved phosphorus is the form that is quickly available for uptake by biological organisms and is considered in this category. Particulate phosphorus is attached to particles and moves through the system the same way as fine sediment does (see Appendix C), although it may detach under certain circumstances. Therefore, particulate phosphorus is treated through the sediment process analysis. Stanley et al. (2005) describe the temporary movement of phosphorus as: “Dissolved phosphorus can be temporarily removed from water via four mechanisms: (1) uptake by biota; (2) adsorption to aluminum (Al) and ferric (Fe) oxides and hydroxides and subsequent precipitation out of solution (Walbridge and Struthers 1993); (3) adsorption to soil particles; and (4) the trapping of sediment that has adsorbed phosphorus. Adsorption to soil particles is most likely to occur in finer soils, such as clays, that have a phosphorus deficit (Sheldon et al. 2005).” The primary alteration to the movement involves a decreased capacity to adsorb phosphorus through the loss of depressional wetlands with mineral soils through filling and channelization.

Wetlands slow down water flow, and the associated plant community can store, through growth, some of the phosphorus moving through the aquatic ecosystems. When wetlands are lost, their ability to remove the phosphorus from the system is eliminated. If an area was once a wetland and a portion of it has been lost, the pixel was scored with a zero. Phosphorus can also be adsorbed by clays in soils. Land cover overlain on soil maps indicates whether phosphorus can be adsorbed by these soils. Areas without clay soils were not scored nor were areas where there were no soils data. In freshwater systems, pixels where there was vegetated land cover over clay soils received four points, whereas in light/medium density areas, one point was given to the pixel on the assumption that some of the phosphorus could be adsorbed by the mineral soils in the area. Urban development received zero points.

In the lake analysis, wind movement that can stir up nutrients from the bottom sediments or alter the thermal stratification regime was also considered. Wind effects can be increased by decreasing the number of trees along the shoreline edge that buffer the impact of winds, particularly on small lakes, but potentially affecting all. Land cover is the best way to analyze how this process might have been altered. Pixels covered by trees, wetlands, snow, rock, ice or water received four points. All other landcover types were considered alterations and received zero points.

For the marine shorelines, clay soils and marine riparian vegetation were used instead of land cover. Areas with continuous adjacent trees and shrubs were given four points. Areas with adjacent patchy trees and shrubs were given two points. Areas with continuous and patchy trees and shrubs separated from the marine shoreline were given one point, while all other vegetation types were given zero points.

Loss

Phosphorus is never truly lost or destroyed; it moves from one system to another. Therefore, loss is not addressed in this analysis.

Modifications from Stanley et al. (2005)

King County split phosphorus and toxins into separate processes to facilitate analyzing of alterations and impacts. King County added developed areas with septic systems versus areas with sewer systems as an indicator of increases in phosphorus (Moore et al. 2003). For more details see Attachment G (Stanley et al. 2005, in Appendix D).

<u>Toxins</u>

There are naturally occurring toxins in the environment, for example metals such as copper, lead, zinc, mercury, cadmium and nickel. Toxic metals are naturally in fairly low concentrations in the Puget Sound lowland streams, and natural processes are not considered a significant source of toxic metal for Puget Sound aquatic ecosystems (Stanley et al. 2005). However, human alterations to the landscape can increase the concentrations of toxins to the landscape through agriculture, urban development, and internal combustion powered boats. The processes and the analyses of toxins are described below under the delivery, movement and loss subheadings. The graphic display for toxins is located in Attachment F.8.

Delivery

Bedrock type does not influence metal concentrations in streams, although in some unusual circumstances, pH and atmospheric deposition can result in higher metal levels (Welch et al. 1998). Thus, there is no significant natural source or key area of these toxins to characterize, but delivery to the system would be generally by the same mechanism as for phosphorus.

The major natural controls for toxins are the surficial geology present, hydrologic processes, and soil erodability, which occurs across the landscape. The major increases of toxins come from the application of pesticides, herbicides and other chemicals, many of which are associated with motorized vehicles.

One of the main pathways for toxins to enter the system is through agricultural practices. For all three analyses, if a pixel was in an agricultural area it received zero points because of the potential use of fertilizer and pesticides, with the exception that pixels covering dairy and livestock farms received one point, since they are generally grassy fields.

If a pixel was not located in an agricultural area, land cover was analyzed to assess the potential delivery of toxins to the system. Water in urban areas commonly violate standards for organochlorines, semi-volatile organics and most herbicides and pesticides (Ebbert et al. 2000). Because of this finding, in freshwater systems, areas that were light/medium development received one point, while urban development received none. Areas covered in trees were given four points, and other vegetated land cover areas were given three points. In the marine system, marine riparian vegetation was used to capture development: continuous trees and shrubs adjacent to the shoreline were given four points; patchy trees and shrubs adjacent to the shoreline were given three points; patchy trees and shrubs separated from the shore were given one point and all other combinations were given zero points.

In addition to land clearing, the presence of roads, boats and sewer outfalls are all significant sources of toxins. Roads contribute toxins from brake pads, oil leaks, and other emissions from vehicles. In all three shoreline areas, if there were no roads present, pixels were given four points. If the road was between 100 and 200 feet from the shoreline edge, the pixel received one point, while if the road was within 100 feet, the pixel received zero points.

Boats are also potential sources of toxins. Therefore, in lakes and rivers where internal combustion engines were allowed, the area received zero points. If outboard engines are not allowed (for lakes) or generally not physically possible in rivers, the area received four points. In the marine system, if marinas were present the pixel received zero points, otherwise it received four points. Combined sewer overflows (CSO) also contribute toxins by transporting toxins collected through stormwater runoff. If a pixel was in a CSO discharge area, it received zero points.

Movement

The movement of toxins is greatly dependent on the movement of water. See Stanley at al (2005, Appendix) for related impacts due to alterations in the movement of water. Metals are temporarily stored through adsorption to wetlands soils, specifically soils with a high organic content or clays (Sheldon et al. 2005, and Kadlec and Knight 1996). Pesticides are often moved through ecosystems via bioaccumulation in plants and animals and are often bound to sediments. This means that in areas where sediments are likely to stored, so too will introduced pesticides. The primary alteration to toxin movement involves a decreased capacity to adsorb toxins because of the loss of depressional wetlands with clay and organic soils due to filling and channelization. Where areas did not have available soils data, this could not be evaluated.

Wetlands slow down water, and plants can store, through uptake and incorporation, much of the toxins found in aquatic ecosystems. When wetlands are lost, the ability to remove toxins from the system is taken away. If an area was once a wetland and a portion of it has been lost, the pixel was scored with a zero.

Impervious surface was also taken into account as a large contributor to the rate at which toxins move in an aquatic ecosystem. Along the freshwater shorelines, areas with less than 12.5% impervious surface were given four points, areas with between 12.5% and 50% impervious surface were given two points and areas with greater than 50% impervious surface were given zero points. In the marine system, areas with low impervious surface received four points, medium impervious surface received one point and high impervious surface received zero points.

Loss

Given that most toxins to do not readily breakdown or leave a system unless they flow from one system into another, loss was not analyzed.

Modifications from Stanley et al. (2005)

King County split phosphorus and toxins into separate processes to facilitate analysis of separate behaviors. For toxin inputs, King County added the indicators of roads, marinas, docks and piers, and sewer discharges to the list of indicators. For more details see Attachment G (Stanley et al. 2005, appendix D).

Nitrogen

Under natural conditions, nitrogen is only available to most organisms after it is fixed from atmospheric nitrogen, either by lightning or via a few biological pathways (Schlesigner 1997). Available nitrogen can often be increased in water through agriculture, failing septic systems, and movement across impervious surfaces. Unlike freshwater systems, nitrogen is the limiting nutrient in marine systems much of the time. It can also become limiting in freshwater systems that have been enriched in phosphorus. Stanley et al. (2005) describe nitrogen as: "Nitrogen occurs in several forms: gaseous nitrogen (numerous forms including N_2, NH_3, N_2O, NO_2, and N_2O_4), ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-). The focus of most environmental efforts is on ammonium and nitrate, as they are most readily available for use by organisms and the most soluble in water, and therefore most often associated with eutrophication. Therefore, this analysis focuses on nitrate and ammonium. The analyses for nitrogen are located in Attachment F6.

Delivery

The major natural controls for nitrogen are related to weather patterns and particular species of biological organisms present in the landscape. Human alterations to delivery involve increases in the amount available through septic systems, and the application of manure and fertilizers.

Agriculture practices can add nitrogen to the system either through direct applications of fertilizer or poor manure management. Agricultural areas were given zero points in all three shoreline analyses. Septic system leakage also contributes to increased nitrogen delivery in many aquatic areas. For the lake and river analyses, areas that were not located in an area served by sewer systems received fewer points than those areas that were sewered. Sewered areas with light/medium density were given two points and urban density was given one point, while all other land cover types received four points. This scoring method captured the potential of lawns and gardens to contribute nitrogen through the use of quickly dissolving fertilizers.

The marine system was evaluated much the same way, except that for areas where land cover is used to identify degrees of development, the marine riparian vegetation data was used instead. In areas that are sewered, trees and shrubs that were continuously adjacent to the shoreline were given four points, patchy trees and shrubs adjacent to the shoreline were given three points and trees separated from the shoreline were given one point. All other vegetation combinations were given zero points. Areas that are not on sewer were evaluated based on whether or not the pixel was in located within Quartermaster Harbor and within marine riparian vegetation. As noted earlier, Quartermaster Harbor has a relatively low flushing rate compared to the rest of the marine shorelines in King County. Thus water quality alterations have a greater impact within the harbor. Continuous trees and shrubs adjacent to the shoreline were given four points regardless of location as they indicated little or no development. Patchy trees and shrubs adjacent to the shoreline were given one point in Quartermaster Harbor and two points elsewhere. All other vegetation types were given zero points in Quartermaster Harbor. Patchy, continuous trees separated from the shoreline outside Quarter Master Harbor were given one point, while other vegetation combinations were given zero points.

Movement/Loss

Stanley et al. (2005) describe the movement of nitrogen as: "nitrogen can be temporarily stored or transformed from one form to another through one of three mechanisms: (1) nitrification; (2) biotic uptake; or (3) adsorption. As nitrogen moves through a watershed, it can be assimilated and then released numerous times, a process called "nutrient cycling." The key areas for the movement of nitrogen to occur are depressional wetlands and headwater streams.

Alterations of these areas through channelizing or filling have important impacts to the movement of nitrogen in a system.

The loss of nitrogen under natural conditions occurs through denitrification (a process that affects nitrate) and volatilization (affects ammonium). Key areas for this to occur are depressional wetlands and riparian areas. The primary cause of change that can be characterized is the alteration of depressional wetlands.

In the analysis, movement and loss were grouped together because often the same components affect both movement and loss. Wetlands slow down water, and plants can incorporate much of the nitrogen found in aquatic ecosystems. When wetlands are lost, the ability to remove the nitrogen from the system is taken away. If an area was once a wetland and a portion of it has been lost, the pixel was scored with a zero.

Channelization of roadside ditches and watercourses also take away the ability for the water to infiltrate the ground, and remove the potential for denitrification. A King County data layer that shows the location of agricultural ditches was used to indicate channelization. Note that this data is primarily associated with agricultural uses and does not fully represent the full extent of roadside ditches. If a pixel was in a ditched area, it received zero points; otherwise it received the full four points.

Modifications from Stanley et al. (2005)
King County also included sewer discharge points as another indicator of increases in the delivery of nitrogen to aquatic systems. For more details see Attachment G (Stanley et al. 2005, Appendix E).

<u>Pathogens</u>

Pathogens are a natural part of the environment, usually finding their way to aquatic ecosystems through fecal material from wildlife (Stanley 2005). Pathogens have increased in areas with increased concentrations of untreated fecal waste, both human and animal. This increase has mainly been associated with septic systems, in addition to agricultural areas. Pathogens include bacteria, protozoans, and viruses considered to be harmful or dangerous to people and other creatures, as well as to the normal functioning of the ecosystem. The chart of the analysis is located in Attachment F.7.

Delivery

Delivery of pathogens occurs through deposition of fecal matter from wildlife under natural conditions. As this occurs all across the landscape, there are no key areas. Failed septic systems, manure applications, and livestock operations are the primary human alterations that increase the levels of pathogens. Concentrations of wildlife in certain areas, such as manicured lawns that attract Canada geese, can also act as sources.

Agricultural areas deliver pathogens through the manure from livestock operations. For all three analyses, areas designated as horticultural were given four points, while mixed use areas of both livestock and horticultural were given three points. Dairy and livestock operations were given zero points. Areas with septic systems were also seen as potentially increasing pathogens. The US Environmental Protection Agency estimates that 10 to 30% of septic systems nationwide are not functioning properly (US EPA 2001). Developed areas with septic systems are likely to contribute pathogens to aquatic ecosystems. For freshwater systems, land cover and sewer system coverage was used to separate out vegetated areas from areas of development. For unsewered areas, if the pixel was defined as light/medium residential it received two points, whereas if it was urban it received zero points. Areas that were vegetated received four points. Along the marine shoreline, areas with septic systems were more scored lower in Quarter Master Harbor. Instead of land cover, the marine riparian vegetation data were used as indicators of development. There are only two small areas along the marine shoreline of unincorporated King County that are currently served by sewer systems, while the rest are on septic systems.

Sewered areas were not considered sources for human pathogens. Primarily, parks, beaches, and expansive lawns can all increase delivery through goose and un-scooped pet waste. Parks and beaches are heavily used by people and their pets and, while “poop scooping” is legally required, the law is often ignored. Expansive lawns on private residences and parks offer premier habitat for Canada geese and semi-domesticated ducks, which can also be large contributors to animal waste in shoreline areas. A geographic information system layer named “the fecal layer” included the parks and beaches with open areas where the likelihood of people exercising their pets is high. Large open areas and private lawns along shorelines were mapped as well. Pixels that were included as a public beach or park in a sewered area received zero points; all other land cover types received four points.

Movement

Stanley et al. (2005) describe the movement of pathogens as: “The movement of pathogens includes three components: transport, adsorption, and sedimentation. Adsorption and sedimentation play an important role in temporarily removing sediment and pathogens from the water column and storing them within the aquatic ecosystem. Natural events, such as high flood flows, can re-suspend sediments and pathogens and transport them downstream into other aquatic ecosystems. Depressional wetlands are key areas for removing sediments and pathogens due to low water velocities, high residence times, filtering vegetation, and soils suitable for adsorption.” The key areas for this to occur are wetlands, streams and rivers which are not disconnected from their floodplains, and especially depressional wetlands with mineral and organic hydric soils. Ditching/channelization, impervious land cover, and filling or draining of wetlands within a watershed are the primary factors causing a reduction in the time that pathogens spend in environments that cause their mortality.

Movement and loss were grouped together in the analysis because the same components affect both pathways. Wetlands will slow down water and the plants will incorporate many of the pathogens found in aquatic ecosystems. When wetlands are lost, so is the ability to remove pathogens from the system. If a pixel was once a wetland and a portion of it has been lost, the pixel was given zero points. Otherwise, if a wetland has been unaltered or never was present, the pixel received four points.

Total Impervious Area (TIA) was also used to measure movement of pathogens. Stanley et al. (2005) stated that if more than 10-25% of the watershed is covered by impervious surface, bacterial standards will frequently be exceeded, especially during wet weather conditions. Also, areas with increased TIA will allow pathogens to move more quickly in overland flow and stormwater runoff to aquatic systems giving less time for natural loss mechanisms to occur. If there was less than 10% TIA in the basin a score of four was given to the pixel. If the TIA was between 10 and 25% the pixel received one point, while anything over 25% received zero points.

Channelization of roadside ditches and watercourses also contribute to the quick movement of pathogens from sources to aquatic areas. Roads and ditched watercourses were used to represent channelization. If a pixel was contained a road, the likelihood of roadside ditch was high, which would then channel the water away from the road to prevent flooding and direct it to the nearest waterbody. Data on ditched watercourses was also used to capture areas where streams have been channelized. If either a road or a ditch were present in the pixel, it received zero points; otherwise it received four points.

Loss

The loss of pathogens occurs through death. While a variety of factors lead to the death of pathogens, the amount of time pathogens are delayed in movement through certain aquatic areas appears to a key element to their mortality. Depressional wetlands are a key area responsible for the loss of pathogens through predation by other microbes. Alterations to these areas cause an increase in the number of pathogens available downstream.

Modifications from Stanley et al. (2005)

No changes were made. For more details see Attachment G (Stanley et al. 2005, appendix F).

Weighting Scores within Processes

The goal of weighting certain scores over others was to improve the analysis tool's ability to represent the functionality of each process. As noted earlier, each process was scored based on three components (delivery, movement and loss), with the addition of sub-basin contexts for sediment, hydrology, and phosphorus. After the initial analyses were completed, the weighting of scores within each process and between processes was evaluated, with the idea that some elements of a process could be more important than others at driving the outcomes, as well as some processes defining conditions more readily than others.

Not enough information on the relationships between processes could be found to justify the weighting of some processes more than others on a pixel-scale, so no weighting of the importance between processes was attempted. However, weighting of specific components within several of the processes appeared appropriate, due to the high importance of certain elements within each process being evaluated (see Table 6). Note that much of the weighting scheme were based on the experience and best professional judgment of staff, since very little information could be found in the literature

Table 6. Weighting of Shoreline Ecological Processes

Process	Marine	Riverine	Lacustrine
Sediment	**D**	none	none
Hydrologic Cycle	none	**M**	none
LWD	none	**D**	**D**
Phosphorus	none	none	**D**
Nitrogen	none	none	none
Toxins	**D**	**D**	**D**
Pathogens	**D**	**D**	**D**
Light	none	none	none
Tidal influences	none	none	none
Wave energy	none	none	none

D = Delivery M = Movement L = Loss

Therefore, the components of each process for each shoreline type were analyzed to determine if a particular component was a driving factor for the process. For example, in the marine sediment process, the delivery component was identified as the driving factor for the overall process because if sediment was not getting into the system, the movement component would not be able to function properly, while movement could be heavily altered, but not necessarily impact the system nearly as much as delivery. Thus the delivery component was selected for weighting. In general, delivery was judged most often to be relatively more important than movement and loss, which is likely due to the shorelines generally being the place at which delivery occurs, and so alterations would have a great deal of impact.

In the analysis tool, if a component was selected for weighting, after the component score was determined, it was multiplied by two. This allowed for the component to be counted as double within the process score. Following the marine sediment process example, the delivery score accounted for two-thirds of the score while movement score accounted for one-third of the score (note that there was no loss component for the marine sediment process)

Defining Reaches and Data Aggregation

The alterations analysis creates an enormous number of pixels (25 ft^2) and calculates alteration scores for each one across all of the jurisdictional shorelines in King County. For example, the analysis output from analyzing the riverine shorelines alone results in scoring a total of 4,237,535 pixels. Aggregation of the pixel scores into larger units (shoreline reaches) is necessary to make the shoreline alterations analysis results useful for considering shoreline designations, along with the other attributes used in designation (see discussion of uses of the analysis results in Section 1.E).

For the three different types of shorelines, separate sets of geomorphic and ecological criteria were identified for defining reaches, in part due to the differences in character, intensity, and effect of identified processes along each shoreline type. There were also differences in the amount of information available from previous studies for each type of shoreline. This resulted in three different methods for choosing reach boundaries, based on the type of shoreline (riverine, lacustrine, or marine).

Defining Reaches for Riverine Shorelines

The Salmon and Steelhead Habitat Inventory and Assessment Project (SSHIAP) provided the only comprehensive, geomorphically-based reach delineation that includes all the King County rivers and streams under shoreline jurisdiction. This delineation was developed jointly by the Washington Department of Fish and Wildlife and the Northwest Indian Fish Commission in order to construct a database that could be used to improve salmonid habitat and fishery management.

The reach delineations were based on gradient (change in elevation between upstream and downstream ends of segment) and confinement (ratio of floodplain width to channel bank-full width). The database contains other attributes that may ultimately be useful for consideration in shoreline management, including habitat types, salmonid use and barriers, temperature, woody debris, water withdrawals, land use, and both literature and information sources. However, these latter attributes are not as consistent and uniformly applied as the gradient and confinement attributes. It should be noted that the SSHIAP database reach lengths are highly variable, ranging from as short as about 100 m to several kilometers. In a future analysis, some reaches may be lengthened or shortened, depending on needs for designation, assessment of cumulative impacts, and restoration analysis. For more information see: http://www.nwifc.wa.gov/sshiap/other.asp)

Defining Reaches for Lacustrine Shorelines

There is very little organized information available for the lakes within the county that can be used to split lacustrine shorelines up into coherent reaches based on geomorphology. Sediment studies, such as grain size analyses, have been done rarely and not systematically. In addition, little or no information has been compiled county-wide on the extent of armoring, artificial beach emplacement, dredging, or other alterations by property owners. Drift cells are not defined for the large lakes, such as the studies on marine shorelines, and no information on circulation patterns is available for lakes other than Washington or Sammamish.

A simple scheme was devised of overlaying maps of lake bathymetry (where known), wetlands adjacent to shorelines, stream inlet and outlet locations, and the slope of land immediately surrounding the lake shorelines. Using these characteristics to differentiate lake shorelines into sections provided initial reach definition that could be used to aggregate pixel scores for the lake shorelines included in the program. Many lakes located in the forest production zone and on federally owned and managed lands were not broken into reaches for analysis, since land use and conditions were relatively uniform around the shorelines.

Defining Reaches for Marine Shorelines

WDNR’s Shorezone segments were initially considered as the reaches for the marine shoreline. However, there was not enough of a satisfactory description of what geomorphic data went into choosing the end points of each segment that it did not appear reproducible. Segments also appeared to be frequently broken up more by habitat patches than geomorphically defined areas. Therefore, reaches in marine shorelines were classified by defining sections of shoreline within a drift cell based on sediment delivery, transport, and accretion data from Johannesen et al. (2005).

Data Aggregation for Each Reach

As noted earlier, pixel scores for each process were on a 0-4 scale (see Table 7), but the final overall score was converted to a percentage scale related to degree of alteration in order to account for differing point totals between processes. The overall pixel score (for all the processes added together) was expressed as percentages of the possible total so that final scores range from 0 – 100. These final pixel scores were then averaged for the reach. Results from the aggregation process should ideally produce a quick and thorough way to assess the reach's essential character, while also giving some information on the extent of variability within the reach and size of the reach. Figure 8 contains a graphical example of how the pixel scores are averaged into reach scores.

The mean score of all pixels within a shoreline type is reported. However, because of the potential for large ranges or variability of scores of the pixels clustered into a reach, some measure was needed to report on whether or not a reach was fairly homogeneous in pixel scores (small range or very few pixels scoring unlike most of the others in the group), or whether there was a great deal of variation in the group (large range with many pixels scoring throughout the range). This was important in order to make sure that important information was not lost by the summarization of pixel scores into larger units.

If the pixel scores within a reach were fairly homogeneous, the coefficient of variation (standard deviation divided by the mean) should be small. If the pixel scores were more heterogeneous, with a large range and pixel scores dissimilar within the group, the coefficient of variation should be large. Another consideration was whether the pixel scores were normally distributed (bell-shaped curve), since the mean describes a normal distribution very well, but may sometimes mischaracterize a non-normal distribution. To look at this, the median was subtracted from the mean. If the difference was small, a normal distribution is indicated, while a larger difference suggested a majority of values were to one side or other of the center, skewing the frequency distribution.

Patchiness of score distribution was analyzed by plotting the coefficient of variation against the difference between the mean and median scores for the combined processes for each reach. If the reach fell outside the middle cluster, the actual pixel scores were examined for distribution, to make sure a concentrated area of low or high scores would be taken into account in designation and management decisions later.

The mean score for each reach was rounded to the nearest whole number and placed into one of five rating categories, as shown below, based on evenly spaced classifications from 0 – 100 and described in general as "reach quality." Reach quality reflects the degree of ecological process integrity (amount of alteration) along the shoreline reach.

- 0-20 was classified as Low (L) quality, which is equivalent to low process integrity or high alteration of processes;
- 21-40 was Medium-Low (ML) quality, which is equivalent to medium-low process integrity (moderately high alteration of processes;
- 41-60 was Medium (M) quality, which is equivalent to medium process integrity (medium alteration of processes);
- 61-80 was considered Medium-High (MH) quality, which is equivalent to medium-high process integrity (moderately low alteration of processes);

- 81-100 was High (H) quality, which is equivalent to high process integrity (low alteration of processes).

Figure 8. The pixels scores on the left are averaged by reach to produce a single reach score on the right.

The mean ratings for reaches are shown in maps contained in the map Folio, Map E5 a-d. The ratings for each reach are not reported in tabular form in this report, but can be viewed for specific reaches at www.metrokc.gov\shorelines.

Summary of Alterations Analysis Results

Results of the shoreline alterations analysis have been summarized by averaging the reach scores by process for each shoreline type for general locations within the county (Table 7). These locations include: the lowland (western third) of the County that primarily supports residential, commercial, and agricultural use; the privately managed Forest Production District (called FPD Non-Federal Lands in the table); and the state and federal forest lands and wilderness areas (called FPD Federal Lands in the table). For each process, the average rating for all reaches in each location is reported. For example, the average rating for all marine shorelines for the process of light energy is Medium (M). Along with the individual process ratings, the overall average rating for all processes for the reaches in each location is shown at the bottom of the process list.

The second portion of Table 7 reports the percent of shoreline reaches (also separated by shoreline type and location) that fell within each rating category. For example, 2.9% of the marine reaches were rated as Low quality and 20.0% were rated as High quality.

Table 7. Alteration Analysis Summary: Average Reach Ratings for Unincorporated King County

	Marine	Lake scores by geographic location			River scores by geographic location		
Ecological Process	**Vashon**	**Lowland**	***FPD Federal lands**	**FPD Non-Federal Lands**	**Lowland**	***FPD Federal lands**	**FPD Non-Federal Lands**
Light	M	MH	H	H	MH	H	H
LWD	M	MH	MH	MH	M	MH	M
Nitrogen	MH	H	H	H	MH	H	H
Phosphorus	MH	MH	H	H	MH	H	H
Pathogens	MH	MH	H	H	MH	H	H
Toxins	M	MH	H	H	MH	H	H
Sediment	ML	MH	MH	MH	M	H	MH
Water cycle	M	M	H	MH	M	H	MH
Wave energy	M	MH	H	H	N/A	N/A	N/A
Tidal influences	MH	N/A	N/A	N/A	N/A	N/A	N/A
OVERALL	**M**	**MH**	**H**	**H**	**MH**	**H**	**H**
Percentage of reaches in each rating category:							
Low	2.9	0.0	0.0	0.0	0.0	0.0	0.0
Medium Low	23.7	1.0	0.0	0.0	2.2	0.0	0.0
Medium	31.7	1.1	0.0	0.0	34.6	0.0	0.1
Medium High	15.6	78.9	9.5	3.1	45.7	2.0	11.1
High	26.1	19.1	90.5	96.9	17.6	98.0	88.8

Note: FPD = Forest Production District.

In general, the analysis verifies that shorelines in the Puget lowlands have undergone more alteration than those in the Forest production zones and alpine areas of the County, which are largely of high quality and relatively unaltered.

The summary shows that lakes in both the Federal and non-Federal forest lands rated below the highest category for the processes of LWD and sediment. A significant amount of land in the Cascade foothills and mountains was classified as “steep slopes/no data” rather than as “rock-snow-ice” in the land cover database (see discussion in Section 2.B, Data Sets Used Frequently in the Alterations Analysis), which probably contributed to the downgrading of the ratings slightly. This was particularly true of the alpine areas, where the lakes are commonly surrounded by very steep slopes that are difficult to classify accurately with Landsat information.

Shoreline reaches with well known conditions were evaluated to verify and illustrate the analysis results (see Table 8). The example reaches include:

- Washington 2: Southwestern shoreline of Lake Washington remaining in King County jurisdiction, between the cities of Renton and Seattle. Known to be more altered.
- Langlois 2: Northern shoreline of Lake Langlois, near Carnation. Known to be less altered.
- River 1702: Right bank of Cedar River, near Dorre Don. Known to be more altered.
- River 1708: Left bank of Cedar River opposite River 1702. Known to be less altered.
- Marine 113: Quartermaster Harbor, north shoreline near the connection between Vashon and Maury Islands (Portage). Known to be more altered.
- Marine 212: Along the northwestern shoreline of Maury Island. Known to be less altered.

Table 8. Results of shoreline alteration analysis on particular reaches

Ecological Process	Washington 2	Langlois 2	River 1702	River 1708	Marine 113	Marine 212
Light	L	H	M	H	L	H
LWD	L	H	M	M	L	H
Nitrogen	ML	H	MH	H	M	H
Pathogens	M	H	MH	MH	M	H
Phosphorus	ML	H	MH	MH	ML	H
Sediment	M	MH	M	MH	L	H
Toxins	ML	H	M	H	L	H
Water	ML	MH	M	M	ML	H
Wave energy	ML	H	N/A	N/A	ML	H
Tidal influences	N/A	N/A	N/A	N/A	ML	H
Percent of reaches in each rating category:						
Low	0.2	0.0	0.0	0.0	77.6	0.0
Medium Low	88.3	0.5	21.7	2.6	22.4	0.0
Medium	11.2	1.9	20.6	0.5	0.0	0.0
Medium High	0.4	1.8	55.6	88.4	0.0	3.7
High	0.0	95.9	2.2	8.5	0.0	96.3

Examination of the process ratings for the selected reaches shows that the analysis tool performs very much as it was designed to do. Shorelines that are known to be highly modified were rated low for most of the processes examined, while the shorelines known to have fewer alterations nearly always rated much higher.

C. Basin Context

The ecological condition of a shoreline is the result of factors acting both within and external to a given shoreline reach. Basin context was factored into the reach ratings for two ecological processes (sediment and hydrologic cycle), but was not broadly considered within the alterations analysis. Thus, in addition to assessing reach-scale conditions, the conditions of the broader basin that contribute to and control shoreline processes were summarized and rated.

For each type of shoreline (river, lake and marine), different terminology is used to denote the basin (sub-basin, catchment and drift cell); this difference is clarified below.

Below is a description of the methodology used to summarize basin conditions that provide the context for river, lakes and marine shorelines. A low, medium or high (worst to best) overall basin condition rating was assigned to each basin. Please see Attachment B for tables that detail the ratings by basin; see Sections 1, 6 and 7 for a discussion of how reach and basin conditions are generally proposed to be used in reevaluating the Shoreline Master Program, and specifically used in cumulative impact analysis and restoration planning.

Rivers

Sub-basin Boundaries

Large river basins were delineated into smaller sub-basins relying on boundaries from WRIA salmon recovery plans, where available, or by delineating sub-basins based on common topography, geomorphology and land use conditions when not.

Sub-basin Conditions

The condition of each sub-basin was assessed using a combination of information from WRIA salmon recovery plans, a sub-basin ecological condition analysis used in implementing the King County Critical Areas Ordinance, shoreline biological data, and a visual review of upstream or headwater land use patterns.

Conditions of upstream areas -- or of headwater and mid-reach areas for sub-basins without upstream areas -- were qualitatively rated for each sub-basin containing one or more shoreline reaches. Ratings were based on available information. Best conditions (highest ratings) occurred when upstream or headwaters were dominated by protected lands (e.g., natural areas, parks and wilderness areas), forestry uses, or when those uses dominated headwater areas and where land development was mostly rural residential, with no or relatively low levels of agriculture, sub-urban and urban land uses concentrated in lowermost reaches of a sub-basin.

Low ratings were applied when urban, suburban, agricultural, commercial and industrial land uses were concentrated in upstream or headwater areas or widely distributed within a sub-basin.

Medium ratings were given when an upstream area did not clearly fit into either the high or low category or when a dam was considered to have relatively large effects on flow, sediment or LWD regimes of downstream areas in an otherwise high condition.

Of the 55 river sub-basins evaluated, 36 were rated high, 15 were rated medium and 4 were rated low.

Lakes

Catchment Boundaries

The catchment basin is defined as the geographical unit of land that drains to any particular lake. A specific catchment for each lake was delineated for this basin context analysis, as available geographical perimeters of drainage areas pertain to river and stream drainages rather than lake catchments.

Catchment Conditions

Assessment of habitat inside catchment boundaries had not been previously completed, but some data already assembled could be used. The ecological condition analysis used in implementing the King County Critical Areas Ordinance basin ratings was considered, with the caveat that often these ratings included areas beyond the lake catchment and so might contain a bias related to areas that are nearby, but not contributing water to a particular lake. Where available, trophic status evaluations (based on data concerning nutrient concentrations and algae populations in the lake water) were also included. The bulk of this information has been collected by King County staff over the years, aided by volunteer monitors in the Lake Stewardship Program or through the County Large Lakes project, which is charged with assessing water quality in Lake Washington and Lake Sammamish. The length of time during which water was analyzed was considered, as well as the trophic classification. There are three levels of trophic status: oligotrophic, mesotrophic, and eutrophic, in ascending order of nutrient concentration and size of algae populations. When a lake is termed borderline, the trophic state named is the higher of the two possibilities: for example, borderline mesotrophic means the lake is on the threshold between oligotrophy and mesotrophy.

Since increased urbanization and land development is positively correlated with increased delivery of nutrients in a catchment (May et al, 1997), there can be a relationship between the water quality of a lake and the quality of the surrounding basin, although other factors can also contribute. To make the basin assessment catchment specific, the amount of land within the basin classified as urbanized (light to heavy) or affected by logging or agricultural activities (based on the 2002 UW landcover information) was considered. These percentages were compared to the critical areas basin rating and trophic state information to come up with the overall qualitative rating for the catchment draining to each lake.

The shoreline alterations rating found in the basin context table reflects the average percent of intact processes calculated for all reaches delineated along the lake shoreline. For some lakes, only a single reach was designated if the geomorphic conditions were similar around the perimeter. However, most lakes had at least 2 and as many as 28 reaches, depending on bathymetry, shoreline slope, number of inlets and adjacent wetlands.

Of the 105 lake catchments evaluated, 81 were rated high, 12 were rated medium and 12 were rated low.

Marine shorelines

Drift Cell Boundaries

Unlike the freshwater systems which are primarily defined by their surrounding watershed or basin, marine shoreline areas are generally defined by the drift cell in which that shoreline is located. Drift cells are an independent segment of shoreline along which littoral movements of sediments occur at noticeable rates depending on wave energy and currents. Each drift cell typically includes one or more sources of sediment (e.g. a “feeder bluff” or stream outlet that spills sediment onto a beach), one or more transport zones (within which the sediment drifts along the shore), and one or more accretion areas (e.g., a sand spit) where the sediment is deposited. Drift cells maps can be viewed on line at https://fortress.wa.gov/ecy/coastalatlas/viewer.htm under the “physical features” data folder.

Drift Cell Conditions

Drift cell conditions were rated based on the extent and distribution of shoreline that was armored, the amount of sediment sources lost due to shoreline armoring and the riparian condition. A series of existing information about drift cell conditions was considered. Land cover and forest conditions were derived from data collected by Anchor Environmental in 2004. The data was compiled by looking at 2002 orthographic and 2001 oblique photos and characterizing the vegetation type 200 feet inland. The data was then field verified. The amount of impervious surface within 200 feet along the shoreline was also collected in the same effort by Anchor Environmental and classified into High, Medium and Low levels of imperviousness. The geomorphic, percent shoreline armored, and percent sediment source lost data comes from a study of King County shorelines in 2005 (Johannessen et al. 2005). The known key biological resources for each drift cell were compiled from the WDFW Priority Habitat and Species database (forage fish and birds) and the WDNR Shorezone database (aquatic vegetation).

Also considered were three existing ratings for each drift cell. The ecological condition analysis used in implementing the King County Critical Areas Ordinance basin ratings was considered, with the caveat that this rating was done the more recent data noted above was collected. The WRIA 9 Salmon Conservation Plan did not rank or prioritize between drift cells, primarily because most of the marine shoreline condition data was not compiled. Since the plan was completed, two reports that supplement the plan have been published which rank some of the drift cells (Johannessen et al. 2005 and Anchor 2006). The drift cell rankings, where available, were included in the table.

Of the 41 marine drift cells evaluated (34 on Vashon Island and 7 on Maury Island), 16 were rated high, 14 were rated medium; and 11 were rated low.

D. Overview of Biological Resources

An inventory of existing biological data available to King County has been compiled for the purpose of informing decisions regarding restoration planning and shoreline designations (see Sections 1 and 7 for discussion). Each dataset was evaluated for its usefulness for each purpose. Most of the data sets included in this inventory are County-wide in scope and, unless noted, are available for all unincorporated shorelines within King County.

The data presented in the Map Folio Maps E7.a, E7.b, and E7.c. and described below represent the best geographic data for the species that the King County Comprehensive Plan directs shall or should be protected. Generally, there are two types of biological data presented on these maps: species occurrence data and species habitat data.

1. Species occurrence data, such as red-tailed hawk point data from DDES, are generally nest observations that were made when someone was on a particular site for a particular reason: in no way are any of these datasets intended to be comprehensive compilations of all the breeding locations for a given species. The data has typically been collected opportunistically, and very rarely have the breeding sites been monitored to determine

the longevity or current status of a site. Nonetheless, it may also be assumed that if a given species were nesting at a given locale historically, the location must have previously and may still contain the habitat elements required by the species for nesting.

2. Habitat data show up in geographic information system files as either terrestrial habitat polygons or stream reaches. The polygons are either fully contained within or partially intersect the area of shorelines jurisdiction and typically contain riparian and/or upland habitat as well as the shorelines. These habitat polygons are assumed to contain habitat elements required by the named species for at least its breeding season. Habitat polygons that are not specific to a particular species are also used and described below; these data may include large forested tracts, old-growth forest, areas of high snag concentrations, or cliffs. The stream reach data are in-stream habitat areas for species such as salmonids and freshwater mussels.

The available biological data is not appropriate to use for characterizing all biological processes or functions occurring in the shorelines jurisdiction. Biological functions include reproduction, resting, and migration, as well as food production and delivery. Some of these functions may be captured for some species within breeding habitat polygons. However, most of these functions will be captured via other elements of the shoreline alterations analysis (see Section 2.A above). Biological processes are extremely complex. In addition to reproduction, they also include predation, excretion, respiration and other functions and interactions of organisms; however no known data are available to address these other biological processes.

Below is a list of the data used to inventory aquatic habitat (E7.a), terrestrial habitat (Map D7.b), and forest value and wildlife network (Map E7.c).

Aquatic Habitat

- Salmonid, steelhead and bull trout distribution in Watershed Resource Inventory Area (WRIA) 7, 8, 9, and Vashon Island – Includes data on likelihood of species presence as well as rating of reliability of data source.
- Vashon Estuary – as mapped from WDFW's Priority Habitat and Species Database (PHS) database.
- Mussel (Margaritifera falcata) habitat in Bear Creek Basin – These data were produced using King County staff observations of live freshwater mussel beds. The presence of native freshwater mussels generally indicates good water quality, and high water quality is required to sustain the extant populations. These reaches were designated by including that part of a stream where mussel beds are known to exist and the full extent of that reach upstream from the beds, because it is assumed that all water upstream of a bed must contain and subsequently maintain good water quality in order to sustain the mussels.
- Waterfowl Concentration Areas – a Priority Habitat as mapped from WDFW's PHS database.
- Cavity-Nesting Ducks – a Priority Habitat as mapped from WDFW's PHS database.
- WDFW PHS data for marine plants and spawning grounds of certain species documented within or near shoreline jurisdiction – These species and habitats include surf-smelt spawning beaches, sand lance spawning beaches, and herring spawning grounds.

- Washington State Shorezone Inventory – Areas of kelp and eelgrass.
- WDFW PHS data for aquatic species documented within the shoreline jurisdiction – Aquatic species include Barrow's Goldeneye, Common Loon, Wood Duck, Harlequin Duck, Tailed Frog, and Western Pond Turtle. These potentially sensitive data are displayed at the basin scale, but site locations could be used for designations and restoration planning.
- Salmon and Steelhead Habitat Inventory and Assessment Program fish barrier data – This includes Dams, Natural Barriers (e.g., high gradient; waterfalls), and Culverts (may be non-barrier, partial barrier, or total barrier).

Aquatic Habitat Data Used but not Displayed

Priority marine species and habitat – as mapped from WDFW's PHS database, but are considered sensitive. Includes habitat for Geoduck clam, Pacific oyster, Dungeness crab, Pandalid shrimp, and red urchin. These are species the King County Comprehensive Plan directs should be protected.

Data Not Used

- Wetlands and riparian areas are also mapped in the PHS database, but because the wetlands and riparian areas associated with the shorelines are covered in the jurisdiction map, the PHS data were not used in addition.
- Benthic Index of Biologic Integrity data can be used to provide information about the quality of specific stream reaches, though the data should always be used in combination with other information (such as historic conditions). These data were collected as two sets of data, using different sets of protocols – WRIAs 8 and 9, and Basin Monitoring and Evaluation Plan sites, and scores are not yet calculated for most recent years.

Terrestrial Habitat

- WDFW Priority Habitats – the only available priority habitat data, though it is not considered comprehensive. Only snag-rich areas and cliffs are mapped as habitat patches lying within the shorelines jurisdiction.
- Large mammal use and/or habitat areas – as mapped from WDFW's PHS database. Large mammals included in this set are Columbia black-tailed deer, Roosevelt elk, Rocky Mountain elk, unspecified elk, and mountain goat.
- WDFW data from Spotted Owl database and Marbled Murrelet database – These sensitive data are displayed at the basin scale, but site locations will be used for designations and restoration planning.
- WDFW PHS data for terrestrial species documented within the shoreline jurisdiction – including Bald Eagle, Beller's ground beetle, Great Blue Heron, and Pileated Woodpecker. These potentially sensitive data are displayed at the basin scale, but site locations will be used for designations and restoration planning.
- WDFW Wildlife Heritage Database (HRTG) – contains information on documented point observations of non-game species of concern, state and federal listed species including

those designated as endangered, threatened, sensitive, candidate, and monitor. Species include American white pelican, bald eagle, Beller's ground beetle, fisher, golden eagle, gray wolf, great blue heron, green heron, grizzly bear, Larch Mountain salamander, lynx, mountain quail, northern goshawk, osprey, Townsend's big-eared bat, peregrine falcon, pileated woodpecker, purple martin, and Vaux's swift. These potentially sensitive data are displayed at the basin scale, but site locations will be used for designations and restoration planning. Together, PHS (above) and HRTG provide locational data on important fish and wildlife.

- King County Department of Development and Environmental Services (DDES) Red-tailed Hawk database – These potentially sensitive data are displayed at the basin scale, but site locations will be used for designations and restoration planning.

Forest Value and Wildlife Network

- Forest connectivity data – This data depicts areas where large (≥157 acres) forest patches were present in King County as of 2002 and potentially connected to other large forest patches. Data are based on 2002 land cover data obtained from the University of Washington. These forests are assumed to indicate areas of significance to forest interior wildlife species.
- Wildlife Habitat Network ("Wildnet1996" data layer) – as required to be mapped by the King County Critical Areas Ordinance. This network was designed to connect publicly owned and protected lands to one another via natural corridors such as rivers.

<u>Data Used but not Displayed on Public Maps</u>

Washington Natural Heritage Program – rare plant data. These data are not shown on public maps because of sensitivity and restrictions on public display. However, presence of rare plants within shoreline jurisdiction will be taken into consideration for designation, restoration planning, or both.

E. Climate Change and Large-Scale Events

Overview

Over time, King County's shorelines will without a doubt be affected by conditions resulting from global climate changes, as well as large-scale, potentially cataclysmic events that include earthquakes, tsunamis, seiches and lahars. Recent climate change has most likely been caused or, at the very least much influenced by, human activities, as documented for the Puget Sound region (Snover et al. 2005). Even if all greenhouse gas (CO_2) emissions were halted today, ambient atmospheric concentrations would continue to change climate conditions in the Puget Sound region for many decades, without taking projected increases in emissions into account.

Cataclysmic events are beyond human control, and their exact timing, magnitude and extent are impossible to predict with any certainty. Yet, given enough time, they are highly likely to occur and, when they do, will have great potential to affect shorelines. As a result, it is important to be cognizant of their potential impacts, and to plan and take some action in advance to avoid or minimize their risk to people and important natural resources.

Climate change impacts are not currently incorporated into the alterations assessment. However, this discussion of the areas where impacts may be felt has been added as a placeholder for future updates, when more precise forecasts should be available that will allow reliable assessment of effects and may suggest how to plan for them.

Climate change

Climate change and its potential effects have been the focus of much attention in recent years. Casola et al. (2005) summarized the information presented at a conference in 2005 to address predicted effects of climate change on Washington's hydropower, water supplies, forests, fish populations, and agriculture (see http://dnr.metrokc.gov/dnrp/climate-change/conference-2005-results/plenary-session/background.htm).

The Intergovernmental Panel on Climate Change (IPCC 2007) predicts that global surface air temperature could increase by 2.5 to 10.4 ºF (about 1 to 6 °C), and global sea level could rise from 8 to 18 inches between 2000 and 2100, depending on both the rate of natural changes and the response of the climate system to greenhouse gas emissions both now and into the future. However, the IPCC models do not take polar ice cap melting into account. Rahmstorf (2007) uses another method of estimation and derives a predicted range of sea level increase of 21 to 55 inches by 2100. Neither of these methods take into account the effects of local earth movements into account, and these processes could also impact the relative sea level in the Puget Sound region.

Temperature

In the Pacific Northwest, Casola et al. (2005) noted that, "The average temperature in the Pacific Northwest (PNW) increased approximately 1.5°F (0.8°C) over the last century; snowpack has been declining over the last 80 years, especially at lower elevations; the onset of snow melt and peak streamflows in snow-fed rivers has moved earlier in the year; and many species of plants are blooming earlier in the year." They also noted that "although direct observations are not available, hydrologic models indicate that spring soil moisture has also been increasing."

In the future, Casola et al. (2005) expect increases in air temperature across all seasons for the Pacific Northwest. Using global climate models, they project that by the year 2020 temperatures will likely increase between 2.5 to 3.7°F (about 1 to 2°C), and by 2040 the increase will be between 3.1 and 5.3°F (about 1.5 to 3°C). At the same time, water temperatures are also expected to increase.

Increases in both water and air temperature will have impacts on many species, but for shorelines in particular, warmer water temperatures will be of major importance. Casola et al. (2005) note that fish will have to respond to changes in habitat caused by responses of vegetation, streamflow, temperature patterns and oxygen to climate change. In some cases, these changes may occur faster or be more extreme than some species can accommodate. For example, although Casola et al. (2005) do not explicitly predict the fate of particular species, it is reasonable to expect that some species, such as sockeye salmon which are near the southern and warmest part of their range in King County, may have more difficulty adapting than others, such as coho and chinook whose current ranges extend much further south into warmer climates.

Marine plant species, such as eel grass and bull kelp, appear to have a narrow range of water temperature tolerance and extensive stands may also suffer as a result of the projected changes (Snover et al. 2005), which could have a cascading effect of habitat change that affects other species that might not have narrow temperature tolerances, but do have an important dependence on those plant stands for food, nesting sites, or refuge.

Similar changes may be expected in lakes. An annual average water temperature increase has been found in Lake Washington using data collected since the 1960s (Winder and Schindler 2004), which is correlated with an increase in the length of time that thermal stratification persists. Based on this data, there could be significant stresses placed on freshwater planktonic species that provide the food base for upper trophic levels, as well as a longer period of thermal barrier to anadromous fish passage through the Lake Washington ship canal. Similar effects might be seen along other shorelines as well throughout the region.

Warmer water temperatures may also change seasonal variation in planktonic community structure in both marine and freshwater systems. Longer periods of warm temperatures in shallow waters will likely favor certain groups, including: (1) bluegreen cyanobacteria, some of which make toxic substances that harm pets and people; (2) dinoflagellates, some of which cause red tides, causing toxic accumulations in shellfish; and (3) chlorophyte algae, some of which form large filamentous masses that cover rocks and structures, as well as wash up on shoreline to cover beaches and cause nuisances.

Precipitation and runoff

Implications for precipitation and runoff are more difficult to predict, due to uncertainty over the interplay among many factors affecting precipitation. However, the majority of models indicate that an increase in cool season precipitation (October to March) will include a greater portion of the precipitation as rain rather than snow, which will result in reduced residual spring snowpack and earlier snowmelt.

Casola et al. (2005) predict that stream flow, stormwater runoff, and water temperature patterns will likely be affected by changes in both air temperature and precipitation. For example, low elevation, “rain dominant” rivers (e.g., the Sammamish River) are expected to have higher autumn and winter flows, while rivers draining intermediate “transient snow zone” elevations (e.g., the Tolt and Cedar Rivers) will “likely have an enhanced winter time peak flow due to the increase in rain, but reduced spring and summer flows due to the reduction in snowpack and an earlier timing of snow melt.” The frequency of moderate floods is expected to increase in basins dominated by transient snow zones, which include the majority of King County’s rivers. By contrast, large floods are not expected to increase because they generally result from warm winds (Pineapple Expresses) that occur when air temperatures are already warm.

A potentially very serious impact on flow is that summer base flows could become lower as a result of smaller snowpack on those streams which are fed by snowmelt through the dry, warm months. This could have major effects on fish and other biota living in and near the rivers throughout the county. In the areas of shoreline jurisdiction, flow changes and flood frequency could affect the delineation of 100-year floodplains and 20 cfs mean annual flow stream points.

Finally, it should be noted that, while many predictions of the future have a degree of uncertainty, the temperature and precipitation predictions are based on much more rigorous and well understood scientific data and relationships for their conclusions than many predictions of the biological impacts.

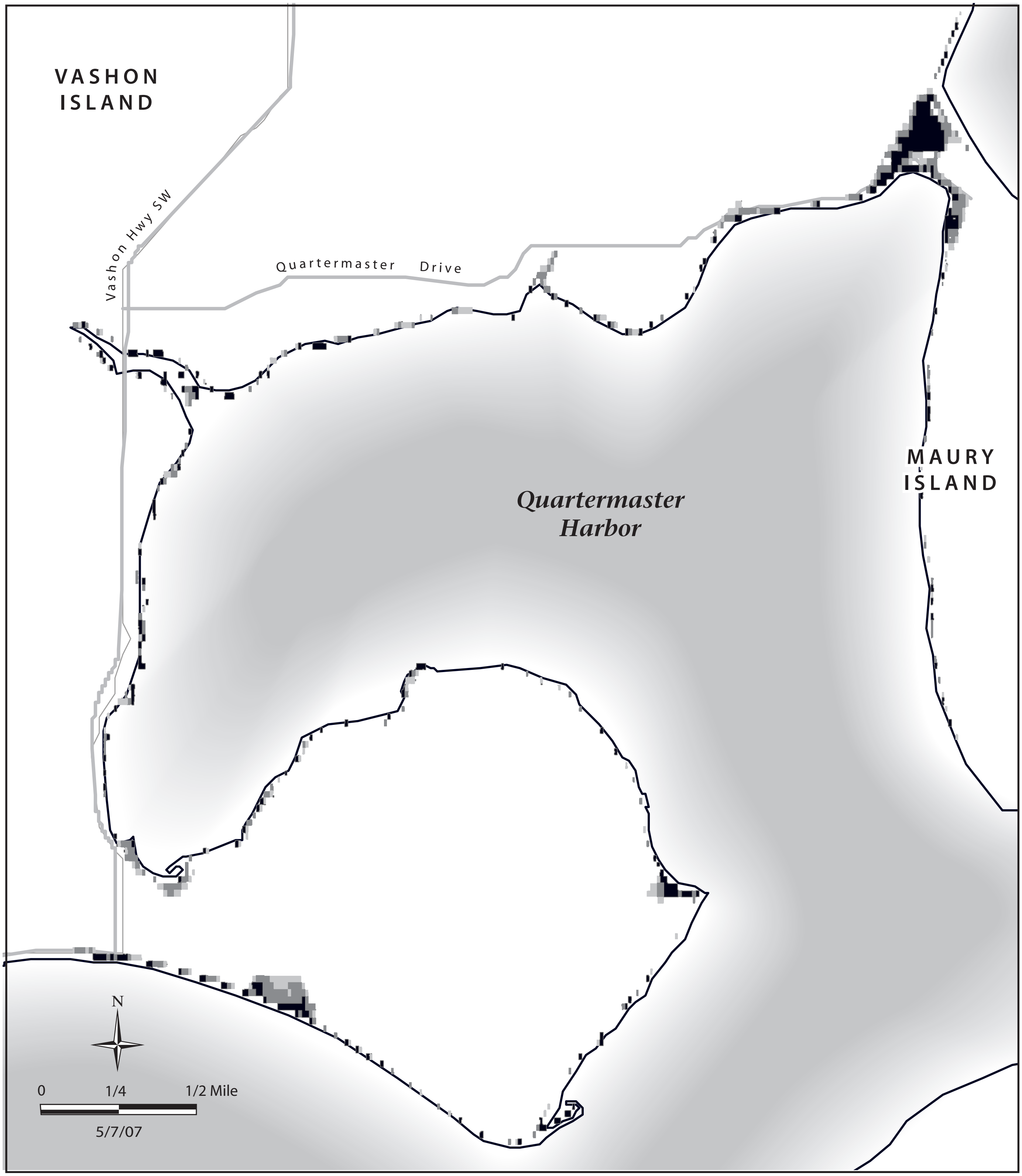

Figure 9

Sea Level Rise

Quartermaster Harbor, Vashon/Maury Islands, Washington

Road

Shoreline

Sea Level Rise

6 Feet

4 Feet

2 Feet

Notes: This map depicts simple elevation-based inundation scenarios designed to identify potential vulnerabilities and inform policy discussions. It does not model dynamic shoreline processes or predict the rate of sea level rise. Adapted from: Petersen, A. (in prep). Anticipating sea level rise in Puget Sound. MS thesis, University of Washington..

Produced by:
DNRP/WLRD
GIS, Visual Communications
& Web Units

King County
Department of Natural Resources and Parks
Water and Land Resources Division

File Name:
0705smpSeaLevel.ai LPRE

Sea level rise

For marine coastal areas, Rahmstorf (2007) predicts a global increase of 2 to 4.5 ft, while the IPCC is conservative, forecasting a rise of 0.7 to 1.5 ft., but does not include polar ice melt. Casola et al. (2005) report that sea level could rise almost 3 feet by the year 2100 in south Puget Sound (Tacoma), taking into account the net subsidence in crustal elevations in the Puget Sound region, although it is not clear if subsidence should be estimated as a continuous rate (Petersen, in prep). Rising relative sea level is a response to a series of complicated processes that are in turn impacted by factors affecting other parameters on a global as well as local scale, such as temperature, wind patterns, oceanic currents, and precipitation.

Looking at sea level rise at the King County scale, increased sea elevations will make development and infrastructure in low-lying areas more susceptible to flooding due to high tides and storms. Waves will encroach further onto low-lying beaches and cause greater beach erosion and threatening or damaging low-lying structures. At the same time steep slopes may receive increased moisture, due to predicted changes in precipitation patterns, potentially resulting in an increase in landslides that deliver more material to the marine shoreline, but which may cause property destruction and threaten human safety as well.

Marine shorelines under King County jurisdiction are comprised mostly of Vashon and Maury Island, along with a small section of the Duwamish River estuary. Petersen (in prep) mapped areas of low elevations along the shoreline of Quartermaster Harbor (Fig. 9) to illustrate how certain areas would be more likely to be inundated than others in the event of 2, 4 and 6 ft increases in sea level from the ordinary high water mark. While the figure does not predict by when such levels of inundation might occur, it does point out locations at which impacts will likely occur at 2 ft increments of sea level increase. This information should prove very useful to consider when planning for projects with relatively long lifetimes along the marine shoreline.

Approximately half of Vashon and Maury island shores are currently armored, so that slightly higher sea level may have minimal impacts on them, but significant rise might begin to allow overtopping of armoring with storms and very high tides.. Shoreline reaches, known as transport zones, are composed of mostly stable bluffs and gentle sloping shorelines. A significant rise in sea level will likely cause these areas to become active feeder bluffs, perhaps endangering residences currently considered safe. A rise in sea level also will likely cause current feeder bluffs to become more active and increase erosion rates.

Another place that will likely be impacted is the connection between Vashon and Maury Islands (Fig. 9), a low-lying, narrow isthmus of land called the “Portage.” This area supports two county roads that link the two island masses, but which, according to anecdotal evidence, in the past was periodically inundated by high tides. Higher sea levels are likely to increase wave inundation at the very least, potentially affecting the roads, and this might even have the potential to sever the land connection between the islands through erosion. There are additional roads around the islands that are located adjacent to the beach, which will also very likely require substantial infrastructure improvements to protect them from the rise in sea level.

A number of other low-lying areas around Vashon Island would also be impacted by increased sea levels, including KVI marsh (Point Heyer), Fern Cove, the Judd Creek estuary, and all tributary mouths, in particular those with low-gradient approaches to the marine shoreline. Effects would include changes in delta and marsh shapes due to changes in accretion and erosion patterns, potential loss of eel grass beds and changes in plant communities associated with the estuarine and marsh areas, and increased erosion in drainage channels upstream of the deltas.

A related impact of sea level rise would be to change the location and amount of land coming under shoreline jurisdiction over time, since a 2-foot vertical rise of the sea can mean a much more substantial incursion inland (Fig 8). This would probably cause flooding of some beach front homes and other property damage.

Currently, the shoreline along the Duwamish estuary in unincorporated King County is highly altered and the bank protected, but it is likely that sea level rise would cause saline water to encroach further up the river, especially during high tides, thus changing flow regime, river height, and salinity, which has implications for habitat quality as well as development.

Another consideration might be the endangerment of archaeological and historical sites that are in low-lying areas along the marine shoreline and Duwamish estuary. Significant sea level rise may also put the preservation of these structures and sites at risk.

Other processes in Puget Sound

Changes in wind and weather patterns are likely to affect water circulation in Puget Sound. This, in turn, may alter sediment and chemical transport and coastal erosion processes. Such weather-driven changes in circulation and erosion due to climate change remain very uncertain and difficult to predict at present with any confidence in accuracy, but should be taken into consideration when formulating shoreline management strategies, particularly in the future.

Volcanoes and earthquakes

King County is located within a very large geographical area characterized by high geologic activity that encircles the Pacific Ocean, commonly referred to as the “Ring of Fire.” Events, which include both erupting volcanoes and earthquakes, are connected to activity along a complex series of colliding crustal plates below the earth’s surface. They can occur suddenly, with dramatic and devastating effect. Over time, they modify and shape the landscape, including shorelines. Earth movements shake and rearrange surface deposits, create and deposit new soil, and can also change surface elevations through subsidence or uplift. In addition, they can trigger tsunamis, seiches, and lahars. Since 1945, there have been seventeen earthquakes of magnitude 2.7 or greater in King County. Earthquakes with the magnitude of the 1965 Seattle-Tacoma and 2001 Nisqually Earthquakes (magnitude 6.5 and 7.2, respectively) appear to have a pattern of occurring about every 30 to 35 years.

All of Washington’s volcanoes could affect King County shorelines to some degree, but Mt. Rainier is the most problematic. The United Nations has designated it as one of fourteen mountains that could cause catastrophic devastation (Parchman 2005). Mount Rainier is also the only active volcano with a direct surface link to King County, including some highly populated areas, via the White River along the County’s southern boundary. While eruptions are often thought to be the primary hazard living near a volcano, a lahar is the more potentially devastating event (see discussion below).

Lahars

A lahar is a mudflow originating from the side of a volcano. (The following discussion summarizes information from: http://pubs.usgs.gov/fs/2002/fs034-02
and http://volcanoes.usgs.gov/Hazards/What/Lahars/lahars.html)

The White River, whose headwaters drain the northeastern flanks of Mt. Rainier, and the nearby Green River, which had a historic connection with the White, are the pathways by which a lahar or its floodwaters could reach and affect King County shorelines. Eruptions, magmatic movement and heating, earthquakes, and destabilization of saturated hillsides caused by excessive rain or snowmelt can trigger a lahar. Lahars can occur without notice and be massive. About 5,600 years ago, a single lahar (the "Osceola Mudflow") ranging from 20 to 600 feet high filled in 30 miles of land along the Green River Valley, creating the flat suburban land around the cities of Kent and Auburn and covering over 200 square miles of surface (Parchman 2005). Smaller, but still massive, lahars have occurred more recently, including in the Nisqually Valley about 2,300 years ago (The National Lahar) and in the Puyallup Valley about 500 years ago (The Electron Mudflow). The USGS estimates a 1-in-7 chance that another major lahar could occur within a human lifespan. In King and Pierce Counties, numerous people and structures in the White, Carbon and Puyallup River valleys are considered at risk from the occurrence of a lahar.

Tsunamis and Seiches

Tsunamis and seiches are powerful wave forces that have the potential to reshape shorelines and cause considerable damage. (The following discussion summarizes more detailed information from the following sources:
http://www.metrokc.gov/prepare/docs/HIVA/TsuanmiSeiches.pdf
and http://www.dnr.wa.gov/geology/hazards/tsunami.htm).

Tsunamis (Japanese for "harbor wave") are sea waves caused by sudden displacement of the ocean floor or by landslides originating either below or above the water. Often erroneously called "tidal waves", tsunamis were once thought to not occur in Puget Sound because of the Sound's relatively small size and confinement compared to the open ocean. It is now known, however, that sizable tsunamis have occurred in Puget Sound and possibly even in Lake Washington. Further, they are virtually guaranteed of occurring again in the future due to geologic setting and history (Gonzalez et al. 2003).

Seiches are a series of cycling standing waves (sloshing water) generated in an enclosed or partially enclosed body of water, either by wind force or earth movements. Seiches have a wide range in scale, with the largest capable of doing a great deal of damage. Typically tsunamis and large-scale seiches are caused by earthquakes that suddenly displace large volumes of sediment and water or cause surface movements or failures due to shaking.

Both tsunamis and large-scale seiches are infrequent. A large (estimated 10 ft or higher) tsunami occurred approximately 1,100 years ago (A.D. 900-930) resulting from what is believed to have been a magnitude 7 or greater earthquake on the Seattle Fault. Since 1891, two small tsunamis, one generated by the 1964 magnitude 9.2 quake in Alaska, and four seiches, including a damaging one in Lake Union in 2002 caused by the magnitude 7.9 Denali Alaska earthquake, have been recorded in King County.

Lakes can also experience seiches as a result of prolonged high winds, but these are generally on a smaller scale and for the most part do not cause property damage or endanger lives.