GREAT BEND WATERSHED

LANDSLIDE HAZARD ZONATION PROJECT

Kitsap and Mason Counties, Washington

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Adaptive Management Program
in coordination with the
Washington State Division of
Geology and Earth Resources

Priority 3
Mass Wasting Assessment
March 2007

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

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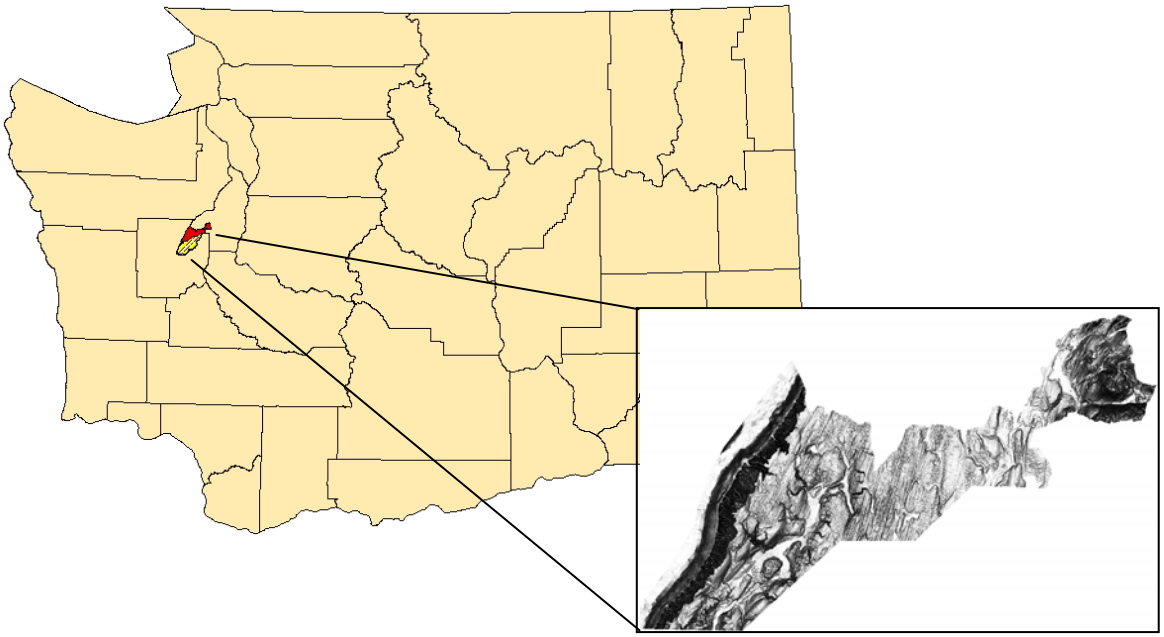

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1.0 Project Summary

The Great Bend watershed administrative unit (WAU) is drained by the Tahuya and Dewatto Rivers that terminate in Hood Canal. The entire WAU consists of 55,125 acres of uplands in Kitsap and Mason Counties. A landslide hazard study in 2005 (Slaughter and Lingley, 2005) evaluated a portion of this WAU. The remaining 22,716 acres located in the northern portion of the Great Bend WAU that were not included within the 2005 study are the focus of this study.

Three hundred and nineteen landslides encompassing 600.7 acres were mapped for this study using aerial photos, lidar (light detection and ranging) imaging, and limited field review. Six mass wasting landforms were created and assigned slope stability hazard ratings from low to very high.
Three of the landforms (Flats, Ridges and Noses, and Low Gradient Hills) have a low hazard rating; Moderate Gradient Hills (41-60%) have a moderate hazard rating; Coastal Bluffs & Steep Slopes (>60%), and Inner Gorges were identified as very high hazard. Hazard ratings are based on landslide history as delineated in the Washington State Landslide Hazard Zonation Project Protocol (Table 1). The overall hazard rating of the WAU is low however; much of the west-facing slope toward Hood Canal has a very high failure rate.

Landform number	Name of landform	Landform slope stability hazard rating	Slope of landform	Total area of landform in acres	No. of delivering landslides in landform	Comment
#1	Flats	Low	<11%	5569	0	LHZ Protocol Low Hazard
#2	Ridge Tops and Noses	Low	<11%	16	0	LHZ Protocol Low Hazard
#3	Low Gradient Hillslopes (11-40%)	Low	11 to 40%	12145	19	LHZ Protocol Low Hazard
#4	Moderate Gradient Hillslopes (41 to 60%)	Moderate	41 to 60%	3470	55	LHZ Moderate Hazard
#5	Coastal Bluffs and High Gradient Hillslopes (>61%)	Very High	>61%	416	36	LHZ Protocol High Hazard
#6	Inner Gorges and Steep Slopes (>70%)	Very High	>70%	1100	152	LHZ Protocol High Hazard
	Totals			22,716	262	

Table 1. Summary of the 6 landforms mapped in the Great Bend watershed.

2.0 Introduction

The Great Bend watershed covers 63,531 acres northwest of Belfair. The WAU extends from the great bend at Ayres Point on Hood Canal north to Holly along the Kitsap Peninsula and east including Green Mountain, the northern half of Gold Mountain and along the eastern shore of the Tahuya River drainage. A previous slope stability study for a portion the WAU was conducted for the Tahuya State Lands Landslide Hazard Block Mapping Project (Slaughter and Lingley, 2005). The 2005 study did not evaluate the entire watershed; therefore, this study pertains to the 26,429 acres not included within the 2005 report. This study area comprises 3,728 acres within the tidal zone of Hood Canal and is below the high mean water. The upland area for the purpose of this study includes 22,716 acres. The term "watershed" or "WAU" in the remaining extent of this report refers solely to the 22,716 acres evaluated in this report (Figure 1).

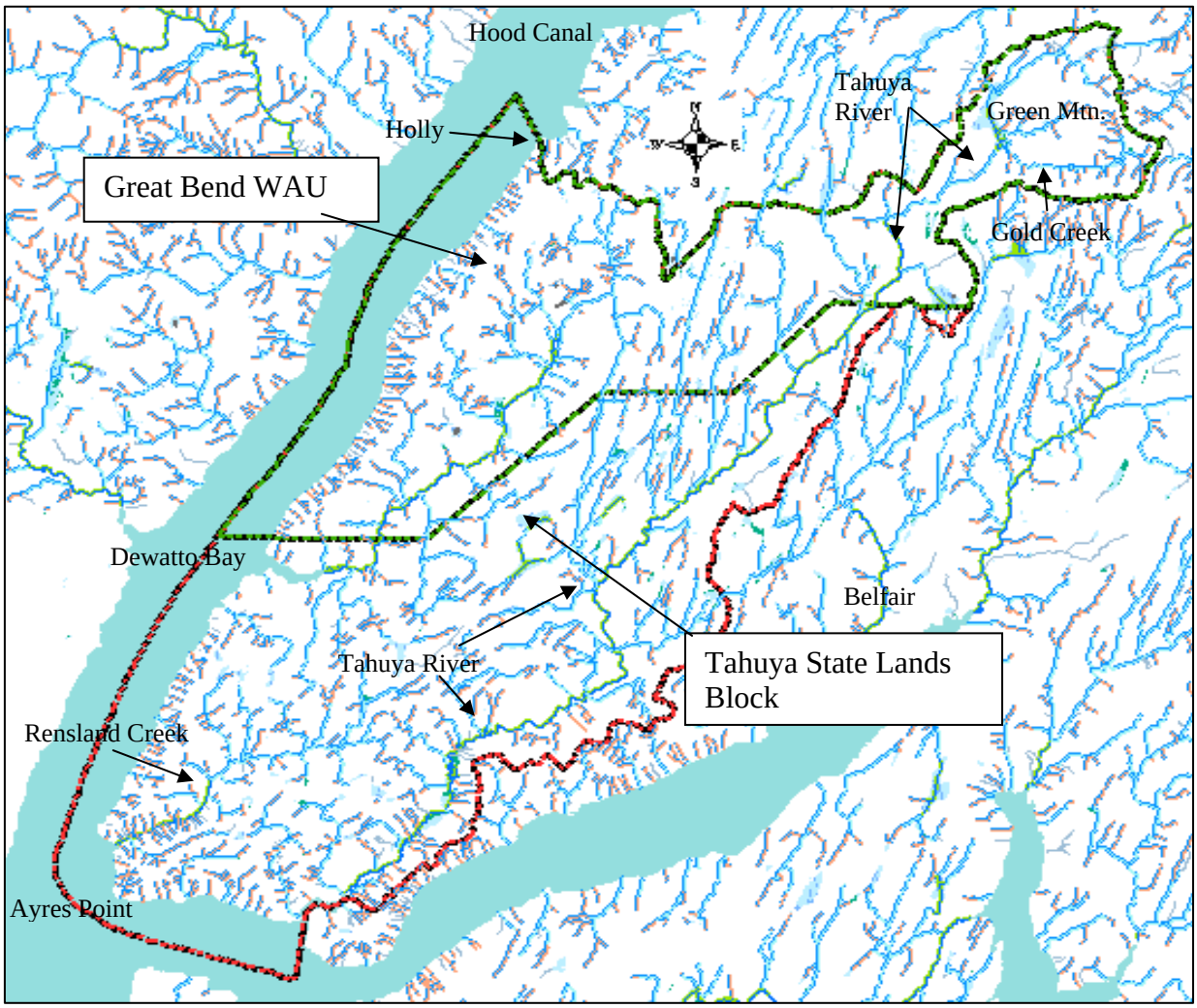

Figure 1. Great Bend Watershed showing this study area and the adjacent Tahuya State Lands Block study area.

All areas in the watershed have been included in this study regardless of ownership. The majority of the Great Bend watershed is in private and state ownership, much of it owned and managed as timberland by the following private timber owners: Olympic Resource Management, Alpine Evergreen Company, McCormick Land Company, Erickson Lake Association, Manke Lumber Company, Helen Smith, Don Huson, Don Knutsen, and Joy Stohr. A portion of the watershed is also managed by the Washington State Department of Natural Resources (DNR) for Common Schools, Scientific Schools, and State Forest Board Trusts (Figure 2). The northwestern corner of the WAU, along Hood Canal includes the town of Holly.

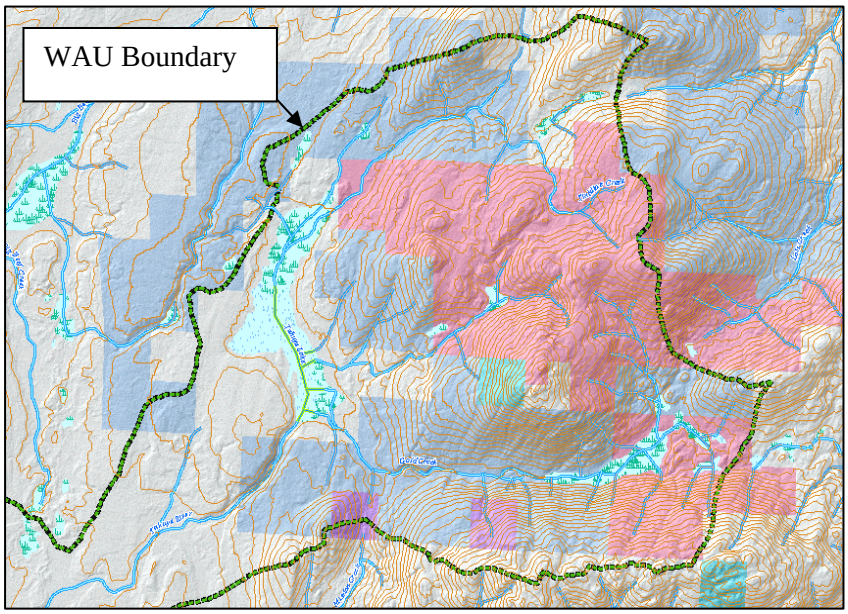

Figure 2. Green Mountain and the northern portion of Gold Mountain contain state managed trust land for Common Schools, Scientific Schools and State Forest Board (colored areas). Non colored areas (in gray) of this map are privately owned lands.

3.0 Topography and Climate

The Great Bend WAU lies along the eastern shoreline of Hood Canal, approximately 20 km (~30mi) east of the Olympic Mountains. Elevations in the Great Bend WAU range from sea level along the eastern shore of Hood Canal to approximately 1,700 ft at the top of Green Mountain in the northeast portion of the WAU (Figure 1).

The topography of the study area was carved by rivers which have dissected a glacial till plain with a west facing terrace slope from the top of the till plain down to Hood Canal. The Dewatto River flows from the north to the south, exiting the watershed at Dewatto Bay on Hood Canal. The Tahuya River also flows in a southerly direction just west of Green Mountain and Gold Mountain with Gold Creek flowing into it. These rivers cut through a flat to low gradient upland terrace till plain sculpted with glacial flutes (or drumlins) that show a general north–south ice flow direction. The terrace edges face Hood Canal and are cut by drainages that have experienced historic slope failures (Gyrta, 1975; Smith and Carson, 1977; Gold, 2004; Slaughter and Lingley, 2005).

Resistant basalt of Green Mountain and Gold Mountain rise above the till plain to an elevation of approximately 1,700 ft. in the northeast portion of the WAU. Ice-sheet glaciations during the Pleistocene reshaped the topography of these mountains. The steepest slopes in the watershed are generally found along the west side facing Hood Canal and along river gorges similar to the slopes around Gold Creek. The majority of the watershed consists of Low Gradient Hill Slopes that range from 11 to 40%.

The average annual precipitation at the Lake Cushman Dam Powerhouse 2 stream gauge location is approximately 90 inches (Western Regional Climate Center). The highest recorded precipitation occurred during the winter of 1998-1999 (Appendix F, Figure 1). The WAU occasionally experiences snow, but rarely does a rain-on-snow event occur. The surface water gauging station located on the Skokomish River near Potlatch, Washington (south of Hoodsport) has recorded stream flow peaks that usually occur in late fall to late winter (Figure 3 and Appendix F). Peak stream flow data is shown in Appendix F, Figure 4. Other related historic information regarding climate can be found in Appendix F.

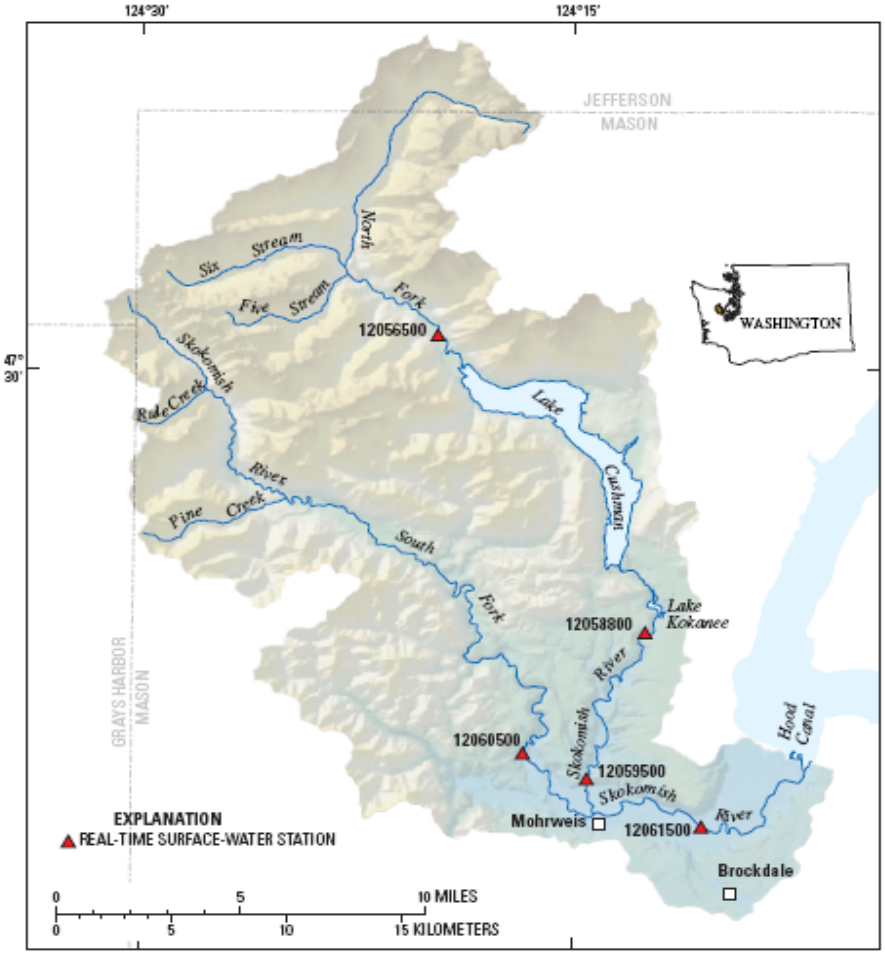

Figure 3. Locations of stream gauges west of the Great Bend WAU. (http://wa.water.usgs.gov/data/realtime/adr/interactive/maps/SouthOlympicSC_basin.pdf)

4.0 Geology

The Great Bend WAU is located within the Puget Lowland east of Hood Canal. The majority of the WAU is covered by Pleistocene continental glacial deposits and bedrock is exposed only at the northeastern corner of the WAU where Eocene basalts of the Crescent Formation crop out on Green Mountain and Gold Mountain. Mass wasting in this area is often related to the movement of thick overburden or thick soils on moderately steep slopes underlain by basalt bedrock. The basalt found around Green Mountain and Gold Mountain may have a higher potential for slope failure due to the presence of adjacent faults.

Glacial deposits have characteristics that significantly influence slope stability. Typically, glacial outwash-deposits are composed of gravels overlying till or clay, or sand layers overlying compacted non-glacial gravels as diagramed in Figure 4. The overlying unconsolidated sediments allow water to infiltrate through them until it reaches more consolidated impermeable material such as the clay or compacted gravels. Water may then accumulate as a perched water table atop the impermeable layer and flow laterally as springs along the coastal bluff faces. For additional geologic information see Appendix E.

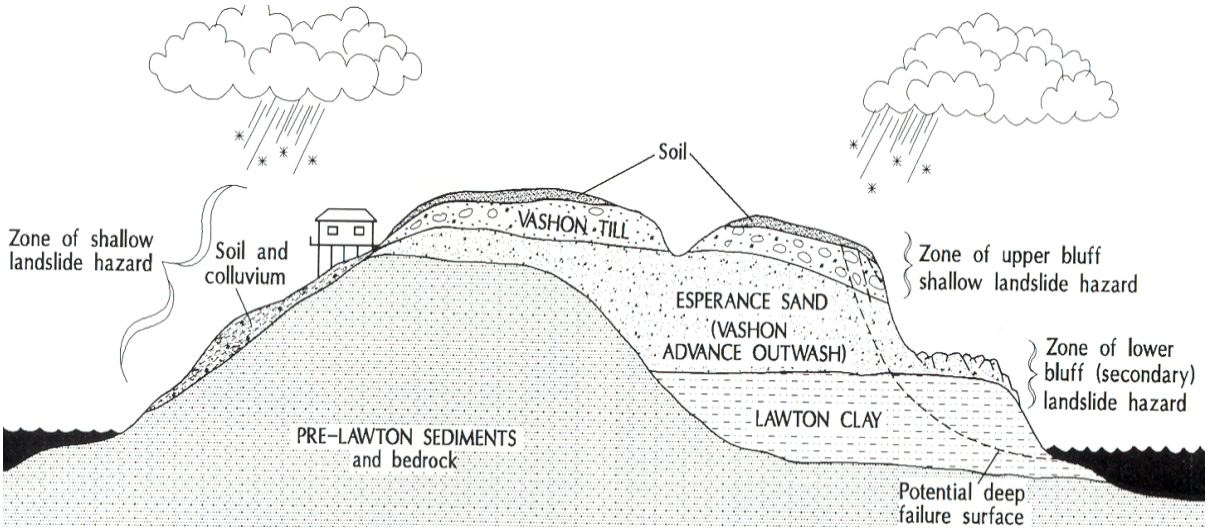

Figure 4. Cross-section depicting glacial sediments and landslide potential. Source: Gerstel and others, 1997, modified from Tubbs, 1974.

5.0 Previous Investigations

Several landslide studies have been conducted in the general vicinity. Some studies were conducted on land adjacent to the Great Bend WAU and some studies include parts of the WAU.

Gyrta's (1975) thesis dealt with landslides along the western shore of Hood Canal directly across from the Great Bend watershed. His maps and cross-sections cover a 13 square mile area along the canal. Five slope stability classes were assigned to this area ranging from stable (no potential for landsliding) to naturally unstable (areas that would not withstand logging operations or other modifications). He described the landslide activity forms, the initiation or contributing factors for failure, and he mapped areas with mass wasting potential. Gyrta had two temporal landslide

classifications: those that occurred post-glaciation but prior to 1925 (Highway 101 road paving); and more recent landslides that occurred between 1950 through 1974.

In 1977, Smith and Carson published a relative slope stability map and report on natural slopes in southern Hood Canal, Mason County, in which 5 classes of relative slope stability were identified. They found that stability is affected by steepness of slope, lithology, groundwater and soil-moisture, undercutting by stream or wave erosion, and modifications to the landscape by humans (road building, forest management practices, and building homes). These activities often oversteepen or overload natural slopes, causing landsliding. Relict landslides were found to be reactivated due to human modifications and/or seismic activity.

Shipman (2001) studied landslides that were triggered by winter storms during 1996-97 and 1998-99. He found that coastal bluff failures in 1996-97 occurred mostly as shallow landslides and debris slides on steep slopes and were caused by intense, heavy rainfall while failures in 1998-99 were mostly deep-seated landslides that followed wet weather that lasted for longer periods of time. A contributing factor to landslides during both winters was the undercutting of steep coastal slopes by wave erosion. An example of a deep-seated landslide from 1999 is the Lilliwaup landslide that temporarily closed Highway 101 on the west side of Hood Canal.

Gold's (2004) thesis was a comparative study of aerial photographs and lidar imagery used for detecting landslides in a portion of Puget Sound. His study area included an eight-kilometer stretch of the slope along the eastern side of Hood Canal, from Hood Point on the north end, south to the Kitsap-Mason County border. The study provided a comparison of accuracy and precision of landslide delineation and certainty between aerial photography and lidar imagery. The results are similar between the two, with variables relating to cost and ease. Both methods should be utilized in developing landslide inventories. Several landslides mapped by Gold have been incorporated into the DNR GIS hazone database.

Slaughter and Lingley's (2005) mass wasting assessment covered approximately 50,000 acres of state lands within the Tahuya Block- including parts of Kitsap and Mason Counties. The Tahuya Block study followed a protocol similar to the LHZ protocol used in this report. Slaughter and Lingley observed many slope failures occurring at the interface between glacial outwash and till or non-glacial gravels of the Olympics. Within the Tahuya Block failures are concentrated along the slope facing Hood Canal and on stream-adjacent uplands. The Tahuya Block study is available on the Department of Natural Resources Forest Practices website: www.dnr.wa.gov/forestpractices/lhzproject/completed/.

6.0 Summary of Landslide Inventory

During the Great Bend WAU review a representative sample of 319 mass-wasting features were inventoried from aerial photography, lidar imagery, and field investigations (Form A-1). Of the landslides identified during this mass wasting assessment, 57% were mapped as shallow undifferentiated failures, 7% were debris flows, 18% were debris slides/avalanches and topples, and 18% were deep-seated landslides (Table 2). The resulting mass wasting coverage is displayed as Map A-1. Pertinent attributes of individual features were recorded on data sheets, Appendix A, Form A-1.

Based on landslide mapping and land use associated with the landslides, it was found that over 75% of the inventoried mass wasting features were located in sub-mature timber (15-50 years old). Land use was determined for each feature (Appendix B, Form A-3).

Mass Wasting Type	Number of Mass Wasting Features Mapped	Area (acres) of Mass Wasting Features	Percentage of Total Landslides
Shallow undifferentiated landslides	182	89.5	57%
Debris flows	21	28.6	6.6%
Debris slide/avalanche	59	36.6	18.5%
Deep-seated landslides	57	446	17.9%
Total	319	600.7	100%

Table 2. Summary of the type and number of LHZ Protocol-specified mass-wasting features mapped in the Great Bend WAU.

7.0 Landforms

Distribution of the six landform units identified in the Great Bend WAU study area is shown on Map A-2 and described in Appendix C, Form A-2. These units are areas having similar mass wasting potential, potential to deliver to public resources, and/or potential to impact public safety. Mass wasting potential is based primarily on landslide process, failure density, lithology, geomorphology, hydrogeology, and topography. The following subsections briefly describe the characteristics of each landform with additional information provided in Appendix C. Landform numbers here match those listed in the Landslide Inventory, Appendix A, and Form A-1. Not all rule-identified landforms occur in a given watershed and therefore the identifying numbers of landforms in any given watershed may not be listed as consecutive. Landslide hazard ratings have been summarized on Form A-4, Appendix D.

7.1 LANDFORM #1: Flats – Low mass wasting and delivery potential. Low gradient (0-10%) glacially-carved valley and stream bottoms are generally composed of alluvium, colluvium, soil, glacial, and landslide deposits. Wetlands are included in this landform. This landform contains those areas in and around rivers and streams and is more likely to be the recipient of debris and alluvial deposits rather than erosional processes. Mass wasting on these naturally stable slopes is unlikely but possible due to improper routing of surface waters and the inherently unstable nature of unconsolidated deposits.

7.2 LANDFORM #2: Ridge Tops and Noses - Low mass wasting and delivery potential. Low gradient (0-10%) areas along the tops of the ridges and along the noses of ridges are included. Landslides have occurred below and outside of some of these low gradient ridge tops but these failures are excluded from of this landform.

7.3 LANDFORM #3: Low Gradient Hillslopes (11-40%) - Low mass wasting and delivery potential. These landforms occur along the slopes facing Hood Canal as well as along the glacially fluted surfaces of continental outwash and till plains. Landslides that may occur within this landform would not likely deliver to waters or public resources of the State.

7.4 LANDFORM # 4: Moderate Gradient Hillslopes (41-60%) - Moderate mass wasting and delivery potential. Slope maps based on 2000 lidar DEM's were used to draw this landform.

Shallow landslides, debris slides, debris flows, and deep-seated landslide have occurred on this landform. Some slope failures in this landform are shown on geologic maps as remnants of ice-contact deposits along the Dewatto-Holly Road and were field-observed in this review.

Figure 5. West facing slopes along Hood Canal show multiple landforms including Moderate Gradient Hillslopes, Inner Gorges and Steep Slopes as well as relict deep-seated landslides. Source: Washington Department of Ecology: Shoreline Aerial Photos.

7.5 LANDFORM #5: Coastal Bluffs and High Gradient Hillslopes (>60%) – Very high mass wasting and delivery potential. This landform includes toes of deep-seated landslides. Also present in this landform are planar slopes adjacent to inner gorges, very steep (>80%) hillslopes, and ridge noses that have failed (Figure 8). These ridge nose slopes now exhibit planar or concave post-failure shapes. This landform also includes coastal bluffs formed by wave action undercutting the toe of the slope. This landform is present along Hood Canal (Figures 6, 7 and 8) with minor occurrences found inland along slopes that were undercut by Pleistocene glacial meltwater streams. Numerous shallow and small deep-seated landslides were observed in the field along extended reaches of shoreline. Due to the number and close proximity of these failures (approximately every 100-500 ft), only a representative sample was mapped in the field. Homes have been constructed on low elevation terraces mapped within this landform. Some of the coastal slopes below and adjacent to homes show signs of instability as suggested by observed bowed and jack-strawed trees during field verification by boat.

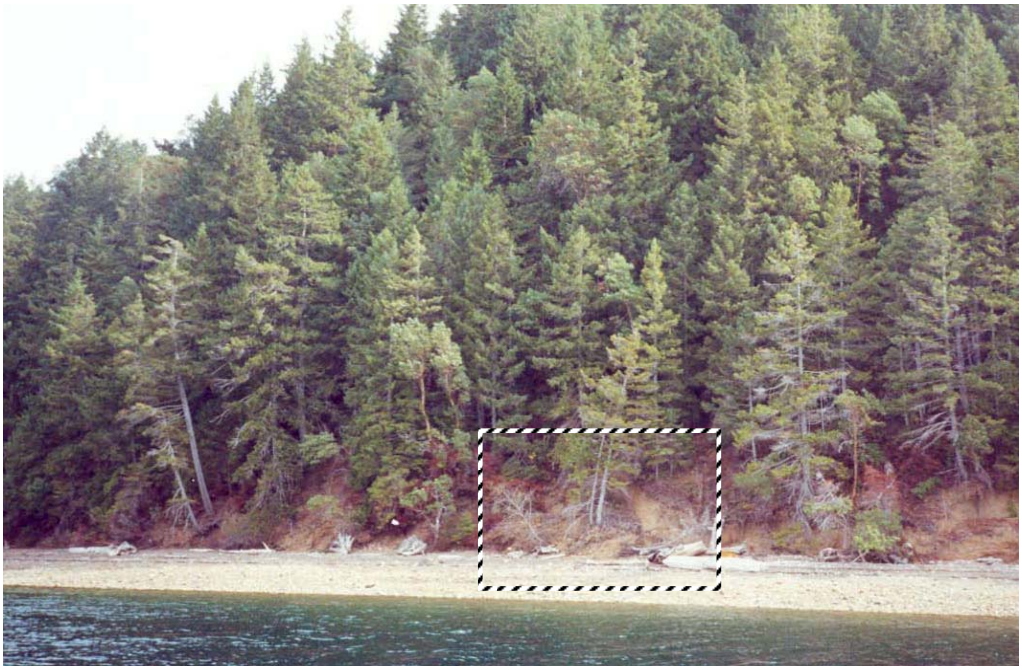

Figure 6. Note jack-strawed trees along coastal bluffs. Inset box is seen as a close up in Figure 7 below.

Figure 7. Author standing adjacent to failing coastal bluff.

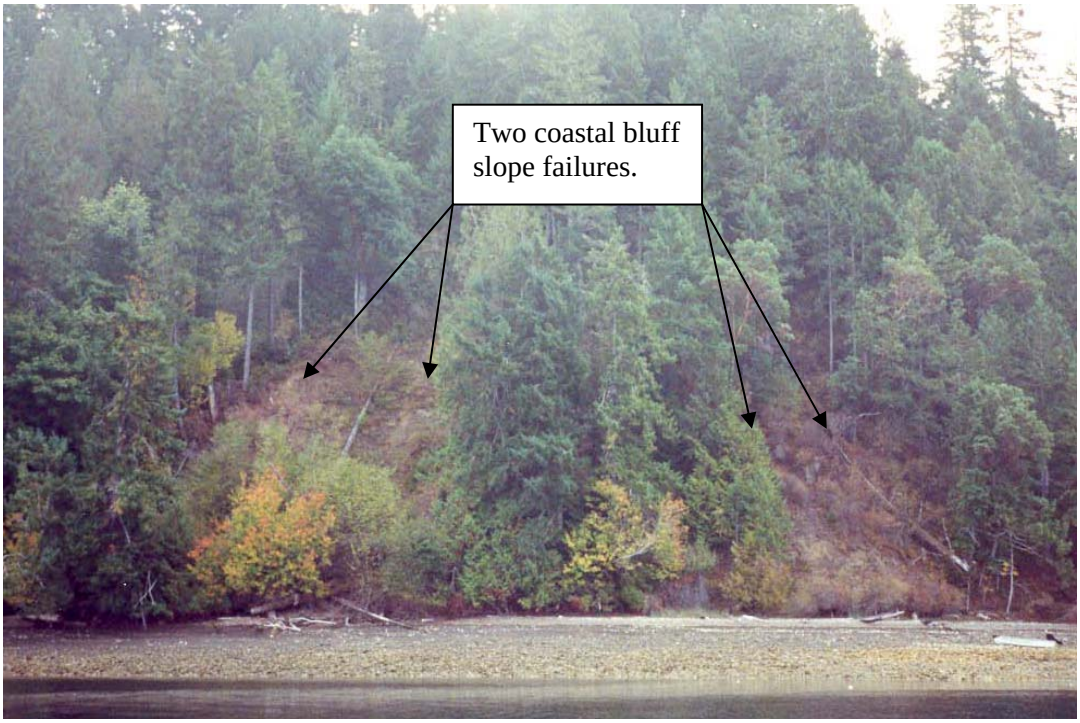

Figure 8. Ridge nose failure along Hood Canal. Coastal bluff landform (Landform #5) is rated as very high hazard potential for landsliding.

7.6 LANDFORM #6: Inner Gorges and Steep Slopes (>70%) – Very high mass wasting and delivery potential. This landform includes rule-identified asymmetrical and symmetrical inner gorges and convergent headwalls. Some incised gorge systems within this landform were observed to contain small meandering streams with failures along the outside of meander bends. No bedrock hollows were observed but may be present. Slopes are generally greater than 70%, these gorge systems may fail on concave to planar slopes of <65%. Shallow and deep-seated landslides are commonly located along gorge walls. Over-steepening of the slopes by stream erosion has caused multiple upslope migrating landslides. Shallow failures on these steep slopes have removed thin soils and vegetation, delivering directly to streams and to Hood Canal. These inner gorges are sensitive to both roads and harvest. Contacts between glacial till overlain by glacial outwash deposits were observed to be a contributing factor in slope failures.

8.0 Summary of Methods

Landslide inventory - The procedures described below follow the Landslide Hazard Zonation Protocol version 2.1 dated September 2006 found at: http://www.dnr.wa.gov/forestpractices/lhzproject/lhz_protocol_v2.1_final.pdf, with minor modification. Four sets of 1:12,000 aerial photographs from 1965 to 1997 and one set of 1:45,000 photos from 1974 were analyzed with a mirror stereoscope with 3-6x magnification (Table 3). Ortho-photographs from 1939 were scanned and geo-rectified then used to map landslides along the shoreline of Hood Canal. Color ortho-photographs from 2005 were used as

a layer during GIS analysis and mapping. The 1965 photos were chosen based on extensive ground cover removal due to a high percentage of the WAU being clearcut prior to the flight.

Cadastral and archival topographic maps produced between 1898 and 1902 were used to determine pre-aerial photography logging activities, transportation routes, and areas affected by forest fires. The early General Land Office plat maps are the earliest map source for a portion of the Great Bend WAU and are used as a basis for the pre-settlement historical landscape. However, most of the logging activity, transportation routes, and areas affected by forest fires came from the 1902 USGS Forest Service Map of Washington showing Classification of Lands. These historical maps were scanned and entered into ArcGIS and geo-referenced in a methodology adapted from Collins and others (2003).

Year	**Scale**	**Image**	**Flight Line Number**	**Reference Ownership**	**Comment**
1939	1:12,000	Black & White Orthophotos	Hood Canal 1939 Aerial Photos	Puget Sound River History Project	Partial coverage (shoreline only)
1965	1:12,000	Black & White	KMT 22B-47 to 37B-29	DNR	Complete coverage
1974	1:45,000	Black & White	NWH-74 3W-45 to 1E-49	DNR	Complete coverage
1978	1:12,000	Black & White	NW-78 22A-89 to 35A-101	DNR	Partial coverage
1997	1:12,000	Black & White	OL-9738-82-134 to 17-95-23	DNR	Complete coverage
2005	3 ft pixel*	Color Digital Orthophotos	OLC-QT05 280-034 to 038 290-034 to 038 300-034 to 038 310-037 to 040	DNR	Complete coverage in corporate geo-database

Table 3. Aerial photographs used in this study.

* Source photography was flown at a scale of 1:32,000.

Slope failures observed on the stereo photos were classified and catalogued according to the mass wasting feature type. For the purposes of this analysis, slopes that failed below rooting depth are categorized as deep-seated landslides (Washington Forest Practices Board, 1995); all remaining landslides are classified as shallow. The mass wasting feature types include shallow-undifferentiated landslides, debris flows, debris slides, topples, and avalanches, and deep-seated landslides.

Mapped landslides were ranked according to their relative level of certainty as questionable, probable, or definite. Features with some combination of distinct head scarps, lateral margins, scoured run-outs, over-steepened toes, obvious deposits with hummocky topography, or vegetation patterns that suggest landslide disturbance were considered to be definite landslides. Features that were more subdued or concealed by vegetation than those mentioned above could not be identified with the same level of certainty and were thus considered to be probable landslides. Features that resemble degraded landslides but could have been formed by non-mass

wasting processes were considered questionable landslides (following Wieczorek, 1984). Most landslides were mapped from air photos; however several that were identified in the field were not evident on the photos, mostly in areas of heavy canopy. Many of these postdated the most recent photo set.

Following stereo air photo analysis, all observed landslides were mapped directly into GIS by "heads-up" digitization of landslides into a GIS map. The final map (Map A-1) also displays these data layers: streams, roads, townships, geology, and a lidar digital elevation model with derived contours, slope gradients, and hillshades. The landslides mapped on A-1 are also itemized in Appendix A - Landslide Inventory.

Lidar from 2000 was available for the entire Great Bend WAU. Maximum resolution of the lidar derived map base is approximately 3 meters (~15 feet). Slope gradients and elevations of small failures that were identified on high-resolution air photos are not accurately estimated by the lidar due to raster data smoothing. Typically, DEM-derived slope gradients are underestimated by at least 10% relative to field-measured gradients (Dragovich and others, 1993), and more so on smaller features that are smoothed over by the DEM's coarse resolution. However, despite these limitations, the lidar was used in place of field measurements for the sake of expeditiousness to estimate landslide gradients. It should be emphasized that all slope gradient estimates presented in this report are likely minimum approximations.

Lidar from the DNR GIS corporate geo-database was originally derived and modified from http://pugetsoundlidar.ess.washington.edu/. Slope gradients for shallow landslides were determined by calculating the maximum lidar DEM-derived slope angle within each landslide initiation polygon. For deep-seated landslides, the average slope angle over the entire landslide polygon was calculated. We found that using the average slope gradient for deep-seated landslides provides the quickest and most reasonable representation of the pre-failure slope surface compared to other GIS slope measurement methods (Bilderback, 2006).

Mass wasting map units – As part of an LHZ project, landforms derived from the landslide inventory and the physical attributes of the landscape where the landslides occurred are mapped. The landforms are intended to predict areas within the WAU that pose hazards for mass wasting.

The aerial photograph survey was used to map landslides as described above and was also used to determine land use and landforms. After low hazard landforms (Flats, Ridge Tops and Noses, and Low Gradient Hills) were delineated by using a slope map with standard landforms slope angles according to the LHZ Protocol, rule-identified landforms and other hazard landforms were delineated. This process resulted in polygon coverage of any corresponding area larger than 0.5 acres. Areas smaller than this were dissolved into the larger surrounding polygons. The remainder of the WAU was divided into analyst-described landforms. These landforms were developed from on the physical attributes of the landscape where the landslides occurred. A combination of slope gradient and elevation data (derived from lidar), slope convergence data (derived from the DNR SLPSTAB model based on a slope morphology model (Shaw and Johnson, 1995)), geologic data (from USGS 1:100,000 geologic maps), and precipitation data aided in the designation of these landforms. The landforms are intended to predict areas within the WAU that pose hazards for mass wasting. The landforms mapped in the Great Bend WAU are presented on Map A-2 and described in Appendix C - Landform Descriptions. Each landform was assigned a landslide frequency rate (LFR), a landslide area rate for delivery (LAR), and an overall hazard rating (low, moderate, or high) as called for by the LHZ Protocol [www.dnr.wa.gov/forestpractices/lhzproject/lhz_protocol_v2.1_final.pdf].

9.0 Hazard Ratings

Each landform identified on Map A-2 and described in Appendix C was assigned an overall Hazard Rating based on landslide frequency rate (LFR) and a landslide area rate for delivery (LAR). The hazard rating (low, moderate, or high) is then assigned as called for by the LHZ Protocol [www.dnr.wa.gov/forestpractices/lhzproject/lhz_protocol_v2.1_final.pdf]. Pursuant to the LHZ Protocol, hazard ratings for mass-wasting landforms were determined by the following: 1) rule-identified status (WAC 222-16-050), 2) the Landslide Frequency Rate (LFR) and Landslide Area Rate for Delivery (LAR), 3) the professional judgment of the analyst, or 4) an interpretation of deep-seated landslide hazard. The Landslide Area Rate for Delivery is the area of delivering landslides normalized for the period of study and the area of each landform. These values are multiplied by one million for easier interpretation. Limited application suggests that Landslide Area Rates for Delivery less than 76 are low hazard, rates of 76 to 150 are moderate hazard, rates of 151 to 799 are high hazard, and rates greater than 799 are very high hazard (Lingley, 2004). Note that higher Landslide Area Rates for Delivery can be achieved by reducing the area of the Landform. While this may appear to be 'data gerrymandering', it helps limit the area of high-hazard landforms to those areas that are actually demonstrated to have high hazard. The Landslide Frequency Rate is calculated similarly; however the *number* of delivering landslide is used instead of the *area* of delivering landslides. Deep-seated landslides are not included in the calculations for Form A-4. As of the writing of this report, the qualitative rating system below is used (Table 3). Landform hazard ratings in the Great Bend WAU are summarized in Appendix D, Form A-4.

Qualitative Ratings	Landslide Frequency Rate (LFR)	Landslide Area Rate for Delivery (LAR)
Low	< 100	<76
Moderate	100 to 199	76 to 150
High	200 to 999	151 to 799
Very High	>999	>799

Table 4: Qualitative rating system for the LFR and LAR.

10.0 Confidence in Work Products

The confidence in this mass wasting assessment ranges from moderate to high based on excellent photo quality, complete lidar coverage, and field observation. This rating is based on the Landslide Hazard Zonation Project design to provide a watershed administrative unit overview of slope stability in a timely manner with minimal field verification. As a consequence of the project design, fieldwork and the number of aerial photograph sets examined are held to reasonable minimums. Omissions will be present due to the limited field verification of individual features; particularly in heavy canopy forested areas, as well as variable success in of obtaining landowner permission to access some portions of this WAU.

It is critical for the reader to understand that while these decisions are sufficient to characterize aspects of the slope failure as functions of forest management, this assessment would be entirely insufficient and misleading if it is used as a stand alone document for protecting private and public resources or for land use planning. As this is only a reconnaissance study, some landslides may have been accidentally omitted and some benign features may be improperly mapped as landslides.

In addition, there are some typical sources of systematic error that reduce the confidence in the work products of this analysis, those being omission, misinterpretation, accuracy, and precision. Misinterpretation may occur when a mass-wasting feature is identified but incorrectly classified or data are transposed, and where unrecognized software/file instability occurs. Accuracy involves the degree to which the physical parameters of a mass-wasting feature are correctly measured, and precision describes how variability within an assessment can be controlled when making multiple measurements over varying time and spatial scales. This mass wasting assessment was primarily conducted with aerial photographs, and as a result, there is a likelihood that errors of omission occurred primarily in areas covered by mature forest canopies, steep north facing slopes always in shadow (Brardinoni and others, 2003.) However, the author has a high level of confidence in the assessment based on excellent photo quality, lidar coverage, and field observations

Because many deep-seated landslide features are quite large, remain heavily vegetated during movement, and may not have obvious scars visible through the vegetation canopy, misinterpretation is more likely. A detailed study in Cowlitz County, Washington, suggests that up to 25 percent of inferred deep-seated landslides identified from aerial photograph analysis are misinterpreted (Wegmann, 2003). In spite of this, confidence in work products related to classification of deep-seated landslide processes in this WAU is high due to visibility, field verification, and completeness of photo coverage.

Another important source of potential error in this assessment is in the accuracy and precision of measurements of mass wasting features. Because very few landslides were actually visited in the field, it is not possible to report the degree to which location and measurement error in the GIS environment compares to on-the-ground field measurements. Similarly, measurements of slope angle from digital elevation models typically misrepresent the true hill slope angle. Given these sources of error, the confidence in the precise location and accuracy of measurements of individual landslides is considered moderate.

11.0 Use of Report

The purpose of this mass wasting assessment is to identify all areas on private and state land within the Great Bend WAU that have a risk of landsliding due to both natural phenomena and to the effects of forest practice activities (logging, roading, thinning, yarding, etc.). All areas and ownerships in the watershed have been included in this study for and is therefore a comprehensive landslide assessment. All lands within the WAU have been divided into mass wasting hazard landforms (Landforms as defined here may be broader than the small-scale unstable landforms defined in the unstable slopes rule (Chapter 222-16-050 WAC), referred to as "rule-identified landforms." Rule-identified landforms in the Great Bend WAU include inner gorges, bedrock hollows, and active deep-seated landslides.) Maps of landforms are designed for use by landowners in determining the areas likely to create landslide hazard and by Department of Natural Resources (DNR) staff to identify sites where future forest practice applications

(Chapter 222-20 WAC) may require detailed investigation prior to forest practice classification (Chapter 222-16-050 WAC).

This is a reconnaissance survey, and its relatively broad resolution must be considered when using this document and its accompanying maps. Moreover, the survey was conducted within a constrained timeline that was budgeted to produce a statewide unstable slopes screening tool as quickly as possible. Thus, the landslide inventory presented in this report (Map A1 and Form A1) is intended to be a representative but not an exhaustive inventory. For these reasons, it is possible that some landslides or unstable landforms have been overlooked, some benign features have been mistakenly mapped as landslides, and some landslides have been classified improperly. In spite of this, representative samples of unstable slopes and landforms have been recognized to the end that the assessment is validated.

This assessment was largely conducted remotely using the best map and image-based resources available, with support from limited field visits to verify mapping results. However, we note that landslide inventories that are conducted primarily using air photos have been demonstrated to omit up to 85% of the landslides that actually exist on the ground in heavily forested areas (Brardinoni and others, 2003). Furthermore, these studies tend to skew the location of the majority of landslide occurrences toward recently harvested areas because they are easier to spot in these areas than under dense canopy on air photos (Brardinoni and others, 2003).

Information was collected and compiled in a manner that was designed to respond to the Critical Questions that are outlined in Section II of the LHZ Protocol, and to direct attention to areas where more detailed analysis is necessary. The objective of the data collection was to generate information sufficient to establish:

- A generalized characterization of mass wasting processes that are active in the WAU;
- Areas of landscape that share similar physical characteristics related to mass-wasting behavior;
- The relative potential for mass wasting to occur among the various landform units.

12.0 Acknowledgments

Funding for this project was provided by a Federal Salmon Recovery grant, administered through the Washington Interagency Commission on Outdoor Recreation. The Upslope Processes Science Advisory Group (UPSAG), a subcommittee of the Cooperative Monitoring, Evaluation and Research (CMER) group, provided technical oversight of this project. The following people have greatly contributed to this project (and special thanks given to): Jack Powell of DNR Forest Practices who tromped through the woods and shared many insights about landslides and the LHZ project. Laura Vaugeois of DNR Forest Practices for her extensive knowledge on GIS, landslides, and forest practices rules. Venice Goetz of DNR Forest Practices for word-smithing and editing the report. Matt Brunengo of DNR Geology for many insights regarding watershed specific climate data. Isabelle Sarikhan of the DNR Geology for GIS support and moral support. Lee Walkling of the DNR Geology Library for her gracious help in identifying reference material. Finally, the authors thank DNR foresters Mike Davies and Dwayne Shotton as well as Olympic Resource Management especially, Dani Priest for their assistance in providing access to field sites, up-to-date road maps, and resources for an understanding of the historic perspective.

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Great Bend WAU																	
Appendix A (Form A-1)																	
slide_id	*Size (acres)*	*Ls_size*	lsi_process	certainty	id_date	init_elev	photo_num	lsi_landform	WAU Landform	gradient	slp_shp	delivery	landuse	geo_unit	Deep-Seated Activity	Deep-Seated Type	Comments
101	3.30	5	4	P	1965	360	KMT65 22B-48	1	6	45	1	Y	3	Qgt	DI	R	along canal bluff
102	11.40	5	4	P	1965	398	KMT65 22B-48	1	6	53	2	Y	3	Qgt	DI	T	along canal bluff
103	3.30	5	4	P	1965	470	KMT65 22B-48	7	3	31	2	N	3	Qgt	DI	C	part of larger area mapped as kettle&kame adj to Dewatto River
104	0.50	4	2	D	1965	357	KMT65 22B-48	1	6	45	1	Y	3	Qapo			within dsls
105	1.40	5	4	D	1965	256	KMT65 22B-48	7	5	59	1	Y	3	Qapo	DD	C	along canal bluff
106	4.00	5	4	P	1965	357	KMT65 22B-48	1	6	47	1	Y	3	Qapo	DI	C	along canal bluff
107	0.80	4	4	D	1965	196	KMT65 22B-48	1	6	49	2	Y	3	Qapo	DD	T	along canal bluff
108	1.10	5	4	D	1965	278	KMT65 22B-48	1	6	51	1	Y	3	Qapo	DD	T	along canal bluff
109	0.60	4	4	P	1965	260	KMT65 22B-48	1	6	51	2	Y	3	Qapo	DI	R	along canal bluff
110	0.90	4	4	P	1965	412	KMT65 22B-48	1	6	58	1	P	3	Qapo	DI	R	along canal bluff
111	1.20	5	4	D	1965	423	KMT65 22B-48	1	6	59	1	P	3	Qgt	DD	R	along canal bluff
112	4.50	5	4	P	1965	501	KMT65 22B-48	1	6	53	1	Y	3	Qgt	DI	C	along canal bluff
113	1.00	5	4	D	1965	200	KMT65 22B-48	1	6	51	1	Y	3	Qapo	DD	R	along canal bluff
114	6.50	5	4	D	1965	475	KMT65 22B-48	1	6	47	1	Y	3	Qgt	DD	C	along canal bluff
115	3.70	5	4	D	1965	535	KMT65 22B-48	1	6	51	1	Y	3	Qgt	DD	C	along canal bluff
116	0.30	3	3	D	1965	176	KMT65 22B-48	7	5	45	2	Y	3	Qapo			along canal bluff
117	1.80	5	4	D	1965	303	KMT65 22B-48	1	6	51	1	Y	3	Qapo	DI	C	along canal bluff
118	0.10	2	2	D	1965	401	KMT65 22B-48	1	6	59	1	Y	3	Qapo			along canal bluff(w/in an unmappedDI/Relict dsls-seen olcqt05)
119	0.30	3	2	D	1965	473	KMT65 22B-48	7	4	43	1	Y	3	Qgt			along canal bluff
120	0.10	2	1	D	1965	152	KMT65 22B-48	7	4	39	3	Y	3	Qapo			along canal bluff w/in inner gorge
121	0.10	2	1	D	1965	171	KMT65 22B-48	1	6	63	3	Y	3	Qapo			along canal bluff w/in inner gorge
122	0.10	2	1	D	1965	171	KMT65 22B-48	1	6	59	3	Y	3	Qapo			along canal bluff w/in inner gorge
123	0.10	2	1	D	1965	227	KMT65 22B-48	1	6	57	3	Y	3	Qapo			along canal bluff w/in inner gorge
124	0.10	2	1	D	1965	193	KMT65 22B-48	7	4	31	3	Y	3	Qapo			along canal bluff w/in inner gorge
125	0.10	2	1	D	1965	225	KMT65 22B-48	7	4	38	3	Y	3	Qapo			along canal bluff w/in inner gorge
126	0.10	2	1	D	1965	249	KMT65 22B-48	7	4	38	3	Y	3	Qapo			along canal bluff w/in inner gorge
127	0.20	3	3	D	1965	266	KMT65 22B-50	1	6	51	3	P	3	Qapo			along canal bluff
128	1.20	5	4	D	1965	229	KMT65 22B-50	1	6	44	1	Y	4	Qapo	DD	R	along canal bluff
129	5.10	5	4	D	1965	502	KMT65 22B-50	1	6	44	2	Y	4	Qapo	DD	C	along canal bluff

slide_id	Size (acres)	Ls_size	lsi_process	certainty	id_date	init_elev	photo_num	lsi_landform	WAU Landform	gradient	slp_shp	delivery	landuse	geo_unit	Deep-Seated Activity	Deep-Seated Type	Comments
130	0.01	1	1	D	1965	317	KMT65 22B-50	7	4	31	3	Y	3	Qapo			along canal bluff
131	2.90	5	4	D	1965	556	KMT65 22B-50	1	6	47	2	Y	4	Qgt	DI	C	along canal bluff
132	2.60	5	4	D	1965	516	KMT65 22B-50	1	6	50	1	Y	4	Qgt	DD	C	along canal bluff
133	0.80	4	2	D	1965	356	KMT65 22B-50	1	6	44	1	Y	3	Qapo			along canal bluff
134	0.70	4	2	D	1965	564	KMT65 22B-50	7	4	43	1	Y	3	Qgt			along canal bluff
135	0.60	4	3	D	1965	585	KMT65 22B-50	7	4	49	3	P	3	Qgt			along canal bluff
136	0.10	2	1	D	1965	180	KMT65 22B-50	1	6	77	2	Y	3	Qapo			along canal bluff
137	0.30	3	2	D	1965	472	KMT65 23-80	7	4	48	1	Y	3	Qga			along canal bluff
138	6.20	5	1	D	1965	358	KMT65 23-80	1	6	43	2	Y	3	Qapo			along canal bluff
139	0.10	2	1	D	1965	78	KMT65 23-80	1	6	56	3	Y	3	Qapo			along canal bluff
140	0.30	3	1	D	1965	182	KMT65 23-80	1	6	52	3	Y	3	Qapo			along canal bluff
141	0.20	3	1	D	1965	243	KMT65 23-80	7	4	46	2	Y	3	Qapo			along canal bluff
142	6.90	5	1	P	1965	394	KMT65 23-80	1	6	43	2	Y	3	Qapo			along canal bluff
143	0.10	2	1	D	1965	330	KMT65 23-80	1	6	18	3	P	3	Qapo			along canal bluff
144	0.10	2	1	D	1965	130	KMT65 23-80	7	3	29	3	Y	3	Qapo			along canal bluff
145	0.10	2	3	D	1965	272	KMT65 23-82	1	6	59	3	P	3	Qapo			along canal bluff
146	0.10	2	1	P	1965	263	KMT65 23-82	7	4	34	3	Y	3	Qga			along canal bluff
147	27.20	5	4	D	1965	504	KMT65 23-82	1	6	53	2	Y	3	Qapo	DI	C	along canal bluff
148	0.10	2	1	D	1965	127	KMT65 23-82	7	5	36	3	Y	3	Qapo			along canal bluff
149	0.10	2	1	D	1965	161	KMT65 23-82	1	6	35	3	Y	3	Qga			along canal bluff
150	0.10	2	1	D	1965	243	KMT65 23-82	1	6	62	1	Y	3	Qga			along canal bluff
151	0.20	3	1	D	1965	313	KMT65 23-82	1	6	57	1	Y	3	Qga			along canal bluff
152	0.40	3	1	D	1965	354	KMT65 23-82	7	4	44	2	Y	3	Qga			along canal bluff
153	4.80	5	3	P	1965	479	KMT65 23-82	1	6	48	2	Y	2	Qga			along canal bluff
154	4.10	5	3	P	1965	337	KMT65 23-82	1	6	44	2	Y	3	Qga			along canal bluff
155	3.00	5	1	D	1965	382	KMT65 23-82	1	6	45	2	Y	3	Qga			along canal bluff
156	0.01	1	1	D	1965	641	KMT65 23-82	7	4	34	3	N	2	Qgt			along canal bluff
157	0.70	4	3	D	1965	325	KMT65 24B-4	1	6	62	2	Y	3	Qgt			stream adj
158	0.10	2	1	D	1965	188	KMT65 24B-4	1	6	14	3	Y	3	Qgt			stream adj
159	0.10	2	1	D	1965	325	KMT65 24B-4	1	6	81	3	Y	3	Qga			stream adj
160	0.10	2	1	P	1965	272	KMT65 24B-6	1	6	67	3	P	3	Qgt			stream adj

slide_id	Size (acres)	Ls_size	lsi_process	certainty	id_date	init_elev	photo_num	lsi_landform	WAU Landform	gradient	slp_shp	delivery	landuse	geo_unit	Deep-Seated Activity	Deep-Seated Type	Comments
161	0.10	2	1	P	1965	350	KMT65 24B-6	7	5	53	2	N	3	Qga			
162	0.40	3	3	D	1965	238	KMT65 24B-6	1	6	35	3	Y	3	Qga			stream adj
163	0.10	2	1	D	1965	266	KMT65 24B-6	1	6	72	3	Y	3	Qga			stream adj
164	0.10	2	1	D	1965	251	KMT65 24B-6	1	6	54	3	Y	3	Qga			stream adj
165	0.10	2	1	D	1965	440	KMT65 24B-8	1	6	74	3	Y	3	Qgt			stream adj
166	0.10	2	1	D	1965	435	KMT65 24B-8	1	6	75	2	Y	3	Qgt			stream adj
167	0.20	3	1	D	1965	440	KMT65 24B-8	1	6	47	1	Y	3	Qgt			stream adj
168	0.10	2	3	D	1965	361	KMT65 24B-8	1	6	46	2	Y	3	Qgt			stream adj
169	0.10	2	1	D	1965	354	KMT65 24B-8	1	6	51	2	Y	3	Qga			stream adj
170	0.10	2	1	D	1965	451	KMT65 24B-8	1	6	78	3	Y	3	Qga			stream adj
171	0.30	3	3	D	1965	513	KMT65 24B-8	1	6	52	1	Y	3	Qgt			stream adj
172	0.10	2	1	D	1965	529	KMT65 24B-8	1	6	61	3	Y	1	Qgt			stream adj
173	0.20	3	1	D	1965	311	KMT65 24B-8	7	4	36	3	P	2	Qga			possible ORV trail?
174	0.10	2	1	Q	1965	682	KMT65 24B-8	7	4	40	2	I	1	Qgt			possible yarding scar
175	0.10	2	1	Q	1965	705	KMT65 24B-8	7	4	43	2	I	1	Qgt			possible yarding scar
176	0.10	2	1	Q	1965	684	KMT65 24B-8	7	4	40	2	I	1	Qgt			possible yarding scar
177	0.01	1	1	Q	1965	652	KMT65 24B-8	7	4	34	2	I	1	Qgt			possible yarding scar
178	0.10	2	1	D	1965	317	KMT65 24B-8	1	6	17	3	Y	3	Qgt			stream adj
179	0.10	2	1	D	1965	306	KMT65 24B-8	1	6	69	3	Y	3	Qgt			stream adj
180	0.50	4	4	D	1965	143	KMT65 24B-10	7	5	39	1	Y	4	Qc	DD	R	along canal bluff; Isabelle's Test LS
181	0.10	2	3	D	1965	567	KMT65 24B-10	7	4	53	3	Y	4	Qgt			along canal bluff
182	5.30	5	4	Q	1965	279	KMT65 24B-10	1	6	44	2	P	4	Qc	DI	T	along canal bluff; possible slow moving dsls
183	0.30	3	3	P	1965	361	KMT65 24B-10	1	6	68	1	Y	3	Qga			along canal bluff
184	0.10	2	1	D	1965	412	KMT65 24B-10	1	6	83	3	P	3	Qga			along canal bluff
185	1.10	5	4	D	1965	534	KMT65 24B-10	1	6	67	1	Y	3	Qga	DD	C	along canal bluff
186	0.60	4	4	D	1965	531	KMT65 24B-10	1	6	60	1	Y	3	Qga	DD	T	along canal bluff; stream adj
187	0.10	2	1	D	1965	455	KMT65 24B-10	1	6	64	3	Y	3	Qga			along canal bluff, stream adj
188	0.10	2	1	D	1965	514	KMT65 24B-10	1	6	86	3	Y	3	Qga			along canal bluff, stream adj
189	0.10	2	1	D	1965	565	KMT65 24B-10	1	6	62	3	Y	3	Qga			along canal bluff, stream adj
190	0.10	2	1	D	1965	524	KMT65 24B-10	1	6	83	3	Y	3	Qga			along canal bluff, stream adj
191	0.10	2	1	D	1965	531	KMT65 24B-10	1	6	62	3	Y	3	Qga			along canal bluff, stream adj

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192	0.60	4	3	D	1965	595	KMT65 24B-10	1	6	63	1	Y	3	Qga			along canal bluff, stream adj
193	0.60	4	1	P	1965	506	KMT65 24B-10	1	6	55	3	P	1	Qga			along canal bluff
194	76.10	5	4	Q	1965	606	KMT65 24B-10	1	6	50	2	Y	3	Qga	DI	C	along canal bluff, marginal streams
195	7.40	5	4	Q	1965	442	KMT65 24B-10	1	6	55	1	Y	3	Qc	DI	C	along canal bluff; overlapping w/R.Gold ls
196	5.40	5	4	P	1965	585	KMT65 24B-10	1	6	71	1	Y	3	Qga	DI	C	along canal bluff
197	0.20	3	1	D	1965	210	KMT65 24B-10	1	6	58	3	Y	3	Qga			along canal bluff; stream adj
198	0.10	2	1	D	1965	305	KMT65 24B-10	1	6	87	3	Y	3	Qga			along canal bluff; stream adj
199	0.20	3	1	D	1965	359	KMT65 24B-10	1	6	86	3	Y	3	Qga			along canal bluff; stream adj
200	0.20	3	1	D	1965	530	KMT65 24B-10	1	6	83	3	Y	3	Qga			along canal bluff; stream adj
201	0.30	3	3	D	1965	530	KMT65 24B-10	1	6	92	1	Y	3	Qga			along canal bluff; stream adj
202	0.10	2	1	P	1965	560	KMT65 24B-10	1	6	88	2	Y	4	Qgd			along canal bluff; stream adj
203	0.10	2	1	P	1965	345	KMT65 24B-10	1	6	52	3	Y	4	Qgd			along canal bluff; stream adj
204	0.10	2	1	D	1965	432	KMT65 24B-10	1	6	83	3	Y	4	Qgd			along canal bluff; stream adj
205	0.10	2	1	D	1965	416	KMT65 24B-10	1	6	89	3	Y	3	Qga			w/in #196
206	0.10	2	1	D	1965	28	KMT65 24B-12	7	4	19	1	Y	3	Qc			along canal bluff
207	3.00	5	4	P	1965	309	KMT65 24B-12	1	6	64	2	Y	3	Qgd	DI	R	along canal bluff, stream adj
208	2.30	5	4	Q	1965	282	KMT65 24B-12	1	6	78	2	Y	3	Qgd	DI	T	along canal bluff, stream adj
209	8.70	5	4	D	1965	592	KMT65 24B-12	1	6	69	1	Y	3	Qgd	DD	R	along canal bluff, stream adj
210	8.60	5	4	D	1965	563	KMT65 24B-12	1	6	62	1	Y	3	Qgd	DD	R	along canal bluff, stream adj
211	0.10	2	1	D	1965	315	KMT65 24B-12	1	6	63	1	Y	3	Qgd			along canal bluff, stream adj
212	0.10	2	1	D	1965	529	KMT65 24B-12	1	6	61	1	Y	3	Qgd			along canal bluff, stream adj
213	0.10	2	1	D	1965	486	KMT65 24B-12	1	6	76	1	Y	3	Qgd			along canal bluff, stream adj
214	0.10	2	1	D	1965	404	KMT65 24B-12	1	6	94	3	Y	3	Qgd			along canal bluff, stream adj
215	2.20	5	4	D	1965	547	KMT65 24B-12	1	6	68	1	Y	3	Qgd	DI		along canal bluff, stream adj, see kmt65 25B-23
216	0.20	3	3	D	1965	288	KMT65 24B-12	1	6	76	2	Y	3	Qgd			along canal bluff, stream adj
217	0.10	2	1	P	1965	440	KMT65 24B-12	1	6	45	3	P	3	Qgd			along canal bluff, stream adj
218	0.10	2	1	D	1965	200	KMT65 24B-12	1	6	53	3	Y	3	Qgd			along canal bluff, stream adj
219	0.20	3	1	P	1965	315	KMT65 24B-12	1	6	67	1	Y	3	Qgd			along canal, stream adj
220	0.10	2	1	P	1965	285	KMT65 24B-12	1	6	72	3	Y	3	Qgd			along canal, stream adj
221	0.70	4	3	D	1965	198	KMT65 24B-12	1	6	78	1	Y	3	Qgd			along canal, stream adj
222	0.10	2	1	D	1965	205	KMT65 24B-12	1	6	74	3	P	3	Qgd			along canal, stream adj

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223	6.40	5	4	P	1965	446	KMT65 24B-12	1	6	52	1	Y	3	Qgd	DI	C	along canal
224	10.10	5	4	P	1965	472	KMT65 24B-12	1	6	48	1	Y	3	Qgd	DI	C	along canal
225	0.20	3	3	D	1965	61	KMT65 24B-12	7	5	42	1	Y	3	Qgd			along canal
226	0.10	2	1	D	1965	353	KMT65 25B-17	1	6	71	1	Y	3	Qga			stream adj
227	0.10	2	2	D	1965	382	KMT65 25B-17	1	6	45	1	Y	5	Qga			stream adj
228	1.00	5	4	D	1965	319	KMT65 25B-19	1	6	36	2	Y	3	Qgt	DI	T	stream adj
229	0.20	3	3	D	1965	299	KMT65 25B-19	1	6	30	1	P	3	Qgt			stream adj
230	21.80	5	4	P	1965	522	KMT65 25B-19	7	4	28	1	P	3	Qgt	DI	C	Field Check, behind MANKE gate/ multiple events
231	2.90	5	4	P	1965	434	KMT65 25B-19	7	4	41	1	Y	3	Qga	DI	R	
232	0.20	3	3	D	1965	416	KMT65 25B-21	1	6	60	1	Y	3	Qga			stream adj, OUSIDE MEANDER BEND, clearcut above
233	0.10	2	3	D	1965	412	KMT65 25B-21	1	6	77	3	Y	3	Qga			stream adj
234	0.40	3	3	P	1965	241	KMT65 25B-21	7	3	16	1	N	5	Qgt			FIELD CHECK, crosses road
235	0.10	2	3	P	1965	369	KMT65 25B-21	1	6	55	1	P	3	Qga			stream adj, top of terrace
236	0.10	2	1	D	1965	439	KMT65 25B-21	1	6	56	1	Y	3	Qga			stream adj
237	0.50	3	4	P	1965	555	KMT65 25B-21	1	6	65	1	Y	3	Qgd	DI	C	along canal bluff, stream adj
239	5.30	5	4	P	1965	601	KMT65 25B-23	1	6	60	1	Y	3	Qgd	DI	R	along canal bluff, stream adj
240	2.60	5	2	Q	1965	438	KMT65 25B-23	1	6	60	1	Y	3	Qgd			along canal bluff, stream adj
241	33.90	5	4	P	1965	594	KMT65 25B-23	1	6	51	1	Y	3	Qgd	DI	C	along canal bluff
242	0.10	2	3	P	1965	205	KMT65 25B-23	1	6	71	1	Y	3	Qgd			along canal bluff, w/in dsls #245
243	0.10	2	3	Q	1965	278	KMT65 25B-23	1	6	74	3	Y	3	Qgd			along canal bluff, w/in dsls #245
244	0.20	3	3	Q	1965	280	KMT65 25B-23	1	6	47	3	Y	3	Qgd			along canal bluff, w/in dsls #245
245	50.50	5	4	P	1965	597	KMT65 25B-23	1	6	50	2	Y	3	Qgd	DI	C	along canal bluff
246	0.60	4	3	D	1965	378	KMT65 25B-23	1	6	53	1	P	3	Qgd			along canal bluff
247	2.00	5	4	P	1965	258	KMT65 25B-23	1	6	54	1	P	3	Qgd	DI	C	along canal bluff
248	0.40	3	3	D	1965	346	KMT65 25B-23	1	6	55	1	Y	3	Qgd			along canal bluff, stream adj
249	0.20	3	3	P	1965	433	KMT65 25B-23	1	6	58	1	P	3	Qgd			along canal bluff
250	0.10	2	3	P	1965	347	KMT65 25B-23	7	4	48	2	P	3	Qgd			along canal bluff
251	0.20	3	3	D	1965	328	KMT65 25B-23	1	6	59	2	Y	3	Qgd			along canal bluff
252	0.50	4	3	D	1965	413	KMT65 25B-23	1	6	62	2	P	3	Qgd			along canal bluff
253	0.10	2	1	D	1965	219	KMT65 25B-23	1	6	82	2	P	3	Qgd			along canal bluff, stream adj
254	0.10	2	1	D	1965	196	KMT65 25B-23	1	6	51	2	Y	3	Qgd			along canal bluff, stream adj

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255	0.10	2	1	D	1965	196	KMT65 25B-23	1	6	35	2	Y	3	Qgd			along canal bluff, stream adj
256	0.10	2	1	D	1965	215	KMT65 25B-23	1	6	34	3	P	3	Qgd			along canal bluff
257	0.10	2	1	D	1965	230	KMT65 25B-23	1	6	51	3	P	3	Qgd			along canal bluff
258	0.01	1	1	D	1965	129	KMT65 25B-23	7	4	12	3	P	3	Qgd			along canal bluff
259	0.50	4	3	D	1965	392	KMT65 25B-23	1	6	71	1	P	3	Qgd			along canal bluff
260	0.10	2	1	P	1965	108	KMT65 25B-23	7	5	46	1	P	3	Qgd			along canal bluff
261	0.10	2	1	P	1965	102	KMT65 25B-23	7	5	84	1	P	3	Qgd			along canal bluff
262	0.10	2	1	P	1965	104	KMT65 25B-23	7	5	76	1	P	3	Qgd			along canal bluff
263	0.10	2	1	P	1965	99	KMT65 25B-23	7	5	70	1	P	3	Qgd			along canal bluff
264	0.01	1	1	P	1965	177	KMT65 25B-23	7	4	49	3	P	3	Qgd			along canal bluff
265	0.10	2	1	P	1965	206	KMT65 25B-23	1	6	38	3	N	3	Qgd			along canal bluff
266	0.10	2	1	P	1965	289	KMT65 25B-23	1	6	67	2	N	3	Qgd			along canal bluff
267	0.10	2	1	D	1965	318	KMT65 25B-23	1	6	61	2	Y	3	Qgd			along canal bluff
268	0.10	2	1	D	1965	353	KMT65 25B-23	1	6	63	2	Y	3	Qgd			along canal bluff
269	0.10	2	1	D	1965	314	KMT65 25B-23	1	6	64	2	Y	3	Qgd			along canal bluff
270	0.10	2	1	P	1965	101	KMT65 25B-23	7	4	47	3	Y	3	Qgd			along canal bluff, stream adj
271	0.10	2	3	D	1965	175	KMT65 25B-23	1	6	61	1	Y	3	Qgd			along canal bluff
272	0.10	2	1	P	1965	213	KMT65 25B-23	1	6	66	2	P	3	Qgd			along canal bluff
273	0.10	2	1	D	1965	389	KMT65 25B-23	1	6	41	1	N	3	Qgd			along canal bluff
274	1.80	5	4	D	1965	103	KMT65 25B-23	7	5	92	2	Y	3	Qgd	DI	R	along canal bluff
275	3.10	5	4	D	1965	12	KMT65 25B-24	7	5	18	2	Y	3	Qgd	DI	R	along canal bluff
276	0.10	2	3	D	1965	120	KMT65 25B-24	7	5	109	1	Y	3	Qgd			along canal bluff
277	15.70	5	4	D	1965	377	KMT65 25B-24	1	6	53	1	Y	3	Qgd	DI	C	already mapped as #23691
278	0.50	4	4	D	1965	390	KMT65 26B-65	1	6	54	1	Y	3	Qgt	DI	R	stream adj
279	0.10	2	1	D	1965	393	KMT65 26B-67	1	6	49	3	Y	3	Qga			stream adj, clearcut above
280	0.10	2	1	D	1965	384	KMT65 26B-67	1	6	59	3	Y	3	Qga			stream adj, clearcut above
281	0.10	2	1	D	1965	380	KMT65 26B-67	1	6	63	3	Y	3	Qga			stream adj, clearcut above
282	0.80	4	2	P	1965	454	KMT65 26B-67	7	4	36	1	Y	3	Qgt			clearcut above
283	0.30	3	1	D	1965	477	KMT65 26B-67	1	6	65	4	Y	2	Qgt			stream adj, clearcut above
284	0.10	2	1	D	1965	351	KMT65 27-82	7	4	33	1	Y	5	Qa			stream adj, clearcut above
285	0.10	2	1	D	1965	354	KMT65 27-82	1	6	26	3	Y	3	Qga			stream adj, clearcut above

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286	0.10	2	1	D	1965	520	KMT65 27-82	7	3	28	3	Y	5	Qgt			stream adj, clearcut above
287	0.20	3	3	P	1965	477	KMT65 29B-76	7	4	17	2	Y	3	Qgt			stream adj
288	1.00	5	2	P	1965	529	KMT65 29B-78	7	3	18	1	Y	3	Qgt			stream adj
289	0.20	3	3	D	1965	583	KMT65 32C-31	7	4	28	3	Y	3	Qgt			stream adj
290	0.01	1	1	D	1965	573	KMT65 32C-31	7	4	32	3	Y	3	Qgt			stream adj
291	7.20	5	4	Q	1965	682	KMT65 32C-31	7	4	27	1	Y	3	Qgt	DI	C	stream adj
292	0.10	2	3	D	1965	716	KMT65 32C-31	1	6	52	1	Y	3	Qgo			stream adj
293	0.10	2	1	D	1965	737	KMT65 32C-31	1	6	71	3	Y	2	Ev(c)			stream adj
294	6.50	5	4	Q	1965	950	KMT65 32C-31	7	5	39	2	Y	3	Ev(c)	DI	R	stream adj
295	23.00	5	4	Q	1965	1035	KMT65 32C-31	7	4	28	2	Y	3	Eigb	DI	R	stream adj, another dsls across cr
296	1.60	5	2	P	1965	1099	KMT65 32C-31	7	4	27	1	Y	3	Eigb			crosses dsls #295
297	32.80	5	4	Q	1965	1089	KMT65 32C-31	7	4	26	1	Y	3	Eit	DI	C	stream adj, sag pond in center, Rd access GM-1
298	1.00	5	2	P	1965	1456	KMT65 32C-31	7	4	37	1	N	3	Eib			
299	2.20	5	2	P	1965	1026	KMT65 32C-33	7	4	23	1	Y	3	Eigb			deposit intoBeaverPond,Rd access GM-14,1997photo=toe gone
300	0.40	3	1	D	1965	842	KMT65 32C-33	7	3	23	3	Y	3	Eib			stream adj
301	1.90	5	2	Q	1965	1282	KMT65 33B-27	7	5	51	1	Y	3	Ev(c)			
302	1.90	5	2	Q	1965	1377	KMT65 33B-27	7	4	44	1	Y	3	Ev(c)			
303	1.50	5	2	P	1965	1413	KMT65 33B-27	7	4	41	1	Y	3	Ev(c)			
304	0.20	3	1	D	1965	979	KMT65 33B-27	7	5	72	3	Y	3	Ev(c)			stream adj, ? Continuation of #303
305	0.10	2	1	D	1965	1269	KMT65 33B-29	7	4	46	3	Y	3	Eigb			stream adj
306	0.10	2	1	D	1965	1088	KMT65 33B-29	7	3	25	3	N	5	Eit			
307	0.10	2	1	P	1978	306	NW78 23C-6	7	4	42	3	N	3	Qgt			
308	0.10	2	1	P	1978	236	NW78 23C-6	7	4	42	3	N	3	Qgt			hardwoods
309	0.20	3	1	P	1978	245	NW78 23C-6	7	4	34	1	N	3	Qgt			hardwoods
310	0.10	2	1	P	1978	148	NW78 23C-6	7	4	18	1	N	3	Qgt			hardwoods
311	0.10	2	1	D	1978	539	NW78 23C-6	7	4	46	1	Y	3	Qgt			along canal bluff
312	0.10	2	1	D	1978	520	NW78 23C-6	7	4	45	1	Y	3	Qgt			along canal bluff
313	0.10	2	1	D	1978	118	NW78 23C-6	7	4	8	3	Y	3	Qgt			stream adj
314	0.20	3	1	D	1978	134	NW78 23C-6	7	3	18	3	Y	3	Qgt			stream adj
315	0.20	3	1	D	1978	173	NW78 23C-6	7	3	21	3	N	3	Qgt			
316	2.00	5	3	P	1978	357	NW78 23C-8	7	4	28	2	P	3	Qgt			

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317	0.10	2	1	D	1978	293	NW78 23C-8	7	4	43	3	Y	2	Qga			stream adj
318	4.20	5	1	P	1978	400	NW78 23C-8	7	4	47	1	Y	3	Qga			along canal bluff
319	0.30	3	1	P	1978	573	NW78 23C-8	7	3	18	2	Y	3	Qgt			stream adj
320	0.10	2	1	D	1978	549	NW78 23C-8	1	6	51	3	P	3	Qga			stream adj
321	1.10	5	3	P	1978	289	NW78 23C-8	1	6	50	2	Y	3	Qc			along canal bluff
322	0.10	2	3	D	1978	144	NW78 23C-8	7	5	88	2	Y	3	Qc			along canal bluff
323	0.10	2	1	D	1978	309	NW78 24A-97	7	4	35	2	Y	3	Qga			along canal bluff, stream adj
324	0.20	3	1	P	1978	415	NW78 24A-97	1	6	61	2	N	3	Qga			along canal bluff
325	0.20	3	1	P	1978	387	NW78 24A-97	1	6	56	2	N	3	Qga			along canal bluff
326	0.40	4	1	D	1978	454	NW78 24A-97	1	6	50	1	N	3	Qga			along canal bluff
327	0.10	2	1	D	1978	526	NW78 24A-97	1	6	62	2	Y	2	Qga			along canal bluff, stream adj
328	0.10	2	1	D	1978	355	NW78 24A-97	7	3	26	3	N	2	Qgt			?part of #329?
329	0.10	2	1	D	1978	329	NW78 24A-97	7	3	8	3	N	2	Qgt			?part of #328?
330	1.30	5	4	D	1978	144	NW78 24A-100	7	5	53	1	Y	3	Qgd	DI		along canal bluff
331	0.80	4	3	D	1978	438	NW78 24A-100	1	6	61	2	Y	3	Qgd			along canal bluff
332	0.10	2	1	D	1978	542	NW78 27A-94	7	3	22	1	N	2	Qgt			
333	0.70	4	3	D	1978	508	NW78 27A-94	7	4	20	1	Y	3	Qgt			adj to Erickson Lake
334	0.40	4	1	D	1978	446	NW78 27A-94	1	6	75	3	Y	3	Qga			stream adj
335	0.10	2	1	P	1978	462	NW78 27A-94	1	6	61	3	Y	3	Qga			stream adj
336	0.10	2	1	P	1978	479	NW78 27A-94	7	4	12	3	Y	2	Qgt			adj to Erickson Lake
337	0.80	4	1	D	1997	252	OL97 39-83-36	1	6	75	3	Y	3	Qc			along canal bluff, clearcut above
338	1.80	5	3	D	1997	549	OL97 39-83-36	1	6	55	2	Y	3	Qgt			stream adj
339	2.90	5	3	P	1997	513	OL97 39-83-36	1	6	47	2	Y	3	Qgt			stream adj
340	0.20	3	1	P	1997	501	OL97 39-83-36	1	6	69	3	P	3	Qga			stream adj
341	1.10	5	3	D	1997	492	OL97 39-83-36	1	6	59	2	Y	3	Qga			stream adj
342	0.50	4	1	D	1939	483	1939OrthoHollysw	1	6	79	1	Y	2	Qgd			along canal bluff, flows into #376
344	0.20	3	1	P	1997	135	OL97 39-84-244	7	3	25	3	Y	3	Qgt			stream adj
345	0.10	2	3	D	1997	145	OL97 39-84-244	7	5	44	3	Y	3	Qgt			stream adj
346	0.20	3	1	D	1997	165	OL97 39-84-244	7	5	53	3	Y	3	Qgt			stream adj
347	0.10	2	1	P	1997	158	OL97 39-84-244	7	3	23	3	Y	3	Qgt			stream adj
348	3.20	5	4	P	1997	290	OL97 39-84-244	7	5	39	1	Y	3	Qgt	DI	R	stream adj

slide_id	Size (acres)	Ls_size	lsi_process	certainty	id_date	init_elev	photo_num	lsi_landform	WAU Landform	gradient	slp_shp	delivery	landuse	geo_unit	Deep-Seated Activity	Deep-Seated Type	Comments
349	0.30	3	1	D	1997	270	OL97 39-84-244	1	6	54	3	Y	4	Qgt			stream adj
350	0.30	3	1	D	1997	336	OL97 39-84-246	1	6	34	3	Y	3	Qga			stream adj
351	1.60	5	3	P	1997	490	OL97 39-84-246	1	6	62	2	Y	3	Qga			stream adj
352	0.40	4	1	P	1997	352	OL97 39-84-246	7	4	38	2	N	3	Qga			
353	0.20	3	1	P	1997	380	OL97 39-84-246	7	4	39	2	N	3	Qga			
354	0.10	2	1	D	1997	515	OL97 39-84-246	1	6	70	3	Y	4	Qgt			stream adj
356	0.10	2	1	D	1997	353	OL97 38-84-250	1	6	47	2	Y	3	Qga			along canal bluff, stream adj
357	0.20	3	1	D	1997	491	OL97 38-84-250	7	4	29	3	P	3	Qga			
358	0.30	3	1	D	1997	449	OL97 38-84-250	7	4	41	3	Y	3	Qga			stream adj
359	0.10	2	1	D	1997	565	OL97 38-84-250	1	6	75	3	Y	3	Qga			stream adj
360	0.30	3	1	D	1997	552	OL97 38-84-250	1	6	66	3	Y	3	Qga			stream adj
361	0.40	4	1	P	1997	599	OL97 38-84-250	1	6	66	3	Y	3	Qga			stream adj
362	0.30	3	1	D	1997	508	OL97 38-84-250	1	6	64	1	Y	3	Qga			stream adj
363	0.10	2	1	D	1997	388	OL97 38-84-250	1	6	90	3	Y	3	Qgd			stream adj
364	0.10	2	1	D	1997	420	OL97 38-84-250	1	6	73	3	Y	3	Qgd			stream adj
365	0.10	2	1	D	1997	386	OL97 38-84-250	1	6	85	3	Y	3	Qgd			stream adj
366	0.10	2	1	D	1997	461	OL97 38-84-250	1	6	86	3	Y	3	Qgd			stream adj
367	0.20	3	1	D	1997	558	OL97 38-84-250	1	6	64	3	Y	3	Qgd			stream adj
368	2.00	5	1	D	1997	338	OL97 38-84-248	7	3	11	1	Y	3	Qgt			
369	1.50	5	1	D	1997	399	OL97 38-84-248	7	3	25	1	P	3	Qgt			
370	0.60	4	1	D	1997	202	OL97 35-85-61	7	3	27	1	Y	3	Qgt			stream adj, rd above FIELD CHECK
371	0.30	3	1	D	1997	172	OL97 35-85-61	7	3	10	1	Y	3	Qa			stream adj, rd above FIELD CHECK
372	0.80	4	1	Q	1997	466	OL97 35-85-61	7	3	21	1	N	5	Qgt			abandon rd?
373	1.00	5	3	P	1997	288	OL97 35-85-61	7	4	44	1	Y	3	Qgo			stream adj
374	2.50	5	2	D	1939	627	1939OrthoHollysw	1	6	43	1	Y	5	Qga			along canal bluff
375	1.00	5	2	D	1939	558	1939OrthoHollysw	1	6	80	1	Y	2	Qgd			along canal bluff, flows into #376
376	7.60	5	2	D	1939	558	1939OrthoHollysw	1	6	60	1	Y	5	Qgd			along canal bluff, shallows flow into this one
377	0.40	3	3	D	1939	105	1939OrthoHollysw	1	6	32	2	Y	2	Qgd			along canal bluff, possible block to df #376
378	3.70	5	1	D	1939	570	1939OrthoEldonse	1	6	57	3	Y	1	Qga			along canal bluff
379	1.10	5	1	D	1939	562	1939OrthoEldonse	1	6	57	3	Y	5	Qga			along canal
380	2.50	5	1	D	1939	620	1939OrthoEldonse	1	6	56	3	Y	1	Qga			along canal

slide_id	Size (acres)	Ls_size	lsi_process	certainty	id_date	init_elev	photo_num	lsi_landform	WAU Landform	gradient	slp_shp	delivery	landuse	geo_unit	Deep-Seated Activity	Deep-Seated Type	Comments
381	3.80	5	1	D	1939	460	1939OrthoEldonse	1	6	57	3	Y	1	Qga			along canal bluff
382	17.20	5	1	D	1939	604	1939OrthoEldonse	1	6	50	3	Y	1	Qc			along canal
383	1.50	5	3	D	1939	253	1939OrthoEldonse	1	6	52	3	Y	1	Qc			along canal
384	9.30	5	1	D	1939	495	1939OrthoHollysw	1	6	55	3	Y	1	Qgd			along canal
385	0.80	4	1	D	1939	597	1939OrthoEldonse	1	6	63	3	P	1	Qga			
386	0.50	4	1	D	1939	528	1939OrthoEldonse	1	6	65	3	Y	1	Qga			
387	0.10	2	2	D	2005	543	OLCQT05 280-34	1	6	62	1	Y	5	Qga			headwall of drainage, channelizing water
388	0.10	2	2	D	2005	552	OLCQT05 280-34	1	6	56	1	Y	5	Qga			headwall of drainage, channelizing water
389	0.10	2	1	D	2005	539	OLCQT05 280-34	1	6	51	1	P	5	Qgd			rd drainage, midslope release/discharge to side
390	0.10	2	1	D	2005	451	OLCQT05 280-34	1	6	66	1	Y	1	Qgd			yarding
391	0.10	2	1	P	2005	71	OLCQT05 280-34	7	5	70	1	P	4	Qgd			W/in #330 dsls
500	7.10	5	4	D	2000	394	Lidar	7	4	25	1	P	3	Qga	DD	C	old feature, not real apparent on 1965
700	0.30	3	3	D	2006	141		7	5	52	1	Y	3	Qapo			Field Observed = f.o.
701	0.20	3	3	D	2006	86		7	5	66	1	Y	3	Qapo			f.o., older
702	0.20	3	1	D	2006	142		7	5	69	2	Y	3	Qapo			f.o., 5 yrs old?
703	0.10	2	1	D	2006	78		7	5	84	3	Y	5	Qapo			f.o.
704	0.10	2	1	D	2006	171		7	5	57	2	N	5	Qapo			f.o., sways&pistolbutted trees-#705-707too
705	0.30	3	1	D	2006	115		7	5	77	2	Y	3	Qapo			f.o., connected to #706 as nose failure?
706	0.30	3	1	D	2006	143		7	5	75	2	Y	3	Qapo			f.o., connected to #705 as nose failure?
707	0.10	2	1	D	2006	72		7	5	72	2	Y	5	Qapo			f.o., below rd
708	0.20	3	1	D	2006	87		7	5	78	3	Y	9	Qapo			f.o., house w/in trees/photos
709	0.60	4	1	D	2006	178		1	6	77	1	P	3	Qapo			f.o., sweeps and bowed trees; multiple shallows to north
710	0.30	3	3	D	2006	125		1	6	74	2	Y	3	Qapo			f.o., multiple large trees on beach
711	0.20	3	3	D	2006	93		7	5	79	2	Y	3	Qapo			f.o., hole in canopy, debris on beach, alder
712	0.20	3	3	D	2006	109		7	5	94	3	P	3	Qapw(1)			f.o., older slide - 10+ yrs?
713	0.60	4	4	D	2006	141		7	5	83	2	Y	9	Qapw(1)	DD	C	f.o., nose failure?
714	0.20	3	1	D	2006	111		7	5	90	2	Y	3	Qapw(1)			f.o., MultiSU's,cutfaceTill@BeachLevel,Face=orangeMatrixW/out
715	0.20	3	3	D	2006	86		7	5	73	1	Y	9	Qapw(1)			f.o., toe made it to water, photow/house&tightline pipe
716	0.10	2	8	D	2006	67		7	5	102	3	Y	9	Qls			f.o., shallow, steep/vert face, rk topple, boulders on beach
717	0.80	4	4	D	2006	142		7	5	76	3	Y	9	Qc	AR	C	f.o.,smScallopsRecentActivW/inLargerSlide-not completely mapp
718	1.20	5	4	D	2006	178		7	5	70	3	Y	9	Qc	AR	C	f.o., small scallops of recent activity

slide_id	*Size (acres)*	*Ls_size*	lsi_process	certainty	id_date	init_elev	photo_num	lsi_landform	WAU Landform	gradient	slp_shp	delivery	landuse	geo_unit	Deep-Seated Activity	Deep-Seated Type	Comments
719	0.10	2	1	D	2006	70		7	5	78	2	Y	9	Qc			f.o., area between 716 and 718 scalloped shallow slides
720	0.70	4	4	D	2006	118		7	5	72	2	Y	9	Qc	DD	C	f.o., multiple trees on beach
721	0.50	4	3	D	2006	92		7	5	75	2	Y	9	Qc			f.o., older
722	0.50	4	3	D	2006	147		7	5	70	2	Y	9	Qc			f.o., older, trees bowed
723	0.50	4	3	D	2006	111		7	5	75	2	Y	9	Qc			f.o.
724	0.30	3	1	D	2006	103		7	5	69	3	Y	9	Qc			f.o.
725	0.20	3	1	D	2006	51		7	4	59	2	Y	9	Qgd			f.o.
726	0.20	3	1	D	2006	69		7	5	72	3	Y	9	Qgd			f.o.
727	0.20	3	1	D	2006	50		1	6	62	2	Y	9	Qgd			f.o.
728	0.50	4	1	D	2006	174		7	4	65	2	Y	9	Qgd			f.o., recent
729	0.20	3	1	D	2006	106		7	5	71	3	Y	9	Qgd			f.o., recent

Great Bend WAU
Appendix B - Form A-3: Mass Wasting Summary Table

This table summarizes the total number of all landslides within each landform based on each landuse activity.

Mass Wasting Summary: Totals						
Activity	**Shallow Landslides**	**Debris Flows**	**Debris Avalanches/ Slides**	**Deep-Seated Landslides**	**Earthflows**	**Total**
1 = clearcut (timber 0-5 yrs)	14		1			15
2 = young stands (timber 5-15 yrs)	11	1	2			14
3 = submature timber (15-50 yrs)	133	15	50	47		245
4 = mature timber (>50 years)	6		1	6		13
5 = road	9	5	1			15
6 = partial cut						0
7 = yarding						0
8 = alpine						0
9 = other-e.g., housing, agric.	9		4	4		17
Totals	182	21	59	57	0	319

Mass Wasting Summary: Landform 1 - Flats						
Activity	Shallow Landslides	Debris Flows	Debris Avalanches/ Slides	Deep-Seated Landslides	Earthflows	Total
1 = clearcut (timber 0-5 yrs)						0
2 = young stands (timber 5-15 yrs)						0
3 = submature timber (15-50 yrs)						0
4 = mature timber (>50 years)						0
5 = road						0
6 = partial cut						0
7 = yarding						0
8 = alpine						0
9 = other-e.g., housing, agric.						0
Landform Totals	0	0	0	0	0	0

Mass Wasting Summary: Landform 2 - Ridge Tops and Noses						
Activity	Shallow Landslides	Debris Flows	Debris Avalanches/ Slides	Deep-Seated Landslides	Earthflows	Total
1 = clearcut (timber 0-5 yrs)						0
2 = young stands (timber 5-15 yrs)						0
3 = submature timber (15-50 yrs)						0
4 = mature timber (>50 years)						0
5 = road						0
6 = partial cut						0
7 = yarding						0
8 = alpine						0
9 = other-e.g., housing, agric.						0
Landform Totals	0	0	0	0	0	0

Mass Wasting Summary: Landform 3 - Low Gradient Hills (11-40%)						
Activity	Shallow Landslides	Debris Flows	Debris Avalanches/ Slides	Deep-Seated Landslides	Earthflows	Total
1 = clearcut (timber 0-5 yrs)						0
2 = young stands (timber 5-15 yrs)	3					3
3 = submature timber (15-50 yrs)	11	1		1		13
4 = mature timber (>50 years)						0
5 = road	3		1			4
6 = partial cut						0
7 = yarding						0
8 = alpine						0
9 = other-e.g., housing, agric.						0
Landform Totals	17	1	1	1	0	20

Mass Wasting Summary: Landform 4 - Moderate Hills (41-60%)						
Activity	Shallow Landslides	Debris Flows	Debris Avalanches/ Slides	Deep-Seated Landslides	Earthflows	Total
1 = clearcut (timber 0-5 yrs)	4					4
2 = young stands (timber 5-15 yrs)	4					4
3 = submature timber (15-50 yrs)	27	9	7	6		49
4 = mature timber (>50 years)			1			1
5 = road	1					1
6 = partial cut						0
7 = yarding						0
8 = alpine						0
9 = other-e.g., housing, agric.	2					2
Landform Totals	38	9	8	6	0	61

Mass Wasting Summary: Landform 5 - Coastal Bluffs and Steep Slopes (>61%)						
Activity	**Shallow Landslides**	**Debris Flows**	**Debris Avalanches/ Slides**	**Deep-Seated Landslides**	**Earthflows**	**Total**
1 = clearcut (timber 0-5 yrs)						0
2 = young stands (timber 5-15 yrs)						0
3 = submature timber (15-50 yrs)	12	1	9	6		28
4 = mature timber (>50 years)	1			1		2
5 = road	3					3
6 = partial cut						0
7 = yarding						0
8 = alpine						0
9 = other-e.g., housing, agric.	6		4	4		14
Landform Totals	22	1	13	11	0	47

Mass Wasting Summary: Landform 6 - Steep Gradient Gorge Systems (>70%)						
Activity	**Shallow Landslides**	**Debris Flows**	**Debris Avalanches/ Slides**	**Deep-Seated Landslides**	**Earthflows**	**Total**
1 = clearcut (timber 0-5 yrs)	10		1			11
2 = young stands (timber 5-15 yrs)	4	1	2			7
3 = submature timber (15-50 yrs)	83	4	34	34		155
4 = mature timber (>50 years)	5			5		10
5 = road	2	5				7
6 = partial cut						0
7 = yarding						0
8 = alpine						0
9 = other-e.g., housing, agric.	1					1
Landform Totals	105	10	37	39	0	191

Great Bend WAU
Appendix C

Form A-2 Descriptions of Landforms for the Great Bend Watershed

Landform #1 - Flats - Low Hazard Slopes

Description of Mass Wasting Unit: This map unit includes all valley and stream bottoms, glacial till plains, flat terraces, prairies, major stream flood plains, and wetlands with gradients between 0 % and 10% that exhibit a low landslide potential, and/or are not likely to deliver sediment to a stream, impact public safety or impact a public resource.

Slopes: Variable 0% and 10% (lidar-measured)
Slope Shape: Variable from convergent to planar
Material: Holocene units: Qapo (Pleistocene – alpine glacial outwash, pre-Fraser), Qapw(1) (Pleistocene – alpine glacial drift, pre-Wisconsin), Qc (Pleistocene – continental sedimentary deposits or rocks), Qgd & Qgt (continental glacial drift – Fraser-age), Qls (Holocene to present – mass-wasting deposits, mostly landslides), and Qa (alluvium); Eocene Crescent Basalts: Eigb (gabbro), Eit (tonalite), Eib (basic intrusive rocks), Evr (rhyolite flows)

Elevation: 0 ft to 1,270 ft
Total Area: 5,569 acres

Mass Wasting Process: Shallow landslides and debris flow deposits may transport debris to this landform but were not observed to occur within it and generally do not deliver to waters of the state or impact public safety or resources.

Forest Practice Sensitivity and Trigger Mechanisms: Roads appear to be the most significant triggering mechanism for erosion within this landform. Undersized culverts may lead to road fill failures and debris flows or may channel water down the road tread delivering fine sediment to streams.

Mass Wasting Potential: Low for road construction and timber harvest based on no slope failures identified in a landform covering 16 acres.

Delivery Potential/Criteria: Low. The LAR for this unit is 0. No mass wasting features were noted within this landform. Delivery is unlikely as lack of delivery to a stream channel precludes transport. Road and landing failures do not travel great distances. Distance from stream channels and topography inhibits transport of landslide debris deposited onto this landform from upper elevation sources and does not impact public safety.

Overall Landform Hazard Rating: Low based on the LHZ Protocol, Table 5.

Confidence: High level of confidence based on excellent photo quality, lidar coverage, and field observations.

Comments: Some areas may have been mapped that include slopes greater than 10% but these areas do not have a likelihood of landsliding.

Form A-2 Descriptions of Landforms for the Great Bend Watershed

Landform #2 - Ridge and Hill Tops – Low Hazard

Description of Mass Wasting Unit: This map unit includes all ridge top and noses of ridges slope forms and gradients between 0 % and 10% that exhibit a low landslide potential, and/or are not likely to deliver sediment to a stream, impact public safety or impact a public resource. These slopes are located in glacial till plains, flat terraces, and prairies that exhibit a low landslide potential, and/or are not likely to deliver sediment to a stream, impact public safety, or impact a public resource.

Slopes: Variable 0% and 10% (lidar-measured)
Slope Shape: Variable from convergent to planar
Material: Holocene units: Qapo (Pleistocene – alpine glacial outwash, pre-Fraser), Qapw(1) (Pleistocene – alpine glacial drift, pre-Wisconsin), Qc (Pleistocene – continental sedimentary deposits or rocks), Qgd & Qgt (continental glacial drift – Fraser-age), Qls (Holocene to present – mass-wasting deposits, mostly landslides), and Qa (alluvium);Eocene Crescent Basalts: Eigb (gabbro), Eit (tonalite), Eib (basic intrusive rocks), Evr (rhyolite flows)

Elevation: 130 ft to 720 ft
Total Area: 16 acres

Mass Wasting Process: Deep-seated landslide head scarps and debris flows may occur but are not common and generally do not have the potential to deliver to waters of the state or impact public safety or resources.

Forest Practice Sensitivity and Trigger Mechanisms: No forest related slope failures were observed within this landform. Undersized culverts may lead to road fill failures and/or debris flows.

Mass Wasting Potential: Low for road construction and timber harvest based on no slope failures identified in a landform covering 5,569 acres.

Delivery Potential/Criteria: Low due to lack of channel access. Distance from a stream channels and topography inhibits transport of debris to public resources. Remote ridge tops do not impact public infrastructure or safety. This landform has a landslide area rate for delivery (LAR) of 0.

Overall Landform Hazard Rating: Low based on the LHZ Protocol, Table 5.

Confidence: High level of confidence based on excellent photo quality, lidar coverage, and field observations.

Comments: Some areas may have been mapped that include slopes greater than 10% but these areas do not have a likelihood of landsliding.

Form A-2 Descriptions of Landforms for the Great Bend Watershed

Landform # 3 - Low Gradient Hills – Low Hazard

Description of Mass Wasting Unit: This map unit is generally the top of the glacial till plain but also includes all hill slope shapes and gradients between 11% and 40% that exhibit a low landslide potential, and/or are not likely to deliver sediment to a stream, impact public safety, or impact a public resource.

Slopes:	Variable 11% and 40% (lidar-measured)
Slope Shape:	Variable from convergent to planar
Material:	Soils, alluvium, colluvium, alpine glacial outwash, continental glacial till, and Crescent Basalts
Elevation:	0 ft to 1,710 ft
Total Area:	12,145 acres

Mass Wasting Process: Shallow undifferentiated landslides dominate this landform, but debris slides, debris flows, and deep-seated landslides can occur with varying slope shapes and fail at gradients between 11 to 40%. These landslides are rare, usually only occurring during storm events commonly associated with historic forest practices techniques.

Forest Practice Sensitivity and Trigger Mechanisms: The loss of root strength, changes in slope gradient, and changes in hydrology resulting from timber harvesting and road or landing construction have the potential to initiate slope failure. Root strength loss may be a triggering mechanism for landsliding within this landform. The majority of landslides were located in the forest category of 15-50 year old trees. Stream-adjacent landslides may be triggered when till slopes are undercut and less competent overlying glacial outwash material ravels into the streams during road building. Roads and landings can cause instability by undercutting and over-steepening slopes. Undersized culverts may lead to road fill failures and may deliver sediment to streams. Side cast and road (or landing) fill can over steepen and add weight to slopes; roads and landings can also capture runoff water or shallow groundwater and channel it to point locations that saturate road or landing fill and/or glacial deposits, triggering slope failures.

Mass Wasting Potential: Low for road construction and timber harvest based on 19 slope failures in a landform covering 12,145 acres. This landform has a landslide frequency rate (LFR) of 23.7 with roads and 18.7 without road related landslides.

Delivery Potential/Criteria: Low. The LAR for this landform is based on 12 “delivering” landslides totaling 6.8 acres is 8.5 with roads and 11 “delivering” landslides totaling 6.7 acres is 8.4 without roads.

Overall Landform Hazard Rating: Low for the entire unit based on the LHZ Protocol, Table 5.

Confidence: High level of confidence based on excellent photo quality, lidar coverage, and field observations.

Comments: Many of the slopes in this landform are failing at the contact between glacial till and glacial outwash when adjacent to streams or along the west facing slope towards Hood Canal. (Note: Due to scale issues inherent in remote sensing, unmapped high-hazard landforms may exist in landform #3.)

Form A-2 Descriptions of Landforms for the Great Bend Watershed

Landform # 4 – Moderate Gradient Hills (41 to 60%) - Moderate Hazard

Description of Mass Wasting Unit: This landform includes portions of the west facing slopes adjacent to Hood Canal as well as areas on the top of the glacial till plain. These slopes vary in shape (the majority being convergent and planar) and have gradients between 41% and 60%. This landform includes head scarps of relict or dormant deep-seated landslides as well as other landslide processes.

Slopes: Variable 41 to 60% (lidar-measured).
Slope Shape: Variable from convergent to divergent
Material: Soils, alluvium, colluvium, alpine and continental glacial outwash and till deposits, and Crescent Basalts
Elevation: 0 ft to 1,700 ft
Total Area: 3,470 acres

Mass Wasting Process: Shallow undifferentiated landslides, debris slides, as well as debris flows, and deep-seated landslides occur within this map unit. The majority of landslides in this landform that deliver to streams occurred in clearcut areas that were older than 15 years which is currently believed to be beyond the time when roots can still hold shallow soils and unconsolidated glacial material in place on steep ground. Therefore it is assumed that a loss of root strength adversely influenced slope stability on this landform.

Forest Practice Sensitivity and Trigger Mechanisms: Timber harvest, road construction and/or landing construction on slopes between 41 to 60% in poorly consolidated glacial deposits can increase slope instability. Loss of root strength can increase rates of mass wasting, as can roads and landings that undercut or load or change the hydrology of these slopes. Side cast and landings can cause instability by over-steepening slopes, loading and undercutting them. Roads and landings can also capture runoff water or shallow groundwater and channel it to point locations that saturate fill and/or unconsolidated deposits triggering slope failures.

Mass Wasting Potential: High for roads and harvest based on 55 slope failures identified over a 66-year photo record in a landform covering 3,470 acres. This landform has a LFR of 240.2 with roads and 235.8 without road related landslides.

Delivery Potential/Criteria: Moderate. The LAR for this landform is based on 43 “delivering” landslides totaling 22.2 acres is 96.9 with roads and 42 “delivering” landslides totaling 22.1 acres is 96.5 without road related landslides.

Overall Landform Hazard Rating: Moderate for the entire unit based on the LHZ Protocol, Table 5.

Confidence: High level of confidence based on excellent photo quality, lidar coverage, and field observations.

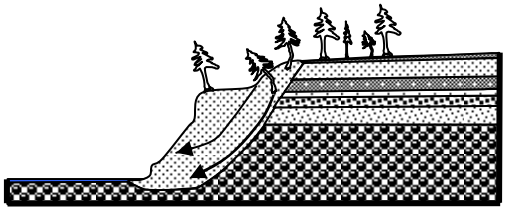
Comments: Caution: Unmapped high-hazard landforms could have been erroneously included in landform #4 through mapping errors.

Form A-2 Descriptions of Landforms for the Great Bend Watershed

Landform # 5 – Coastal Bluffs and High Gradient Slopes - Very High Hazard

Description of Mass Wasting Unit: This landform consists of coastal bluffs composed of glacial deposits in near proximity to Hood Canal and slopes that are generally between 61 and 80%. These slopes are varied in shape (with the majority being convergent to planar). Unstable areas contain shallow and deep-seated landslides. Areas that are mapped near Hood Canal may contain secondary landslides on the toes of dormant or relict deep-seated landslides that have been reactivated by undercutting from wave action. (Note: Some toes of deep-seated landslides have been included in landform #5.)

Slopes: Variable, generally >60% (lidar-measured).
Slope Shape: Variable from convergent to divergent
Material: Soils, alluvium, colluvium, alpine and continental glacial outwash and till deposits, and Crescent Basalts
Elevation: 0 ft to 1,760 ft
Total Area: 416 acres



Mass Wasting Process: Coastal wave action undercuts adjacent upland slopes causing mass wasting along the over steepened slopes in the form of shallow undifferentiated slides, debris slides, and deep-seated landslides. Deep-seated landslides are commonly rotational or a combination of rotational and translational. Stream-adjacent landslides were observed and mapped in the glacial till plain within this landform. Over-steepened slopes and the sheared broken nature of material in the toes of deep-seated landslides promote the development of smaller deep-seated landslides within this landform. This situation was observed on air photos and in the field on deep-seated landslide toes along coastal bluff areas along Hood Canal.

Forest Practice Sensitivity and Trigger Mechanisms: Loss of root strength, changes in slope gradient, and changes in hydrology due to any activity that disturbs vegetation on or near coastal bluffs and steep slopes can destabilized slopes. Roads and landings can cause instability by undercutting and over-steepening slopes and channeling water to point source locations. Side cast and road or landing fills can over-steepen and add weight to slopes; roads and landings can also capture runoff or shallow groundwater and channel it to point locations that saturate road or landing fill and/or unconsolidated glacial deposits, triggering slope failures. The majority of the landslides in this landform were found to be in forests >15 years old. Coastal bluffs may be particularly sensitive to slope failure when timber harvest has occurred in glacial recharge areas directly upslope from them due to added water from the loss of canopy interception and evapotranspiration. Landslides can also be triggered when groundwater perches on impermeable till, clay, and/or more consolidated outwash deposits and saturates less consolidated deposits above the more competent layers.

Mass Wasting Potential: Very High for roads and timber harvest based on 36 slope failures in a landform covering 416 acres. This landform has a LFR of 1,311.2 with roads and 1,201.9 without road related landslides.

Delivery Potential/Criteria: High. The LAR for this landform is based on 34 “delivering” landslides totaling 8.6 acres is 313.2 with roads and 31 “delivering” landslides totaling 8.4 acres is 305.9 without road related landslides.

Overall Landform Hazard Rating: Very High based on the LHZ Protocol, Table 5.

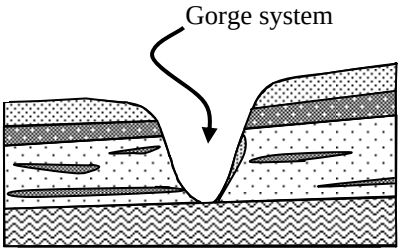
Confidence: Moderate level of confidence based on the number of landslides in this landform and limited field verification due to access issues. Excellent photo quality, lidar coverage, and limited field observations were used.

Comments: The Coastal Bluffs and Steep Slopes landform is primarily found adjacent to the shore of Hood Canal, with minor occurrences inland on slopes between 61-80%. Some areas within this landform may contain slopes <61%.

Form A-2 Descriptions of Landforms for the Great Bend Watershed

Landform #6 – Inner Gorges and Steep Slopes (>60%) – Very High Hazard

Description of Mass Wasting Unit: This landform contains inner gorges, steep gradient slopes (>60%) and rule-identified outsides of meander bends, and inner gorges. Inner gorges are steep (>70%) walled canyons or gullies eroded by stream action with evidence of mass wasting along their sidewalls. Inner gorges may be either symmetrical or asymmetrical in profile and are commonly intermittent in lateral extent. Asymmetrical inner gorges occur largely along the west-facing slope toward Hood Canal.



Slopes: Generally > 70%
Slope Shape: Convergent to planar
Material: Soils, alluvium, colluvium, alpine and continental glacial outwash and till deposits, and Crescent Basalts
Elevation: 0 ft to 830 ft
Total Area: 1,100 acres

Mass Wasting Process: This landforms contains numerous shallow undifferentiated landslides, debris slides, deep-seated landslides, and several small debris flows.

Forest Practice Sensitivity and Trigger Mechanisms: Root strength within and adjacent to inner gorges has been found to be a factor in increasing rates of mass wasting (Krogstad, 1995) therefore trees adjacent to the inner gorge can have roots extending into the slopes of the gully providing slope stability. Roads and landings can destabilize slopes by undercutting and over steepening slopes. Side cast and road (or landing) fill can also over steepen slopes and can add weight; roads and landings can also capture runoff water or shallow groundwater, channeling it to point locations that saturate road or landing fill and/or thin soils over unconsolidated glacial deposits, triggering landslides. Landslides can also be triggered when groundwater perches on impermeable till, clay, and/or more consolidated outwash deposits and saturates less consolidated deposits above the more competent layers.

Mass Wasting Potential: Very High for roads and timber harvest based on 152 slope failures in a landform covering 1,100 acres. This landform has a LFR of 2,093.7 with roads and 1,997.2 without road related landslides.

Delivery Potential/Criteria: High. The LAR for this landform is based on 146 “delivering” landslides totaling 112 acres is 1,542.7 with roads and 139 “delivering” landslides totaling 100.4 acres is 1,382.9 without road related landslides.

Overall Landform Hazard Rating: Very High based on the LHZ Protocol, Table 5.

Confidence: Moderate level of confidence based on the number of landslides in this landform and limited field verification due to access issues. Excellent photo quality, lidar coverage, and limited field observations were used.

Comments: Minor occurrences of outsides of meander bends have lumped into this landform. This landform may contain scarps of dormant, dormant indistinct, or relict deep-seated landslides. Access to portions of the WAU along the steep gorges was limited by landowner access issues.

Great Bend WAU

Appendix D – Landform Hazard Rating Table: Form A-4

Landforms Including Road Related Landslides							
Landforms	**Landform 1**	**Landform 2**	**Landform 3**	**Landform 4**	**Landform 5**	**Landform 6**	**Total WAU**
Years	66	66	66	66	66	66	66
Landform Area (acres)	5569	16	12145	3470	416	1100	22716
Number of Landslides	0	0	19	55	36	152	262
Landslide Frequency Rate (Number of slides/Landform Area/Years) x 10^6	0	0	23.7	240.2	1311.2	2093.7	174.8
Number of 'Delivering' Landslides	0	0	12	43	34	146	235
Area of 'Delivering' Landslides (acres)	0	0	6.8	22.2	8.6	112	149.6
Landslide Area Rate for Delivery (Delivering Landslide Area/Landform Area/Years) x 10^6	0	0	8.5	96.9	313.2	1542.7	99.8
Overall Rating	Low	Low	Low	Moderate	Very High	Very High	Low

Landforms Without Road Related Landslides							
Landforms	**Landform 1**	**Landform 2**	**Landform 3**	**Landform 4**	**Landform 5**	**Landform 6**	**Total WAU**
Years	66	66	66	66	66	66	66
Landform Area (acres)	5569	16	12145	3470	416	1100	22716
Number of Landslides	0	0	15	54	33	145	247
Landslide Frequency Rate (Number of slides/Landform Area/Years) x 10^6	0	0	18.7	235.8	1201.9	1997.2	164.7
Number of 'Delivering' Landslides	0	0	11	42	31	139	223
Area of 'Delivering' Landslides (acres)	0	0	6.7	22.1	8.4	100.4	137.6
Landslide Area Rate for Delivery (Delivering Landslide Area/Landform Area/Years) x 10^6	0	0	8.4	96.5	305.9	1382.9	91.8
Overall Rating	Low	Low	Low	Moderate	Very High	Very High	Low

Great Bend WAU
Appendix E
Geology

Bedrock Geology and Structure

The Great Bend WAU is located within the Puget Lowland, on a glacial till plain east of Hood Canal. Bedrock is exposed only at the northeastern corner of the WAU, where Eocene basalts of the Crescent Formation crop out on Green Mountain and Gold Mountain (Haeussler and Clark, 2000). These lavas are equivalent to Crescent basalts on the Olympic Peninsula, suggesting that similar bedrock underlies the entire WAU (Brocher and others, 2004). The Crescent Formation consists of a very thick sequence of submarine and sub-aerial basalts, accompanied by subordinate felsic igneous rocks, which formed in a continental margin rift setting between ~60 – 45 Ma and was subsequently accreted to the edge of North America (Babcock and others, 1992).

Three major faults cut the northeast portion of the WAU: the Tin Mine Lake Fault, the Green Mountain Fault, and the Gold Creek Fault - all are E-W to NE-SW trending (Figure 1). The Holly Road Fault and the Seattle Fault are present just north of the WAU. The Seattle Fault is an active, south dipping reverse fault (south side thrust up) striking E-W (Johnson and others, 1994; 1999; Haeussler and Clark, 2000). Sub-parallel faults located within the WAU may be strands of the Seattle Fault Zone or fault tears. Quaternary offset has not been identified on these faults

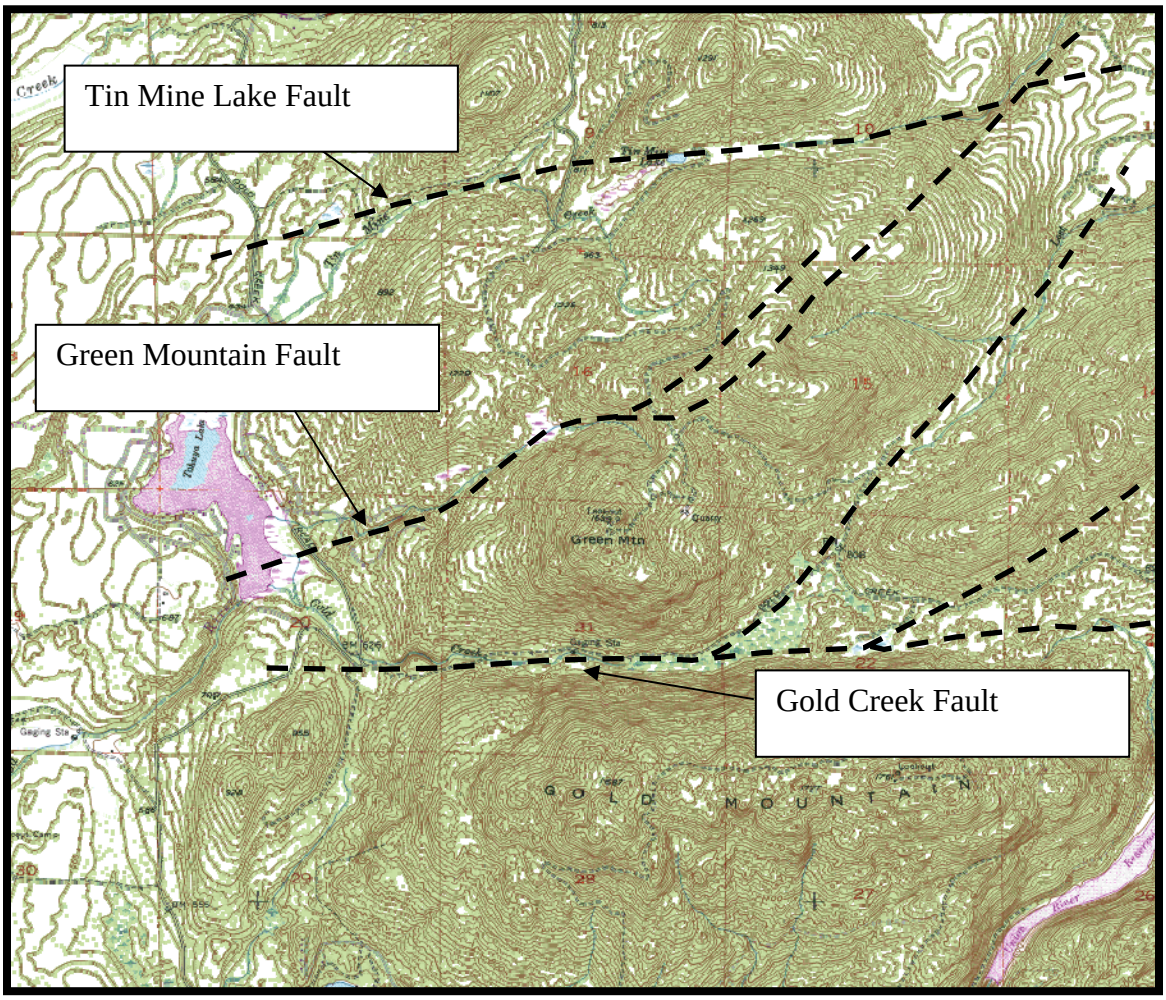


Figure 1. Faults mapped around the northeastern section of the Great Bend WAU.

within the WAU (Haeussler and Clark, 2000; Blakely and others, 2002; Brocher and others, 2004), however, several exposures of Quaternary surface rupture have been identified along the eastern part of the Seattle Fault zone (Sherrod, 2002). The Seattle Fault is also believed to be the epicenter of a large earthquake approximately 1100 years BP (Atwater, 1994 and 1999; Johnson and others, 1999; Nelson and others, 2003). The other major structure in the region is the Hood Canal Fault that runs up the center of Hood Canal in a mostly north-south direction (Haug, 1998; Brocher and others, 2001; Dragovich and others, 2002). Structures associated with this fault are extensional, and include horst and graben and half-graben topography that experienced considerable co-seismic deformation following the 1100 BP earthquake on the Seattle Fault (Haug, 1998). In addition, although not linked to specific structures, Atwater (1994, 1999) has identified slope failures and areas of uplift near the Great Bend WAU that he attributes to Holocene age earthquakes associated with ongoing subduction of the Juan de Fuca plate beneath North America. A more recent earthquake occurred in 1997 (Magnitude 4.9) just west of Bainbridge Island (Blakely and others, 2002), had the soil saturation been prime there could have been slope failures. Future seismic activity in the general vicinity of the WAU may be a concern for slope stability.

Surficial Geology

Pleistocene continental ice sheets advanced over the Great Bend WAU at least four times between 1.8 Ma and 13,000 BP. Deposits left by the glaciers cover most of the watershed today and the character of these unconsolidated deposits significantly influences slope stability (e.g., outwash gravels overlying till, or sand layers overlying compacted non-glacial gravels).

The four glacial advances (stades), referred to as the Orting, Stuck, Salmon Springs, and Vashon, each began with development of alpine glaciers that radiated outward from the Olympic Mountains. These alpine advances were followed by the advance of the Puget Lobe – a southward advancing lobe of the Cordilleran Ice Sheet, which had accumulated in British Columbia. Alpine tills are distinct from those left by the Puget Lobe, which makes it possible to establish the origin of individual till deposits (Gryta, 1975). Alpine glacial deposits (Qapo and Qapw(1)) from the Olympics are overlain by sediments deposited by continental ice (Qgd, Qga, Qgt, and Qgo) that originated in the northwestern part of the North American continent along the Canadian part of the Cordillera (Logan, 2003). The Vashon stade left signs that the ice was 900-1200 m thick over Kitsap County (Bretz, 1913; Deeter, 1979). The last retreat of the ice sheet occurred 13,000-14000 years ago (Deeter, 1979).

During their advances and retreats the ice sheets produced numerous types of glacial deposits. Advancement features include till deposits (Qgt), drumlins and glacial fluting (which record ice movement direction), meltwater stream channels and broad outwash deltas (Qga) south of the ice margin. Glacial retreat features include recessional outwash plains (Qgo), ice-marginal stream channels, and pro-glacial lakes (Deeter, 1979; Thorson, 1980; Logan 2003). Remnants of the meltwater channels are mapped along the Tahuya and Union Rivers near Green Mountain and Gold Mountain (Thorson, 1980). Some of the fluting on the till plain within the WAU is cut by what appear to be dry flat-bottomed channels implying that these channels were carved by glacial meltwater streams (Mullineaux, 1970; Thorson, 1980; Logan, 2003; Haugerud, USGS, written communication, 2006).

Other glacial features present in the WAU include deposits mapped on Green Mountain and Gold Mountain, both of which were obstacles for the ice. Ice was deflected around and over the mountains leaving deposits in these areas. During ice retreat, ice-contact areas characterized by pock marked, hummocky topography (mapped as kettle and kame terrain) were left on the north

and west side of Dewatto River near Dewatto Bay (Haugerud, USGS, written communication, 2006).

Deglaciation and Seismic Activity

Through radiocarbon dating, Gyrta (1975) found that landslide activity on the west side of Hood Canal increased following the latest deglaciation due in part to isostatic rebound. In the vicinity of the Great Bend WAU Atwater (1994, 1999) mapped areas of uplift as well as slope failures that he attributes to Holocene age earthquakes generated from the subduction of the Juan de Fuca plate below the North American plate. Seismic activity in the Puget Sound region may have been temporarily suppressed by the weight of the ice during the time the Puget Lobe blanketed Puget Sound and its underlying faults (Thorson, 1996). As deglaciation proceeded there may have been a short period of intense seismic activity due to the decreased overburden stress, elastic rebound of the crust, and release of the stresses that had accumulated along fault zones below the ice (Thorson, 1996). Since glacial deposits are characterized by inherently reduced shear strength due to the cohesionless nature of the material, and increased pore water pressure due to saturated conditions associated with the melting ice sheet, isostatic rebound, which may have triggered seismic activity, may also have been the cause of landsliding within the WAU. This may be especially true of the dormant indistinct deep-seated landslides mapped along the Hood Canal slope as delineated on Map A-2.

Great Bend WAU
Appendix F
Historical and Climate Considerations

Additional information is provided below to better understand contributing factors and triggering mechanisms for the landslides found in the Great Bend watershed inventory.

General History

Timber harvest by American settlers began in the mid-1800's in western Washington. During the early days, water access to markets was discovered to be a great benefit. Without modern equipment, great old growth logs were dragged and rolled down to the shore using crude methods that tore up the land. It is this legacy that we are trying to heal and prevent from reoccurring.

At present, the Great Bend WAU is producing third growth timber for the numerous large forest landowners including the State of Washington Trust Lands, Manke Lumber, and Olympic Resources Management, (Pope & Talbot), the latter having the largest holdings in the Great Bend WAU.

Residential development along the shoreline in the Great bend WAU continues to change the landscape. While much of the land along the shoreline is still managed as forestland, there is pressure to convert to residential land use due to the high value of water view real estate. However, most of the remaining undeveloped land is unstable wherein lies the problem that houses built too close to the bluff edges do not often fare well after large storms.

Forest History

Forests within the Great Bend WAU consisted of old growth fir in the early 1900's (Gannett, 1902), whereas presently they are predominantly Douglas fir, western hemlock, and western red cedar. With deciduous trees (red alder, vine and big leaf maple, cottonwoods and willows) commonly found adjacent to streams. As noted on aerial photographs and in the field, areas associated with landsliding have concentrations of red alder growing on them.

Past harvest patterns were driven by topography, with lower elevations along the shoreline of Hood Canal logged first. The coastal areas of the WAU were mapped in 1902 as having been harvested and the inland portion of the WAU was covered in timber ranging between 10,000 to 25,000 board feet per acre (Plummer, 1902). The areas along the Hood Canal shoreline had been cut and transported to market via log booms pulled by tugboats. Large areas along the northern and northeastern portion of the Olympic Peninsula had burned by 1902, but only a "trifling area" in the southern portion of Kitsap had been burned (Gannett, 1902). The growth rate for trees along the eastern slopes of the Olympic Mountains are generally much greater than other locations around the peninsula due to climate, aspect, soil, etc. (Gannett, 1902).

Climate

Precipitation data shown below is the result of combining two gauging station records. Cushman Dam - #451934 is located at an elevation of 760 ft. above Hood Canal near Potlatch, Washington (south of Hoodsport). Cushman Powerhouse 2 - #451939 is located at an elevation of 20 ft. adjacent to Hood Canal. The Cushman Dam data is recorded from January 1931 to September 1973 and the Cushman Powerhouse 2 data is from July 1973 to present. Although the higher elevation gauging station has a slightly higher average annual precipitation, combining these two stations provides 76 years of precipitation data (Figure 1).

The average annual precipitation at the Lake Cushman Dam Powerhouse 2 gauging station is approximately 90 inches (Western Regional Climate Center). The monthly total precipitation was collected continuously (with few exceptions) from January 1931 until September 1973 at Cushman Dam at an elevation of 760 ft. and from July 1973 until present at the Cushman Powerhouse 2 with an elevation of 20 ft. The Cushman Powerhouse 2 is located west across Hood Canal from the Great Bend WAU. The highest recorded water year peak precipitation occurred during the winter of 1998-1999.

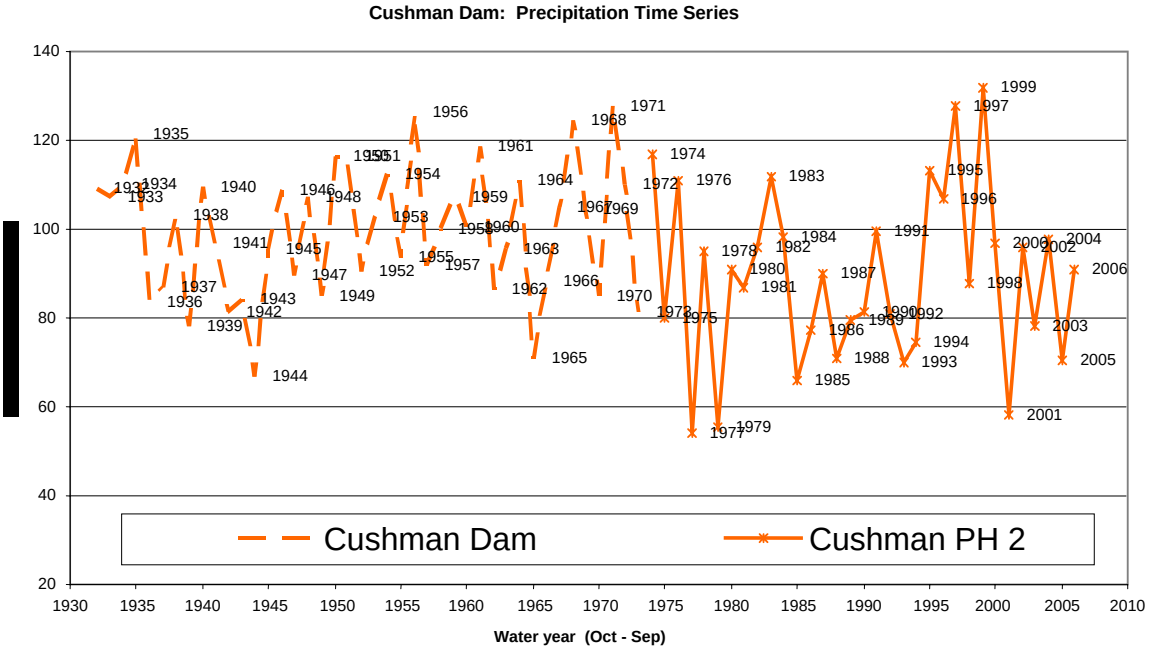


Figure 1. Annual precipitation data at the Cushman Dam and Cushman Powerhouse 2 gauging stations (Western Regional Climate Center).

It is well established that rates of slope failure tend to be higher during and after prolonged periods of above average precipitation (Gerstel and others, 1997; Shipman, 2001). However, annual precipitation records (Figure 1) provide limited insight into the role of precipitation in slope failure as they do not convey how rainfall was distributed over the year. A better indication of rainfall intensity is provided by looking at monthly rainfall totals, expressed in inches above the monthly average (Figures 2 and 3). To aid in recognition of time intervals when there were multiple consecutive months with above average precipitation, the data is presented in three month running averages. Examination of Figure 3 clearly shows that the water year 1998-99 was exceptional over the past 35 years, having 4 consecutive months with precipitation totals more than ten inches above the average. Similar but less dramatic high-precipitation intervals occurred in 1961 (Figure 2). Based on the available data, it seems appropriate to conclude that events such as these will occur on the order of once every 20-40 years.

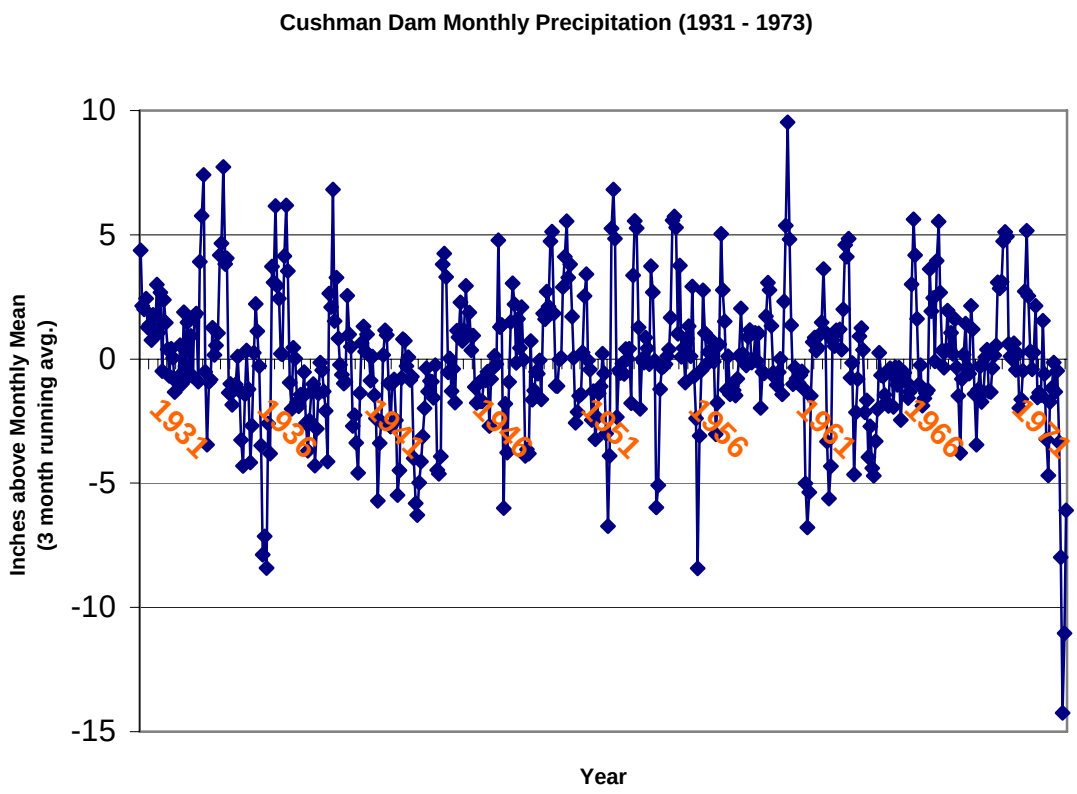


Figure 2. Three month running average of precipitation recorded above the monthly mean from the Cushman Dam gauging station from 1931 to 1973.

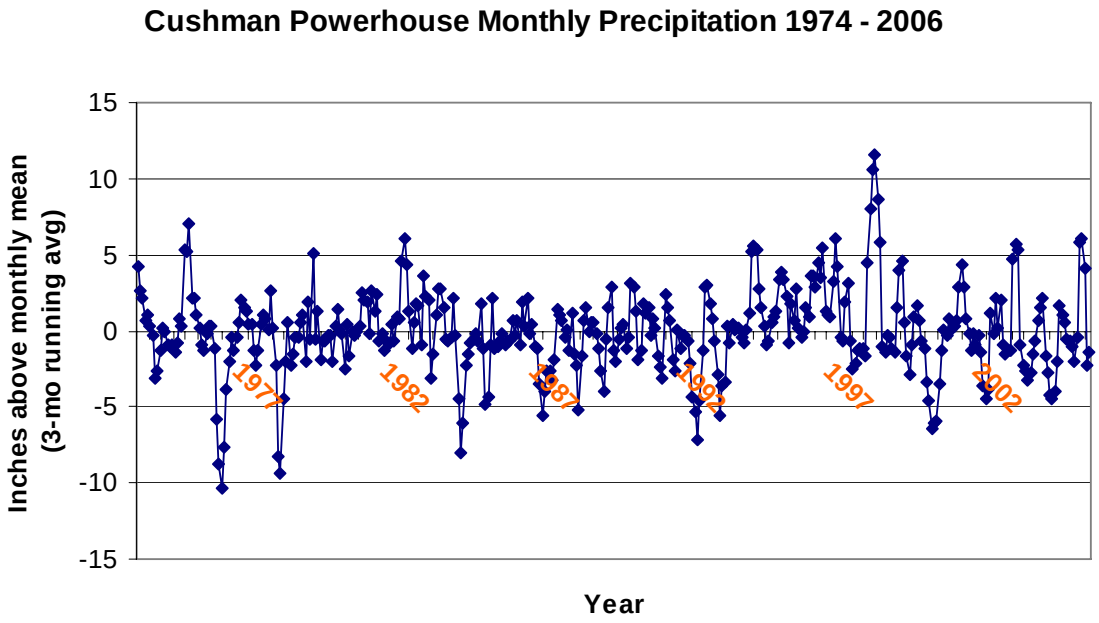


Figure 3. Three month running average of precipitation recorded above the monthly mean from the Cushman Powerhouse 2 gauging station from 1973 to 2006.

USGS stream gauges previously measured surface water within the Great Bend WAU. The Tahuya River within the WAU has data from June 1945 until September 1956, and just outside the WAU from June 1945 until September 1956. The Dewatto River near Dewatto, Washington recorded data from July 1947 until September 1974. And also within the WAU was the gauge on Gold Creek from October 1945 through October 1970. All of these gauging stations show exceptional precipitation in January 1953 and February 1954, but do not show recent data.

A more complete data set has been recorded on nearby Skokomish River near Potlatch, Washington (south of Hoodsport). Figure 3 (p.5) in the Great Bend WAU Report shows the location of this stream gauge. The data was recorded from July 1943 September 2005. Stream flow data is shown in Appendix F, Figure 4.

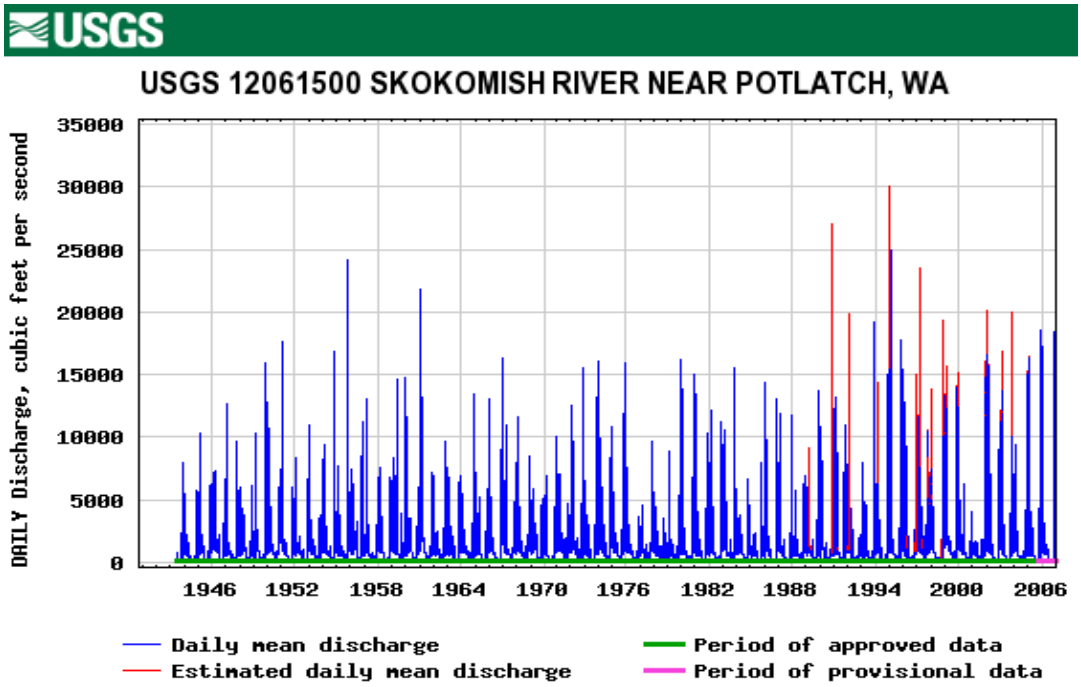


Figure 4. Peak Stream flow from USGS gauging station (#12061500) near Potlatch,WA – near the estuary of the Skokomish River and Hood Canal at the great bend.