U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES MAP MF-2346
Version 1.0

MAP SHOWING RECENT AND HISTORIC LANDSLIDE ACTIVITY ON COASTAL BLUFFS OF PUGET SOUND BETWEEN SHILSHOLE BAY AND EVERETT, WASHINGTON

By
Rex L. Baum,[1] Edwin L. Harp,[1] and William A. Hultman[2]

2000

Abstract

Many landslides occurred on the coastal bluffs between Seattle and Everett, Wash., during the winters of 1996 and 1997. Shallow earth slides and debris flows were the most common, but a few deep-seated rotational earth slides also occurred. The landslides caused significant property damage and interfered with rail traffic; future landslides in the area pose significant hazards to property and public safety. Field observations indicate that ground-water seepage, runoff concentration, and dumping at the tops of the bluffs all contributed to instability of the bluffs. Most landslides in the study area occurred in colluvium, residuum, and landslide deposits derived from the Vashon Drift, particularly the advance outwash. In the northern part of the area, colluvium derived from the Pleistocene Whidbey Formation was also involved in shallow landslides. Comparison of recent activity with historic records in the southern part of the map area indicates that landslides tend to occur in many of the same areas as previous landslides.

Introduction

Landslides have been a significant problem in the Seattle area for many years, and numerous landslides occurred there as a result of major storms in 1996 and 1997. During this period, four major episodes of landsliding along the bluffs between Seattle and Everett impacted residential and commercial properties and the Burlington Northern Santa Fe (BNSF) Railway, which runs along the shore of Puget Sound at the base of these bluffs. The landslides filled ditches along the tracks, covered railroad tracks, uprooted trees, blocked culverts, broke flexible surface drainage pipes ("tightlines"), caused bluff retreat (land damage) and structural damage to several homes on the bluffs, and derailed part of a freight train. In all, at least 100 different landslides covered one or both tracks of the railroad during the 1995/1996 and 1996/1997 wet seasons. Millions of dollars in direct costs accrued from debris removal, repairs, recovery operations, environmental rehabilitation, landslide remediation, and lost or destroyed property. Additionally, significant indirect costs accrued to the BNSF Railway from delays, lost revenues, and rerouting of rail traffic. Fortunately, no deaths or injuries resulted from any of these landslides.

Three of the four landsliding episodes occurred during or immediately after major winter storms. The first significant episode occurred during the storm of February 5-8, 1996 (Harp and others, 1996), which triggered several shallow slides and debris flows. However, the greatest concentration of landslides from that storm was mainly to the south of the study area. The second episode occurred the following winter from December 31, 1996 to January 2, 1997 (Gerstel and others, 1997; Baum and others, 1998). Wind and warm rain melted 1-2 ft of snow that had accumulated during the previous week; the resulting meltwater triggered numerous shallow landslides and debris flows throughout the study area (map and figs. 1 and 2). Two weeks later during the third episode, a deep-seated rotational landslide occurred at Woodway, Washington (fig. 3). The Woodway landslide derailed five cars of a freight train operated by the BNSF Railway. (Shannon and Wilson, Inc., 1997a[1]). The fourth episode occurred March 18-19, 1997, when a major rainstorm triggered more shallow landslides.

The inventory of recent landslides presented in this map constitutes a part of the information needed to assess the potential for landslides in the coastal bluffs that might impact rail traffic or damage private property. In the paragraphs that follow, we summarize the local geology, briefly review the findings of previous investigators, describe our methodology, describe the characteristics and causes of the landslides, and compare the locations of recent (1995-96 and 1996-97) landslides with locations of previous (1933-1960) landslides documented by Shannon and Wilson, Inc. (1960[2]). The map shows the distribution of the recent landslides along the bluffs next to Puget Sound in the entire map area and of the previous landslides in the southern part of the map area. We mapped outlines of recent landslides from aerial photographs taken in 1997 and supplemented our mapping with field mapping by Shannon and Wilson, Inc., (1997b[3]) in three selected areas indicated on the map. We conclude by discussing landslide susceptibility and frequency in the area, and what additional information is needed to quantify landslide hazard so that appropriate actions can be taken to reduce landslide losses in this area.

Sound Transit (The Central Puget Sound Regional Transit Authority) has proposed to add the operation of commuter trains in the BNSF rail corridor to the existing traffic, so exposure of rail traffic to landslides is likely to increase in the future even if the average frequency of landslides remains constant. Assessing the potential for future landslide impact to the railway is important for determining the safety of such operations.

Continuing population growth in the Seattle area will likely result in increased residential development on and near the bluffs between Seattle and Everett. Information contained in this map may help potential developers, homeowners, and officials of local governments to identify areas of high landslide incidence so that they can take appropriate actions to minimize landslide losses in these areas.

Background

Surficial geology

The surficial geology of the study area consists mainly of Pleistocene glacial, alluvial, and marine sediments; little or no bedrock is exposed in the map area. Major Quaternary stratigraphic units in the map area include nonglacial sand, silt, and clay of the Whidbey Formation and sequences of glacial deposits, including the Double Bluff Drift, the Possession Drift, and the Vashon Drift (Crandell and others, 1965; Mullineaux and others, 1965; Smith, 1975, 1976). The basal member of the Vashon Drift is a widespread deposit of dense glaciolacustrine clay and silt, called the Lawton Clay Member (Mullineaux and others, 1965). The Esperance Sand Member of the Vashon Drift overlies the Lawton Clay Member. For convenience we will refer to these units as the Lawton and the Esperance. The contact between the Lawton and the Esperance is transitional over several tens of feet, where layers of sand and clay interfinger; within this transition zone individual strata are laterally discontinuous. Tubbs (1974) identified this transition zone as the source area of many landslides in Seattle. The Esperance becomes pebbly near the top and grades into the coarser, more poorly sorted Vashon advance outwash. Till of the Vashon Drift, which is generally compact and hard, overlies the Vashon advance outwash or the Esperance. Recessional outwash locally overlies the till. In the northern part of the map area, the Esperance unconformably overlies glaciolacustrine silts and clays of the Possession Drift or the medium-bedded alluvial deposits of the Whidbey Formation. The Whidbey Formation rests unconformably on the Double Bluff Drift, which consists of cemented gravel, pebbly glaciolacustrine silt, and massive silt.

Several large post-glacial landslide deposits occur along the bluffs (Smith, 1975, 1976). These include deposits from deep rotational and translational landslides that range in age from late Pleistocene to Holocene. Smith (1975) attributed some of these slides to lowering of water levels during ablation of the Vashon ice sheet. Some are active or show evidence of recent movement; others show no evidence of recent movement.

Methods and what is shown on the map

The map shows three kinds of data: (1) outlines of landslides that resulted from the winter storms of 1995-96 and 1996-97, (2) point locations where landslides affected the railroad in 1995-96 and 1996-97, and (3) areas of historic (pre-1960) landsliding in the southern part of the map area. We compiled the landslide inventory from a combination of USGS data and BNSF data on file at the office of its consultant, Shannon and Wilson, Inc. The railroad data are included by permission of BNSF. Most of the original data were in foot-pound units and most potential end users of this report are likely to use foot-pound units, therefore we have used foot-pound units rather than SI (metric) units in this report.

We mapped the outlines of landslide scars and deposits on 1:24,000-scale USGS topographic maps primarily by interpretation of 1:12,000-scale color aerial photography acquired by the USGS through a private contractor on May 7, 1997. We performed ground reconnaissance of several areas between Seattle and Mukilteo in the winter and spring of 1997 to observe locations and characteristics of reported landslides (Baum and others, 1998). Harp, assisted by W.Z. Savage, performed aerial reconnaissance of landslides along the bluffs in April 1997. We checked this inventory against 1:6,000-scale color aerial photography acquired earlier in 1997 for use by Shannon and Wilson, Inc. under contract to BNSF. This check resulted in several additions or modifications to the inventory mapping in a few places. The 1:6,000-scale photographs had a low sun angle, which made many of the landslide scars and deposits more difficult to see than on the 1:12,000-scale photographs; however, the larger scale enabled us to see a few details locally that were not readily visible on the 1:12,000-scale photographs. We also added landslides that Shannon and Wilson, Inc. (1997b) had mapped in the field under contract to BNSF for detailed studies of three areas where landsliding was particularly severe in 1996 and 1997 (see map).

Point locations, referenced by railroad milepost, show approximately where landslides impacted or came near the railroad. These point locations were derived from a table prepared by Shannon and Wilson, Inc. (1997c[4]) on the basis of their field investigations. Generally, this table included only landslides that were close to the railroad or threatened it. A table of landslide data referenced to these locations appears in Appendix A. This table contains landslide classification, dimensions, slope angle, geologic materials, seepage, and related information compiled by Shannon and Wilson, Inc. from their field investigations. We have reinterpreted the landslide classifications to make them consistent with the nomenclature of Varnes (1978). These include earth slides, debris flows, rapid earth flows, and rotational earth slides (slumps) or combinations thereof. Our reinterpretation is based on Shannon and Wilson's descriptions of individual landslides and our field reconnaissance of the area. We could determine the map locations of a few railroad mileposts from the railroad's track chart; milepost locations between the known locations were interpolated linearly along the track. Consequently, some of the point locations do not correspond exactly with the locations of mapped landslides. In most instances we do not know which mapped locations correspond to the point locations.

Shannon and Wilson, Inc. (1960) previously documented historic landslide areas (areas known to have produced landslides in the past) for the Great Northern Railway. We have plotted these areas from about milepost 7.2 to about milepost 12, the only area for which location data were readily available. These areas were originally drawn on oblique aerial photographs of the bluffs so their representation on the inventory map is approximate. The 24 areas of historic landsliding shown on the map account for approximately 159 individual landslides that occurred between 1933 and 1960 (table 1). Few data on the classification or dimensions of these historic landslides are available, but study of the oblique aerial photographs indicates that at least some of the landslides were similar to recent ones.

Previous work regarding landslide triggers

Landslide occurrence in the area has been linked to precipitation, snowmelt, and groundwater seepage. Several landslides occur almost every year during the wet season, which usually lasts from October through April (Thorsen, 1989). Winter storms have triggered significant numbers of landslides in 1934, 1972, 1986, 1990, 1996, and 1997 (Tubbs, 1974; Laprade, 1986; Miller, 1991; Gerstel, 1996; Harp and others, 1996; Baum and others, 1998). Tubbs (1974) identified numerous seeps and landslide source areas in the transitional contact between the Lawton and the Esperance and concluded that groundwater seepage there contributed to landslide occurrence. Tubbs also recognized several human activities, including drainage diversion and hillslope grading, that contributed to the 1972 landslides. Thorsen (1989) attributed most landslides in the Seattle area to excess ground water, whereas Gerstel (1996) concluded that both seepage of perched ground water and infiltration of surface water contributes to instability of thin colluvium and fill overlying glacial materials.

Landslide Characteristics

Shallow earth slides and debris flows were the most common types of landslides that occurred along the bluffs, but a few other types also occurred. Field observations by Shannon and Wilson, Inc. (1997b) and the USGS and study of aerial photographs indicate that many of the slides were shallow features that removed vegetation and colluvium from the slope. In particular, shallow earth slides or earth-slide and debris-flow combinations occurred at 89 of the 121 sites where landslides affected the railroad in 1995-96 and 1996-97 (for example, see fig. 1). Another 21 were classified as debris flows or rapid earth flows. A few rotational earth slides occurred, including the deep-seated Woodway landslide, which was a combination rotational slide and debris flow (fig. 3). Several of the shallow landslides formed by slumping at the toes of pre-existing deep rotational or translational slides.

Landslides ranged in size from a few cubic yards to about 100,000 yd^3 and they covered the tracks in about 100 places. Appendix A summarizes the surface dimensions of landslides that affected the railroad. Length and width vary significantly, but the long dimension is generally downslope. Observed or estimated thickness of the shallow earth slides in colluvium on steep slopes ranges from 2 to 10 ft and probably averages about 5 ft. Some slides originated in colluvium on mid-slope benches; colluvium ranged in thickness from 5 to 10 ft at the downhill edges of the benches. Large translational slides ranged in thickness from 10 to 30 ft or more, and the large rotational slide at Woodway was 50 ft thick (perpendicular to the bluff face) at the source and left deposits 10-40 ft thick.

The few available observations of the speed or duration of these landslides coupled with local experience indicate that most landslides were rapid and lasted less than a minute. Some landslides consisted of several separate pulses that occurred several hours apart, but each pulse lasted a less than a minute. Circumstances surrounding the main pulse of the Woodway landslide are consistent with duration of less than 20-30 seconds. The main pulse of the Woodway landslide struck the train as it was passing and pushed several cars into Puget Sound. Three engines and one other car had pushed through thin debris on the track before the slide struck. A secondary pulse that occurred several hours later lasted about 15-20 seconds according to eyewitnesses (Shannon and Wilson, Inc., 1997a). Accounts of other recent landslides around Puget Sound similarly indicate duration of a few seconds or tens of seconds (Bjorhus and Tu, 1997); however a few large, persistent, slow-moving slides also exist in the area (for example, large slow translational landslides occur on a mid-bluff bench north of Carkeek Park). Shallow earth slides and debris flows that covered the tracks originated at the toes of some of these slow-moving slides (fig. 1).

Factors that Contributed to Landslide Occurrence

Field observations point to some natural geologic and hydrologic factors as well as human-influenced factors that contributed to landsliding in 1996-1997. The immediate cause of recent landslides was the action of excess water due to heavy precipitation in the area. The occurrence of landslides during or immediately after precipitation events makes it clear that the action of water is the triggering mechanism. The underlying instability of Puget Sound coastal bluffs results from their steep slopes in combination with the stratigraphy, structure, shear strength, and hydraulic properties of the geologic materials that make up the bluffs. Wave erosion probably helped maintain the steepness of the bluffs until the BNSF railway right-of-way was developed in the late 1800's with a seawall and [illegible]

Certain geologic units appear to be more susceptible to landsliding than others, and different units are more susceptible in the northern and southern parts of the study area. [illegible]

In the northern part of the map area, landslides formed in colluvium derived from the Vashon Drift and the Whidbey Formation. [illegible] Pleistocene) landslides mapped by Smith (1975, 1976). Recent landslides also occurred within the boundaries of 16 of the 21 active landslides that Smith (1975, 1976) mapped.

Observations confirm that groundwater seepage contributed to many of the landslides. Seeps were present at about 60 percent of sites where landslides impacted the railroad (Appendix A). Seepage was likely present at many other landslides at the time they occurred, but evidence was not directly observed later when Shannon and Wilson, Inc. did their landslide inventory. Seeps related to landslides were present in several settings: at the heads of shallow landslide scars on steep slopes, at the downhill edges of benches and basins, and on the surfaces of large landslides.

Runoff concentration was locally a significant cause of landslides on the bluffs. Several shallow landslides were centered on small streams that originated at natural seeps on the benches or at the mouths of drain lines. Broken drain lines originating from upslope residences were observed in the source areas of many shallow landslides and debris flows. Where the stream channels have become incised, shallow landslides also occurred on the channel walls.

Erosion at the base of the bluffs by wave action probably contributed to their instability from the end of the Vashon glaciation until the railroad right of way was developed to protect the toe of the slope. The sea wall and stone revetments that protect the railroad embankment were probably constructed in the late 1800's. Since then, they have protected the base of the bluffs from wave erosion and have probably increased the stability of the bluff. Continued landslide activity higher up on the bluff face indicates that any such increase has been insufficient to completely overcome the long-term instability of the bluffs. However, retreat of the bluffs during the winters of 1995-96 and 1996-97 might have been greater had the sea wall and embankment not been present.

Aside from these natural causes, several human-induced changes to the area may have altered the stability of the bluffs. In a few instances, dumping of material at the top of the bluff has resulted in unstable masses perched at the bluff tops. Such cases are easily identified by the abundance of yard waste, construction waste, and other artificial material in the landslide debris. Where the dumped material is soil or earth fill, it can usually be recognized as such in the landslide scar. These include landslides at mile posts 16.9 and 26.37 that covered the tracks. Dumping fill at the top edge of bluffs has also been recognized as a contributing cause of landslides on Capitol Hill in Olympia, Wash. (Gerstel and others, 1997).

Additional Information Needed to Quantify Landslide Hazards

This inventory provides a starting point for considering landslide hazards to private property, rail operations, and other activities in the map area. Additional steps of mapping landslide susceptibility, estimating potential landslide runout (travel distance), determining frequency of landslide occurrence, and combining those factors into a probabilistic landslide hazards map are needed as input for a modern risk-based decision-making process to evaluate potential landslide mitigation strategies for the area.

The relationship between locations of recent and historic landslides is relevant to landslide susceptibility provided external factors do not skew the spatial distribution of locations. Skewing might result from factors such as incomplete or short records of landslides or peculiar characteristics of a given storm. Using a long enough period of record to represent multiple triggering events should subdue effects of varying rainfall, wind direction, and other characteristics of single storms that might tend to skew the landslide distribution. Combining field reconnaissance with mapping from aerial photographs that have been taken after a landslide event helps to produce more complete records of the landslides. Recent landslides shown on the map resulted from three different storms and the areas where historic (1933-60) landslides occurred resulted from many storms. Remaining factors that could influence the distribution of landslides should be related to the topography (slope, slope aspect, and relief) or geology (structure, physical properties, and hydrology).

The locations of recent landslides mapped in this study coincide closely with locations of historic landslides documented by Shannon and Wilson, Inc. (1960). The recent landslides occurred in or adjacent to nearly every area of known historic landslides (see map). We infer from the coincident locations of recent and historic landslides that the distribution of bluff instability has not changed significantly since 1933 and that future landslides are likely to occur in the same general areas as past landslides. Field observations indicate that it is particularly common for shallow landslides to occur in the same places on the steep slopes where colluvium and landslide material accumulates downslope from large landslides. Many examples of this occur near Carkeek Park (see map). Repeated occurrence of shallow earth slides and debris flows is less likely from the same spot in other geologic settings along the alignment. For example, after a landslide occurs in the colluvium and residuum that forms on thick sequences of outwash between Edmonds and Meadowdale (near 5,298,000 m N.) it takes several years for loose material to accumulate to sufficient thickness to spawn another slide. In these areas, shallow slides or debris flows will occur in adjacent areas before repeating in the source area of a past slide.

Correlation noted earlier between locations of mapped landslide deposits (Smith, 1975, 1976) and locations of recent landslides similarly suggests that areas of past landsliding are prone to repeated landsliding. Roughly two-thirds of the recent landslides occurred within the bounds of mapped landslide deposits. The remaining one-third of the recent landslides occurred in several steeply sloping areas where Smith (1975, 1976) had mapped other deposits. Shallow landslides may have occurred previously in these areas but left little evidence behind. Vegetation commonly obscures the scars and deposits of shallow landslides within a few years of their occurrence. Consequently a map showing areas of previous landslide activity may be a better indicator of bluff stability than a map showing landslide deposits.

A comprehensive landslide susceptibility map of the area would show all the potential source areas of landslides. Potential source areas have similar geologic, hydrologic, and topographic characteristics to the source areas of recent landslides (described above). Susceptibility mapping could be accomplished either by application of deterministic slope stability models that account for these characteristics, by field mapping, or a combination of both. Areas where landslide remedial measures are in place and functioning according to design could be accounted for in ranking the susceptibility.

Frequency of landslide occurrence along these coastal bluffs is significant to determining appropriate mitigation for landslide events of different magnitudes. Broad estimates of frequency can be derived from available historic data. Year of occurrence is known for about one-fifth of the landslides listed in table 1 and of that fifth, at least one landslide occurred during 15 of the 28 years of record (1933-1960) somewhere in one of the areas of historic landsliding shown on the map. These sparse data indicate that isolated landslides occurred, on average, at least once every 2 years. This estimate is an upper bound; actual average time between single occurrences is probably less than 1 year, considering that dates are known for only one-fifth of the landslides. A minimum of three slides occurred in at least 4 of the 28 years of record, in 1933, 1949, 1951, and 1960 (table 1). Assuming that slides in a given year occurred in response to the main storms of that year, events having three or more landslides occurred, on average, at least once every 9 years. The occurrence of six major storms that triggered multiple landslides in the 26-year period 1972-1997 are consistent with a shorter interval for multi-landslide events of about once every 5 years. These storms occurred in late February and early March 1972 (Tubbs, 1974), January 1986 (Laprade, 1986), January 1990 (Miller, 1991), February 1996 (Gerstel, 1996; Harp and others, 1996), December 1996 (Gerstel, 1996; Baum and others, 1998), and March 1997 (Baum and others, 1998). More detailed data on landslide occurrences could be analyzed to determine accurate return periods and to assess the feasibility of forecasting times of increased likelihood for multiple and single landslide events.

Summary

Landsliding on the bluffs between Seattle and Everett, Wash., poses a significant but intermittent hazard to private property and rail operations in the area. Recent landslides damaged several residences on the bluffs. Landslides blocked one or both tracks in about 100 places and came close to the tracks in about 30 more locations during 1996 and 1997. Although most landslides that temporarily blocked the tracks did not collide with trains, one large slide derailed part of a train and caused significant damage. Frequent commuter train traffic to be developed in the BNSF right of way under a light-rail plan adopted by Sound Transit (Sound Transit Resolution No. R2000-10) could increase exposure of passengers to landslides. These small, relatively light commuter trains might be easily derailed or damaged by impact of small- to medium-sized landslides. Additional data that would enable the operators of the commuter rail system to anticipate the onset of landslide activity might help them to avoid landslide-related accidents. Careful analysis of landslide probability and processes along the bluffs could aid in evaluating the need for other remedial measures.

References Cited

Arndt, B., 1999, Determination of the conditions necessary for slope failure of a deep-seated landslide at Woodway, Washington: Golden, Colo., Colorado School of Mines Master of Engineering thesis, 216 p.

Baum, R.L., Chleborad, A.F., and Schuster, R.L., 1998, Landslides triggered by the December 1996 and January 1997 storms in the Puget Sound area, Washington: U.S. Geological Survey Open-File Report 98-239, 16 p.

Bjorhus, Jennifer, and Tu, J.I., 1997, 2 witnessed fatal slide: Seattle Times, January 24, p. A1, A23.

Crandell, D.R., Mullineaux, D.R., and Waldron, H.H., 1965, Age and origin of the Puget Sound trough in western Washington, *in* Geological Survey research 1965, Chapter B: U.S. Geological Survey Professional Paper 525-B, p. B132-B136.

Gerstel, W.J., 1996, The upside of the landslides of February 1996—Validating a stability analysis of the Capitol Campus Bluffs, Olympia, Washington: Washington Geology, v. 24, no. 3, p. 3-16.

Gerstel, W.J., Brunengo, M.J., Lingley, W.S., Jr., Logan, R.L., Shipman, Hugh, and Walsh, T.J., 1997, Puget Sound Bluffs—The where, why, and when of landslides following the holiday 1996/97 storms: Washington Geology, v. 25, no. 1, p. 17-31.

Harp, E.L., Chleborad, A.F., Schuster, R.L., Cannon, S.H., Reid, M.E., and Wilson, R.C., 1996, Landslides and landslide hazards in Washington State due to February 5-9, 1996 storm: U.S. Geological Survey Administrative Report to the Federal Emergency Management Agency, 29 p.

Laprade, W.T., 1986, Unusual landslide processes, January 17 and 18, 1986 storm, Seattle, Washington: Association of Engineering Geologists, 29th Annual Meeting; Better living through Engineering Geology, v. 29, p. 55.

Laprade, W.T., Gilbert, J.W., and Hultman, W.A., 1998, Woodway landslide—A reminder and an opportunity: Landslides in the Puget Sound Region Seminar, Seattle Wash., April 4, 1998, ASCE Seattle Section Geotechnical Group, 11 p.

Miller, D.J., 1991, Damage in King County from the Storm of January 9, 1990: Washington Geology, v. 19, no. 11, p. 28-37.

Mullineaux, D.R., Waldron, H.H., and Rubin, Meyer, 1965, Stratigraphy and chronology of late interglacial and early Vashon glacial time in the Seattle area, Washington: U.S. Geological Survey Bulletin 1194-O, 10 p.

Smith, Mackey, 1975, Preliminary surficial geologic map of the Edmonds East and Edmonds West quadrangles, Snohomish and King Counties, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-14, scale 1:24,000.

——1976, Preliminary surficial geologic map of the Mukilteo and Everett quadrangles, Snohomish County, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-20, scale 1:24,000.

Thorsen, G.W., 1989, Landslide provinces in Washington, *in* Galster, R.W., ed., Engineering geology in Washington: Washington Division of Geology and Earth Resources Bulletin 78, v. I, p. 71-89.

Tubbs, D.W., 1974, Landslides in Seattle: Washington Division of Mines and Geology Information Circular 52, 15 p., scale 1:31,680.

Varnes, D.J., 1978, Slope movement types and processes, *in* Schuster, R.L., and Krizek, R.J., eds., Landslides analysis and control—Transportation Research Board Special Report 176: Washington, D.C., National Research Council, p. 11-33.

---

[1] Letter report to the Burlington Northern Santa Fe Railroad regarding Woodway landslide, MP 15.8 and 15.9 North, Scenic Subdivision, Seattle, Washington, unpublished, May 22, 1997.

[2] Report of landslide investigation, Great Northern Railway, Ballard to Everett, Seattle, Washington, unpublished, September 30, 1960.

[3] Draft Report, Evaluation of three landslide areas between Seattle and Everett, Scenic Subdivision, Pacific Division, April 1997.

[4] "Landslide Table" pages 1-12, unpublished, June 1997.

Figure 3. The January 15, 1997, Woodway landslide, Snohomish County, Wash. This complex landslide began as a deep-seated, rotational slide. Much of the slide mobilized into a debris flow that derailed several cars of a passing freight train. Shallow earth slides and debris flows also occurred on the slope directly south (to the right) of the rotational slide.

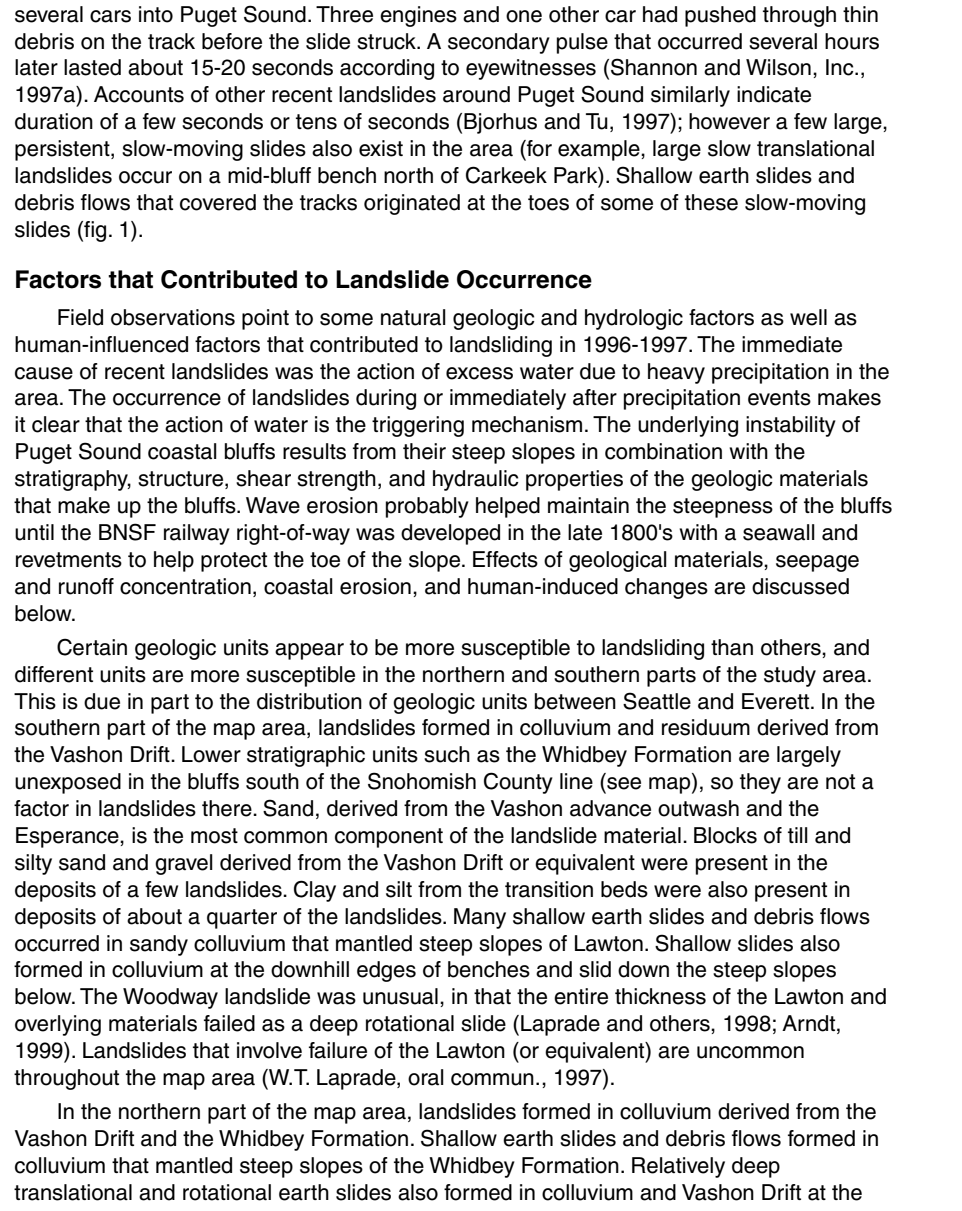
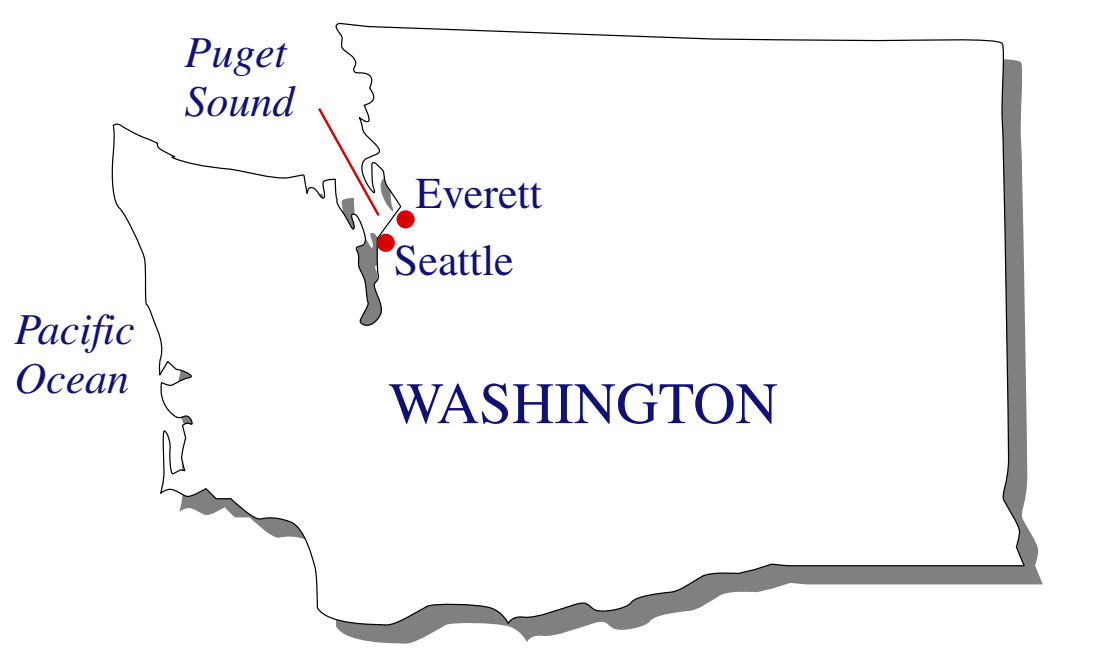
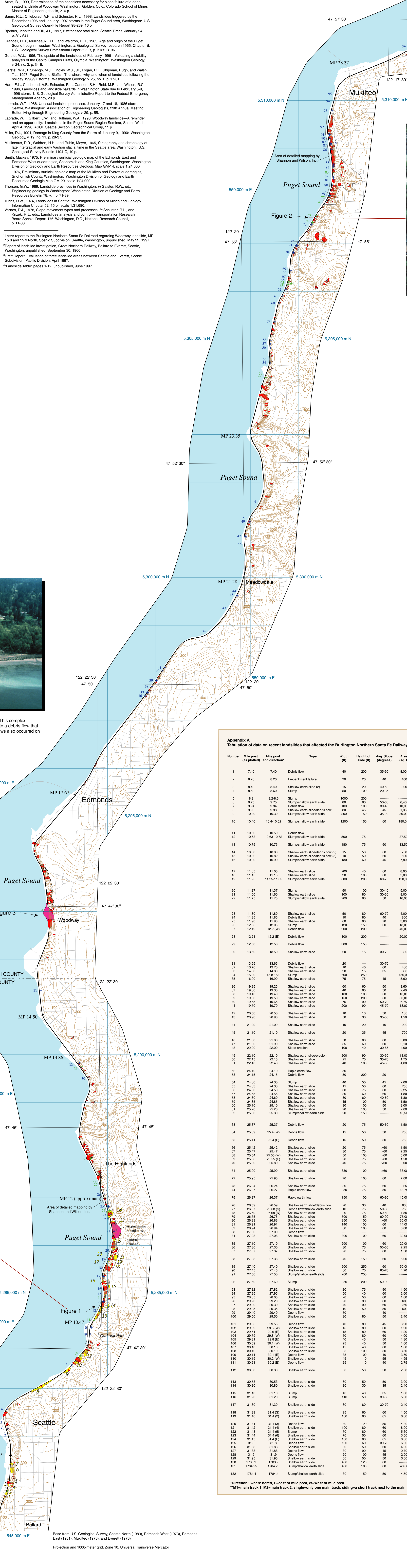


Figure 1. Shallow landslides north of Carkeek Park, Seattle, Wash. Much of the material in these slides originated at the edge of the mid-bluff bench. Slow-moving, deep-seated landslides occupy the bench, and material calves off the toes of these slides during or after severe rainstorms.





Base from U.S. Geological Survey, Seattle North (1983), Edmonds West (1973), Edmonds East (1981), Mukilteo (1973), and Everett (1973)

Projection and 1000-meter grid, Zone 10, Universal Transverse Mercator

Scale 1:24,000

1 0 1 Kilometer

1000 0 1000 2000 3000 Feet

Contour Interval 25 feet
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

- MP 14.50 — Burlington Northern Santa Fe (BNSF) Railway—Line segment crosses track at location of railroad mile post [illegible]
- 🟥 Shallow earth slide or debris flow that occurred in 1996-97
- ▨ Deep-seated landslide that occurred in 1996-97
- 23 Historic landslide areas mapped by Shannon and Wilson, Inc. (1960)—Keyed by number to table 1
- Landslide scarp—May predate 1996 landslides
- 14 Locations where a debris flow or rapid earth flow covered the tracks or otherwise affected the railroad in 1996-97—Keyed by number to Appendix A
- 21 Locations where a slump or shallow earth slide covered the tracks or otherwise affected the railroad in 1996-97—Keyed by number to Appendix A

Figure 2. Landslides south of Mukilteo, Snohomish County, Wash. These slides severely damaged the lawns behind two homes, stripped vegetation from the steep slopes above the railroad, and deposited material on the tracks. Movement near the top of the slope is predominantly translational and the extension fractures in the lawn are consistent with retrogressive failure from the edge of the steep slope.

Table 1. Areas of historic landsliding along coastal bluffs (1933-1960) from Ballard to the Highlands, Seattle, Washington
[Summarized from plates 3-8 of Shannon and Wilson, Inc. (1960). Area number keyed to map. The approximate mile post location is given in the second column to aid in locating individual areas.]

Area number	Mile post	Number of landslides	Description
1	7.35	1	Landslide, 1933
2	7.4	2	Two landslides, 1950, 1956
3	7.5	5	Five landslides, 1949-1960
4	7.5	1	Landslide, about 1960
5	7.55	1	Landslide, active in 1936
6	7.74	1	Landslide, 1937
7	7.8	2	Landslides, 1949, 1955
8	8.9-9.2	13	Thirteen landslides recorded through 1960
9	9.4-9.5	3	Three small landslides, 1940, 1957, 1960
10	9.6	4	Four landslides, 1951, 1954, 1957, 1958
11	9.7	4	Series of landslides in 1941 and two landslides in 1951
12	9.8	1	Landslide, 1933
13	10.4-10.6	50	Approximately 50 landslides recorded 1933-1960
14	10.45	1	Minor slumping or spalling near top of bluff
15	10.7	1	Minor slumping or spalling near top of bluff
16	10.8	5	Five landslides, 1949-1960, evidence of earlier slides on earlier photographs.
17	11	28	Fresh landslide scar visible on 1960 oblique aerial photograph, approximately 30 landslides recorded between mile post 11.0 and 11.2 from 1933 through 1960.
18	11.05	1	Minor slumping or spalling near top of bluff
19	11.08	1	Fresh landslide scar visible on 1960 oblique aerial photograph.
20	11.1	1	Fresh landslide scar visible on 1960 oblique aerial photograph.
21	11.1	1	Landslide active in 1960
22	11.25-11.4	20	Approximately 20 landslides recorded through 1960, fresh landslide scars visible on 1960 oblique aerial photograph.
23	11.55	11	Eleven landslides recorded 1955, 1956
24	11.75	1	Landslide December 1959-January 1960 covered tracks and deposited material on the beach. Slide was 350-400 ft wide.
		159 Total	

Appendix A

Tabulation of data on recent landslides that affected the Burlington Northern Santa Fe Railway (modified from Shannon and Wilson Inc., 1997c). Approximate locations are keyed by number to the map.

Number	Mile post (as plotted)	Mile post and direction*	Type	Width (ft)	Height of slide (ft)	Avg. Slope (degrees)	Area (sq. ft)	Covered tracks**	Soil type(s)	Seepage (gpm=gallons per minute)	Description
1	7.40	7.40	Debris flow	40	200	35-90	8,000	M1/M2	Gravelly, clayey, silty sand over clay/silt	Yes (30-50 gpm)	Slide started at the crest of the slope (colluvium in old slide bowl) and flowed over lower portion of slope.
2	8.20	8.20	Embankment failure	20	20	40	400	No	----------	No	Shallow embankment failure. Existing crack is located about 12 ft from end of tie on Main 1.
3	8.40	8.40	Shallow earth slide (2)	15	20	40-50	300	No	Slide debris sand/clay/silt	No	Two small shallow earth slides.
4	8.60	8.60	Slump	50	100	20-35	----------	--------	Slide debris sand/clay/silt	Water on ground surface, flowing	Slump toeing out in ditchline. Complex slide as much as 400 ft long with track.
5	8.3	8.2-8.6	Slump	1000	200	--------	----------	No	Sand over silt/clay	Yes	Existing landslide. This slide generally moves several months after heavy rainfall.
6	9.75	9.75	Slump/shallow earth slide	80	80	50-60	6,400	M1/M2	Sand over clay/silt	Yes	Shallow earth slide February 1996.
7	9.94	9.94	Debris flow	100	100	30-45	10,000	M1/M2	Sand	Yes (50 gpm)	----------
8	9.98	9.98	Shallow earth slide/debris flow	30	45	45	1,350	No	Sand	No	----------
9	10.30	10.30	Slump/shallow earth slide	200	150	35-90	30,000	M1/M2	Till and sand	Yes	Large blocks of advance outwash sand, till, and trees slumping to the railroad over the clay.
10	10.40	10.4-10.62	Slump/shallow earth slide	1200	150	60	180,000	M1/M2	Sand over clay	Yes	Colluvium and advance outwash sliding over the Lawton Clay Member bench and onto the railroad. Shallow earth slides/debris flows occur on the steep slopes adjacent to the railroad.
11	10.50	10.50	Debris flow	----	----	--------	----------	--------	----------	----------	----------
12	10.63	10.63-10.72	Slump/shallow earth slide	500	75	--------	37,500	M1/M2	Sand over clay	Yes	Colluvium and advance outwash sliding over the Lawton Clay Member bench and onto the railroad.
13	10.75	10.75	Slump/shallow earth slide	180	75	60	13,500	M1/M2	Sand over clay	Yes (~40 gpm)	Historic slump and earth flow area. Recent activity consists of shallow earth slides originating from the steep slopes adjacent to the railroad.
14	10.80	10.80	Shallow earth slide/debris flow (2)	15	50	60	750	M2	Sand	Wet	Two debris flows that started as shallow slides.
15	10.82	10.82	Shallow earth slide/debris flow (5)	10	50	60	500	M2	Sand/clay	Wet	Five debris flows that stated as shallow slides, spread over a length of 170 ft.
16	10.90	10.90	Slump/shallow earth slide	130	60	45	7,800	No	Fine sand	Yes (5-40 gpm)	Three small debris flows on south flank of 440-ft-wide older slump. Seepage along both flanks. Shallow slides along head scarp. Bench area wet, water at ground surface.
17	11.05	11.05	Shallow earth slide	200	40	60	8,000	M2	Sand/ clay	No	Shallow (less than 12 in. thick) earth slide exposing clay/ silt.
18	11.15	11.15	Shallow earth slide	20	100	60	2,000	No	Sand/clay	No	Shallow earth slide that did not reach track.
19	11.25	11.25-11.35	Slump/shallow earth slide	600	200	60-70	120,000	M1/M2	Till over clay	Yes	Weathered till or advance outwash sand slumping over the clay bluff above the railroad. Soil streaks down face of clay bluff show how the material failed over the top of the clay and accumulated on the colluvium bench above the railroad.
20	11.37	11.37	Slump	50	100	30-40	5,000	M2	Gravelly sandy silt/silty sand	Yes (50 gpm)	----------
21	11.60	11.60	Shallow earth slide	100	80	30-60	8,000	M1/M2	Sand over clay/silt	No	----------
22	11.75	11.75	Slump/shallow earth slide	200	80	50	16,000	M1/M2	Sand over clay/silt	Yes	Small slumps and shallow earth slides from face of steep bluff above railroad. Slumps originated along seepage at clay and sand contact. Current failure is on southern flank of a larger, 200-ft-wide slide. Head scarp is about 200 ft from the railroad.
23	11.80	11.80	Shallow earth slide	50	80	60-70	4,000	M1/M2	Gravelly sand/clay	Wet	----------
24	11.85	11.85	Debris flow	10	80	40	800	No	----------	Yes (50 gpm)	----------
25	11.90	11.90	Shallow earth slide	60	60	70	3,600	M2	Sand	No	----------
26	12.05	12.05	Slump	120	150	60	18,000	No	Sand	Yes	Slump. Did not reach track. Seepage at clay silt/sand contact.
27	12.19	12.2 (W)	Debris flow	200	200	--------	40,000	M2	Sand and gravel	No	Debris flow from adjacent property blocked railroad culvert with debris and overtopped track.
28	12.21	12.2 (E)	Debris flow	100	200	--------	20,000	M1/M2	Sand and gravel	No	Debris flow from adjacent property blocked railroad culvert with debris and overtopped track.
29	12.50	12.50	Debris flow	300	150	--------	----------	M1/M2	Sand, clay, and silt	Yes	Large debris flow that covered both mains. A smaller shallow earth slide (50 ft wide and 100 ft high) that did not reach the track is located 50 ft to the south.
30	13.50	13.50	Shallow earth slide	20	15	30-70	300	No	Gravelly sand	No	Small shallow earth slide that involved colluvium over till. Numerous flexible drainage pipes are present on the bluff. They discharge into the colluvium in the lower part of the slope.
31	13.65	13.65	Debris flow	20	----	30-70	----------	M2	Gravelly sand	----------	----------
32	13.70	13.70	Shallow earth slide	10	40	60	400	M2	Gravelly sand	No	----------
33	14.80	14.80	Shallow earth slide	20	15	35	300	No	Sand	No	Blocked ditch.
34	15.90	15.8-15.9	Slump	600	250	--------	150,000	M1/M2	Sand/clay	Yes	Large rotational slide, known as the Woodway landslide.
35	16.90	16.90	Shallow earth slide	75	75	45	5,625	Single	Sand and yard waste	No	Shallow earth slide caused by weight of saturated yard waste and discharge from flexible drainage pipe.
36	19.25	19.25	Shallow earth slide	60	60	50	3,600	M1/M2	Sand and gravel	Yes (1-2 gpm)	----------
37	19.30	19.30	Shallow earth slide	40	60	50	2,400	M2	Sand and gravel	Yes	----------
38	19.40	19.40	Shallow earth slide	100	100	50	10,000	M1/M2	Sand and gravel	Slight	----------
39	19.50	19.50	Shallow earth slide	150	200	50	30,000	M1/M2	Sand and gravel	Slight	Shallow slide, several undercut areas have potential to slide eventually.
40	19.65	19.65	Shallow earth slide	75	90	50-70	6,750	M1/M2	Sand, some gravel	No	Slide originated in upper 40 ft of 100-ft-high slope.
41	19.70	19.70	Shallow earth slide	200	90	45-70	18,000	M1/M2	Sand, some gravel	No	Several interconnected shallow earth slides originated from the upper 40 ft of the bluff.
42	20.50	20.50	Shallow earth slide	10	10	50	100	No	Gravelly silty sand	No	Slide occurred on lower part of hydroseeded old slide.
43	20.90	20.90	Shallow earth slide	50	30	35-50	1,500	M2	Medium-coarse sand, till on top	Yes	Shallow slide exposed old drainage pipe buried in yard waste and colluvium. Scarp extends beyond recent slide limits. Potential for more sliding.
44	21.09	21.09	Shallow earth slide	10	20	40	200	No	Sand	No	Small shallow earth slide (15 ft high x 10 ft wide) about 80 ft south of larger slide at mile post 21.1.
45	21.10	21.10	Shallow earth slide	20	35	45	700	M2	Sand	No	Slide occurred in upper 20 ft of 35-ft-high slope. Broken drainage pipe at top of slope. Scarp is present at midslope above colluvium.
46	21.80	21.80	Shallow earth slide	50	60	60	3,000	M1/M2	Gravelly sand	Yes	Runoff drained onto slope from new development upslope of bluff.
47	21.90	21.90	Shallow earth slide	35	60	60	2,100	M1/M2	Sand, sandy silt	Yes	----------
48	22.00	22.00	Slope erosion	100	40	30-65	4,000	M2	Gravelly sand	Yes	Three washouts occurred in the lower 30 ft of 70-ft slope. Erosion occurred where the slope flattened out in the colluvium.
49	22.10	22.10	Shallow earth slide/erosion	200	90	30-50	18,000	M1/M2	Sand	Yes	Three shallow earth slides to the south, slope erosion at two spots to the north.
50	22.15	22.15	Shallow earth slide	25	70	35-70	1,750	No	Sand	No	Shallow earth slide with erosion channels through the center of scar.
51	22.40	22.40	Shallow earth slide	40	100	45-50	4,000	M2	Sand	No	Shallow earth slide occurred about midslope on a 120-ft-high bluff. Most slide debris stopped at bench about 45 ft above track.
52	24.10	24.10	Rapid earth flow	50	----	--------	----------	M2	Sand	Yes (30-50 gpm)	Existing landslide toe next to railroad.
53	24.15	24.15	Debris flow	50	200	20	----------	M1/M2	Sand, silt	No	Shallow slide that started at top of slope. Material flowed over ground surface at toe and buried both mains.
54	24.30	24.30	Slump	40	50	45	2,000	M1/M2	Sand, silt, clay	Yes	----------
55	24.33	24.33	Shallow earth slide	15	50	60	750	M2	Sand, silt, clay	Yes	Shallow earth slide. Common origin point at crest, but two flow paths to toe of slope.
56	24.50	24.50	Shallow earth slide	30	75	60	2,250	M1/M2	Sand, silt, clay	Yes (100 gpm)	Old slide area.
57	24.55	24.55	Shallow earth slide	30	60	60	1,800	No	Sand, silt, clay	Wet	Shallow slide.
58	24.60	24.60	Shallow earth slide	30	60	40-60	1,800	M1/M2	Sand, silt, clay	Yes	Shallow slide.
59	24.85	24.85	Shallow earth slide	15	100	50	1,500	M2	Sand	No	Slide was 15 ft wide on Main 2 but about 50 ft wide on the slope.
60	25.10	25.10	Shallow earth slide	30	100	50	3,000	M2	----------	Yes (1-2 gpm)	----------
61	25.20	25.20	Shallow earth slide	20	100	50	2,000	M2	----------	No	----------
62	25.30	25.30	Slump/shallow earth slide	90	150	--------	13,500	M2	----------	Yes	Slide bowl located near the crest of the slope and partially undermines two properties. It appears that the slide occurred in the soils above the mid-slope bench. Debris flowed to railroad.
63	25.37	25.37	Debris flow	20	75	50-60	1,500	M2	Gravelly silty sand w/cobbles (till)	No	Slide orginated at the top of the slope and slid over lower slope. Failure occured along the drainage pipe alignment.
64	25.39	25.4 (W)	Debris flow	15	50	50	750	M2	Gravelly silty sand w/cobbles (till)	Yes (10 gpm)	Weathered sandy till flowing over ground above contact with clayey till. Seepage at sandy till/clayey till contact. Slump block above clayey till.
65	25.41	25.4 (E)	Debris flow	15	50	50	750	M2	Gravelly silty sand w/cobbles (till)	Yes	Sandy till flowing over ground above contact with clayey till. Perched slump block positioned between two slides that will eventually fail to railroad.
66	25.42	25.42	Shallow earth slide	20	75	>60	1,500	M2	Silt to silty fine sand w/gravel	No	Shallow slide.
67	25.47	25.47	Shallow earth slide	30	75	>60	2,250	No	Gravelly silty sand over clay	----------	Colluvium slide over clay bluff.
68	25.54	25.55 (W)	Shallow earth slide	50	100	>60	5,000	M2	Clayey silt	Wet	Old slide area.
69	25.56	25.55 (E)	Shallow earth slide	20	75	>60	1,500	M2	Fine sandy silt	Wet	Lower 2/3 of slope is a shallow slide. Bench located above 2/3 point of slope.
70	25.80	25.80	Shallow earth slide	40	75	>60	3,000	M2	Silty gravelly sand	No	Shallow slide flowed over lower part of slope. Yard waste and gardening equipment in slide.
71	25.90	25.90	Shallow earth slide	330	100	>60	33,000	M1/M2	Gravelly clayey silt/silty clay	Yes (1-10 gpm)	Shallow earth slide. Small bench at top of slope. Sand, cobbles, boulders exposed in slope.
72	25.95	25.95	Shallow earth slide	70	100	60	7,000	M1/M2	Clay and silt	No	Shallow earth slide occurred in the upper portion of the slope and the debris slid over lower slope.
73	26.24	26.24	Shallow earth slide	30	75	60	2,250	M2	Gravelly clay (till)	Wet	----------
74	26.27	26.27	Rapid earth flow	250	75	50	18,750	No	Gravelly silty sand over gravelly clay (till)	Yes	Fill failed at the top of slope and flowed over in-place clay down to retaining wall. Several small slides.
75	26.37	26.37	Rapid earth flow	150	100	60-90	15,000	M1/M2	Gravelly, silty sand over sand	Yes (10 - 20 gpm)	Failed in fill or outwash sand at top of slope. Flowed over lower slope to railroad. Several seeps from top of slope, 10-20 gpm.
76	26.59	26.59	Shallow earth slide/debris flow	20	30	40	600	M1/M2	Gravelly sandy silt w/cobbles	Wet	Small shallow earth slide/debris flow in old slide area.
77	26.67	26.68 (S)	Debris flow/shallow earth slide	10	75	50-60	750	M2	Clayey silt, trace sand and gravel	Wet	At toe of large historic slide.
78	26.69	26.68 (N)	Shallow earth slide	20	75	50-60	1,500	M2	Clayey silt, trace sand and gravel	Wet	At toe of large historic slide.
79	26.75	26.75	Shallow earth slide	500	150	60-90	75,000	M1/M2	Gravelly sand	Yes (~20 gpm)	20 gpm seepage on north end, historic landslide.
80	26.83	26.83	Shallow earth slide	350	100	>60	35,000	M1/M2	Gravelly sand	----------	----------
81	26.91	26.91	Shallow earth slide	140	100	60	14,000	M1/M2	Cobbles, gravel, sand	Yes	Seepage from bench above railroad.
82	26.94	26.94	Shallow earth slide	60	100	60	6,000	M1/M2	Gravelly sand	Wet	----------
83	27.00	27.00	Debris flow	----	----	--------	----------	--------	----------	----------	Started at Mukilteo Speedway.
84	27.08	27.08	Shallow earth slide	300	100	60	30,000	M1/M2	Gravelly sand	Yes (30-50 gpm)	Three shallow earth slides in historic slide area. Seepage over ledge in existing slide bowls.
85	27.10	27.10	Shallow earth slide	200	100	60	20,000	Single	Gravelly sand	Yes (20 gpm)	----------
86	27.30	27.30	Shallow earth slide	30	75	50-60	2,250	No	Gravelly sandy silt	No	----------
87	27.37	27.37	Shallow earth slide	20	75	60	1,500	No	Gravelly sandy silt	No	Three to four small (<20 ft wide) shallow earth slides that did not break slide fence but partially blocked the ditch.
88	27.38	27.38	Shallow earth slide	40	150	60	6,000	Single	Gravel and sand	Wet	----------
89	27.40	27.40	Shallow earth slide	200	250	60	50,000	Single	Gravel and sand	Yes (flow not estimated)	----------
90	27.45	27.45	Shallow earth slide	60	70	60-70	4,200	No	Gravel and sand	Wet	----------
91	27.50	27.50	Slump/shallow earth slide	200	250	--------	----------	No	Gravel, sand, silt	Yes	Numerous small shallow earth slides from steep part of slope near head scarp. Slides did not reach the track.
92	27.60	27.60	Slump	250	200	50-90	----------	No	Gravel, sand, silt	Yes	Existing slump. Cracked block of till in head scarp. Toe was undercut by erosion from 1996-1997 storms.
93	27.82	27.82	Shallow earth slide	20	75	90	1,500	No	Sand over gravelly sand	No	----------
94	27.95	27.95	Shallow earth slide	50	40	60	2,000	No	Gravelly sand	Wet	----------
95	28.05	28.05	Shallow earth slide	20	50	60	1,000	No	Gravelly sand	Wet	Small shallow earth slide at mile post 28.05 did not affect track.
96	29.20	29.20	Shallow earth slide	20	30	60	600	M2	Sand, silty sand	No	Shallow earth slide in colluvium on bluff below Mukilteo Blvd.
97	29.30	29.30	Shallow earth slide	40	90	60	3,600	No	Sand and clay	Yes	----------
98	29.35	29.35	Shallow earth slide	10	50	50	500	No	Sand	No	----------
99	29.40	29.40	Debris flow	50	---	40	----------	M1/M2	Organics	Yes	----------
100	29.50	29.50	Shallow earth slide	30	80	50	2,400	M1/M2	Gravelly sand/silty clay	Yes	Shallow earth slide was about 20 ft wide at the top of the 100-ft-high bluff. Mud flowed through a narrow chute and covered about 30 ft of track.
101	29.55	29.55	Debris flow	40	80	45	3,200	M2	Organics and gravelly sandy colluvium	Yes	Debris flow from the upper part of the slope was deposited on the track.
102	29.59	29.6 (W)	Shallow earth slide	15	80	60	1,200	M2	Organics and gravelly sandy colluvium	Yes	----------
103	29.61	29.6 (E)	Shallow earth slide	15	80	60	1,200	M2	Organics and gravelly sandy colluvium	No	----------
104	29.79	29.8 (W)	Shallow earth slide	50	80	60	4,000	M2	Organics and gravelly sandy colluvium	Yes	----------
105	29.81	29.8 (E)	Shallow earth slide	40	45	50	1,800	M2	Organics and gravelly sandy colluvium	No	----------
106	30.09	30.1 (W)	Shallow earth slide	25	40	50	1,000	M2	Organics only	No	----------
107	30.10	30.10	Shallow earth slide	45	40	60	1,800	M2	Organics only	No	----------
108	30.10	30.10	Shallow earth slide	35	100	50	3,500	M2	Organics only	No	----------
109	30.11	30.1 (E)	Debris flow	35	100	40	3,500	M2	Organics and gravelly sandy colluvium	Yes	----------
110	30.19	30.2 (W)	Shallow earth slide	45	110	55	4,950	M1/M2	Organics and gravelly sandy colluvium	No	Shallow earth slide above and on the southwest side of intact colluvium.
111	30.21	30.2 (E)	Debris flow	25	110	40	2,750	M1/M2	Organics and gravelly sandy colluvium	Yes	Flow and shallow earth slides on both sides of eroded chute deposited debris over both tracks.
112	30.30	30.30	Shallow earth slide	50	50	50	2,500	M2	Organics and gravelly sandy colluvium	No	Shallow earth slide on the southwest flank of what may be an old slide bowl. Large amount of construction debris may have contributed to the slump in upper part of slope. The debris did not reach track.
113	30.53	30.53	Shallow earth slide	60	50	50	3,000	No	Organics and gravelly sandy colluvium	No	----------
114	30.80	30.80	Shallow earth slide	80	30	35	2,400	Siding	Sand, minor clay	No	Two shallow earth slides, each about 25 ft wide, separated by 20-ft-wide strip of intact colluvium.
115	31.10	31.10	Slump	40	40	35	1,600	M2	Sand and clay	Yes	----------
116	31.20	31.20	Slump	110	50	30-50	5,500	M1/M2	Sand over clay	Yes	Sand sliding over clay in 100-ft-wide slump. Steep head scarp as much as 15 ft high. Seepage over railroad retaining wall at several locations.
117	31.30	31.30	Shallow earth slide	30	80	30-70	2,400	M2	Sand over clay	Yes	Sand and yard waste sliding over clay. Spring from groundwater perched on clay flowing over retaining wall.
118	31.39	31.4 (S)	Shallow earth slide	25	60	60	1,500	No	Sand over clay	Yes	Debris from shallow earth slide overtopped retaining wall.
119	31.40	31.4 (2)	Shallow earth slide	100	60	65	6,000	M2	Sand over clay	Yes	Sand sliding over clay. Springs at sand/clay contact. Blowouts in sand just above clay.
120	31.41	31.4 (3)	Debris flow	40	120	55	4,800	M1/M2	Sandy colluvium	Yes	Debris flow covered both tracks.
121	31.42	31.4 (4)	Shallow earth slide	100	80	60	8,000	M1/M2	Gravelly sand	Yes	Large shallow earth slide possibly initiated by surface runoff over crest of slope.
122	31.43	31.4 (5)	Slump	70	80	60	5,600	M1/M2	Gravelly sand	Yes	Deep seated slump with sand sliding over clay. Spring at sand-clay contact.
123	31.44	31.4 (6)	Shallow earth slide	70	50	60	3,500	M1/M2	Sand over clay	Yes	----------
124	31.45	31.4 (E)	Shallow earth slide	100	60	65	6,000	M2	Sand over clay	Yes	----------
125	31.8	31.8	Debris flow	100	60	30-70	6,000	M2	Gravel, sand, clay	Yes	Runoff from upslope source eroded slope and deposited debris on M2.
126	31.83	31.83	Shallow earth slide	80	50	60	4,000	M2	Gravel, sand, clay	Yes	----------
127	31.88	31.88	Debris flow	30	90	45	2,700	M2	Colluvium	Yes	Runoff from upslope source eroded slope and deposited debris on M2.
128	31.9	31.9	Debris flow	20	100	45	2,000	No	Colluvium	Yes	----------
129	31.95	31.95	Shallow earth slide	60	50	50	3,000	M2	Sand over clay	Yes	----------
130	1783.9	1783.9	Shallow earth slide	400	120	60	----------	Highline	Sand over clay	Yes	Multiple shallow earth flows from steep slope adjacent to the railroad.
131	1784.25	1784.25	Slump/shallow earth slide	400	100	60	40,000	Highline	Sand over clay	Yes	Large slump on bench above railroad. Sandy colluvium sliding over silt/clay deposit. Multiple shallow earth flows from steep slope adjacent to the railroad.
132	1784.4	1784.4	Slump/shallow earth slide	30	150	50	4,500	Highline	Sand over clay	Yes	Shallow earth slide for steep slope adjacent to railroad.

***Direction: where noted, E=east of mile post, W=West of mile post.**
****M1=main track 1, M2=main track 2, single=only one main track, siding=a short track next to the main track, highline=elevated main track**

---

[1] U.S. Geological Survey, Box 25046, M.S. 966, Denver, CO 80225
[2] Shannon and Wilson, Inc., P.O. Box 300303, Seattle, WA 98103

Manuscript approved for publication October 6, 2000

This map was produced on request, directly from digital files, on an electronic plotter.

For sale by U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225
1-888-ASK-USGS

This map is also available as a PDF and as Arc/Info coverages at http://greenwood.cr.usgs.gov/greenwood-pubs.html