Landslide Mitigation Action Plan

Final Report
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Washington State
Department of Transportation

Washington State Department of Transportation (WSDOT) Rail Division

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Snohomish County

City of Everett

City of Mukilteo

City of Shoreline

City of Seattle

City of Edmonds

Town of Woodway

Port of Everett

Executive Summary

Each year, landslides along the Pacific Northwest Rail Corridor interrupt rail service for passenger and freight trains. High numbers of landslides between Seattle and Everett have been especially problematic for Sound Transit commuters and Amtrak Cascades passengers. Record numbers of service interruptions (sum of annulments and disruptions for all passenger trains) during the 2012-2013 winter season prompted collaboration among Washington State Department of Transportation (WSDOT), BNSF Railway Company, Sound Transit, Amtrak, and stakeholders to quantify the landslide-related impacts, identify the primary factors within the corridor that contribute to landslides, and develop mitigation strategies to reduce the occurrence and impact of landslides.

WSDOT created the Landslide Mitigation Work Group and convened bi-weekly meetings over a nine-month period. The mission of the Work Group was to develop short- and long-term strategies to reduce landslide impacts and improve transportation reliability throughout the corridor.

Documented landslide impacts for Sound Transit commuters and Amtrak passengers include direct costs, such as annulments (cancelation of trains), busing customers around the closure area, loss of ridership; and costs to BNSF for landslide debris cleanup. Indirect costs are also substantial but harder to quantify, and may include declining ridership due to perceived unreliability of winter service, devaluation of property values and subsequent loss of tax revenue, loss of commercial productivity, and increased congestion on roads when rail service is interrupted.

The majority of landslides that impact the rail line are shallow in depth and are sensitive to well-established factors and conditions. These factors include heavy or prolonged precipitation during the rainy season; the steep, high slopes that are prevalent along the corridor; underlying geology frequently associated with shallow landslides; and poor slope management practices carried out by adjacent landowners, such as discharging stormwater above or on steep slopes and disposing of yard, construction and earthen debris onto slopes. Commonly, it is a combination of factors that converge to start landslides.

Potential strategies to reduce landslide interruptions and impacts were explored by the Work Group. Strategies were outlined and evaluated for implementation time, complicating factors, and short, moderate-, and long-term effectiveness to reduce or prevent landslides.

The Work Group recognizes that measurable long-term reduction in landslide-related impacts to passenger service will require substantial investments in capital improvement projects. Depending on the financial resources available, as well as factors such as permitting, design, and construction scheduling, the time required to achieve significant reductions in landslide-related service interruptions will likely take one or more decades.

Key Findings

Short-term, low-cost strategies include:

- Develop education and public outreach to engage adjacent landowners to improve slope management practices.
- Continue low-cost mitigation options, such as maintenance of slide fences, ditches and other drainage facilities.
- Provide a drainage improvement incentive, such as reduced permit fees from BNSF to adjacent landowners (limited duration).
- Review landslide data through 2007 and develop landslide maps to be completed during the fall 2013. Inventory can be used to develop detailed landslide hazard maps to assist local agencies in the development of land use regulations on steep slopes.

Intermediate strategies include:

- Research and implement a landslide potential assessment model to inform decisions between agencies and provide additional time for contingency planning; model validation is targeted for the 2014-2015 rainy seasons.
- Design and construct up to six projects in high-priority landslide areas from 2013-2016 to mitigate landslide problems and improve service reliability.

Long-term strategies include:

- Continue community education and public outreach.
- Develop a permit process for improvements to private residential land adjacent to and/or above the track area, and identify a funding source or sources to implement improvements.
- Explore solutions for long-term slide debris removal and restoration process, such as beach nourishment.
- Optimize design of containment structures and evaluate effectiveness of stabilization measures for shallow slope failures.
- Develop a management system to prioritize and implement slope stabilization projects.
- Consider acquisition of additional right-of-way or long-term maintenance/construction easements on adjacent property in landslide-prone sections to improve opportunities to implement best-suited mitigation measures. (Note that this long-term strategy would require additional funding.)
- Explore justification for further public investment, recognizing that a significant increase in capital investment will be required to significantly reduce landslide-related closures.

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Introduction

Frequent landslides along the railroad corridor, especially between Seattle and Everett during the wet winter season pose periodic service interruptions for passengers on the Amtrak Cascades, Amtrak Long Distance, and Sounder. Landslides result in rail closures and emergency project activities every year, particularly during the rainy season from October to April. Disruption of rail service within the Seattle to Everett corridor has been especially problematic, with a record number of annulled and disrupted daily passenger trains (sum of both Sounder and Amtrak Cascades trips) due to landslides in 2013.

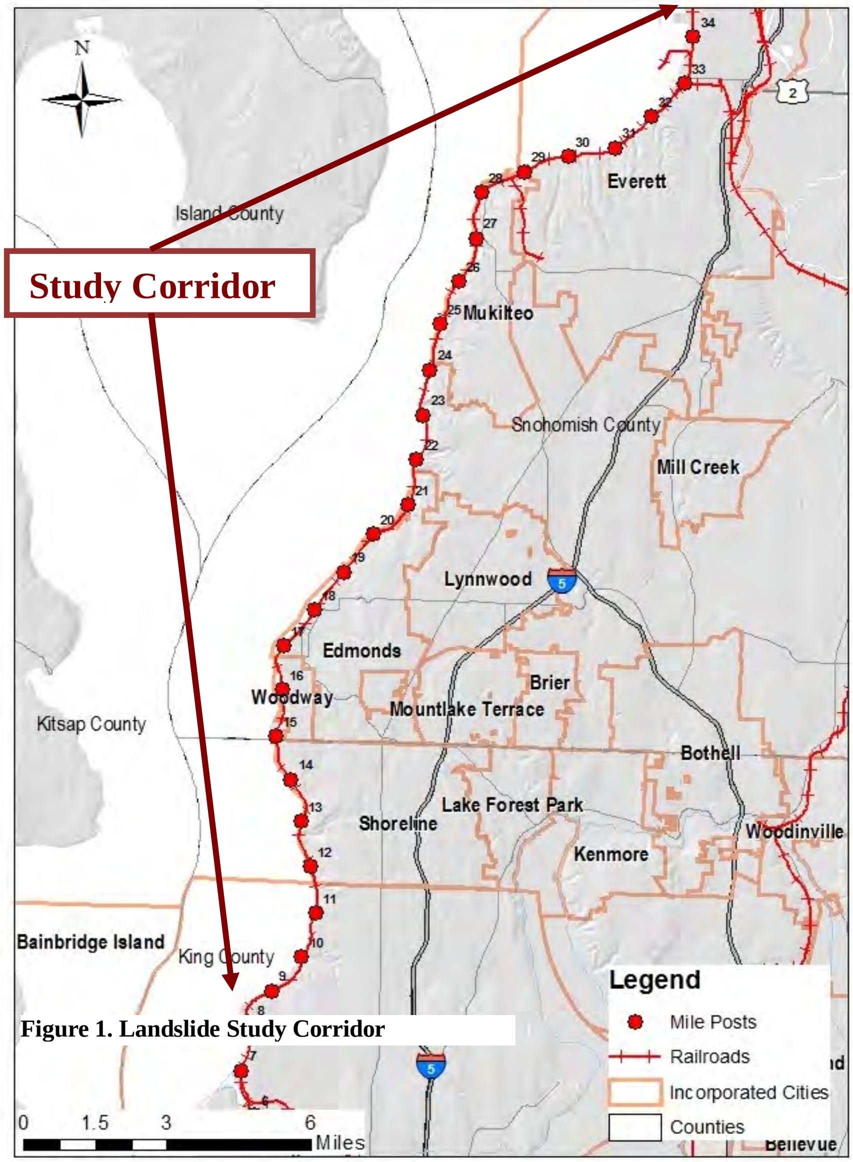

Figure 1. Landslide Study Corridor

At the request of the Washington State Secretary of Transportation, the Washington State Department of Transportation (WSDOT) initiated a joint work group effort with BNSF Railway Company (BNSF), Amtrak, Sound Transit, and local jurisdictions and stakeholders called the Landslide Mitigation Work Group. The mission was to investigate contributing factors to landslides within the corridor and determine a path to solutions.

The Work Group developed the Landslide Mitigation Action Plan to evaluate causes of landslides within this 26.6-mile-long railway corridor (Figure 1), and form reasonable mitigation strategies to reduce impacts to the traveling public. The extent of the study area was defined by the high frequency of events. Landslides within the study corridor are triggered by a combination of factors including climatic/hydrologic factors (e.g., heavy or prolonged precipitation during the rainy season), geomorphic factors (i.e., steep topography), geologic conditions and impacts from human activities.

Effect of the Plan

The purpose of this Plan:

- Document potential improvement strategies.
- Identify actions to minimize impacts to traveling public.
- Identify recommended actions for measureable improvements in interruptions due to landslides.

This Plan is *not* intended to:

- Guarantee landslides will not occur in the corridor.
- Prevent other government agencies or group members from advocating a particular improvement.
- Provide funding for proposed action strategies.

Work Group Coordination

Rail transportation is dependent on partnerships among government agencies, private industry and other stakeholders. The Work Group was a cooperative effort with WSDOT, BNSF, Sound Transit, Amtrak and local jurisdictions/stakeholders within the study corridor, such as the Washington Department of Natural Resources, Washington Department of Ecology, National Oceanic Atmospheric Administration, and Governor's Office of Regulatory Innovation and Assistance. Local jurisdictions include the cities of Everett, Mukilteo, Shoreline, Edmonds, and Seattle; the town of Woodway; and Snohomish County. The group implemented a reasonable strategy to identify contributing factors to landslides within the corridor, develop conclusions based on research, and create an implementation plan with recommendations for measurable improvements to the traveling public.

Roles and Responsibilities

- The WSDOT Rail Division sponsors the Amtrak Cascades and its intercity passenger rail service along the Pacific Northwest Rail Corridor, contracting with Amtrak as the service provider. Sound Transit and Amtrak contract with BNSF for track use.

  In WSDOT's Amtrak operating agreement, Amtrak is responsible for operating the Amtrak Cascades service.
- BNSF and Amtrak notify WSDOT of operational changes.

- BNSF owns and maintains the rail rights of way and track structures. BNSF is responsible for maintaining the railway infrastructure in compliance with Federal Railroad Administration safety standards. As the owner of the track, BNSF is responsible for addressing landslides within the BNSF right of way (ROW) only. However, landslide stabilization projects must often be constructed, at least in part, on property outside of BNSF-owned ROW to be effective, as a majority of landslide activity in this corridor originates from above and off BNSF property.

- Local agencies within the corridor are responsible for permitting development activities in geologically hazardous and/or sensitive areas (such as steep or unstable slopes) within their jurisdictions. This includes, but is not limited to, vegetation management and implementing development standards, such as building setbacks from steep slopes/bluffs, defining and communicating stormwater runoff requirements, erosion/sediment control during construction and communicating seasonal restrictions during the rainy season.

Study Schedule, February-September 2013, and Process

February	Develop framework for final product; initiate data collection.
March	Data collection and documentation.
April	Interim report: data collection; develop action strategies.
May	Continue development of action strategies; prioritize action strategies.
June	Interim report: immediate action strategies.
July-August	Implement immediate action strategies; draft final report.
September	Final report; executive summary; recommended solutions.

Landslide Impacts

Washington State supports a rail system that is integral to maintaining our economy, environment and quality of life. The rail system provides transportation for freight rail (BNSF), commuter rail (Sound Transit), intercity passenger rail (Amtrak Cascades), and long distance passenger rail (Amtrak).

Washington and Oregon jointly sponsor Amtrak Cascades, a 467-mile-long regional service that operates between Eugene, Ore., and Vancouver, British Columbia (Figure 2). Since 2000 Sound Transit has been operating a system of express buses, commuter rail and light rail to provide faster, more dependable ways to commute within the counties of Snohomish, King and Pierce. Sound Transit uses a portion of the BNSF line to provide daily commuter rail service between Everett and Seattle.

More than 60 areas along the 467-mile-long Amtrak Cascades route have been identified as at risk for landslides. However, the majority of landslides occur within a 26.6-mile-long corridor, from north Seattle to Everett along steep coastal bluffs. Since 1914, more than 900 blocking landslides have occurred along the Seattle-Everett rail corridor, with 5.5 miles of quarter-mile sections experiencing 10 or more blocking landslides (Appendix A).

Figure 2. Amtrak Cascades Route

Service and Cost Impacts of Landslides

Landslides not only present risks to passenger service operations, but also have social and economic effects. Landslides can destroy or damage residential and commercial developments and agricultural areas, and negatively affect water quality in rivers, lakes and the Puget Sound. Increased development in landslide prone areas, deforestation and precipitation can all contribute to higher landslide activity (Schuster 1996).

Direct costs of landslides, such as repair, replacement or maintenance, are more easily identified than indirect costs, such as loss of property values, loss of tax revenue, loss of commercial productivity and adverse effects to water quality (Schuster 1996). The Work Group evaluated direct and indirect costs of landslides within the study corridor.

Direct Costs

Direct costs include capital improvement projects and maintenance costs, such as debris cleanup and disposal. In most instances, BNSF must dispose of landslide debris offsite. Since 2008 direct costs for BNSF, as a result of landslide impacts, are estimated at more than $10 million (Table 1). This does not include losses associated with freight train delays.

Table 1. BNSF Railway Landslide Related Costs

Year	Expenditures
2013*	$4,041,000
2012	$2,442,000
2011	$796,000
2010	$2,628,000
2009	$374,000
2008	$110,000

** Data through May 2013.*

In addition to BNSF capital improvement projects, WSDOT has provided approximately $6.3 million of federal funding for landslide mitigation efforts, with an additional $92,000 directly from state funds. These expenditures represent progress on expected project costs budgeted at $16.1 million in federal dollars and $304,000 in state funds.

The Port of Everett identified direct impacts from landslides in the corridor that included property damage and interruption of seaport operations. For example, the Port spent significant money cleaning and repairing stormwater treatment facilities (bioswales) and cleaning a public access trail and Terminal Avenue due to slide damage (Figure 3). The Port cited difficulty maintaining compliance with stormwater permit conditions when treatment facilities fill with landslide debris. Landslide debris that spills across Terminal Avenue also impacts cargo staging areas, construction projects and access to land needed for operations.

Figure 3. Terminal Avenue train car derailed by landslide (photograph courtesy of Port of Everett).

Indirect Impacts/Costs

Indirect costs for Amtrak Cascades and Sounder Commuter Rail within the study corridor include disruptions to service and subsequent loss of ridership. Record numbers of service disruptions (total number of cancelled or disrupted passenger trips for Amtrak Cascades and Sounder) occurred during the 2012-2013 season. Costs to the local communities include direct loss of property, devaluation of property, higher insurance costs for homeowners along the bluff, and homeowner costs for repairs and/or prevention.

Local jurisdictions, such as the cities of Mukilteo and Everett, identified commuter disruption, impacting time lost to the individual, as well as increased roadway congestion. The impact to property owners can include direct loss of property, but also the expense of repair and/or construction, permitting costs and emotional impact. Some property owners lose access to their property, which requires time, money and effort to repair. For property owners without resources to fix the damages, funding is not available and they are profoundly affected.

In addition, the disruption of rail service from a catastrophic event can greatly impact the local and regional economy. These impacts affect the private sector and all governmental agencies, from smaller entities to the state level.

Amtrak Cascades

Amtrak Cascades trains have been impacted by landslides since daily intercity passenger rail service was re-established between Seattle and Vancouver, B.C. in May 1995. Since 2009, WSDOT maintained detailed data on service impacts resulting from landslides. These service impacts occur in two ways:

1. Trains are canceled and do not operate over any portion of their scheduled route. These service impacts are called annulments.
2. Trains operate over a portion of their route, with buses deployed to cover one or more segments of impacted areas between cities. These service impacts are called disruptions.

Seasonal service impacts from 2009 to 2013 ranged from 20 to 71 annulments, and 27 to 104 seasonal disruptions during the season (October-June) from 2009-2013 (Table 2).

Table 2. Amtrak Cascades Seasonal Annulments and Disruptions from 2009-2013

October – June	Annulments	Disruptions
2012 - 2013	50	81
2011 - 2012	23	31
2010 - 2011	71	104
2009 - 2010	20	27

Calculating the financial impacts during service annulments and disruptions is challenging because many factors influence a person's decision to ride Amtrak Cascades (ticket prices, automobile fuel prices and on-time performance of train service). The calculation of financial impacts is further complicated by the fact that travelers holding tickets when a landslide occurs will still be transported to their destination by either a bus or a combination of a bus and a train.

A comparison between ridership and revenue data for Amtrak Cascades trains between Seattle and Everett for the past four seasons showed a precipitous drop (20 to 35 percent for major city pairs) in ridership and revenue from 2012-2013 (Table 3). While this decline in ridership and revenues was observed in most of Amtrak's national network during April 2013, customers may have chosen not to ride the trains due to concerns for their safety after Amtrak's long-distance Empire Builder train was partially derailed by a landslide near Everett, specifically on April 7, 2013.

Table 3. Amtrak Cascades Trains 510, 513, 516 and 517-Ridership and Revenue 2009-2013

October-June	Ridership	Revenue
2012 - 2013	143,676	$5,860,420
2011 - 2012	163,207	$6,540,335
2010 - 2011	160,275	$6,052,903
2009 - 2010	162,995	$6,018,360

Sounder Commuter Rail

Sounder Commuter Rail, operated by Sound Transit, started its north line service between Everett and Seattle in December 2003 with a single daily round trip. Landslides began to significantly impact Sounder service in the 2005-2006 winter with 10 days of cancelled service and 40 annulments. All but one winter since 2008-2009 has experienced service disruptions from landslides with the number of impacts growing as service increased from one to four daily round trips. In the 2012-2013 winter, 28 days of Sounder rail service were disrupted, resulting in 206 annulments (Table 4).

Table 4. Sounder Commuter Rail Seasonal Annulments, Days Impacted, and Daily Trips Scheduled from 2003-2013

October – June	Annulments	Days Impacted	Daily Trips Scheduled
2012 – 2013	206	27.5	8
2011 – 2012	41	7	8
2010 – 2011	70	9	8
2009 – 2010	24	3	8
2008 – 2009	0	0	8
2007 – 2008	18	3	6
2006 – 2007	16	4	4
2005 – 2006	40	10	4
2004 – 2005	0	0	2
2003 – 2004	3	2	2

When Sounder service is cancelled, customers are directed to special bus transportation that Sound Transit arranges to transport riders to Sounder stations. These buses augment existing bus service, which are often overloaded from absorbing the additional commuters unable to commute by rail transit. There are also occasions when limited partial service is offered (i.e., morning or afternoon train, or a train to one or two stations not impacted by slide activity), rather than cancelling an entire train. For instance, if landslides occur north of Mukilteo, service may be possible between Seattle and Edmonds/Mukilteo, but not Everett. On these occasions, the replacement bus service is only required for customers that travel between Seattle and Everett.

The largest financial impact to Sounder north line service as a result of landslides is lost farebox revenue from declining ridership. However, quantifying these financial impacts is challenging because it is unknown how many customers chose not to ride Sounder rail after a particular landslide event has impacted service. Other than the original $368 million provided to BNSF for the permanent easements and track improvements necessary to meet track-capacity requirements, as well as station construction, Sound Transit does not have additional capital investments in the corridor beyond what was approved in the 1996 Sound Move ballot measure. In 2008, voters approved a second platform and other station access improvements at the Mukilteo facility in the Sound Transit 2 ballot measure. Additional operating costs are incurred by Sound Transit when buses are required because of cancelled trains, which can cost several thousand dollars per day. These costs, however, are offset by the elimination of operating costs from cancelled train trips.

In the 2010 to 2011 season, when there were 70 cancelled trips in a season, average daily ridership decreased by approximately 10 percent, and it was more than a year before ridership returned to previous levels. The 2012-2013 season took a particularly heavy toll on Sounder north ridership, where 206 trips were cancelled, which nearly tripled the earlier high of 70 in the 2010-2011 season (Table 4). Although overall annual growth in Sounder ridership exceeded 10 percent during 2012, Sounder north line ridership was down 7 percent (1,215 average boardings) in July 2013 from the October 2012 high of 1,304 average daily boardings (Table 5).

Table 5. Sounder Commuter Rail North-line Service

Year	Annual Boardings	Average Daily Boardings	Percent Growth on Average Daily Boardings
2013	TBD	1,147*	6%*
2012	307,846	1,144	21%
2011	280,767	946	-9%
2010	303,060	1,024	-5%
2009	319,719	1,080	2%
2008	314,072	1,062	26%
2007	252,299	843	27%
2006	201,299	665	43%
2005	151,773	466	68%
2004	88,903	277	

*YTD through June 2013 Data

Amtrak Long-Distance Service

The Amtrak Empire Builder and Coast Starlight trains operate in Washington State with a terminal in Seattle at King Street Station. Because the landslide activity occurs primarily north of Seattle, the Empire Builder has experienced more impacts from the landslides than the Coast Starlight. The Amtrak long-distance train service has been impacted by landslides as long as service has been in existence.

Calculating the financial impacts that occur when there are service annulments and disruptions is challenging for the same reasons mentioned for Amtrak Cascades (i.e., other factors such as ticket prices, automobile fuel prices and on-time performance of train service). The table below compares ridership and revenue data for Amtrak long-distance trains that traveled within Washington state for the past four seasons. The 2010-2013 time periods were impacted by outages on the Empire Builder line.

Table 6. Amtrak Long Distance Trains 7, 8, 11, and 14
Ridership and Revenue Data from 2009-2013

October – June	Ridership	Revenue
2012 - 2013	247,259	$29,615,975
2011 - 2012	243,438	$29,007,289
2010 - 2011	218,625	$25,567,097
2009 - 2010	239,832	$25,296,150

Currently Funded Capital Projects

Recently, the Federal Railroad Administration (FRA) awarded $16.1 million to WSDOT to identify, design and construct slope stabilization improvements. WSDOT and BNSF are collaborating on environmental and engineering work. These long-term improvements will be in various stages of design and construction from 2013-2016.

Current Practice of Managing Landslide Impacts

As the owner of the rail corridor, BNSF is ultimately responsible for the operational and maintenance aspects of the track structure. BNSF routinely inspects and maintains the slopes, ditches, retaining structures and tracks to minimize impacts to railroad operations when landslides occur. BNSF also uses an extensive network of slide fences through much of the corridor. When the wires of a slide fence are severed by landslide debris, an indication is provided to the BNSF dispatcher and train crews are signaled accordingly. Inspection and monitoring of the rail corridor between Seattle and Everett is heightened during the rainy season. When a landslide occurs that blocks one or more tracks (referred to as a blocking event), BNSF imposes an automatic 48-hour moratorium on passenger rail service through the impacted segment of the corridor. Alternate bus service is then deployed for riders. Impacts to riders vary, ranging from longer commutes to missed appointments and work days.

Over the years, BNSF has invested millions of dollars in installing slide fences, building catchment walls and widening ditches to contain the landslide debris and stabilize the slopes.

Contributing Factors to Landslides

The occurrence of a landslide is dependent on a combination of site-specific conditions and influencing factors. Common factors that contribute to landslides fall into four broad categories:

1. Climatic/hydrologic (rainfall or precipitation)
2. Geomorphic (slope form and conditions - i.e., slope shape, height, steepness, vegetation and underlying geology)
3. Geologic/geotechnical/hydrogeological (groundwater)
4. Human activity.

Climatic

> **Antecedent conditions**
>
> Refers to the amount of rainfall that has fallen in previous weeks, months or even years.

Climatic factors influencing landslides include the duration of rainfall events, intensity of rainfall, and type of precipitation (i.e., snow or rain), as well as rainfall conditions over a period of time (antecedent conditions). Typically, numerous landslide events are associated with intense and/or prolonged periods of rain (Baum et. al., 2000). Recorded landslides impacting the corridor largely occurred during the winter wet season between October and April. An example of an unusually large, deep-seated landslide occurred in January 1997 south of Edmonds in the town of Woodway (railroad milepost 14.80) following a two-week period of heavy precipitation (Figure 4). Some episodes of widespread landsliding corresponded with storms involving the rapid melting of previously accumulated snow by wind and warm rain, which is referred to as "rain-on-snow" storm event. The landslide cut 50 feet into the property above, passed over the railroad tracks and knocked a freight train into the Puget Sound.[1] Many of the shallow landslides prevalent along the corridor have occurred during a single storm event involving one or more days of intense rainfall (Baum et al, 2000).

Figure 4: 1997 Woodway landslide.

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[1] www.ecy.wa.gov/programs/sea/landslides/show/woodway.html

Shape and Condition of Slope

Geomorphic (Slope Form)

The form and condition of a slope can affect its stability. Geomorphic factors affecting slope form include height and steepness, as well as vegetation and underlying geology. Increased steepness and slope height generally correlate with reduced stability. Many of the landslide-prone slopes along the corridors are more than ten stories (100 feet) in height and quite steep (35-45 degrees slope gradient). This steep orientation exceeds the long-term stability of the relatively weak sediments that comprise the slopes, and such slopes or segments of slopes are often referred to as being in an "oversteepened condition." Increased slope height and the lack of vegetative cover, especially conifers, increase the amount of rainfall that reaches the slope surface. Vegetation generally contributes to how well the near-surface soils hold together and thus helps resist surface erosion. Bare slopes tend to be more prone to erosion than well-vegetated slopes. Large trees, however, can also be a detriment to localized slope stability, where they root on steep slopes underlain by dense soils. For this reason, the presence and type of vegetation and its contribution or detraction from stability needs to be evaluated on a site-specific basis by qualified professionals.

Whether water infiltrates into the ground or runs off is influenced by the permeability (porousness) of the geologic substrate, its degree of saturation (affected by antecedent conditions) and precipitation intensity. The compact (solid) and fine-grained nature of some of the underlying geologic units within the corridor limits infiltration and increases the likelihood of saturating and weakening the near-surface, loosened soils. Within the corridor, this condition commonly results in the separation and rapid transport of relatively thin, slab-like portions of the slope, known as ***debris avalanches***. Concentrated surface water runoff within drainages and swales can further lead to channel-confined slope failures, involving the rapid transport of highly fluidized debris, known as ***debris flows***. More than 80 percent of the documented landslides between 1914 and 2001 were shallow landslide types (debris avalanches and debris flows) (Shannon & Wilson, 2001). Figure 5 illustrates how precipitation and groundwater can influence the occurrence of deep-seated landslides.

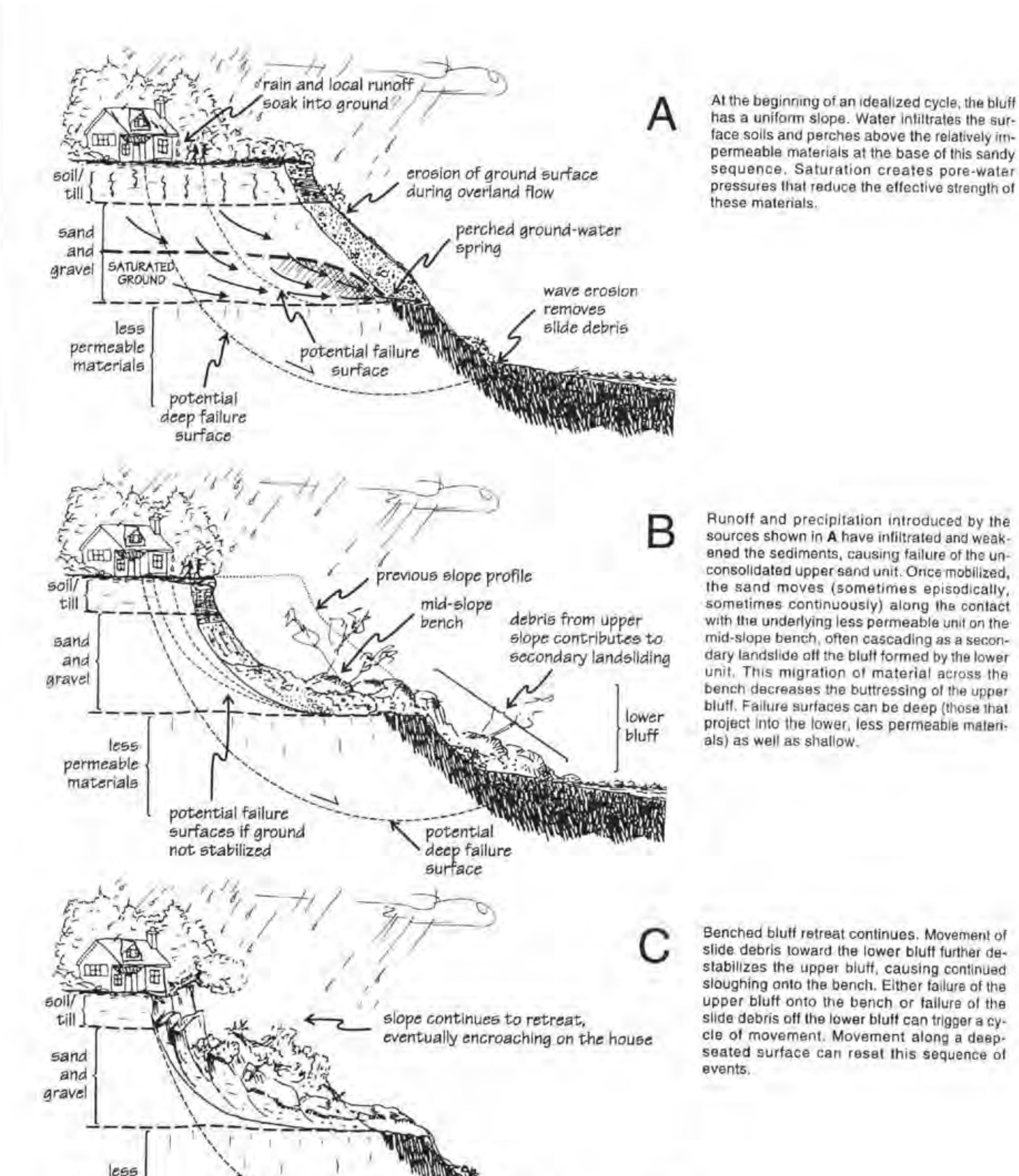

Figure 5: This sequence of sketches shows a conceptual process that forms bluffs in the northern Puget Sound area and causes them to retreat. More permeable soils/sediments sit on top of less permeable sediments. Water run off infiltrates this upper layer until it meets the lower layer, where water is "perched." This causes the soils at this interface to saturate to the point of failing. Lower soil layer failure removes the support for the upper layers and they also fail (Gerstel et al. 1997).

Geologic/Geotechnical/Hydrogeologic (Geology and Groundwater)

The geologic conditions, and engineering (geotechnical) and groundwater (hydrogeologic) characteristics of the geologic units that compose the slope greatly influence its stability. Generally, the upper portions of the slopes along the corridor are underlain by a sequence of glacial sediments deposited in advance, beneath and during the last continental glaciation (Vashon Stade). Fine-grained lake sediments that formed in front of and then compacted by the advancing ice sheet typically underlie the coarse-grained Vashon advance deposits, and have been referred to as transitional beds (Minard, 1982, 1983, 1985; Yount et al., 1993). These transitional beds are underlain by a variable sequence of very compact interglacial deposits (called the Olympia beds and Whidbey Formation) and older glacial deposits (known as Possession and Double Bluff Drifts), which typically outcrop in the middle to lower portions of the slope. Of all the geologic units within the corridor, several are recognized as “bad actors” — over 60 percent of the landslides reported between 1914 and 2001 originated within the transitional beds or the Whidbey Formation (Shannon & Wilson, 2001).

> **Glaciation**
>
> Alteration of any part of the earth’s surface by passage of a glacier, such as erosion or deposition.

Landslides also commonly recur in the same areas. Remobilized landslide debris from previous landslides was another geologic unit significantly contributing (approximately 13 percent) to landsliding (Shannon & Wilson, 2001). Baum et al. (2000) noted that roughly two-thirds of the landslides generated during the winter storms of 1995-96 and 1996-97 initiated within the bounds of mapped landslide events.

Human Activity

Human activities have repeatedly been observed to be a substantial contributor to landslides within the corridor. These adverse and widespread activities primarily involve the discharge of stormwater onto or above slide-prone slopes; the cutting and re-grading of slopes; and the disposal of yard, construction, and earthen or other debris onto the upper portion of the slope (Shannon & Wilson, 2001). In addition to these adverse practices by adjacent landowners, the density of upslope development, even hundreds of feet behind the top of the slope, has the potential to significantly contribute to groundwater recharge through more concentrated discharge of storm water runoff. This in turn has the potential to adversely impact stability of the slopes along the rail corridor.

> **Transpiration**
>
> The evaporation of water from leaves.

More complex in its relationship to slope stability is the effect of removing vegetation. Rooting depth and the interception and transpiration potential offered by mature conifers during the winter wet season can be important contributors to stability. Conversely, the effect of wind on mature conifers, referred to as *windthrow*, can disturb the substrate in which they root, resulting in localized slope instability. For these reasons, the presence and type of vegetation and its contribution or detraction from stability needs to be evaluated on a site-specific basis by qualified professionals.

Implications

While a landslide on an adjacent slope does not always impact the rail line, about 80 percent of the documented landslides between 1914 and 2001 generated debris that reached one or both railroad tracks. Despite the investigation bias of this data (landslides are generally only investigated when they might affect the tracks), the close proximity of the tracks to the base of the steep slopes and the very limited area available for debris containment is a primary reason for the apparent high likelihood of impact to the tracks when a landslide does occur. The volume of debris, material and transport characteristics [i.e., material composition, velocity, viscosity (thickness), path of travel, etc.], location of landslide initiation, and the potential to gather additional material during transport (bulking) further influence the potential for debris run-out onto the tracks and the extent of impacts.

Given the wide range of potential factors that influence landslide initiation characteristics, it is virtually impossible to predict the location and impacts of a single event within such a long landslide-prone corridor. However, of all the potential influencing factors, five factors were judged by Shannon & Wilson (2001) to be the most differentiating in quantifying risk of landslide-related impacts to the tracks:

1. Density of slides – Number of historic landslides per quarter mile of track.
2. Catchment area – Available area between the base of the slope and tracks to contain debris.
3. Slope height – Influences both debris volume and impact/run-out characteristics.
4. Geology – Tendency of specific geologic units to experience landslides.
5. Line closures – Percentage of total number of landslides per quarter mile of track that impacts tracks.

Such experience is invaluable for prioritizing where and what type of future mitigation should be considered when funding for capital improvements is available. There is ongoing research to develop better understanding of the precise climatic conditions that have a high potential of generating shallow landslides.

Typical Mitigation Strategies

There are four basic strategies to mitigate for a particular landslide:

- Stabilization
- Protection
- Avoidance
- Maintenance and monitoring

Only stabilization seeks to counter one or more key failure mechanisms and improve stability of the slope. The latter three strategies (protection, avoidance, and maintenance and monitoring) allow slope failure and seek to avoid, protect against or limit the associated impacts. The last mitigation strategy, maintenance and monitoring, is different than a “do-nothing” alternative; a “do-nothing” alternative is a management approach/decision, not a mitigation strategy.

Stabilization (Capital Improvement Projects)

Typical landslide stabilization measures include grading the unstable portion of the slope to a lower gradient, construction of rock buttresses and retaining walls, and drainage improvements. Examples shown below entail grading with slope armoring/buttressing (Figure 6) to address a large deep-seated landslide at railroad milepost (MP) MP 24.5; and patterned reinforcement of high-tensile-steel wire mesh that could potentially be used to address the abundant shallow-type landslides that originate upslope of BNSF’s ROW (Figure 7). With the exception of drainage improvements, stabilization measures are typically moderate to high cost, but provide a long-term solution with low, long-term maintenance costs. Cessation of adverse human activities by diverting stormwater away from steep slopes, maintaining appropriate native vegetation, and properly disposing of debris off-site are also considered measures that would improve stability.

Figure 6. Recent slope reinforcement project at rail line MP 24.5 (Photographs courtesy of BNSF).

Figure 7. Slope reinforcement project in Germany involving a steep cut in highly weathered sandstone. Reinforcement consists of high-tensile-steel wire mesh secured with patterned ground anchors, showing installation and re-vegetation (photographs courtesy of Geobrugg).

Protection

Protection measures for landslides primarily focus on containment and/or diversion of the moving debris. Such measures include walls, berms, ditches and catchment basins, which can be low to moderate in cost. However, considerable long-term maintenance costs are often associated with these measures to clean out and dispose of accumulated debris. BNSF currently employs a number of timber and steel containment walls (Figure 8).

Figure 8. Debris containment wall along BNSF rail line consisting of steel "H" piles with precast concrete lagging to facilitate cleanout (photograph courtesy of BNSF).

Avoidance

Avoidance measures constitute a permanent solution to a landslide hazard. Measures include realignment away from the slope, relocation of the facility, tunnels and elevated structures that allow passage of debris beneath the facility. The typically high cost of these measures is offset by the elimination of further landslide-related maintenance costs and exposure to landslide risk.

Maintenance and Monitoring

Maintenance and monitoring measures may involve proactive cleanout of available catchment areas, routine observation and assessment of slope conditions, landslide-warning (slide) fences, monitoring slope and weather instrumentation and preemptive closures. Generally, these measures are relatively low cost and can be highly effective in reducing public exposure to slide risk. With the exception of cleaning existing catchment areas, these measures do not reduce the likelihood of a landslide event or the potential of landslide debris reaching the tracks. Slide fences are used extensively through the corridor to warn of the potential for debris on the tracks (top of the wall in Figure 8). Another measure employed by BNSF is the passenger rail moratorium imposed for 48 hours following a blocking event due to a landslide.

Figure 9. Slide fence on top of a wall along the BNSF right of way (photograph courtesy of BNSF).

Selection of the most appropriate mitigation strategies is influenced by many factors that often have little relationship to the factors contributing to the landslide. Some of these include available funds, right-of-way/property ownership, required permits, access constraints, environmental effects and service interruption during construction.

Proactive Versus Reactive Mitigation Strategies

The mitigation strategies above can be implemented reactively or proactively. Reactive responses are instituted at the time of failure with little to no advanced planning. Expenditures are made when necessary, and are tailored to address actual conditions. No unnecessary expenditures are made on slopes that might not otherwise fail and impact the facility within a reasonable timeframe. However, reactive responses are often required at inconvenient times and locations, and are generally more costly to construct than when the same work is performed proactively at a more opportune time. Also, there are often more barriers to designing and constructing what is most effective and best suited for the site under emergent conditions. Further, direct and indirect costs/impacts — especially those indirect — are more difficult to manage by relying solely on reactive responses. Problems with a reactive management approach for unstable slope impacts to transportation facilities include high public expectations of the reliability, convenience and safety of the system (Lowell and Norrish, 2013).

Proactive responses, on the other hand, require considerable planning, especially when having to choose among hundreds of landslide-prone slopes. Some of the benefits of a proactive response generally include lower costs, better conditions to design and build under, and higher reliability. With the responsibility of managing many unstable slopes along transportation facilities, several public transportation departments (including WSDOT) instituted management systems for proactively identifying, prioritizing, programming, funding and ultimately mitigating these hazards. It is important to stress that implementation of a proactive management system to address large numbers of landslide-prone slopes does not relieve the need for reactive responses or eliminate the potential of further closures. When managing numerous unstable slopes, it is not possible to predict which slope will fail first or when it will fail. In addition, program implementation requires long-term commitments, since it can take many years to make necessary improvements to significantly reduce landslide-related closures on such a landslide-prone corridor. As an example, in 1974 a rock slope maintenance program was implemented along a rail corridor in British Columbia involving 750 rock fall sites. In the opinion of the geotechnical specialist involved since program inception, it took nearly three decades for the program benefits to become clearly recognizable (WSDOT, 2006).

Strategies to Reduce Landslide-Related Interruptions and Impacts

The work group evaluated potential strategies to reduce landslide interruptions and impacts. Strategies were outlined and evaluated for implementation time, complicating factors and effectiveness to reduce or prevent landslides over the short-, moderate- and long-term (Table 7). Strategies include:

1. Conduct community outreach and education:
   - Engage adjacent landowners to improve slope management practices.
   - Develop a public information campaign on best practices.
   - Construct demonstration projects in coordination with adjacent land owners.
   - Work with municipalities, Washington Department of Ecology and BNSF to streamline slope management permit process and provide clear direction on best practices (i.e., stormwater, vegetation management).

2. Implement vegetation management program:
   - Work with adjacent landowners to identify and implement vegetation management plans in specific areas based on recommendations from geotechnical and vegetation specialists.
   - Work with adjacent landowners to retain and replant native vegetation where it benefits slope stabilization.

3. Review feasibility of improving monitoring tools:
   - Research available systems and tools. Representatives from participating agencies have discussed whether monitoring tools can be developed.

4. Explore options for long-term debris disposal plan:
   - Evaluate beach nourishment as an option to remove slide debris. The strategy seeks to improve near-shore habitat and ecological function, as well as to reduce the amount of landslide debris to be removed offsite. Provides benefit for salmon restoration efforts through the restoration of forage fish spawning habitat.
   - Above strategy requires collaboration with U.S. Army Corps of Engineers (Corps), Ecology and BNSF for permitting revisions.

5. Continue maintenance and monitoring:
   - Proactively clean out available catchment areas and drainages.
   - Continue routine observation and assessment of slope conditions.
   - Maintain slide fences.

6. Consider acquisition of additional right-of-way or long-term maintenance/construction easements on adjacent property in landslide-prone sections:

- Recognizes difficulty of ensuring long-term implementation and maintenance of best slope management practices by adjacent landowners, and that adjacent landowners may lack resources to implement necessary improvements.
- Provides opportunity to implement best-suited mitigation measures, but assumes more responsibility.

7. Develop and maintain an inventory of landslide sites for possible implementation of a public-domain landslide management program:
   - Develop inventory and a systematic hazard/risk evaluation (rating), which would be subsequently used for project scoping and preliminary cost estimating, prioritization (benefit-cost analysis), programming, design and final construction estimating and plan development.
   - Use inventory as the basis for project selection, evaluating and justifying project merit, long-term management of the problem and measurement of program success.
   - Maintain a public-domain inventory of landslides, which provides a basis to relate landslide locations and frequency of occurrence to their associated impacts (e.g., annulments, volume of debris, closure duration and direct costs). Data would be invaluable for implementing a public-domain landslide management system, if deemed appropriate and justifiable.

8. Capital Improvement Projects:
   - Increase capital investment in landslide mitigation projects. Measurable long-term reduction in landslide-related impacts will require a significant increase in expenditure on capital improvement projects. The time required to significantly reduce landslide-related service interruptions is likely to require one or more decades, depending on the amount of financial resources available, permitting, design, and construction scheduling.

Complicating Factors for Landslide Reduction

Developing a plan that measurably reduces landslide-related interruptions to passenger rail service within the corridor is complicated by the following:

- *Large Problem Area* – More than 900 landslides have occurred at hundreds of locations within the 26.6-mile-long corridor since 1914. Many of the adjacent unstable slopes are greater than 100 feet high.
- *Land Ownership* – Most of the landslides on private property are outside BNSF's control or responsibility. Many of the landslides are partially due to poor slope management practices conducted by adjacent landowners.
- *Limited Right-of-Way (ROW)* – BNSF has a narrow ROW (about 50 feet upslope of the tracks) available to contain landslide debris or to construct protection structures. Construction of slope stabilization measures generally requires work outside of BNSF's ROW.
- *Differences in Organizational Priorities/Roles/Responsibilities* – Sound Transit, Amtrak, and WSDOT are charged with providing public service, and they do not own and are not directly responsible for track maintenance. BNSF, as a private corporation, is responsible for track maintenance and identifying, prioritizing and funding its own capital

improvement projects. Priorities for spending available funds may be different depending on the (public or private) source of the funds. Landslide origination point is often on private property outside BNSF right-of-way.

- *Low Risk Tolerance* – The risk tolerance for public safety is very low, so closure decisions will always err toward safety.
- *Assumption of Responsibility* – BNSF is responsible for determining safe operating conditions in their Seattle to Everett corridor. Implementation of some of the proposed mitigation strategies may involve more shared responsibilities or liabilities between stakeholders as several strategies are not constrained to State- or BNSF-owned right of way.
- *Funding* – Currently, there is no long-term source of public funds for capital improvements to proactively address landslide-prone slopes. Determining which, if any, slopes warrant expenditure for remediation, as well as the type and extent of remedial work, is the responsibility of BNSF.
- *Permitting* – Permitting process and timelines vary between agencies such as Ecology and the Corps, local jurisdictions, and BNSF.

Table 7. Potential Strategies to Reduce Landslide Interruptions and Impacts.

Potential Strategies to Reduce Landslides								
Strategies	**Implementation Time**			**Complicating Factors**		**Benefit**		
	Short-term	Intermediate	Long-term	Low	High	Low	Moderate	High
Conduct Education/ Outreach (drainage improvements/best slope management practices)	Ongoing – brochure developed and distributed; public workshops scheduled				Land ownership (difficult to ensure long-term implementation); permitting, funding		Potential to reduce landslide initiation with best slope management practices	
Implement Vegetation Management Program		Specific site to be identified and recommendations developed			Land ownership, limited right of way, funding, permitting		May reduce damage to structures/stabilize slopes over time	
Improve Monitoring Tools		Ongoing – validation planned within one to two years			Organizational priorities/responsibilities	Does not prevent or reduce landslides, but informs parties of potential landslide exposure		
Explore Long-Term Debris Disposal Plan			No current plan in place		Permit modifications needed; funding	Does not prevent or reduce landslides, but has benefit for salmon recovery efforts		
Conduct Maintenance and Monitoring Measures	Currently implemented by BNSF			Lower cost than capital projects		Highly effective in reducing public risk exposure, but does not reduce landslides		
Construct Capital Improvement Projects (containment structures/stabilization projects/realignment projects)	Ongoing – 6 proposed locations funded by WSDOT grants (current funding is $16.1 million)		Requires obtaining funding, planning (prioritization), designing, permitting, construction		Funding, prioritization of projects, organizational priorities/responsibilities, limited right-of-way			Reaches goal of long-term stabilization of slopes and/or prevention of landslides in corridor
Acquire Additional Right of Way in Landslide-Prone Sections			Funding, land ownership		Funding, prioritization of areas needed; organizational priorities/responsibility	Does not prevent or reduce landslides, but provides opportunity for best slope management practices		
Develop Public-Domain Inventory and Implement Landslide Management Program		Information gathered for action plan could be used as starting point for program			Funding, land ownership, organizational priorities/responsibility	Does not prevent or reduce landslides, but guides capital projects; can be used to justify further public investment		

Implementation Plan Status

Short-Term Improvement Strategies

Community Outreach and Education

The Landslide Work Group identified the need for increased education and outreach to the community upslope of the rail corridor. Previous studies of landslides in Seattle, with similar geology, slope conditions, and urban development have shown that more than 80 percent of landslides are at least partially related to human influence, including poor slope management practices (Seattle, 2001). Landowner involvement is essential for prevention of landslides as these studies indicate that improper vegetation removal, inadequate and/or unmaintained drainage, cutting or grading slopes and dumping debris on slope edges can cause slope instability and contribute to landslides.

A brochure was developed and delivered to landowners along the top of the slope through the study corridor in early 2013. In addition, landslide workshops in the city of Mukilteo and the development of resources on city websites are in progress. To further investigate public perception of the landslides, a survey was created to gauge public response to education and outreach efforts and catalog frequently asked questions and/or concerns.

Drainage Improvement Incentive

Improper or poorly designed drainage systems can contribute to slope instability, such as drainage pipes which outlet mid-slope. To stabilize slopes, drainage should be brought down to the bottom of the slope. BNSF owns a drainage system at the bottom of the slope.

BNSF can issue permits to property owners for drainage on its ROW. BNSF is offering an incentive to upslope residents by waiving permit fees (up to $3,500 per permit) until April 2015 to place approved drainage structures onto BNSF property. Insurance requirements are still in place.

Maintenance and Monitoring

This lower-cost option is currently employed by BNSF in management of the Seattle to Everett corridor. BNSF will continue to maintain slide fences, ditches and drainage along their right of way to minimize impacts to railroad operations.

Corridor Landslide Inventory

A landslide inventory database and maps were compiled by the work group (Appendix A) using previous studies by Shannon & Wilson (2001 and 2007) with data provided by BNSF. Inventory maps can be used to identify priority areas for remedial work and to develop detailed landslide hazard maps to assist local agencies in the development of land use regulations for steep slopes.

Intermediate Strategies

Capital Improvement Projects

Capital improvement projects are intended to improve passenger service reliability by reducing the number and severity of track outages due to slope failures along the corridor. Projects are intended to prevent and minimize service-disrupting landslides by improving the overall slope stability and implementing measures, such as walls, to prevent landslide debris from impacting the tracks.

Six mitigation projects funded by WSDOT's American Recovery and Reinvestment Act (ARRA) grants are in design and a minimum of three (funding dependent) are planned for construction between 2013 and 2016 (construction is currently underway on two of the six projects). The six sites were prioritized based on slide history (high frequency of slides and service disruptions), geotechnical investigation and constructability as well as budgetary, schedule and property ownership constraints. Improvements primarily involve removing slide material, terracing slopes, installing trench drains, installing catchment walls, installing slide fences and appropriately capturing and directing drainage from adjacent properties.

Development of a Landslide Potential Assessment Model

Work is being done to determine whether the likelihood of a landslide event can be reliably determined by gathering improved rainfall and soil moisture data, and by improving models used to monitor slide activity. The accuracy of the model will be assessed using historical and 2013-2014 data. Work in 2013-2014 will focus on installing additional rain gauges at key locations in the corridor and working with the U.S. Geological Service (USGS) to update their model; validation of the model would take place in the 2014-2015 rainy season. This work will be complemented by efforts to improve slope stability at a number of locations in the corridor.

Long-Term Strategies and Recommendations

Continue community outreach and education efforts to the local communities along the corridor bluff. Recommendations include:

- Update education and outreach materials based on community feedback gained through brochure survey, workshops and local jurisdiction interaction.
- Provide support for community workshops.
- Develop a streamlined permit process and funding source to implement drainage improvements and best slope management practices by landowners along the corridor.

Explore solutions for long-term slide debris removal and restoration of near-shore processes, such as beach nourishment. Recommendations include:

- Cooperatively develop restoration plan and updated permit process with agencies (Ecology and the Corps), BNSF, and local stakeholders (e.g. Puget Sound Partnership and Snohomish County Marine Resources Committee). Such solutions may not impact BNSF's operations or limit BNSF's ability to return its tracks to service under current regulatory structure.

Explore justification for further public investment:

- Consider acceptable target level-of-service (how many landslide-related interruptions are tolerable), recognizing that interruption-free service from landslides is likely not achievable or affordable.
- Estimate order-of-magnitude, long-term improvement (capital) costs.
- Evaluate projected cost of impacts against long-term improvement (i.e., capital) costs for a reasonable lifecycle to justify further public investment.
- Distinguish public benefit from private benefit on privately owned infrastructure to ensure taxpayer dollars are used to benefit Washington State, its businesses and communities.

The science and structural response of a fluid-like mass impacting a rigid structure, like the debris containment walls commonly used along the corridor, are not well understood, and current design methodology is poorly constrained. Similarly, the use of patterned-reinforced wire mesh to address shallow slope instability has not yet achieved widespread use in North America but is gaining widespread use in Europe. Research efforts should be undertaken to optimize design of debris containment structures and evaluate effectiveness of slope stabilization methods for shallow failures. Recommendations include:

- Make design improvements to ensure reliability and optimize design of low-deflection, debris containment structures;
- Evaluate test sections of reinforced mesh to determine suitability for more widespread application.

If further public investment is deemed worthwhile, a landslide management system should be implemented and managed by a public agency that is closely coordinating with BNSF to proactively identify, prioritize, program and fund mitigation projects.

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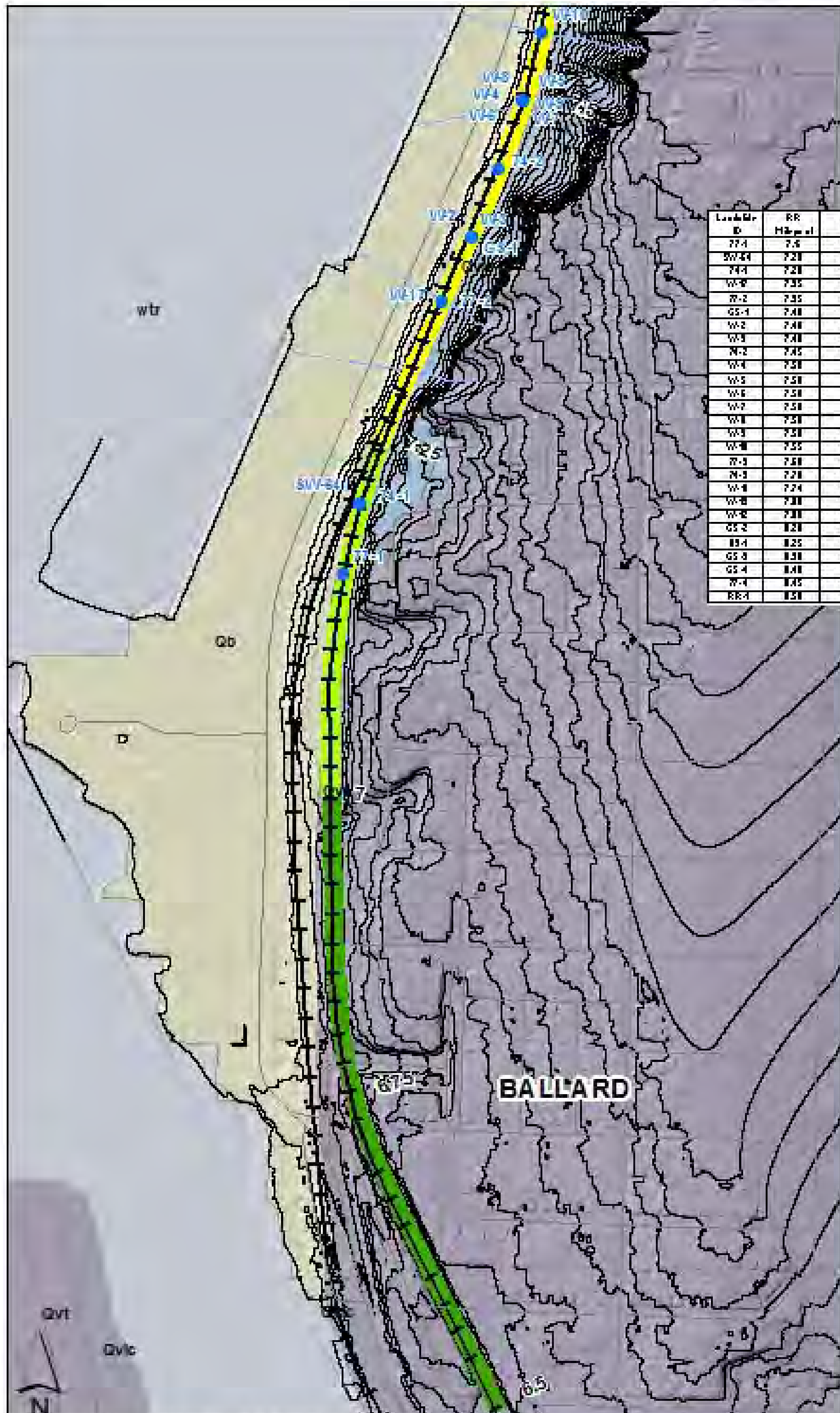

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[illegible]	7.35	[illegible]	YES	Qva
77-2	7.35	[illegible]	NO	Qva
GS-1	7.40	[illegible]	YES	Qva
W-2	7.40	[illegible]	YES	Qva
W-3	7.40	[illegible]	YES	Qva
74-2	7.45	[illegible]	NO	Qva
W-4	7.50		YES	Qvl
W-5	7.50		YES	Qvl
W-6	7.50		YES	Qvl
W-7	7.50		YES	Qvl
W-8	7.50		YES	Qvl
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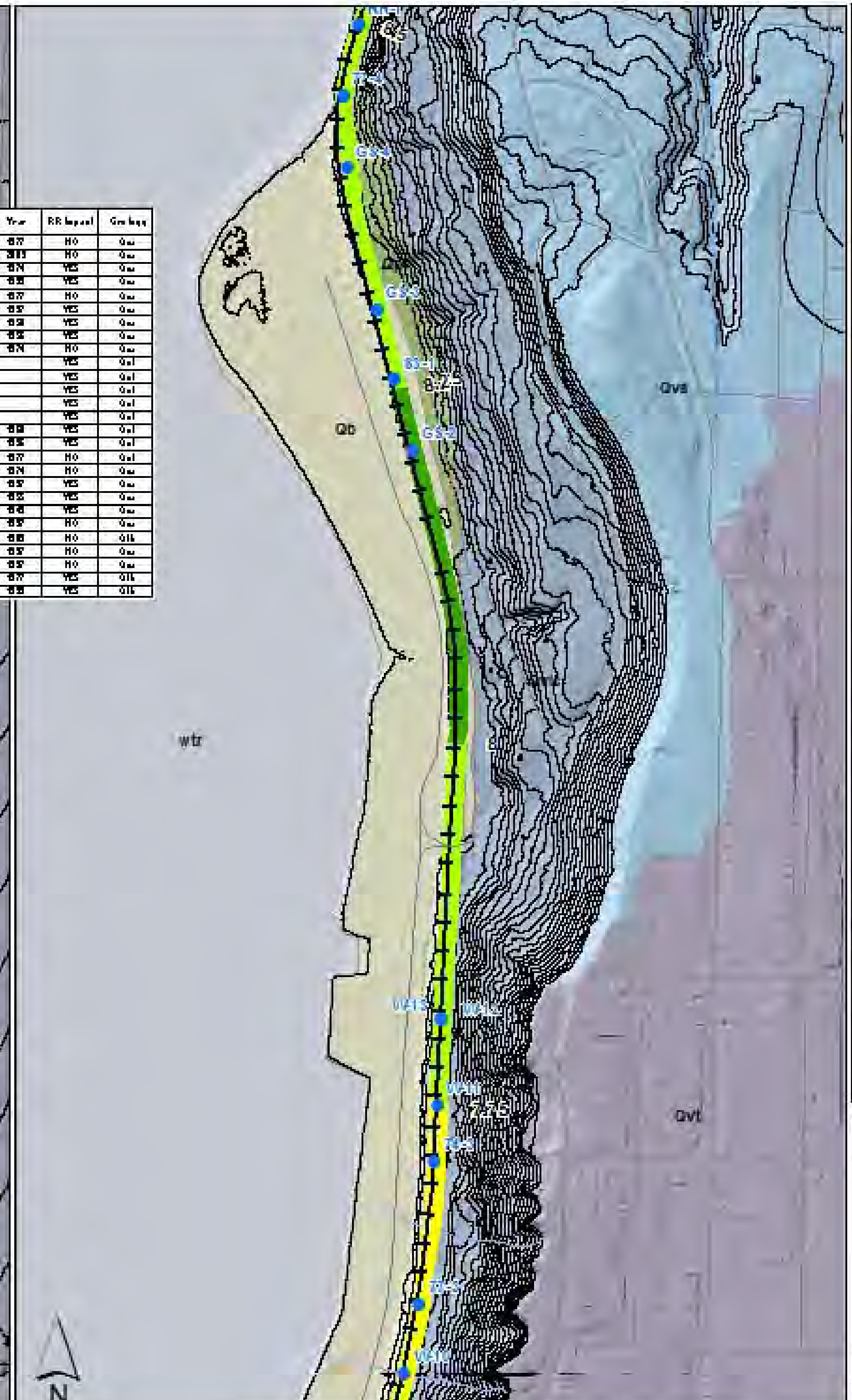

LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density
Number of Slides (1933 - 2006) per 1/4 mile section

- <= 1
- 2 - 5
- 6 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene

- Qb - beach deposits

Pleistocene

- Qpf - glacial deposits (pre-Fraser)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvlc - Lawton Clay (Vashon Drift)
- Qvt - till (Vashon Drift, Fraser glaciation)

Other

- wtr - water

1:24,000 Scale Geologic Mapping:
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FEET
0 125 250 500 750 1,000
1:6,000
1 INCH = 500 FEET

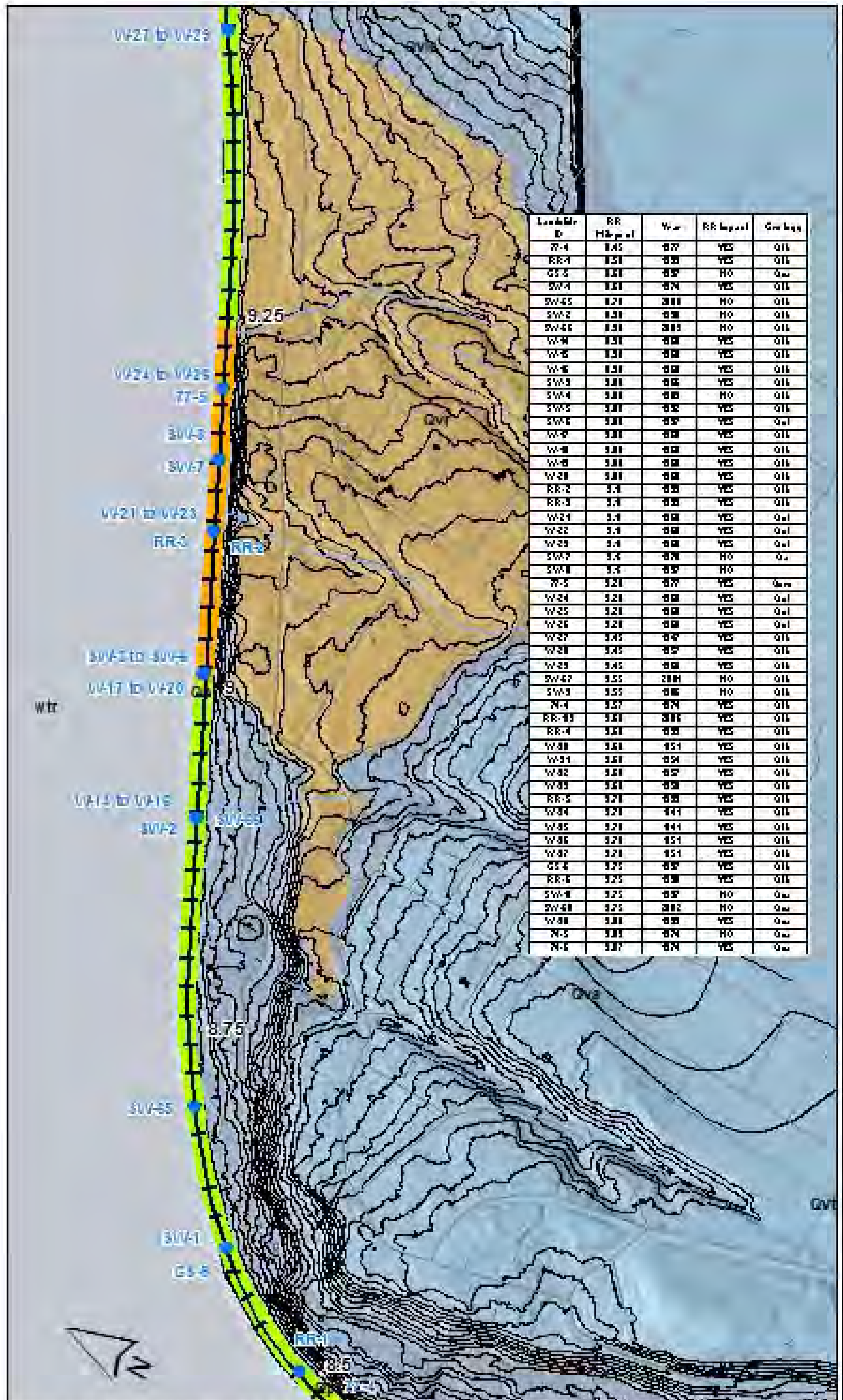
FIGURE:

Seattle - Everett Rail Corridor
Landslide Inventory
MP 6.5 - 8.5

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY: Tracy Trople   DATE: October 16, 2012

File Location: [illegible]



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GS-6	8.50	[illegible]	NO	Qva
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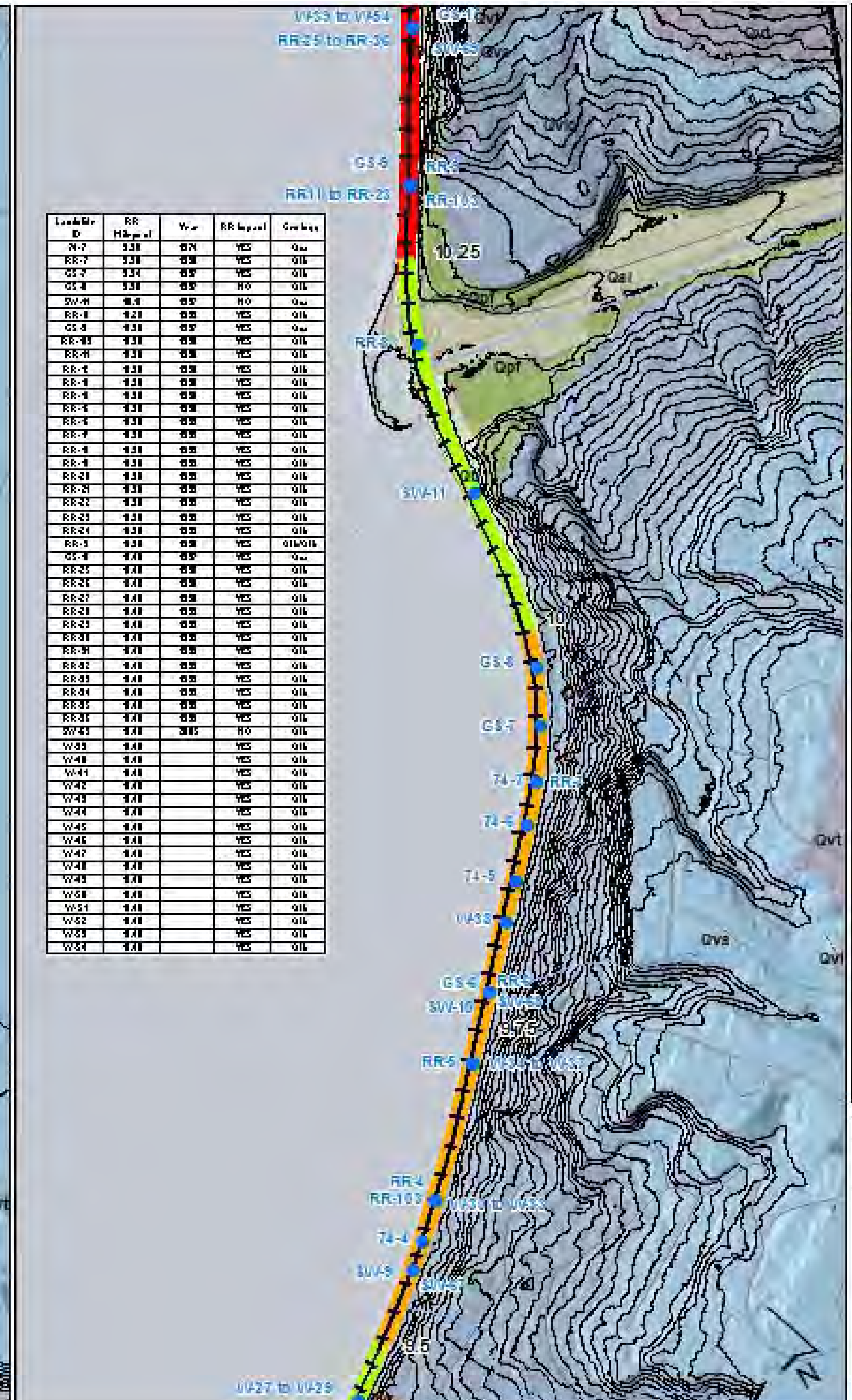

Landslide ID	RR Milepost	Year	RR Impact	Geology
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RR-21	10.30	[illegible]	YES	Qtb
RR-22	10.30	[illegible]	YES	Qtb
RR-23	10.30	[illegible]	YES	Qtb
RR-24	10.30	[illegible]	YES	Qtb
RR-9	10.30	[illegible]	YES	Qtb/Qtb
GS-10	10.40	[illegible]	YES	Qva
RR-25	10.40	[illegible]	YES	Qtb
RR-26	10.40	[illegible]	YES	Qtb
RR-27	10.40	[illegible]	YES	Qtb
RR-28	10.40	[illegible]	YES	Qtb
RR-29	10.40	[illegible]	YES	Qtb
RR-30	10.40	[illegible]	YES	Qtb
RR-31	10.40	[illegible]	YES	Qtb
RR-32	10.40	[illegible]	YES	Qtb
RR-33	10.40	[illegible]	YES	Qtb
RR-34	10.40	[illegible]	YES	Qtb
RR-35	10.40	[illegible]	YES	Qtb
RR-36	10.40	[illegible]	YES	Qtb
SW-69	10.40	2005	NO	Qtb
W-39	10.40		YES	Qtb
W-40	10.40		YES	Qtb
W-41	10.40		YES	Qtb
W-42	10.40		YES	Qtb
W-43	10.40		YES	Qtb
W-44	10.40		YES	Qtb
W-45	10.40		YES	Qtb
W-46	10.40		YES	Qtb
W-47	10.40		YES	Qtb
W-48	10.40		YES	Qtb
W-49	10.40		YES	Qtb
W-50	10.40		YES	Qtb
W-51	10.40		YES	Qtb
W-52	10.40		YES	Qtb
W-53	10.40		YES	Qtb
W-54	10.40		YES	Qtb

LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10' Foot Contour

Slide Density
Number of Slides (1933 - 2006) per 1/4 mile section

- <= 1
- 2 - 5
- 6 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene
- Qal - alluvium
- Qb - beach deposits

Pleistocene
- Qpf - glacial deposits (pre-Fraser)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvlc - Lawton Clay (Vashon Drift)
- Qvr - recessional outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)

Other
- wtr - water

1:24,000 Scale Geologic Mapping:
Troost, K. G.; Booth, D. B.; Wisher, A. P.; Shimel, S. A., 2005, The geologic map of Seattle (Duwamish Head, Seattle North and South, and Shilshole Bay 7.5-minute quadrangles)—A progress report: U. S. Geological Survey Open-File Report 2005-1252, version 1.0, 1 sheet, scale 1:24,000. [http://pubs.usgs.gov/of/2005/1252/]

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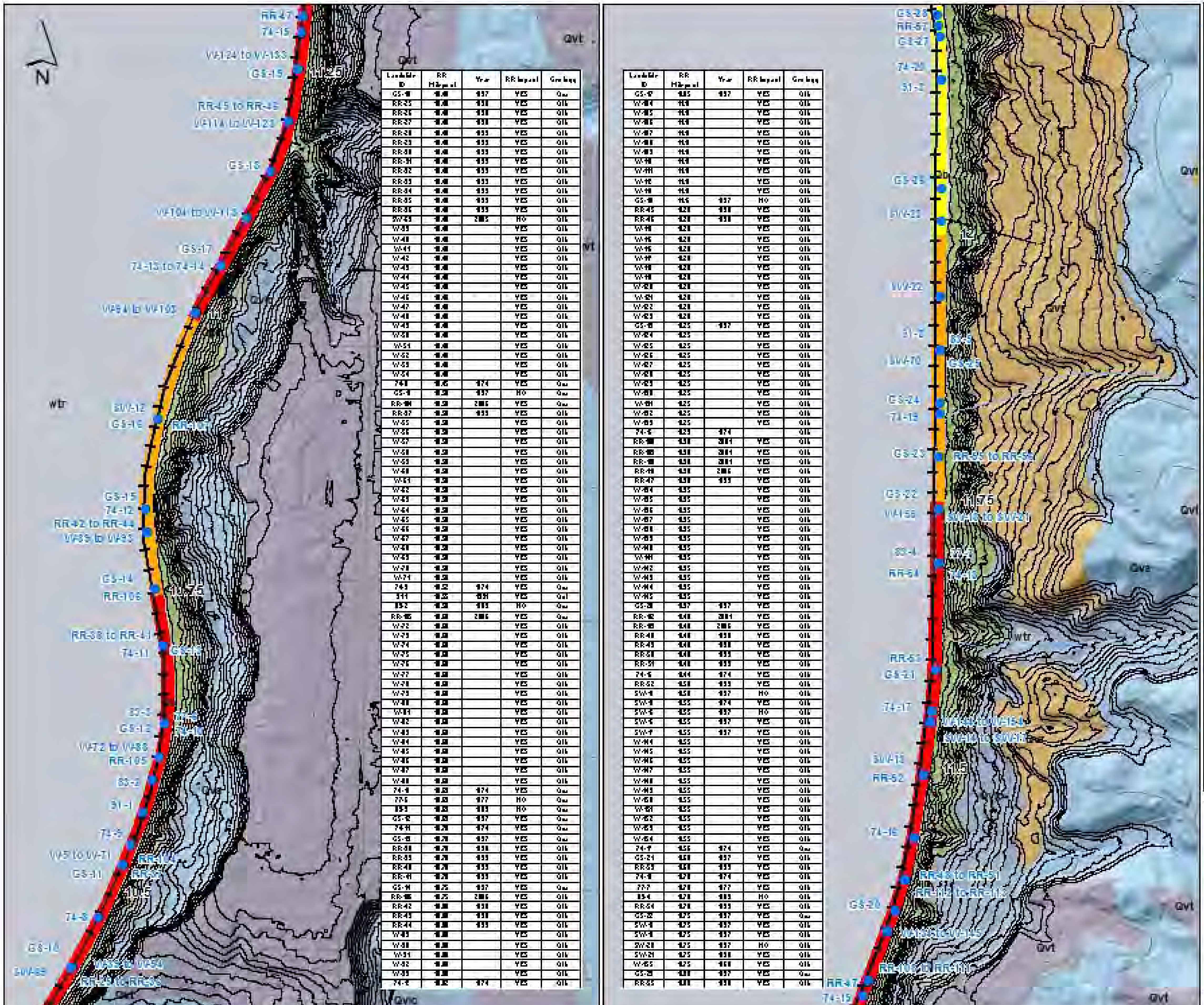
FIGURE:

Seattle - Everett Rail Corridor
Landslide Inventory
MP 8.5 - 10.25

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY: Tracy Trople DATE: October 17, 2013

File Location: [illegible]



LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density
Number of Slides (1933 - 2006)
per 1/4 mile section

- <= 1
- 2 - 5
- 5 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene

- Qb - beach deposits

Pleistocene

- Qpf - glacial deposits (pre-Fraser)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvlc - Lawton Clay (Vashon Drift)
- Qvr - recessional outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)

Other

- wtr - water

1:24,000 Scale Geologic Mapping:
Troost, K. G.; Booth, D. B.; Wisher, A. P.; Shimel, S. A., 2005, The geologic map of Seattle (Duwamish Head, Seattle North and South, and Shilshole Bay 7.5-minute quadrangles)—A progress report: U.S. Geological Survey Open-File Report 2005-1252, version 1.0, 1 sheet, scale 1:24,000.
[http://pubs.usgs.gov/of/2005/1252/]

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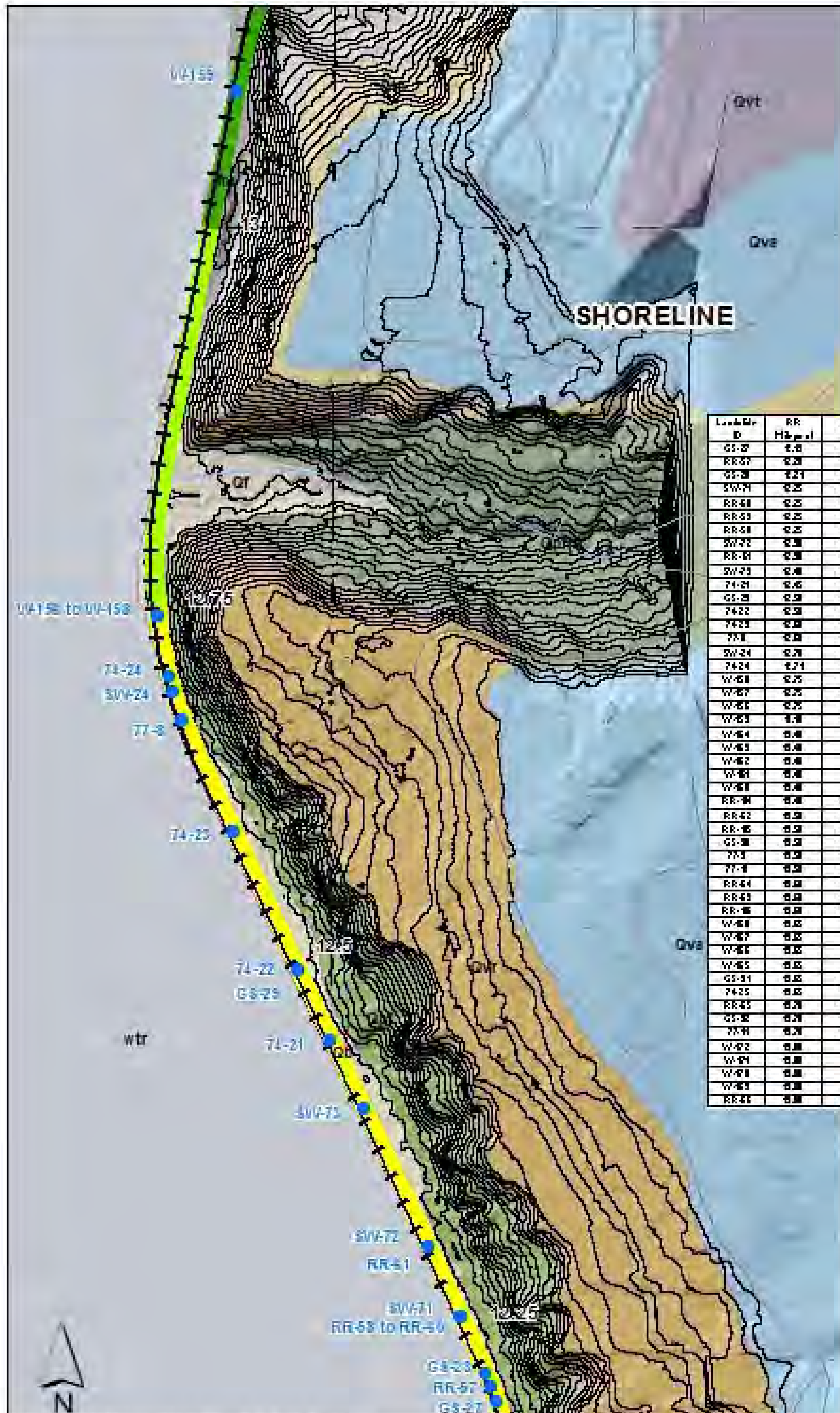
FIGURE:

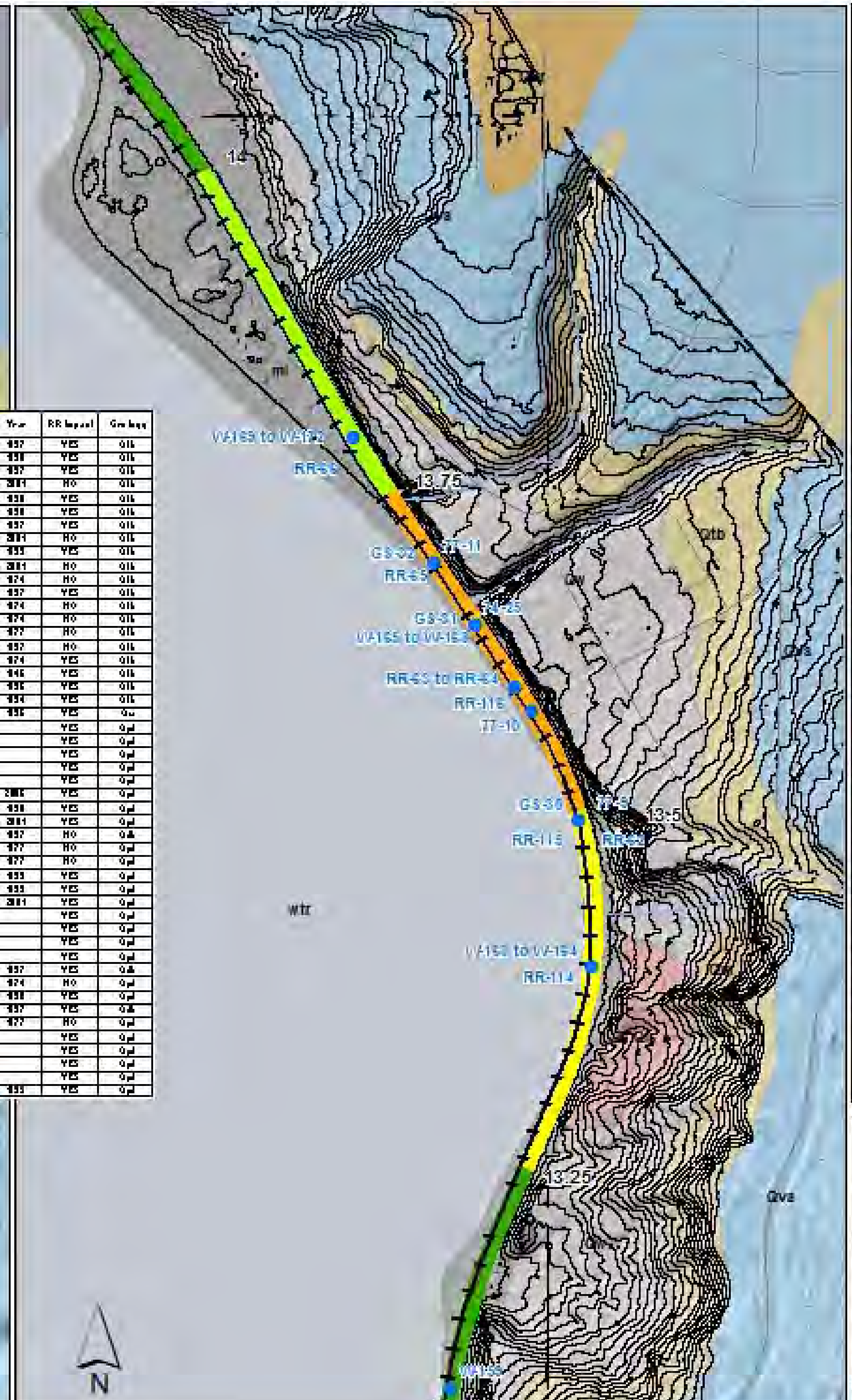
Seattle - Everett Rail Corridor
Landslide Inventory
MP 10.5 - 12

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY: Tracy Tropie   DATE: October 17, 2013



Landslide ID	RR Milepost	Year	RR Impact	Geology
GS-27	12.18	1997	YES	Qtb
RR-57	12.20	1998	YES	Qtb
GS-28	12.21	1997	YES	Qtb
SW-71	12.25	2001	NO	Qtb
RR-58	12.25	1998	YES	Qtb
RR-59	12.25	1998	YES	Qtb
RR-60	12.25	1997	YES	Qtb
SW-72	12.30	2001	NO	Qtb
RR-61	12.30	1995	YES	Qtb
SW-73	12.40	2001	NO	Qtb
74-21	12.45	1974	NO	Qtb
GS-29	12.50	1997	YES	Qtb
74-22	12.50	1974	NO	Qtb
74-23	12.50	1974	NO	Qtb
77-8	12.50	1977	NO	Qtb
SW-24	12.70	1997	NO	Qtb
74-24	12.71	1974	YES	Qtb
W-158	12.75	1946	YES	Qtb
W-157	12.75	1996	YES	Qtb
W-156	12.75	1954	YES	Qtb
W-155	13.10	1996	YES	Qva
W-154	13.40		YES	Qpf
W-153	13.40		YES	Qpf
W-152	13.40		YES	Qpf
W-151	13.40		YES	Qpf
W-150	13.40		YES	Qpf
RR-114	13.40	2005	YES	Qpf
RR-62	13.50	1998	YES	Qpf
RR-115	13.50	2001	YES	Qpf
GS-30	13.50	1997	NO	Qb
77-9	13.50	1977	NO	Qpf
77-10	13.50	1977	NO	Qpf
RR-64	13.58	1995	YES	Qpf
RR-63	13.58	1995	YES	Qpf
RR-116	13.58	2001	YES	Qpf
W-168	13.65		YES	Qpf
W-167	13.65		YES	Qpf
W-166	13.65		YES	Qpf
W-165	13.65		YES	Qpf
GS-31	13.65	1997	YES	Qb
74-25	13.65	1974	NO	Qpf
RR-65	13.70	1998	YES	Qpf
GS-32	13.70	1997	YES	Qb
77-11	13.70	1977	NO	Qpf
W-172	13.80		YES	Qpf
W-171	13.80		YES	Qpf
W-170	13.80		YES	Qpf
W-169	13.80		YES	Qpf
RR-66	13.80	1995	YES	Qpf



LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10' Foot Contour

Slide Density
Number of Slides (1933 - 2006) per 1/4 mile section

- <= 1
- 2 - 5
- 6 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping
Holocene

- ml - modified land
- Qls - landslide deposits
- Qb - beach deposits

Pleistocene

- Qf - outburst flood deposits
- Qpf - glacial deposits (pre-Fraser)
- Qpf(f) - fine grained deposits
- Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvr - recessional outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other

- wtr - water

1:24,000 Scale Geologic Mapping:
Troost, K. G.; Booth, D. B.; Wisher, A. P.; Shimel, S. A., 2005, The geologic map of Seattle [Duwamish Head, Seattle North and South, and Shilshole Bay 7.5-minute quadrangles]—A progress report: U.S. Geological Survey Open-File Report 2005-1252, version 1.0, 1 sheet, scale 1:24,000. [http://pubs.usgs.gov/of/2005/1252/]
Minard, J. P., 1983, Geologic map of the Edmonds East and part of the Edmonds West quadrangles, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1541, 1 sheet, scale 1:24,000. [http://ngmdb.usgs.gov/Prodesc/proddesc_7448.htm]

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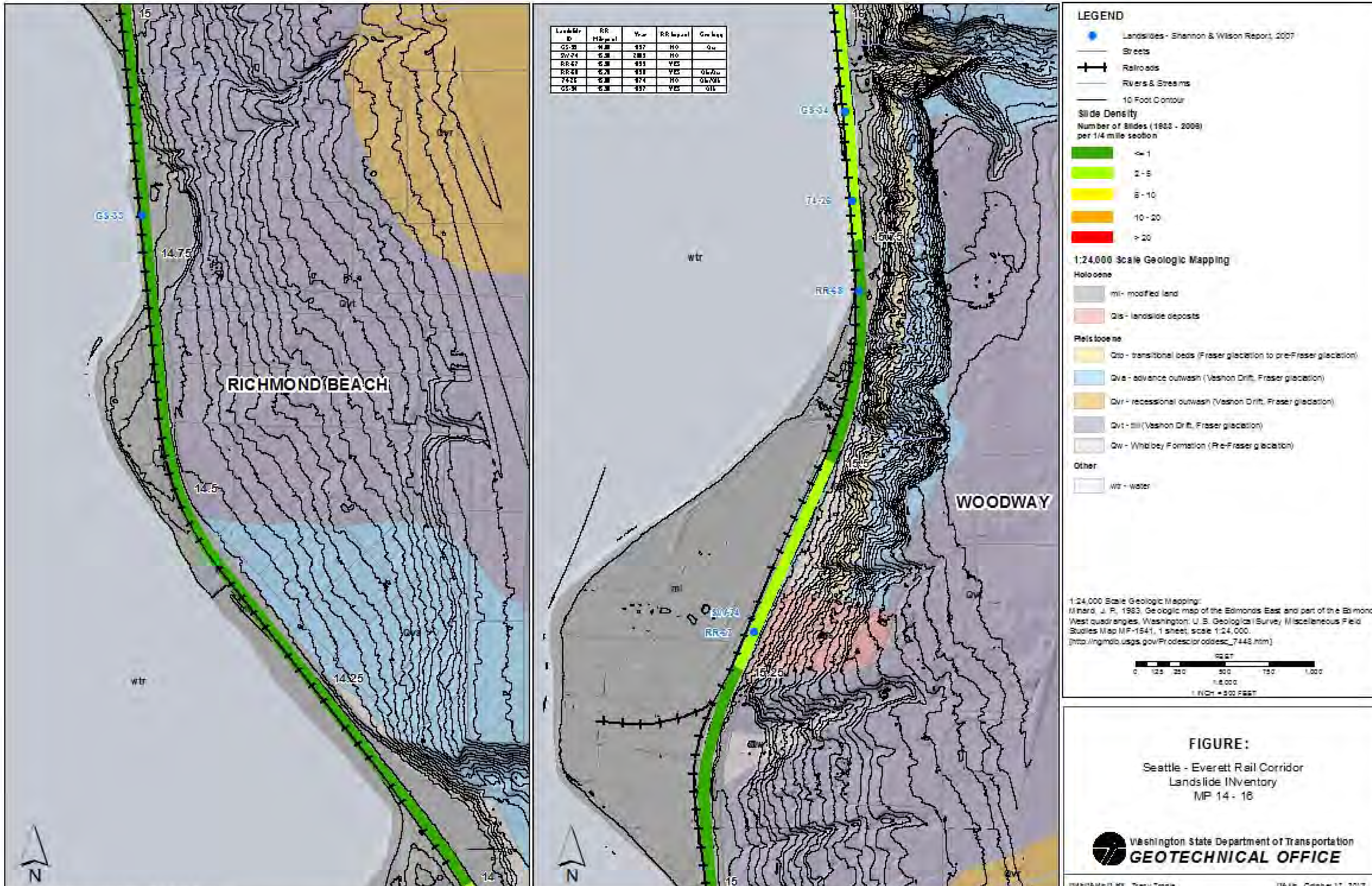
FIGURE:

Seattle - Everette Rail Corridor
Landslide Inventory
MP 12.25 - 14

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY: Tracy Tropia   DATE: October 17, 2013

File Location: M:\GIS\GIS Projects\SR-01\SR-01-MP\3.25-22-SlideReport\Projects


15
GS-33
14.75
RICHMOND BEACH
14.5
14.25
14
wtr
Qvt
Qvr
Qva
Landslide ID
RR Milepost
Year
RR Impact
Geology
GS-34
74-26
15.75
RR-68
wtr
15.5
WOODWAY
ml
SW-74
RR-67
15.25
Qvt
Qvr
N
LEGEND
Landslides - Shannon & Wilson Report, 2007
Streets
Railroads
Rivers & Streams
10 Foot Contour
Slide Density
Number of Slides (1983 - 2009) per 1/4 mile section
<= 1
2 - 5
6 - 10
10 - 20
> 20
1:24,000 Scale Geologic Mapping
Holocene
ml - modified land
Qls - landslide deposits
Pleistocene
Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
Qva - advance outwash (Vashon Drift, Fraser glaciation)
Qvr - recessional outwash (Vashon Drift, Fraser glaciation)
Qvt - till (Vashon Drift, Fraser glaciation)
Qw - Whidbey Formation (Pre-Fraser glaciation)
Other
wtr - water
1:24,000 Scale Geologic Mapping:
Minard, J. P., 1983, Geologic map of the Edmonds East and part of the Edmonds West quadrangles, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1541, 1 sheet, scale 1:24,000.
[http://ngmdb.usgs.gov/Prodesc/proddesc_7448.htm]
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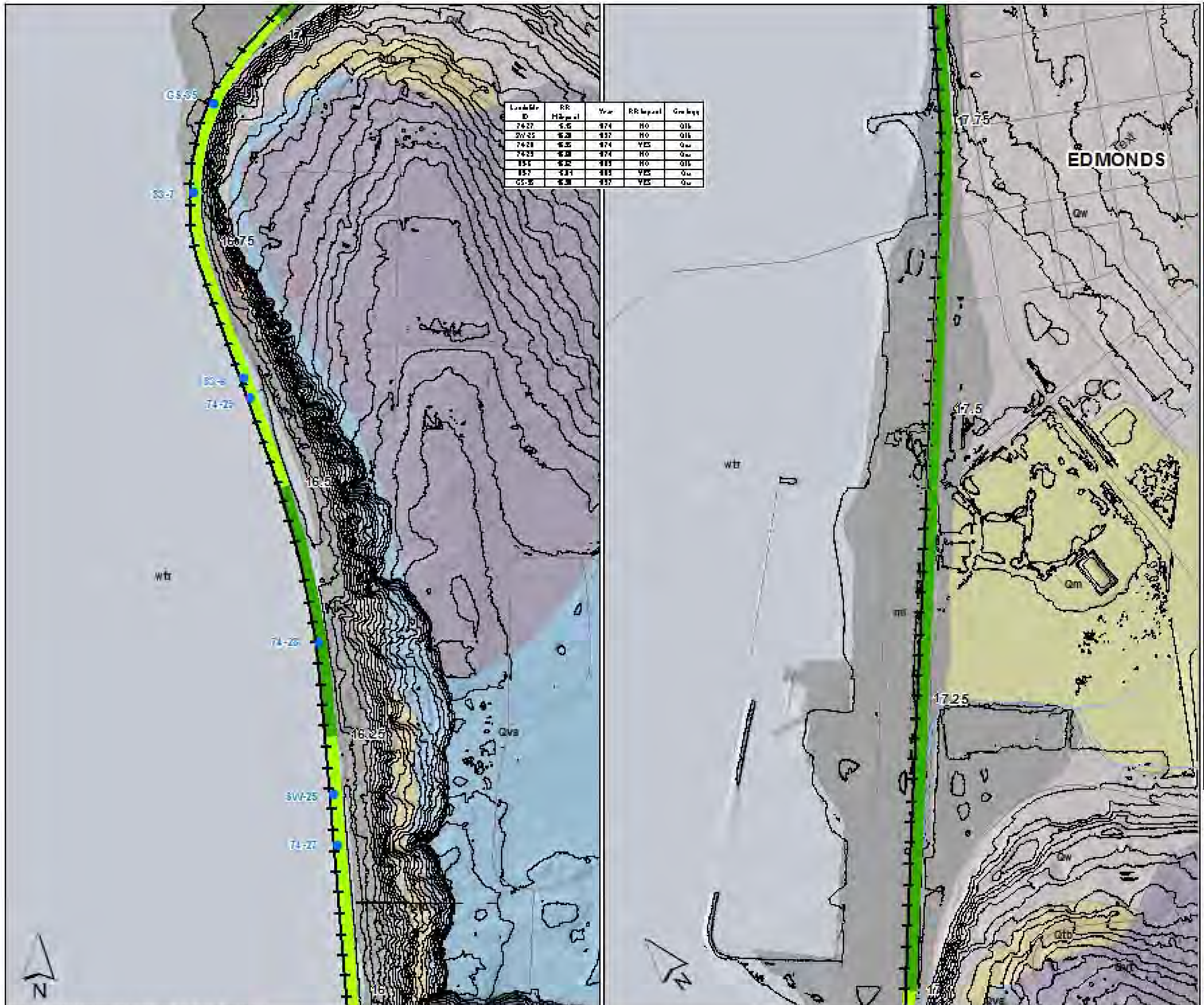
1 INCH = 500 FEET
FIGURE:
Seattle - Everett Rail Corridor
Landslide INventory
MP 14 - 16
Washington State Department of Transportation
GEOTECHNICAL OFFICE
PREPARED BY Tracy Trogle
DATE October 17, 2012



Landslide ID	RR Milepost	Year	RR Impact	Geology
74-27	[illegible]	1974	NO	Qtb
SW-25	[illegible]	1997	NO	Qtb
74-28	[illegible]	1974	YES	Qw
74-25	[illegible]	1974	NO	Qw
85-6	[illegible]	1985	NO	Qtb
85-7	[illegible]	1985	YES	Qw
GS-35	[illegible]	1997	YES	Qw

File Location: M:\GS\GIS Projects\SP401\SP401-U75\09-23-SlideRepair\Projects

LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density

Number of Slides (1933 - 2009) per 1/4 mile section

- <= 1
- 2 - 5
- 6 - 10
- 10 - 20
- > 20

1:24K,000 Scale Geologic Mapping

Holocene

- ml - modified land
- Qm - marsh deposits

Pleistocene

- Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other

- wtr - water

1:24K,000 Scale Geologic Mapping:
Minard, J. P., 1983, Geologic map of the Edmonds East and part of the Edmonds West quadrangles, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1541, 1 sheet, scale 1:24,000.
[http://ngmdb.usgs.gov/Prodesc/proddesc_7448.htm]

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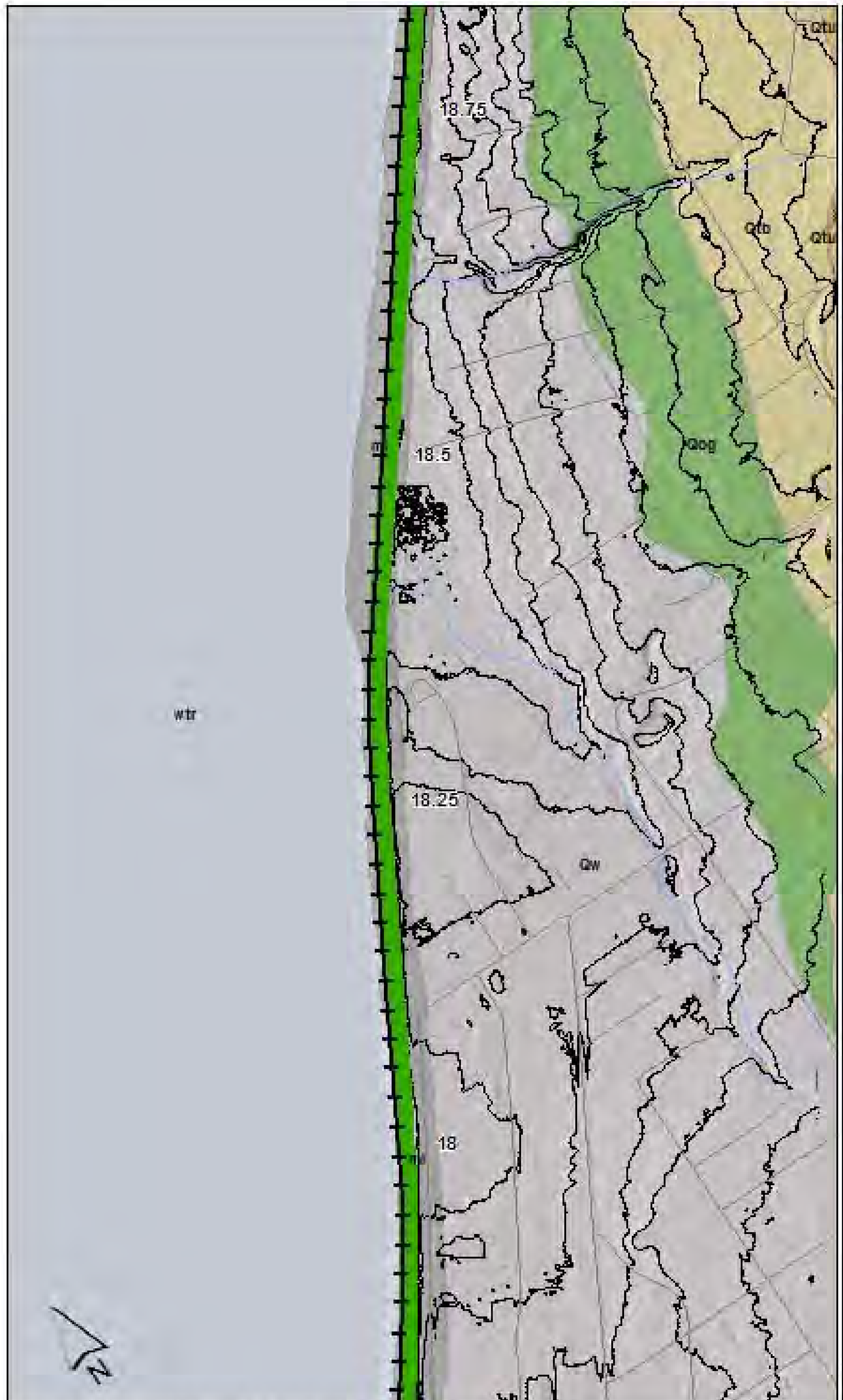
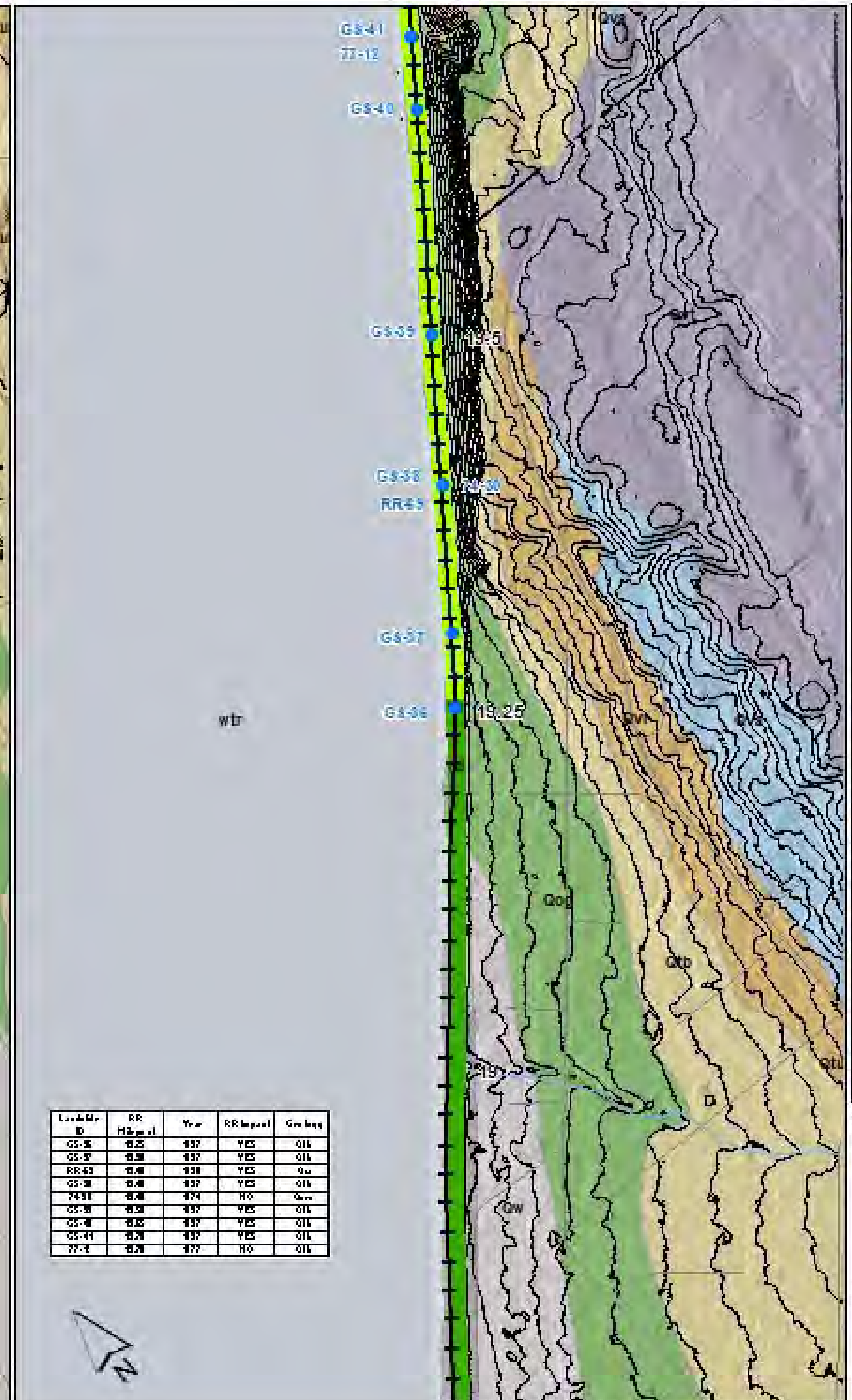
1 INCH = 500 FEET

FIGURE:
Seattle - Everette Rail Corridor
Landslide Inventory
MP 16 - 17.75

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY: Tracy Trople   DATE: October 17, 2013





Landslide ID	RR Milepost	Year	RR Impact	Geology
GS-36	19.25	1997	YES	Qtb
GS-37	[illegible]	1997	YES	Qtb
RR-69	[illegible]	1998	YES	Qw
GS-38	[illegible]	1997	YES	Qtb
74-30	[illegible]	1974	NO	Qvr
GS-39	[illegible]	1997	YES	Qtb
GS-40	[illegible]	1997	YES	Qtb
GS-41	[illegible]	1997	YES	Qtb
77-12	[illegible]	1977	NO	Qtb

LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density
Number of Slides (1933 - 2008) per 1/4 mile section

- <= 1
- 2 - 5
- 6 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene
- ml - modified land

Pleistocene
- Qog - Olympia gravel (pre-Fraser glaciation)
- Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
- Qtu - till, undivided (Fraser? glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvr - recessional outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other
- wtr - water

1:24,000 Scale Geologic Mapping:
Minard, J. P., 1983, Geologic map of the Edmonds East and part of the Edmonds West quadrangles, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1541, 1 sheet, scale 1:24,000.
[http://ngmdb.usgs.gov/Prodesc/proddesc_7448.htm]

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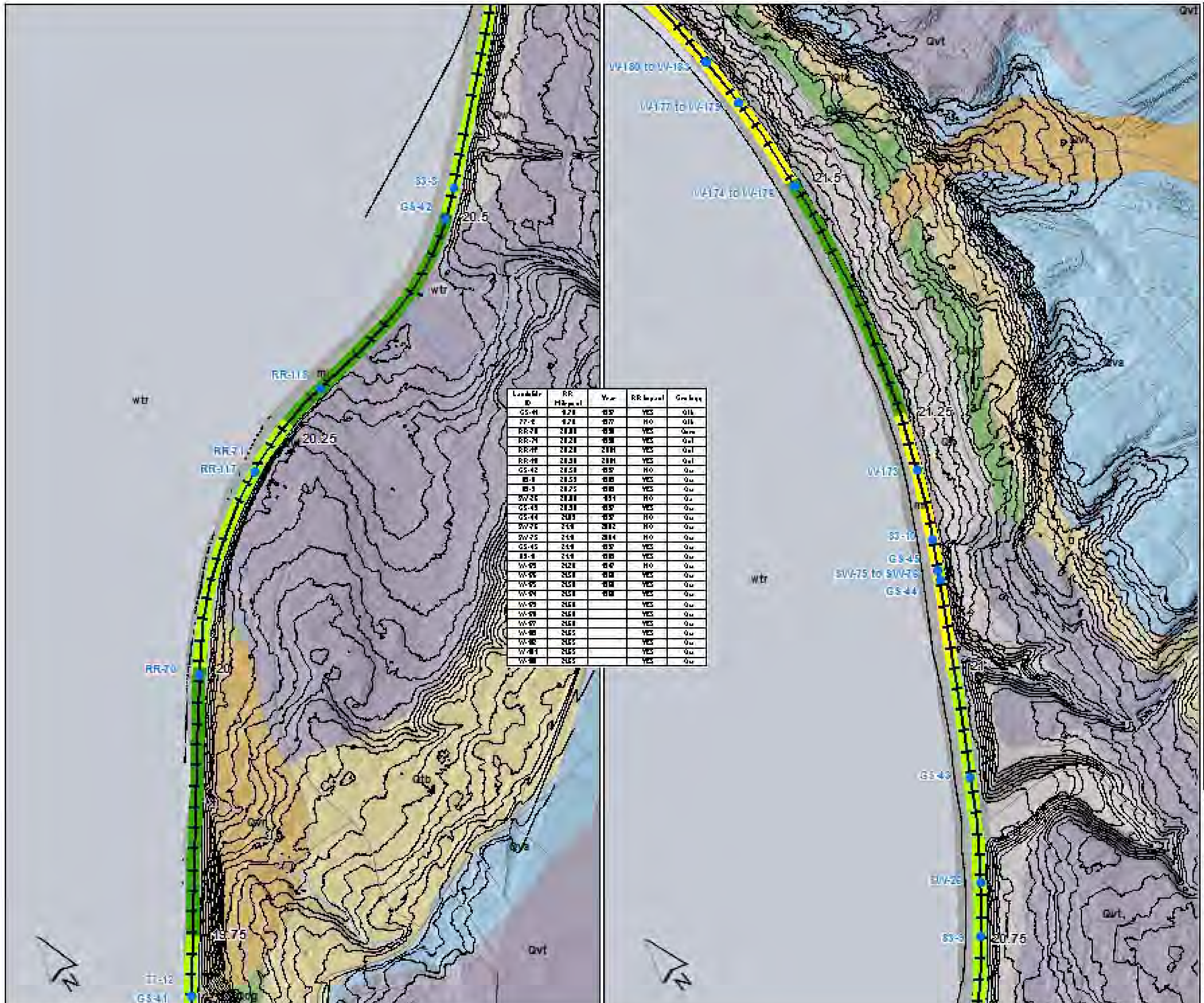
FIGURE:

Seattle - Everett Rail Corridor
Landslide Inventory
MP 18 - 19.5

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY Tracy Tragle DATE October 17, 2012

File Location: M:\GEOGIS Projects\...



Landslide ID	RR Milepost	Year	RR Impact	Geology
GS-41	19.70	1997	YES	Qtb
TT-12	19.70	1977	NO	Qtb
RR-70	20.00	1996	YES	Qvr
RR-71	20.20	1996	YES	Qal
RR-117	20.20	2011	YES	Qal
RR-115	20.30	2011	YES	Qal
GS-42	20.50	1997	NO	Qvt
SS-5	20.53	[illegible]	YES	Qvt
SS-3	20.75	[illegible]	YES	Qvt
SW-26	20.80	1997	NO	Qvt
GS-43	20.90	1997	YES	Qvt
GS-44	21.05	1997	NO	Qvt
SW-76	21.10	2002	NO	Qvt
SW-75	21.10	2004	NO	Qvt
GS-45	21.10	1997	YES	Qvt
SS-10	21.10	1998	YES	Qvt
W-173	21.20	1997	NO	Qvt
W-174	21.51	1998	YES	Qvt
W-175	21.51	1998	YES	Qvt
W-176	21.51	1998	YES	Qvt
W-177	21.60		YES	Qvt
W-178	21.60		YES	Qvt
W-179	21.60		YES	Qvt
W-180	21.65		YES	Qvt
W-182	21.65		YES	Qvt
W-181	21.65		YES	Qvt
W-183	21.65		YES	Qvt

LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density
Number of Slides (1983 - 2009) per 1/4 mile section

- <= 1
- 2 - 5
- 5 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene

- ml - modified land
- Qyal - younger alluvium

Pleistocene

- Qog - Olympia gravel (pre-Fraser glaciation)
- Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvr - recessional outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other

- wtr - water

1:24,000 Scale Geologic Mapping:
Minard, J. P., 1983, Geologic map of the Edmonds East and part of the Edmonds West quadrangles, Washington: U. S. Geological Survey Miscellaneous Field Studies Map MF-1541, 1 sheet, scale 1:24,000. [http://ngmdb.usgs.gov/Prodesc/proddesc_7448.htm]

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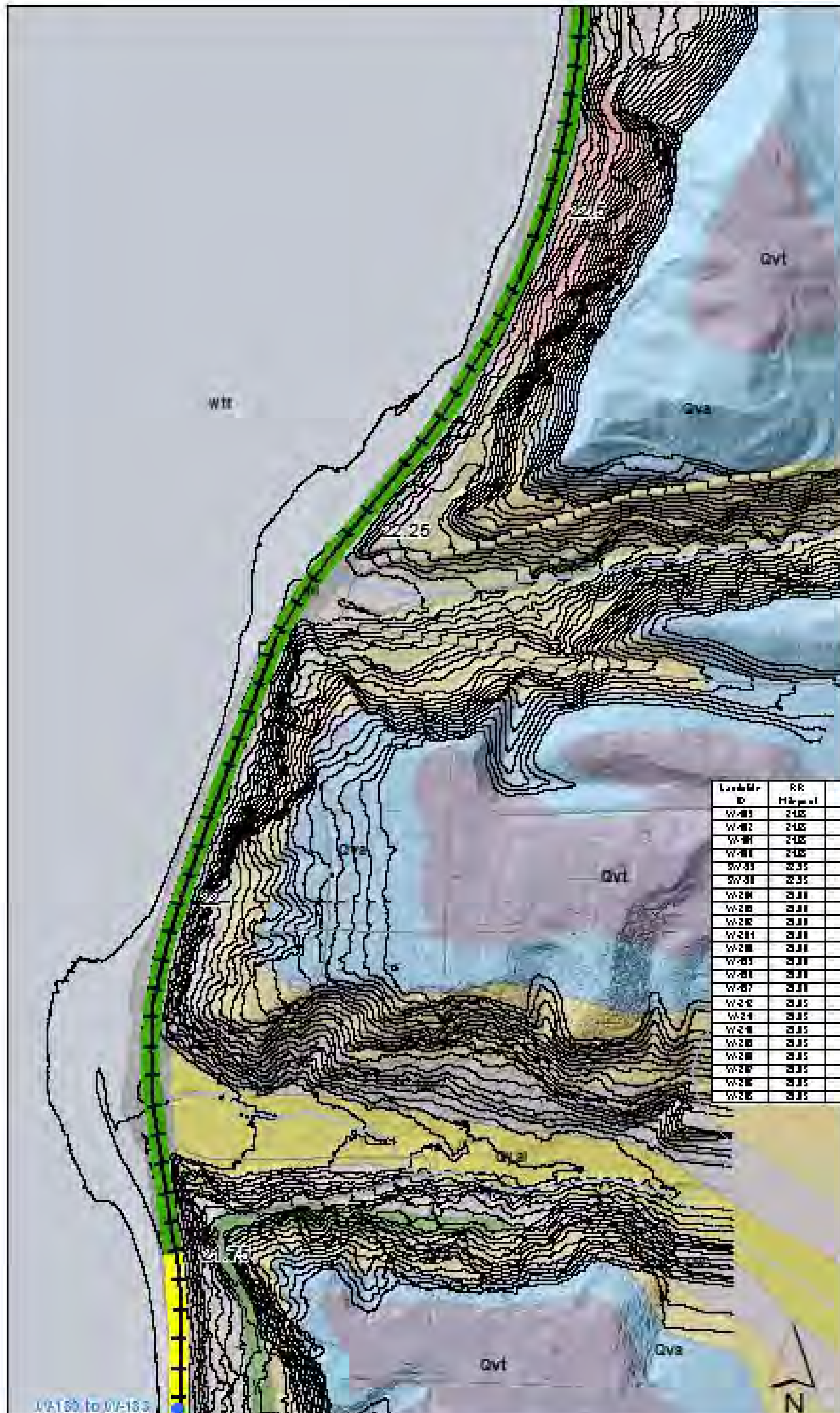
FIGURE:

Seattle - Everette Rail Corridor
Landslide Inventory
MP 19.75 - 21.5

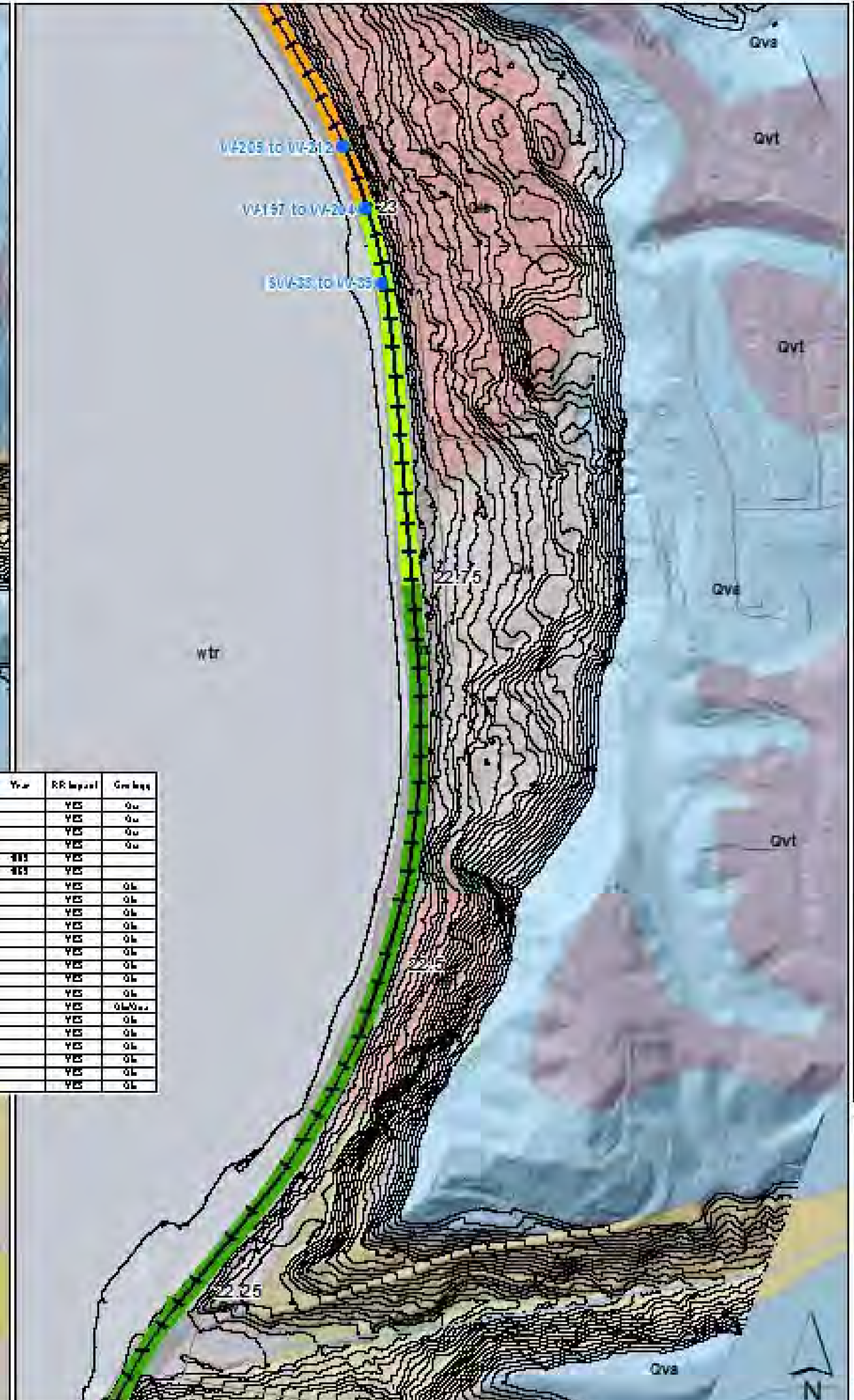
Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY Tracy Tropie DATE October 17, 2012

File Location: ...



Landslide ID	RR Milepost	Year	RR Impact	Geology
W-183	[illegible]		YES	Qva
W-182	[illegible]		YES	Qva
W-181	[illegible]		YES	Qva
W-180	[illegible]		YES	Qva
SW-33	[illegible]	[illegible]	YES	
SW-38	[illegible]	[illegible]	YES	
W-204	[illegible]		YES	Qls
W-203	[illegible]		YES	Qls
W-202	[illegible]		YES	Qls
W-201	[illegible]		YES	Qls
W-200	[illegible]		YES	Qls
W-199	[illegible]		YES	Qls
W-198	[illegible]		YES	Qls
W-197	[illegible]		YES	Qls
W-212	[illegible]		YES	Qls
W-211	[illegible]		YES	Qls/Qva
W-210	[illegible]		YES	Qls
W-209	[illegible]		YES	Qls
W-208	[illegible]		YES	Qls
W-207	[illegible]		YES	Qls
W-206	[illegible]		YES	Qls
W-205	[illegible]		YES	Qls



LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density

Number of Slides (1983 - 2008) per 1/4 mile section

- <= 1
- 2 - 5
- 6 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene

- ml - modified land
- Qls - landslide deposits
- Qyal - younger alluvium

Pleistocene

- Qog - Olympia gravel (pre-Fraser glaciation)
- Qpd - Possesion Drift (pre-Fraser glaciation)
- Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other

- wtr - water

1:24,000 Scale Geologic Mapping:
Minard, J. P. 1983. Geologic map of the Edmonds East and part of the Edmonds West quadrangles, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1541, 1 sheet, scale 1:24,000. [http://ngmdb.usgs.gov/Prodesc/proddesc_7448.htm]

Minard, J. P. 1982. Distribution and description of geologic units in the Mukilteo quadrangle, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1438, 1 sheet, scale 1:24,000.

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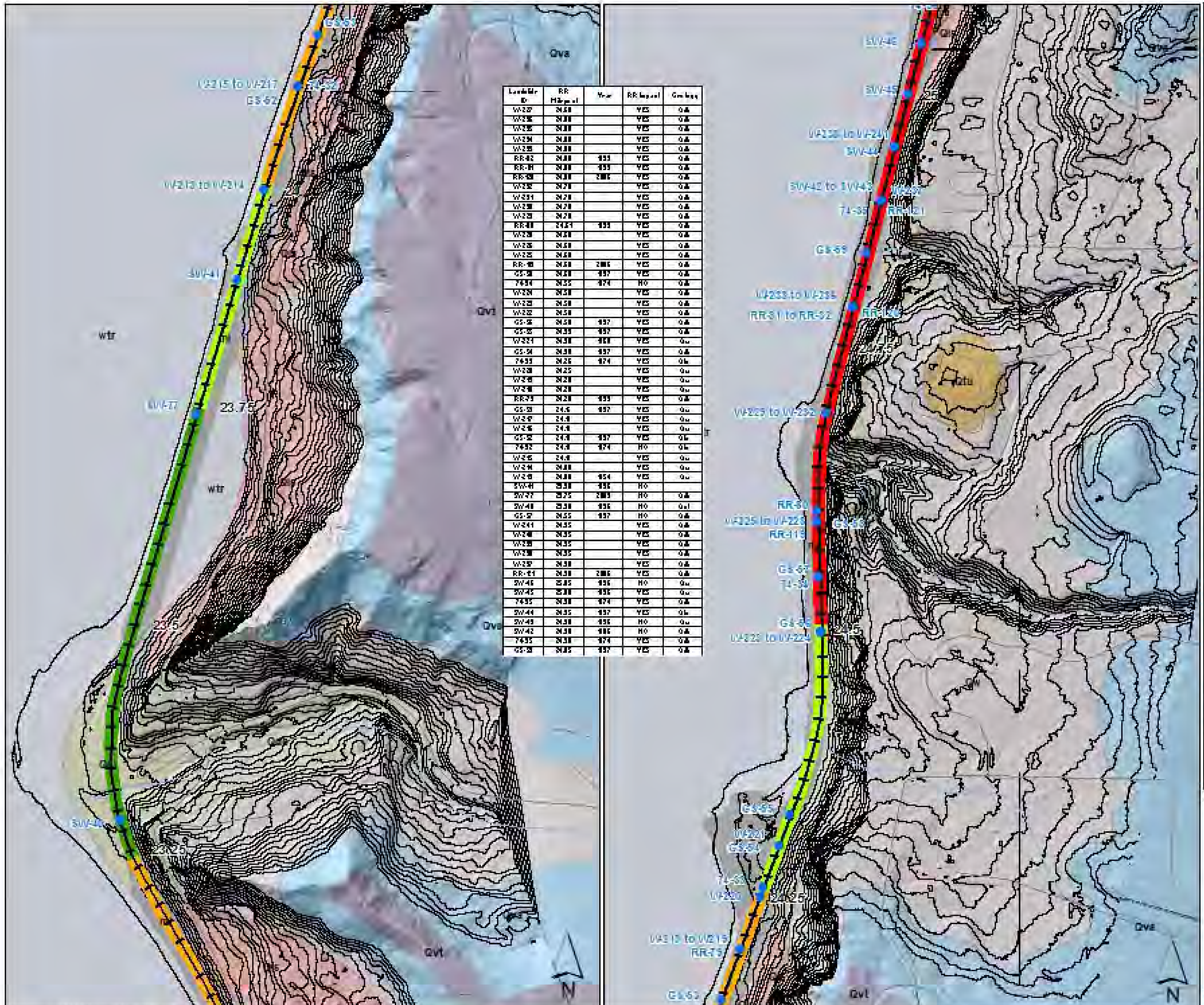
1 INCH = 500 FEET

FIGURE:

Seattle - Everette Rail Corridor
Landslide Inventory
MP 21.75 - 23

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY: Tracy Trogle   DATE: October 18, 2012



Landslide ID	RR Milepost	Year	RR Impact	Geology
W-237	24.50		YES	Qls
W-236	24.80		YES	Qls
W-235	24.80		YES	Qls
W-234	24.80		YES	Qls
W-233	24.80		YES	Qls
RR-42	24.80	1999	YES	Qls
RR-31	24.80	1999	YES	Qls
RR-32	24.80	2006	YES	Qls
W-232	24.70		YES	Qls
W-231	24.70		YES	Qls
W-230	24.70		YES	Qls
W-229	24.70		YES	Qls
RR-30	24.51	1999	YES	Qls
W-228	24.50		YES	Qls
W-226	24.50		YES	Qls
W-225	24.50		YES	Qls
RR-119	24.50	2006	YES	Qls
GS-58	24.50	1997	YES	Qls
74-34	24.55	1974	NO	Qls
W-224	24.50		YES	Qls
W-223	24.50		YES	Qls
W-222	24.50		YES	Qls
GS-56	24.50	1997	YES	Qls
GS-55	24.35	1997	YES	Qls
W-221	24.30	1968	YES	Qw
GS-54	24.30	1997	YES	Qls
74-33	24.25	1974	YES	Qb
W-220	24.25		YES	Qw
W-219	24.20		YES	Qw
W-218	24.20		YES	Qw
RR-75	24.20	1999	YES	Qls
GS-53	24.6	1997	YES	Qw
W-217	24.4		YES	Qw
W-216	24.4		YES	Qw
GS-52	24.4	1997	YES	Qb
74-32	24.4	1974	NO	Qb
W-215	24.4		YES	Qw
W-214	24.80		YES	Qw
W-213	24.80	1954	YES	Qw
SW-41	23.30	1996	NO	
SW-37	23.75	2003	NO	Qls
SW-40	23.30	1996	NO	Qal
GS-57	24.55	1997	NO	Qls
W-241	24.35		YES	Qls
W-240	24.35		YES	Qls
W-239	24.35		YES	Qls
W-238	24.35		YES	Qls
W-227	24.30		YES	Qls
RR-121	24.30	2006	YES	Qls
SW-46	23.85	1996	NO	Qw
SW-45	23.80	1996	YES	Qw
74-35	24.30	1974	YES	Qls
SW-44	24.35	1997	YES	Qb
SW-43	24.30	1996	NO	Qw
SW-42	24.30	1996	NO	Qls
74-35	24.30	1974	YES	Qls
GS-59	24.85	1997	YES	Qls

LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density
Number of Slides (1983 - 2009) per 1/4 mile section

- <= 1
- 2 - 5
- 5 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene

- m - modified land
- Qls - landslide deposits
- Qal - alluvium

Pleistocene

- Qdb - Double Bluff Drift (pre-Fraser glaciation)
- Qtu - till, undivided (Fraser? glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other

- wtr - water

1:24,000 Scale Geologic Mapping:
Minard, J. P., 1983, Geologic map of the Edmonds East and part of the Edmonds West quadrangles, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1541, 1 sheet, scale 1:24,000.
[http://ngmdb.usgs.gov/Prodesc/proddesc_7443.htm]

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1 INCH = 500 FEET

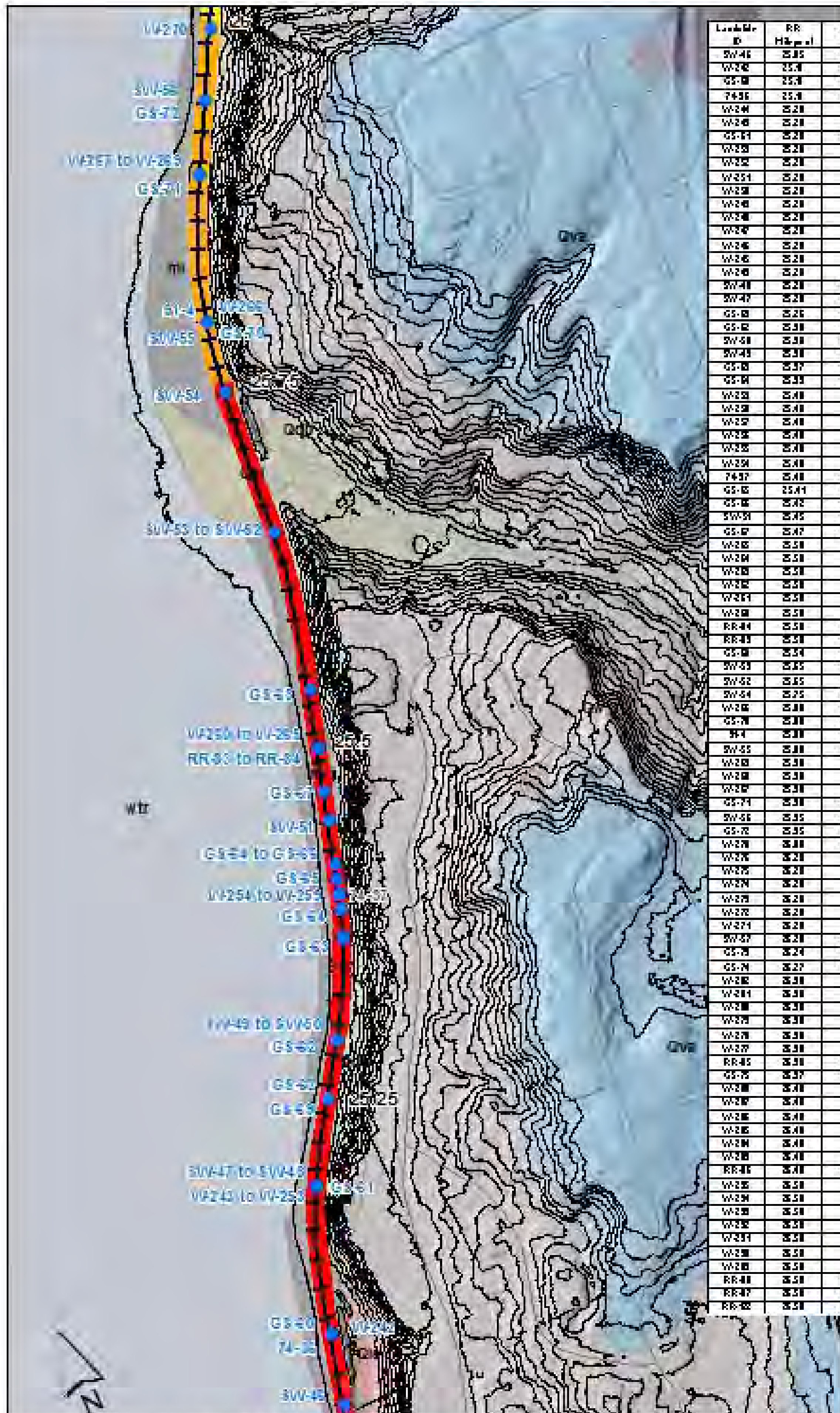
FIGURE:

Seattle - Everett Rail Corridor
Landslide Inventory
MP 23.25 - 25

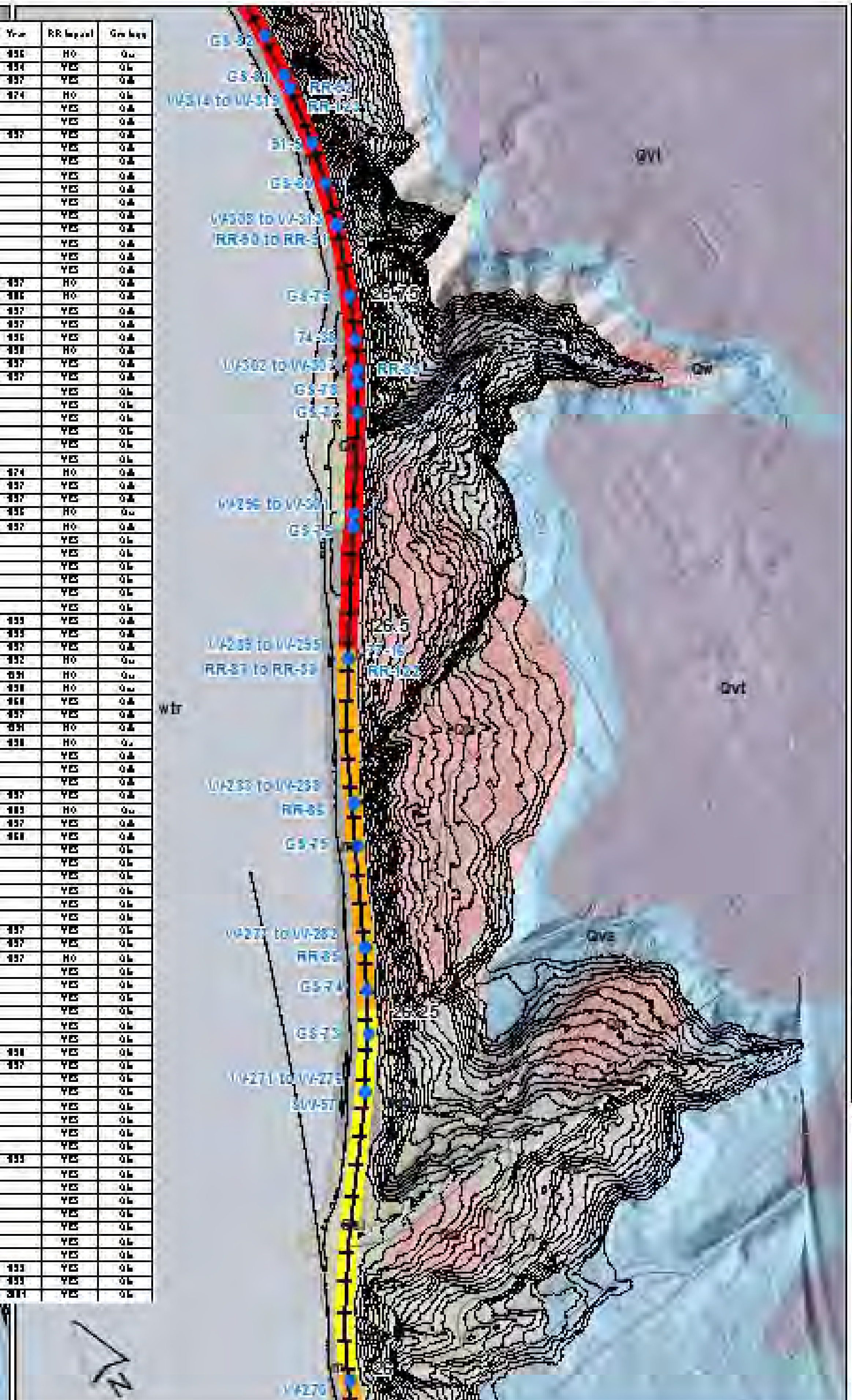
Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY: Tracy Tropia   DATE: October 15, 2013

File Location: [illegible]



Landslide ID	RR Milepost	Year	RR Impact	Geology
SW-46	25.05	1956	NO	Qw
W-242	25.1	1954	YES	Qls
GS-58	25.1	1957	YES	Qtb
74-36	25.1	1974	NO	Qls
W-244	25.20		YES	Qtb
W-243	25.20		YES	Qtb
GS-61	25.20	1957	YES	Qtb
W-253	25.20		YES	Qtb
W-252	25.20		YES	Qtb
W-251	25.20		YES	Qtb
W-250	25.20		YES	Qtb
W-249	25.20		YES	Qtb
W-248	25.20		YES	Qtb
W-247	25.20		YES	Qtb
W-246	25.20		YES	Qtb
W-245	25.20		YES	Qtb
W-2[illegible]	25.20		YES	Qtb
SW-48	25.20	1957	NO	Qtb
SW-47	25.20	1956	NO	Qtb
GS-60	25.25	1957	YES	Qtb
GS-62	25.30	1957	YES	Qtb
SW-50	25.30	1956	YES	Qtb
SW-49	25.30	1958	NO	Qtb
GS-63	25.37	1957	YES	Qtb
GS-64	25.39	1957	YES	Qtb
W-258	25.40		YES	Qls
W-259	25.40		YES	Qls
W-257	25.40		YES	Qls
W-256	25.40		YES	Qls
W-255	25.40		YES	Qls
W-254	25.40		YES	Qls
74-37	25.40	1974	NO	Qtb
GS-65	25.41	1957	YES	Qtb
GS-66	25.42	1957	YES	Qtb
SW-51	25.45	1956	NO	Qw
GS-67	25.47	1957	NO	Qtb
W-265	25.50		YES	Qls
W-264	25.50		YES	Qls
W-263	25.50		YES	Qls
W-262	25.50		YES	Qls
W-261	25.50		YES	Qls
W-260	25.50		YES	Qls
RR-84	25.50	1955	YES	Qtb
RR-83	25.50	1955	YES	Qtb
GS-68	25.54	1957	YES	Qtb
SW-53	25.55	1952	NO	Qw
SW-52	25.55	1951	NO	Qw
SW-54	25.75	1958	NO	Qw
W-266	25.80	1968	YES	Qtb
GS-70	25.80	1957	YES	Qtb
SI-4	25.80	1951	NO	Qtb
SW-55	25.80	1958	NO	Qw
W-269	25.90		YES	Qtb
W-268	25.90		YES	Qtb
W-267	25.90		YES	Qtb
GS-71	25.90	1957	YES	Qtb
SW-56	25.95	1953	NO	Qw
GS-72	25.95	1957	YES	Qtb
W-270	26.00	1968	YES	Qtb
W-276	26.20		YES	Qls
W-275	26.20		YES	Qls
W-274	26.20		YES	Qls
W-273	26.20		YES	Qls
W-272	26.20		YES	Qls
W-271	26.20		YES	Qls
SW-57	26.20	1957	YES	Qls
GS-73	26.24	1957	YES	Qls
GS-74	26.27	1957	NO	Qls
W-282	26.30		YES	Qls
W-281	26.30		YES	Qls
W-280	26.30		YES	Qls
W-279	26.30		YES	Qls
W-278	26.30		YES	Qls
W-277	26.30		YES	Qls
RR-85	26.30	1958	YES	Qls
GS-75	26.37	1957	YES	Qls
W-288	26.40		YES	Qls
W-287	26.40		YES	Qls
W-286	26.40		YES	Qls
W-285	26.40		YES	Qls
W-284	26.40		YES	Qls
W-283	26.40		YES	Qls
RR-86	26.40	1955	YES	Qls
W-295	26.50		YES	Qls
W-294	26.50		YES	Qls
W-293	26.50		YES	Qls
W-292	26.50		YES	Qls
W-291	26.50		YES	Qls
W-290	26.50		YES	Qls
W-289	26.50		YES	Qls
RR-88	26.50	1955	YES	Qls
RR-87	26.50	1955	YES	Qls
RR-122	26.50	2001	YES	Qls



LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density
Number of Slides (1983 - 2009) per 1/4 mile section

- <= 1
- 2 - 5
- 5 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene
- ml - modified land
- Qls - landslide deposits
- Qal - alluvium

Pleistocene
- Qdb - Double Bluff Drift (pre-Fraser glaciation)
- Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
- Qtu - till, undivided (Fraser? glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other
- wtr - water

1:24,000 Scale Geologic Mapping:
Minard, J. P., 1982, Distribution and description of geologic units in the Mukilteo quadrangle, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1438, 1 sheet, scale 1:24,000.

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1 INCH = 500 FEET

FIGURE:

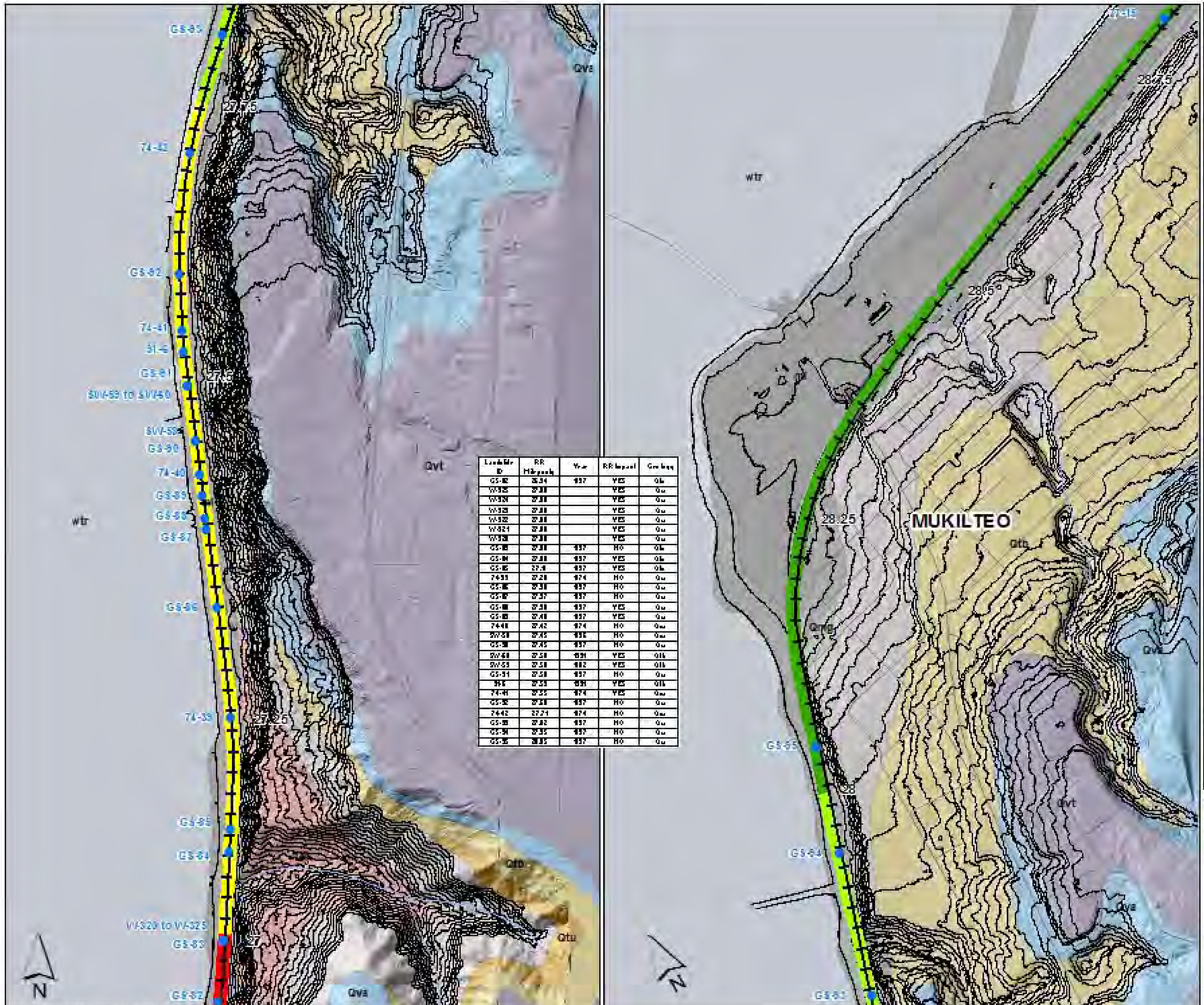
Seattle - Everette Inventory
Landslide Inventory
MP 25.25 - 26.75

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY Tracy Tringle

DATE October 18, 2012

File Location: [illegible]



Landslide ID	RR Milepost	Year	RR Impact	Geology
GS-82	26.94	1997	YES	Qls
V-325	27.00		YES	Qtu
V-324	27.00		YES	Qtu
V-323	27.00		YES	Qtu
V-322	27.00		YES	Qtu
V-321	27.00		YES	Qtu
V-320	27.00		YES	Qtu
GS-83	27.00	1997	NO	Qls
GS-84	27.00	1997	YES	Qls
GS-85	27.1	1997	YES	Qls
74-39	27.20	1974	NO	Qtu
GS-86	27.30	1997	NO	Qtu
GS-87	27.37	1997	NO	Qtu
GS-88	27.38	1997	YES	Qtu
GS-89	27.40	1997	YES	Qtu
74-40	27.42	1974	NO	Qvt
SW-58	27.45	1996	NO	Qvt
GS-90	27.45	1997	NO	Qtu
SW-60	27.50	1991	YES	Qtb
SW-59	27.50	1982	YES	Qtb
GS-91	27.50	1997	NO	Qtu
SI-6	27.53	1991	YES	Qtb
74-41	27.55	1974	YES	Qvt
GS-92	27.58	1997	NO	Qtu
74-42	27.71	1974	NO	Qvt
GS-93	27.82	1997	NO	Qtu
GS-94	27.95	1997	NO	Qtu
GS-95	28.15	1997	NO	Qtu

LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density
Number of Slides (1933 - 2009) per 1/4 mile section

- <= 1
- 2 - 5
- 5 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene

- ml - modified land
- Qls - landslide deposits

Pleistocene

- Qmg - marine glacial drift (Fraser to pre-Fraser glaciation)
- Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
- Qtu - till, undivided (Fraser? glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other

- wtr - water

1:24,000 Scale Geologic Mapping:
Minard, J. P., 1982, Distribution and description of geologic units in the Mukilteo quadrangle, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1438, 1 sheet, scale 1:24,000.

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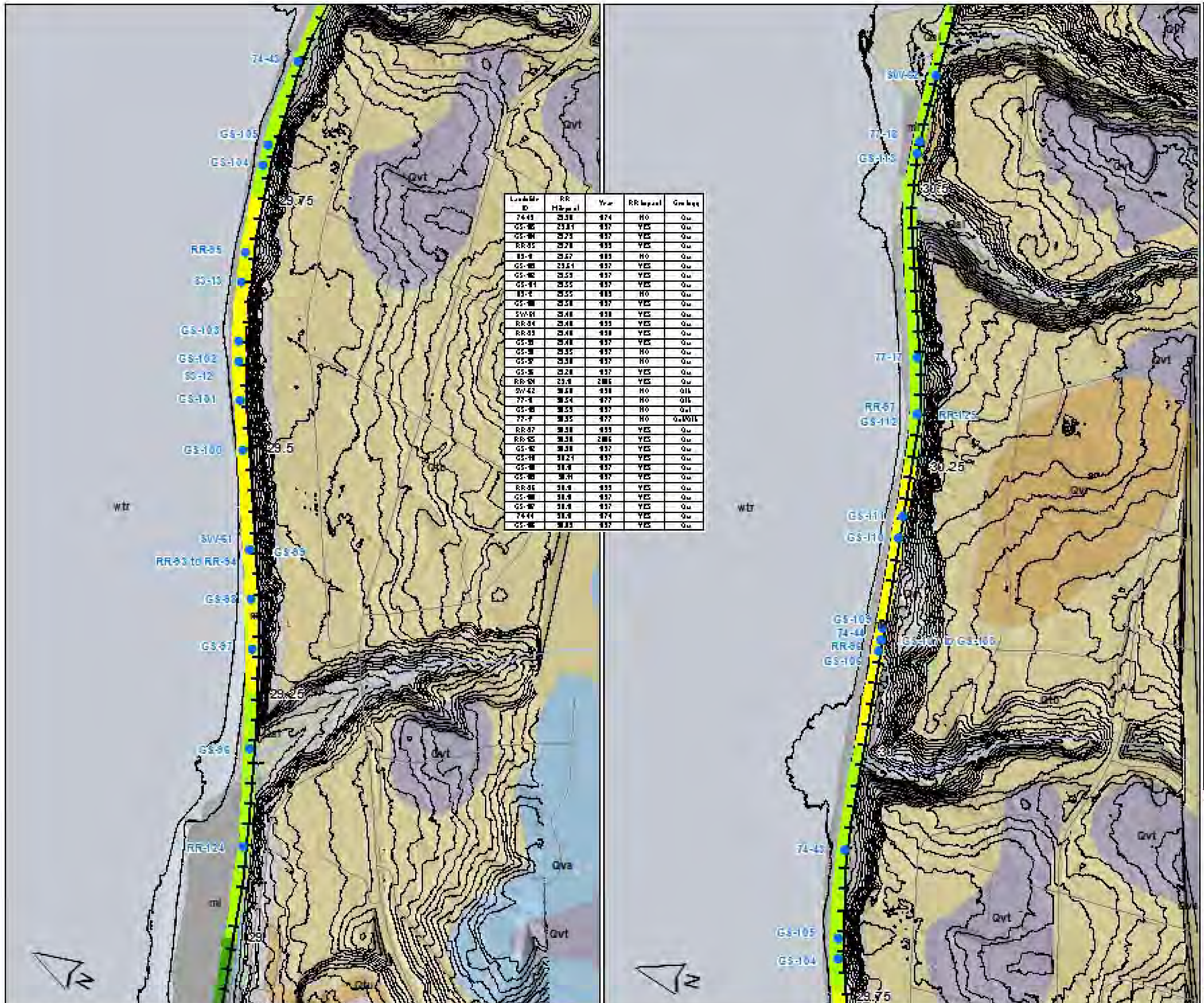
1 INCH = 500 FEET

FIGURE:

Seattle - Everette Rail Corridor
Landslide Inventory
MP 27 - 28.75

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY Tracy Tropie DATE October 15, 2013



Landslide ID	RR Milepost	Year	RR Impact	Geology
74-43	29.90	1974	NO	Qw
GS-105	29.81	1997	YES	Qw
GS-104	29.75	1997	YES	Qw
RR-95	29.70	1995	YES	Qw
SS-13	29.67	1985	NO	Qw
GS-103	29.61	1997	YES	Qw
GS-102	29.59	1997	YES	Qw
GS-101	29.55	1997	YES	Qw
SS-12	29.55	1985	NO	Qw
GS-100	29.50	1997	YES	Qw
SW-61	29.40	1998	YES	Qw
RR-94	29.40	1995	YES	Qw
RR-93	29.40	1998	YES	Qw
GS-99	29.40	1997	YES	Qw
GS-98	29.35	1997	NO	Qw
GS-97	29.30	1997	NO	Qw
GS-96	29.20	1997	YES	Qw
RR-124	29.1	2006	YES	Qw
SW-62	30.50	1998	NO	Qtb
77-18	30.54	1977	NO	Qtb
GS-113	30.53	1997	NO	Qal
77-17	30.35	1977	NO	Qal/Qtb
RR-97	30.30	1995	YES	Qw
RR-125	30.30	2006	YES	Qw
GS-112	30.30	1997	YES	Qw
GS-111	30.21	1997	YES	Qw
GS-110	30.2	1997	YES	Qw
GS-109	30.11	1997	YES	Qw
RR-96	30.1	1995	YES	Qw
GS-108	30.1	1997	YES	Qw
GS-107	30.1	1997	YES	Qw
74-44	30.1	1974	YES	Qw
GS-106	30.05	1997	YES	Qw

LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density

Number of Slides (1933 - 2009) per 1/4 mile section

- <= 1
- 2 - 5
- 5 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene

- ml - modified land
- Qal - alluvium

Pleistocene

- Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
- Qtu - till, undivided (Fraser? glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvr - recessional outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other

- wtr - water

1:24,000 Scale Geologic Mapping:
Minard, J. P., 1982, Distribution and description of geologic units in the Mukilteo quadrangle, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1438, 1 sheet, scale 1:24,000.

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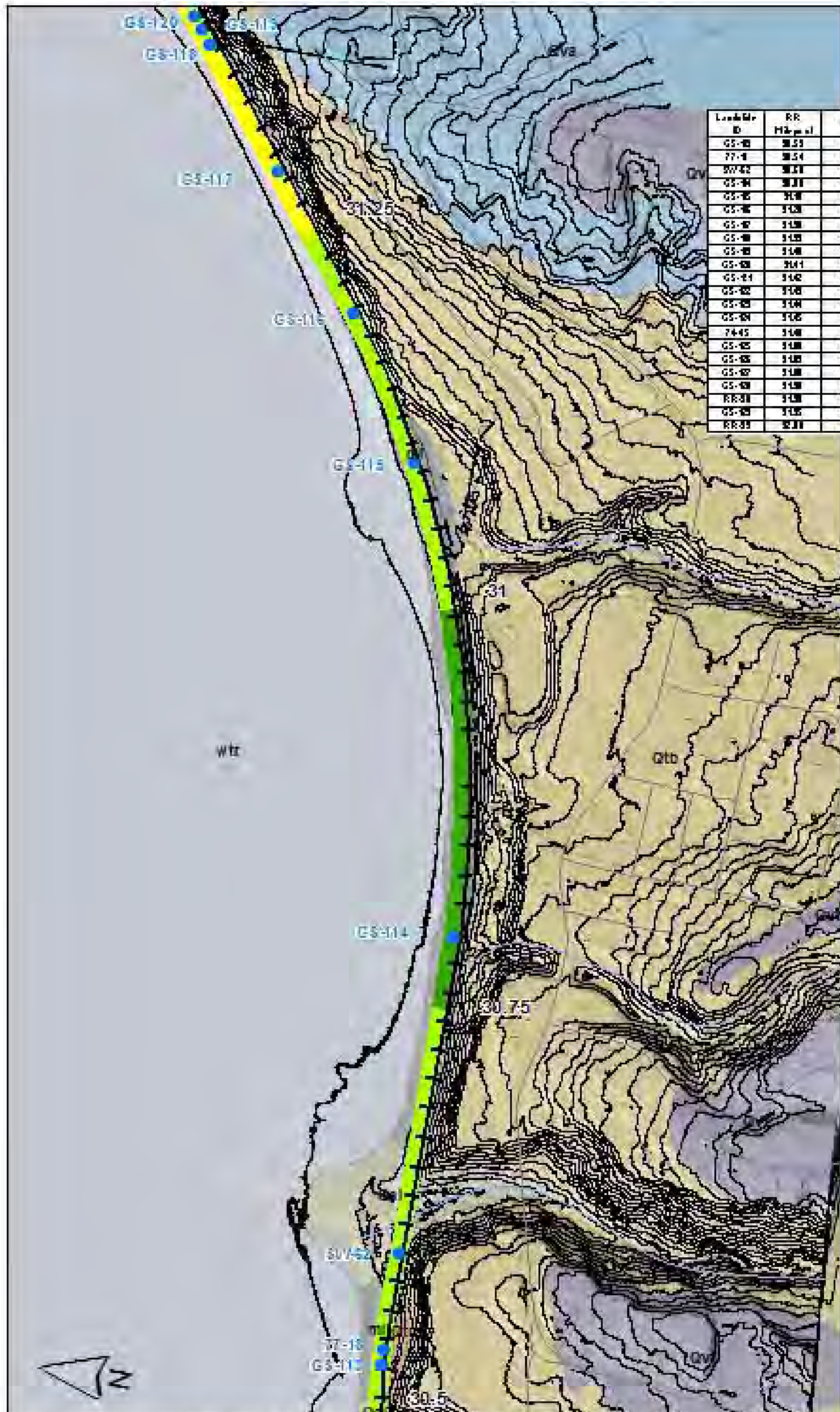
1 INCH = 500 FEET

FIGURE:

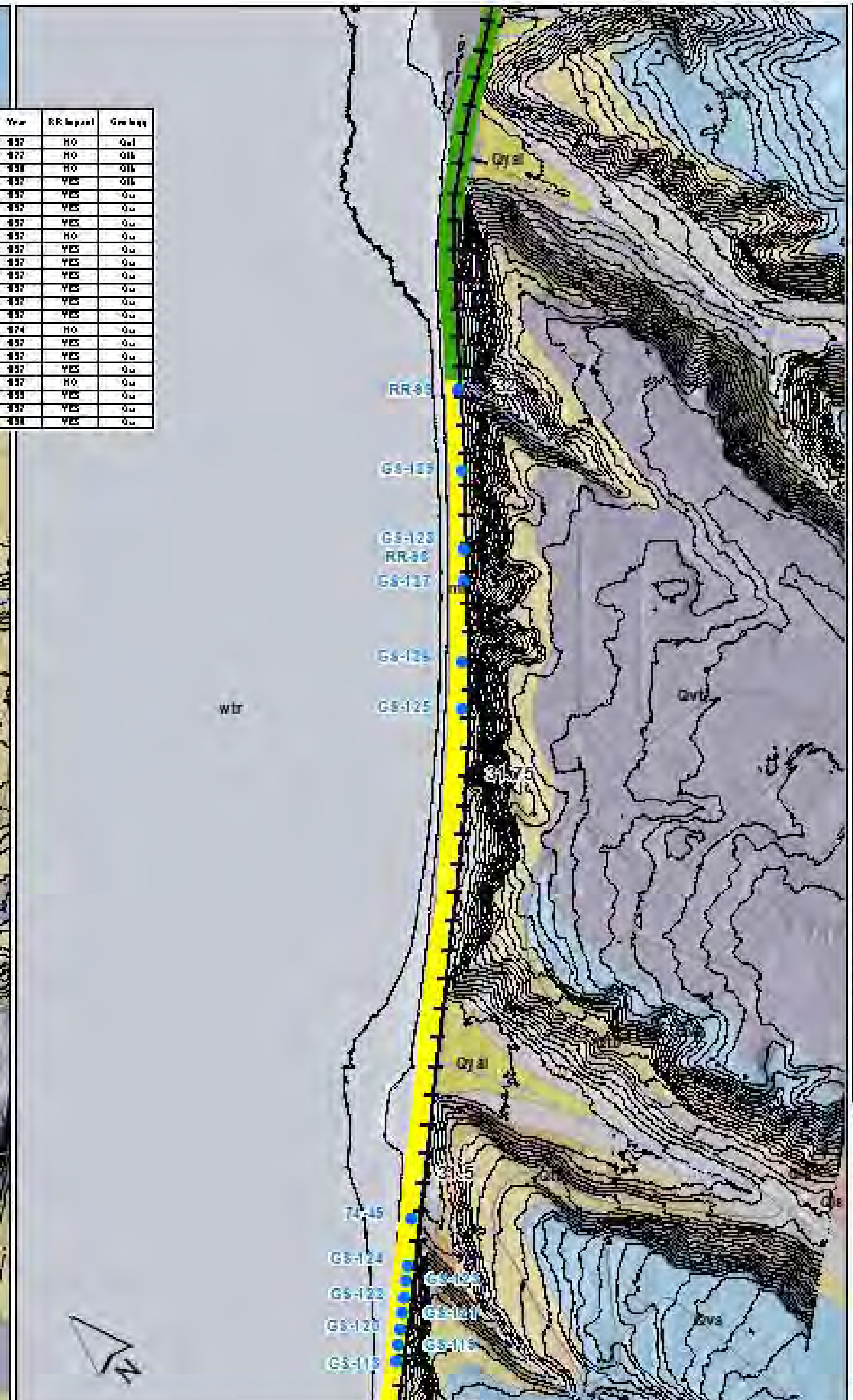
Seattle - Everette Rail Corridor
Landslide Inventory
MP 29 - 30.5

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY: Tracy Tropla DATE: October 18, 2012



Landslide ID	RR Milepost	Year	RR Impact	Geology
GS-113	30.53	1997	NO	Qal
77-18	30.54	1977	NO	Qls
SV-62	[illegible]	[illegible]	NO	Qls
GS-114	[illegible]	1997	YES	Qls
GS-115	[illegible]	1997	YES	[illegible]
GS-116	[illegible]	1997	YES	[illegible]
GS-117	[illegible]	1997	YES	[illegible]
GS-118	[illegible]	1997	NO	[illegible]
GS-119	[illegible]	1997	YES	[illegible]
GS-120	31.41	1997	YES	[illegible]
GS-121	[illegible]	1997	YES	[illegible]
GS-122	[illegible]	1997	YES	[illegible]
GS-123	[illegible]	1997	YES	[illegible]
GS-124	[illegible]	1997	YES	[illegible]
74-45	[illegible]	1974	NO	[illegible]
GS-125	[illegible]	1997	YES	[illegible]
GS-126	[illegible]	1997	YES	[illegible]
GS-127	[illegible]	1997	YES	[illegible]
GS-128	[illegible]	1997	NO	[illegible]
RR-96	[illegible]	[illegible]	YES	[illegible]
GS-129	[illegible]	1997	YES	[illegible]
RR-95	[illegible]	[illegible]	YES	[illegible]



LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density

Number of Slides (1933 - 2009) per 1/4 mile section

- <= 1
- 2 - 5
- 5 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene

- ml - modified land
- Qls - landslide deposits
- Qal - alluvium
- Qyal - younger alluvium

Pleistocene

- Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
- Qtu - till, undivided (Fraser? glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other

- wtr - water

1:24,000 Scale Geologic Mapping:
Minard, J. P., 1982, Distribution and description of geologic units in the Mukilteo quadrangle, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1438, 1 sheet, scale 1:24,000.

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1 INCH = 500 FEET

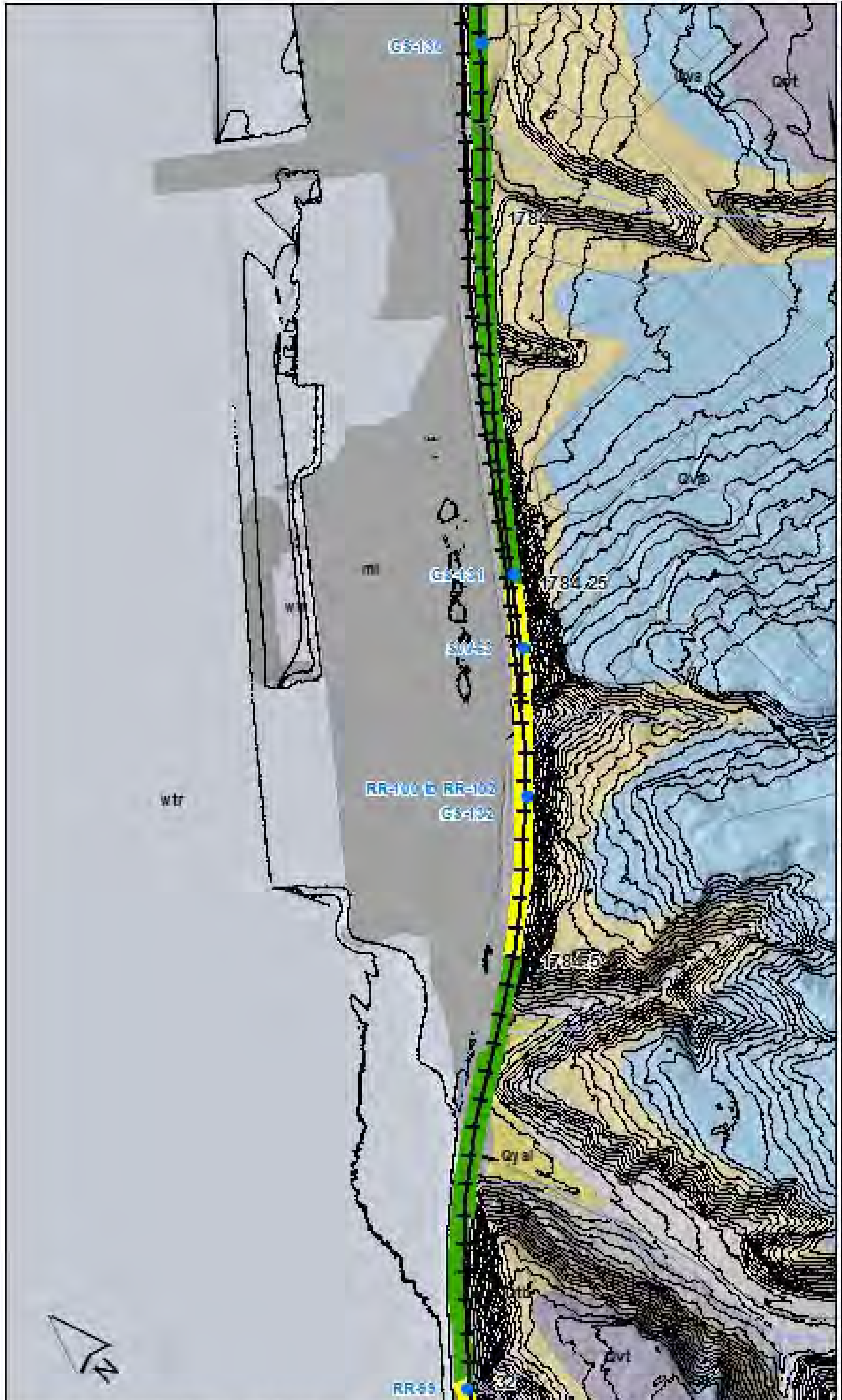
FIGURE:

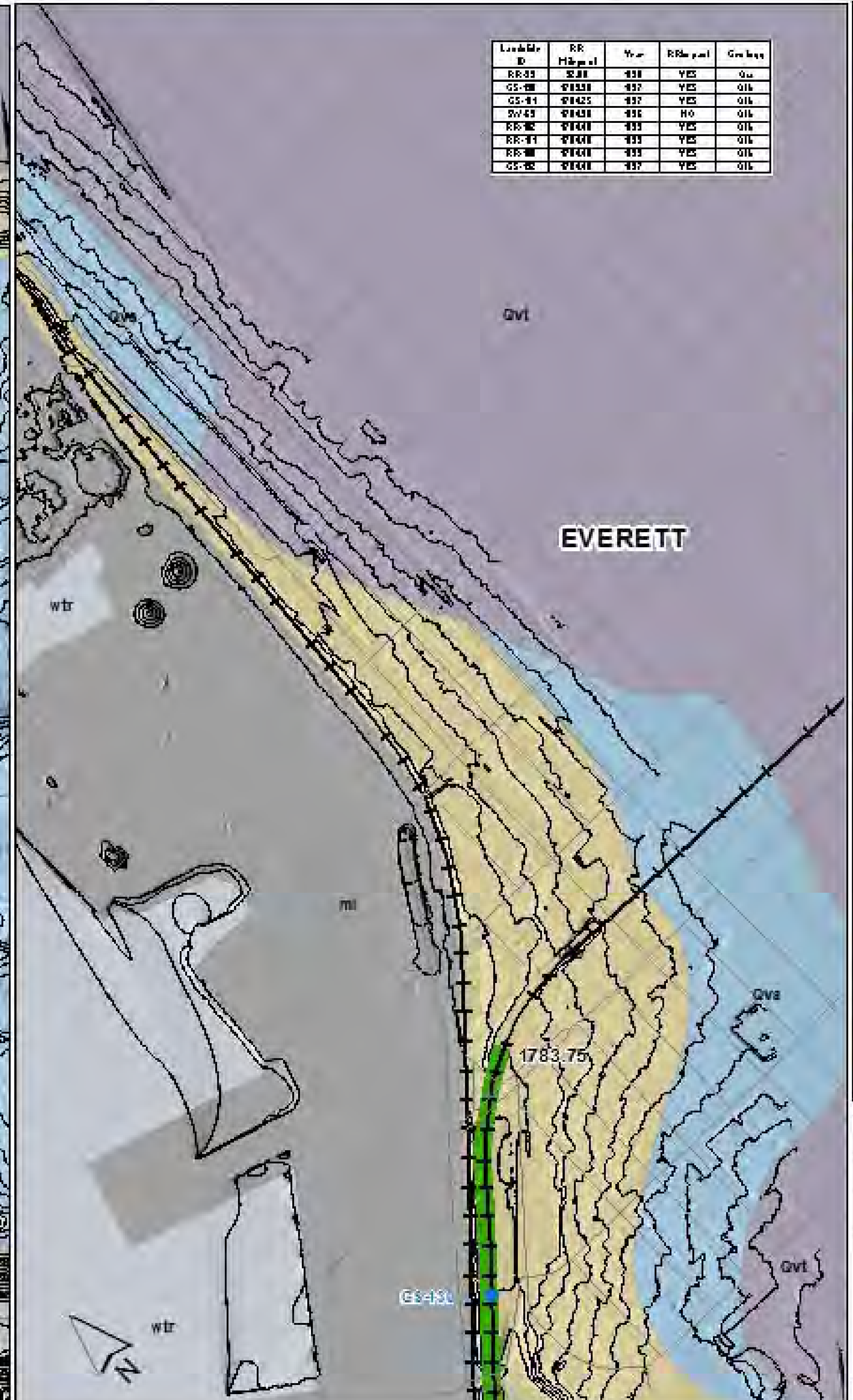
Seattle - Everett Rail Corridor
Landslide Inventory
MP 30.5 - 32

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY: Tracy Trople DATE: October 18, 2012

File Location: M:\GIS\GIS Projects\SR\071\SR001-\SR\...





Landslide ID	RR Milepost	Year	RR Impact	Geology
RR-99	32.00	1998	YES	Qw
GS-130	1783.98	1997	YES	Qtb
GS-131	1784.25	1997	YES	Qtb
SW-62	1784.38	1996	NO	Qtb
RR-102	[illegible]	1995	YES	Qtb
RR-101	[illegible]	1995	YES	Qtb
RR-100	[illegible]	1995	YES	Qtb
GS-132	[illegible]	1997	YES	Qtb

LEGEND

- Landslides - Shannon & Wilson Report, 2007
- Streets
- Railroads
- Rivers & Streams
- 10 Foot Contour

Slide Density
Number of Slides (1933 - 2009) per 1/4 mile section

- <= 1
- 2 - 5
- 5 - 10
- 10 - 20
- > 20

1:24,000 Scale Geologic Mapping

Holocene

- ml - modified land
- Qls - landslide deposits
- Qyal - younger alluvium

Pleistocene

- Qtb - transitional beds (Fraser glaciation to pre-Fraser glaciation)
- Qva - advance outwash (Vashon Drift, Fraser glaciation)
- Qvt - till (Vashon Drift, Fraser glaciation)
- Qw - Whidbey Formation (Pre-Fraser glaciation)

Other

- wtr - water

1:24,000 Scale Geologic Mapping:
Minard, J. P., 1985, Geologic map of the Everett 7.5-minute quadrangle, Snohomish County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-1748, 1 sheet, scale 1:24,000. [http://ngmdb.usgs.gov/Prodesc/proddesc_7449.htm]

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1:6,000
1 INCH = 500 FEET

FIGURE:

Seattle - Everett Rail Corridor
Landslide Inventory
MP 32 - 1783.75

Washington State Department of Transportation
GEOTECHNICAL OFFICE

PREPARED BY: Tracy Trople   DATE: October 18, 2013