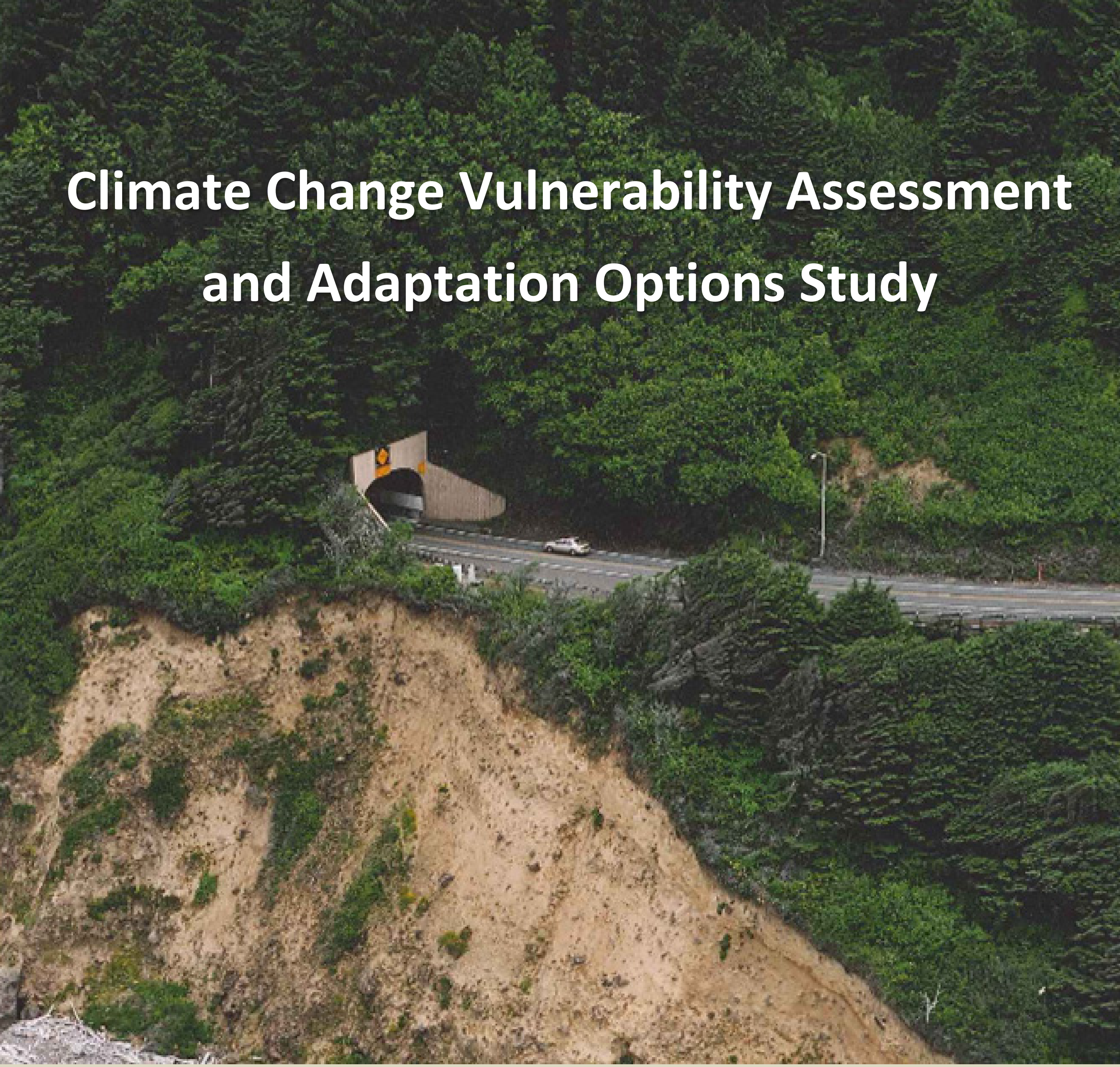
Climate Change Vulnerability Assessment and Adaptation Options Study



Final Report – December 2014

Oregon Department of Transportation

U.S. Department of Transportation
Federal Highway Administration

This report was developed by the Oregon Department of Transportation in accordance with a grant from the Federal Highway Administration (FHWA). The statements, findings, conclusions and recommendations are those of the author(s) and do not necessarily reflect the views of FHWA or the U.S. Department of Transportation.

Acknowledgments

FHWA 2013-14 Climate Change Resilience Pilot Program

In fulfillment of the match grant of Surface Transportation Research, Development and Deployment Funds as obligated by the FHWA-Oregon Division, FHWA program code M445.

This study is one of several pilots being conducted across the county focused on climate change vulnerability and adaptation strategies, and was funded in part by a Federal Highway Administration (FHWA) grant. The Oregon Department of Transportation (ODOT) greatly appreciates FHWA's funding support and guidance during the course of the pilot project.

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ODOT's pilot was guided by the Department's Adaptation Work Group. All adaptation work tasks, methods and products are reviewed by the Work Group (see page 14 for a member list).

ODOT would also like to thank the following partners for their support and guidance:

- Oregon Climate Change Research Institute
- Department of Land Conservation and Development
- Department of Geology and Mineral Industries

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Executive Summary

1 Executive Summary

The Oregon Department of Transportation (ODOT) recognizes that the State's transportation infrastructure is vulnerable to the impacts of extreme weather and climate events. To better understand and respond to these impacts, ODOT conducted a regional vulnerability assessment and adaptation options study. This pilot study identifies vulnerable highway corridors and evaluates a range of site-specific adaptation strategies that address landslides, coastal erosion, and storm surge hazards. The study was prepared with funding from the Federal Highway Administration (FHWA) Climate Change Resilience Pilot Program. FHWA's Vulnerability Assessment Framework was used to help guide our evaluation of state highways.

1.1 Approach

The pilot covers Tillamook and Clatsop counties on Oregon's north coast, within ODOT's Maintenance District 1. This area is served by ten State highway routes that run along coastal bluffs, rivers and estuaries, and across the Coast Range. Nearly 300 miles of State highways were assessed as part of the study. The project involved:

- Analysis of projected climate changes and sea level rise,
- Qualitative assessment of vulnerabilities and risks from climate impacts,
- Baseline data collection and adaptation strategies developed for high-risk sites,
- Benefit-cost analysis, and,
- Review of regulatory constraints.

ODOT conducted a workshop with maintenance and technical staff to collect climate risk information and identify priorities. Vulnerable hazard sites along north coast highways were identified using the best available climate science, existing conditions data, and known and anticipated hazards information. We ranked highway corridors and critical connections (Seismic Lifeline Routes) for vulnerability to climate impacts. Adaptation options were developed at five locations identified as vulnerable "climate hazard sites" and selected for analysis within a 25-mile Study Corridor. A benefit-cost analysis was then prepared at two sites to enable comparison between the options and inform the overall assessment. ODOT also reviewed regulatory and land use constraints that have the potential to limit the feasibility of coastal adaptation projects.

1.2 Key Findings

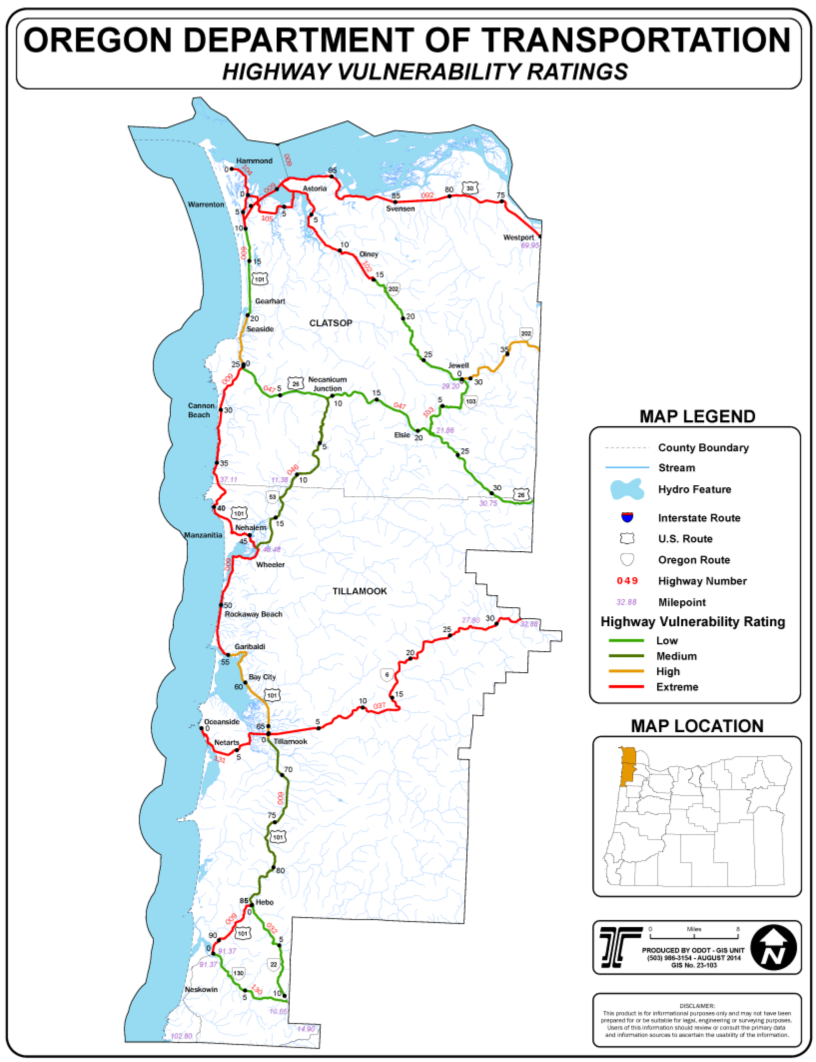
North coast highways are highly vulnerable to a wide range of climate hazards and projected impacts, specifically from extreme precipitation events, and flood and storm surge risks from higher sea levels. Climate projections point to increasing risks of damage and weather-related roadway hazards, along with increasing maintenance and operations costs. These impacts will affect maintenance cycles and decisions for when and where to invest, protect, or reconstruct roadways. These decisions are particularly complex on the coastal highways.

The most vulnerable highways were located:

- In the Coast Range (mountainous areas subject to rock fall and landslides),
- Along larger road cuts or fill slopes,
- In low-elevation areas subject to flooding (adjacent to rivers and estuaries); and,
- Coastal areas subject to storm surge and inundation from sea level rise.

The most vulnerable corridors were:

- Highway 30, Astoria to Westport,
- The lower elevation (tidally influenced) portions of Highway 202,
- Highway 101, through Warrenton and Astoria,
- Highway 101, from Cannon Beach south to Tillamook, and from Hebo junction to the Nestucca River estuary,
- Netarts highway, from Tillamook to the coast, and,
- Landslide prone areas of Highway 6, over the coast range.



Nearly all designated Seismic Lifeline Routes were found to be vulnerable to projected climate impacts. Specifically, vulnerable Tier 1 Lifeline Routes include the entirety of Highway 30 (from Westport to Astoria), and US 101 from Tillamook south to Nestucca Bay (MP 65 to 91.37).

A sea level rise mapping analysis found over 15 miles of ODOT right-of-way potentially impacted by future extreme tides and higher sea levels by 2050. Most of these impacts were in Tillamook County, however areas in and around Astoria and the Columbia River were not mapped due to lack of data. Based on the initial mapping work, many of these low-lying areas will also experience impacts from coastal inundation. While refinements are needed, ODOT's sea level rise mapping provides tangible results and products that can inform project planning and development in the near-term.

Adaptation options were developed at five hazard sites and provide a wide range of strategies and costs to mitigate potential impacts based on larger and more frequent storm events. The lower cost solutions are heavily dependent on continued maintenance support, whereas more permanent options have much higher construction costs. Additional data collection at high risk sites was identified as a need to inform project priorities, timing, and design solutions.

A benefit-cost analyses comparing options at two landslide sites found that even though the most effective design options result in some costs being avoided at the end of the analysis period, the benefits are not sufficient to justify the costs associated with implementing the adaptation actions. The availability of detour routes and lower traffic volumes (during the off-peak winter months) were found to be key factors in the BCA outcomes. The results highlight the importance of viable detour routes on the coast which kept traffic "moving", even in the case of catastrophic events and closure. Results may differ if the BCAs were to be conducted at a corridor-level, where detours are unavailable, or in more populated areas that experience higher traffic volumes.

1.3 Key Accomplishments

The pilot study gave ODOT a broader understanding of climate risks and impacts on the Oregon coast, and highlighted connections with seismic resilience planning in these same areas. We engaged the expertise of maintenance field staff which was important to help identify risks and priorities. We also used maintenance dispatch records as a means to identify and prioritize climate vulnerabilities, and engaged maintenance crews on weather-related road hazards and risks. New forms of climate data and management tools were accessed and developed, including sea level rise maps.

ODOT also developed adaptation options at high risk sites, and identified important gaps in data and historic records. As a result of these findings we used the project to collect baseline data at the Arch Cape site using ground-based LiDAR.[1] ODOT's goal will be to continue annual data collection at this site to inform erosion rates and risks to the highway.

[1] LiDAR stands for "Light Detection and Ranging" – (a technology for rapid 3-dimensional data acquisition that can be used to map, visualize, measure, and understand coastal bluff erosion processes).

Through the project, coordination between state and local agencies was enhanced on a range of issues regarding coastal adaptation planning. A case study of one of ODOT's coastal hazard mitigation projects was also prepared. The study provides context and potential pathways to address regulatory constraints that may limit the efficacy of certain adaptation actions.

1.4 Priority Actions and Next Steps

ODOT's pilot study was a valuable test of assessment methods for common coastal hazards that will likely worsen with the effects of climate change. The findings and lessons learned from the project will help inform priorities for future adaptation planning and assessments, data collection, and program guidance. ODOT's Adaptation Work Group recommends the following implementation priorities:

- Implement a program for data monitoring and research at high-risk sites; this includes a long-term monitoring strategy at the Arch Cape coastal erosion site.
- Develop a strategy for project review guidance using sea level rise GIS mapping.
- Integrate adaptation with other hazards resilience planning efforts; investigate opportunities to prioritize adaptation planning in Lifeline Routes most vulnerable to climate impacts.
- Formalize detour routes in priority corridors: viable detour routes are essential to system resilience; use the seismic lifeline identification study as a starting place for this effort.

This study helps address goals and policies to build system resilience, provide cost-effective investments, and minimize long-term economic costs stemming from climate change impacts. The project goals are consistent with Oregon Transportation Plan sustainability strategies.

Information gained from this pilot will inform best practices in how we manage the transportation system in order to adapt to changing conditions. Adaptation planning will help ODOT prioritize its next steps to reduce the vulnerability and increase the resilience of its infrastructure and operations. The results of the study will be presented to ODOT's executive management and Sustainability Council, and used to make decisions regarding future implementation and priorities.

2 Introduction

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2 Introduction

ODOT recognizes that Oregon's transportation infrastructure and systems are vulnerable to the impacts of extreme weather and climate events. ODOT is responsible for more than 19,000 lane miles of state highway, 2,700 bridges, thousands of culverts, and other critical infrastructure. This infrastructure is potentially vulnerable to the impacts of climate change, such as increased incidence of landslides, flooding, coastal erosion, and wildfires.

Climate change will impact the way ODOT does business, potentially impacting the way the agency plans and develops projects and responds to emergencies. Adaptation planning will help ODOT prioritize its next steps to reduce the vulnerability and increase the resilience of its infrastructure and operations.

2.1 Background and Purpose

A section of U.S. 101 failed south of Gold Beach after extreme storms in March 2012.

ODOT has been engaged in climate change adaptation planning since 2008. ODOT participated in [Oregon's Climate Change Adaptation Framework], published in December 2010. This interagency Framework outlines anticipated climate-related risks, short-term priority actions, and longer-term steps to build adaptive capacity. In 2011, ODOT worked with scientists from the Oregon Climate Change Research Institute (OCCRI) to take a closer look at impacts specific to the transportation system. OCCRI is a part of the Oregon University System and by statute is the authority on climate science in Oregon. Based on input from OCRRI and ODOT's experience in the field, ODOT published its [Climate Change Adaptation Strategy Report] in April of 2012, which received the Oregon Transportation Commission's approval.

The Adaptation Strategy provides a preliminary assessment of climate change impacts on our assets and system operations, and underlines the need for vulnerability assessments and a long-term adaptation plan. The Strategy also highlights potential adaptation measures and existing adaptive capacity within ODOT.

ODOT's adaptation planning is supported by the agency's Sustainability Council, Sustainability Executive Committee, and Adaptation Work Group. ODOT's Director established the crossdiscipline Sustainability Council to provide leadership for the agency on sustainability measures and practices. The Sustainability Executive Committee approves all sustainability plans and policies, and is made up of ODOT executive, government relations and communications managers.

Adaptation Work Group

ODOT's pilot project was guided by the Adaptation Work Group. This group was formed in early 2012 to help steer the agency's overall adaptation planning efforts. The Work Group is made up of experts from asset management, Geographic Information Systems (GIS), planning, geology, and other programs. All adaptation pilot work tasks, methods and products were reviewed by the Work Group. Group members include:

- Paul Wirfs, Deputy Geo-Environmental Section (GES) Manager, Technical Services
- Curran Mohney, Geology Program Leader, GES, Technical Services
- Nancy Murphy, Principal Planner, Transportation Planning, Transportation Development Division (TDD)
- Dave Ringeisen, Transportation Data Manager, TDD
- Brett Juul, GIS Unit Manager, TDD
- Phil Smith, GIS Environmental Manager, TDD
- Laura Wipper, Asset Management Integration Section Manager, Technical Services
- Bert Hartman, Bridge Program Managing Engineer, Technical Services
- Steve Lindland, Roadway Engineering Unit Manager, Technical Services
- Geoff Crook, Sustainability Program Manager, Statewide Programs Unit, TDD
- Patti Caswell, Environmental Manager, Maintenance and Operations Branch

Why pursue a regional adaptation pilot?

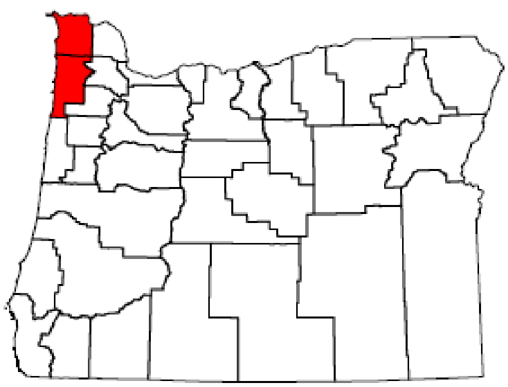
In 2012, ODOT began to collect data and plan its approach for a statewide vulnerability assessment. Later that year, we opted to pursue a regional approach through the FHWA pilot program. A regional focus on the Oregon coast allowed us to test assessment methods and adaptation strategies on a more manageable set of assets and risks, while taking on assessment and site-level strategies at the same time. The pilot is an opportunity to develop a range of (prototype) solutions to a common set of coastal hazards that will likely worsen with the effects of climate change.

A regional pilot also helps bring local knowledge into the planning process and allows for the development of adaptation approaches that best fit the local context for where risks are located and most vulnerable to extreme weather events.

ODOT's pilot followed the FHWA's Climate Change and Extreme Weather Vulnerability Framework. The results of this pilot project will help further the state of the practice and guide future climate assessments and adaptation planning on a statewide basis. The work we do now will help inform future guidance to protect public transportation investments from climate conditions now and into the future.

2.2 Project Scope

Climate change models are projecting more concentrated rainfall events and extreme storms in Oregon by mid-century, along with higher seas and storm surge. Some of the most severe impacts from these changes will be felt on the North Coast. This part of the coast is a rugged and highly mountainous area with steep slopes in the Coast Range and with miles of unstable cliffs and bluffs along the coastal highway routes. Along coastal Highway 101, the roadway relies on hundreds of bridges and culverts to cross streams, rivers and estuaries that are vulnerable to sea level rise and coastal erosion. This area experiences a relatively high number of natural hazards and some of the highest rainfall totals in the state.



North Coast Pilot Study Area

Larger and more frequent precipitation and storm events will greatly increase the risk of landslides and rock falls, flooding and erosion along these routes. These events often force road closures in the proposed pilot area, as witnessed in December 2007, when all roads to the northern coast were closed due to weather related hazards, isolating cities from Tillamook to Astoria. ODOT has responded to a number of emergency hazards and Disaster Declarations in this area over the last 15 years.

The project covers ODOT's Maintenance District 1. The assessment covers a two-county area focused on state-owned highways in Tillamook and Clatsop counties. This area is served by ten (10) state highway routes that run along coastal bluffs, rivers and estuaries, and across the Coast Range. Highway corridors in this area serve as vital connections between communities, and from coastal towns to larger cities, services and economic centers (such as Portland and Salem) to the east and southeast.

Over 293 miles of State highways were assessed as part of the study. Adaptation options were developed at five locations identified as vulnerable "climate hazard sites" and were selected for analysis within a 25 mile Study Corridor. A benefit-cost analysis was conducted at two sites to enable comparison between the options and inform the overall assessment. ODOT also reviewed regulatory and land use constraints that have the potential to seriously limit the range of options for coastal adaptation projects.

The adaptation study was developed with the following caveats:

- This study includes a corridor-level vulnerability assessment and adaptation options study—and is not a traditional risk assessment as the data required for that type of study is not currently available. Although the *consequences* of climate impacts were captured and rated for various sites during the maintenance workshop, we did not assign specific *probabilities* to the impacts reviewed.
- ODOT only assessed its highway rights-of-way, and so ancillary and supporting facilities such as maintenance stations or other facilities were not directly assessed.
- The adaptation options study focuses on concepts that may provide decision makers with cost-comparisons and potential strategies for building resilience in the system. This is high level analysis intended to guide future work or planning that would need to be performed at a finer resolution for particular assets or facilities.
- Adaptation options presented in the report should not be considered recommendations. In most cases these options would require supplemental data to inform longer-term solutions, and more detailed costs and benefits related to the specific options considered.

2.3 Project Goals

The overall goal of the pilot is to conduct a regional vulnerability assessment and coastal adaptation options study. Findings and conclusions from the project will inform ODOT's future adaptation planning, program guidance, and climate risk assessments.

Rock fall scaling on Neahkahnie Mountain above U.S. 101 north of Manzanita.

Through the pilot the agency met the following objectives:

- Conduct a workshop with ODOT maintenance and technical staff to collect climate risk information and identify priorities.
- Identify vulnerable assets based on the best available climate science, existing conditions, and known and anticipated hazards information.

- Rank highway corridors and Lifeline Routes for vulnerability to climate impacts.
- Prioritize a Study Corridor for more detailed analysis.
- Identify areas to mitigate hazards and build resiliency based on engineering and technical reviews.
- Develop a set of adaptation options and a benefit-cost analysis for vulnerable infrastructure.
- Collaborate with state and local agencies planning for resilience to natural hazards on the north coast.

The project goals are consistent with Oregon Transportation Plan sustainability strategies and policy priorities to preserve and maintain the existing system. The project also addresses ODOT's goals for building system resilience, providing for cost-effective investments, and minimizing long-term economic costs.

2.4 Partners and Regional Stakeholders

One of ODOT's project goals is to partner with local, state, and federal agencies on new approaches to transportation hazard assessments that take into account climate change science. The department is striving to learn from the expertise and experiences from these agencies and is participating in other adaptation-related pilots on the North Coast. Key partnerships are described below.

Oregon State University (OSU) and the Oregon Climate Change Research Institute (OCCRI)

OCCRI is lead in the state of Oregon for conducting climate research and assessments, and produces biennial climate assessments. Based out of OSU, OCCRI's climate experts encouraged ODOT to use the most recent downscaled global climate models. In a first for ODOT, we began working directly with this climate data and downloaded a series of datasets from the fifth iteration of the coupled model inter-comparison project (CMIP5), available through the University of Idaho download portal. ODOT coordinated with OCCRI regarding best practices for the use and presentation of climate data.

- OSU is leading a project called Envision: Tillamook County Coastal Futures, a scenario planning exercise that models coastal process outcomes and land use changes considering climate change and higher sea levels.

Oregon Department of Geology, Minerals and Industry (DOGAMI)

DOGAMI is Oregon's lead agency on geology (landslide mapping and risks), coastal processes, hazards assessment and mapping, and sea level rise. For the adaptation pilot, ODOT worked with DOGAMI to understand available data for selected coastal sites, and also to obtain county-specific tidal data, an extreme value analysis, and other key assumptions used to develop sea level rise maps.

Oregon Department of Land Conservation and Development (DLCD)

DLCD administers the state land use program and oversees the Oregon Coastal Management Program (OCMP). A focus of the OCMP is to assist local communities with coastal hazards and resilience planning. OCMP also works with cities and counties to address climate change adaptation in their local planning. DLCD is managing two resilience pilots on the North Coast:

- The North Coast Adaptation Alignment project is working to share information, identify research gaps and planning needs, and establish a regional adaptation policy framework for use by public agencies. The project has helped foster coordination between local, state and federal agencies on a range of climate change adaptation issues across sectors.
- DLCD is also leading a Community Resilience Network Pilot on the north coast. This climate change and seismic hazards planning effort is focused on several North Coast communities, including Cannon Beach, Seaside, and Clatsop County, and is facilitated by the Oregon Partnership for Disaster Resilience.

Local Partners and Stakeholders

Local partners were engaged in the project through various outreach efforts. ODOT participated in the coastal adaptation pilots noted above and reached out to the County Public Works Directors for Tillamook and Clatsop counties for input.

We also presented to the Northwest Area Commission on Transportation (NWACT), made up of county and city leaders and members of ODOT's Region 2. The NWACT has 29 voting members from local cities, counties, transportation districts and tribal and public interests. [2]

[2] Area Commissions on Transportation are advisory bodies chartered by the Oregon Transportation Commission. ACTs address all aspects of transportation, with primary focus on the state transportation system. ACTs play a key advisory role in the development of, and priority setting for the Statewide Transportation Improvement Program (STIP), which schedules funded transportation projects.

The Project Team stayed engaged with ODOT's Region 2, Maintenance District 1, and the Adaptation Work Group. Presentations about the pilot were given to the Department's Asset Management Team, Maintenance Leadership Team, and Sustainability Council. In addition, presentations were given at other forums that reached internal staff, management and interested parties, such as at the 2013 ODOT Planner's Workshop, and the 2014 AASHTO Standing Committee on the Environment (SCOE) Conference in Portland, Oregon.

ODOT's pilot has the support of the agency's Sustainability Council, Sustainability Executive Committee, and the Oregon Transportation Commission.

3 Approach

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This section outlines the methods taken to collect and analyze data for the vulnerability assessment and for developing adaptation options for selected sites. The approach taken for these two distinct phases of the study are described below.

3.1 Data Gathering and Analysis - Vulnerability Assessment

ODOT conducted an assessment to identify, quantify and prioritize vulnerable areas along Oregon's north coast highways. We closely followed the methodology as outlined in FHWA's Vulnerability Assessment Framework and conceptual model, and refined our approach to meet agency objectives.

The focus of ODOT's assessment is to:

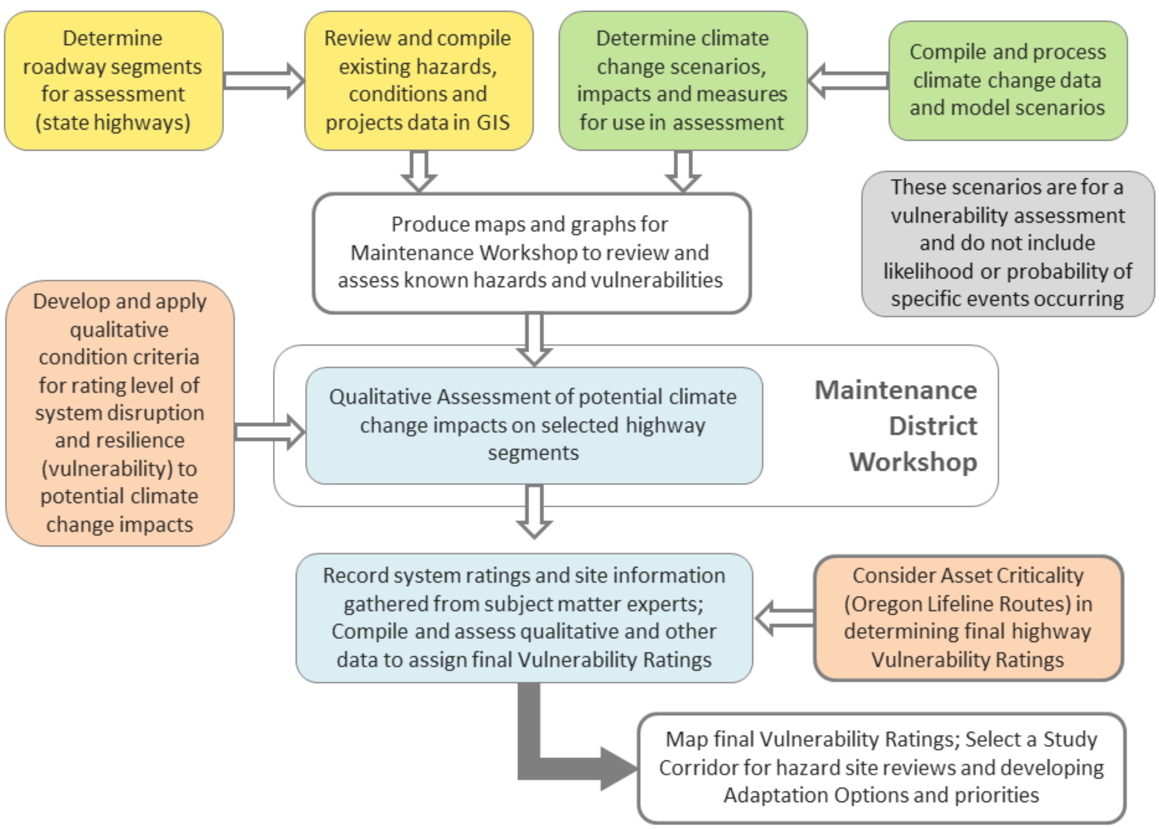
1. Develop an inventory of assets, hazards and roadway conditions;
2. Gather climate information; and,
3. Assess a range of vulnerabilities to the transportation system from projected climate change and future sea levels.

The project team collected data and results from these various steps, and where applicable, loaded this into ODOT's Geographic Information System (GIS) for mapping and analysis. ODOT used an online ArcMap product so that team members and others could view results and access and interact with the map layers. The assessment involved the following steps:

- **Inventory and Select Relevant Assets**: The project team reviewed assets for assessment within the north coast, two-county Study Area.
- **Compile Existing Conditions Data:** The project team reviewed and compiled asset conditions, hazards data, and ODOTs' project data in the GIS.
- **Assess Future Climate Impacts**: Future climate and extreme weather impacts were reviewed for their potential impacts on selected assets. This was completed through compiling and processing climate change data and model scenarios, and determining what climate change impacts and measures to use in the assessment.
- **Produce Maps and Graphs**: Maps and data were prepared for presentation at a District level Maintenance Workshop.
- **Hold Maintenance Workshop**: An interactive maintenance workshop was held as a qualitative assessment of potential climate change impacts on north coast highways. Members of the local maintenance crew are subject matter experts with important information about known hazards locations and potential system vulnerabilities.

- **Apply Vulnerability Ratings**: A set of qualitative condition and rating criteria were developed and applied to rate level of system disruption and resilience (vulnerability) to potential climate change impacts. The system ratings were applied to discrete highway corridors and combined site information gathered from subject matter experts with GIS data analysis.
- **Consider Asset Criticality**: ODOT's "Lifeline Routes" were compared with the final highway Vulnerability Ratings to consider potential impacts on those coastal highways most important to population centers, emergency response, and economic and regional connectivity.
- **Select a Study Corridor and Adaptation Sites**: Information captured through the vulnerability assessment was used to select a Study Corridor for further analysis of specific adaptation sites, options and priorities.

Figure 1 – ODOT Assessment Approach



Asset Inventory and Selection

The Project Scope was limited in geography to Oregon's North Coast (maintenance District 1) and focused on twelve (12) state state-owned highway corridors in Tillamook and Clatsop counties. All together, the roadways selected for the assessment total nearly 294 miles. There are 129 state highway bridges and 72 culverts in Clatsop County. In Tillamook County, ODOT manages 86 state highway bridges and 81 culverts.[3]

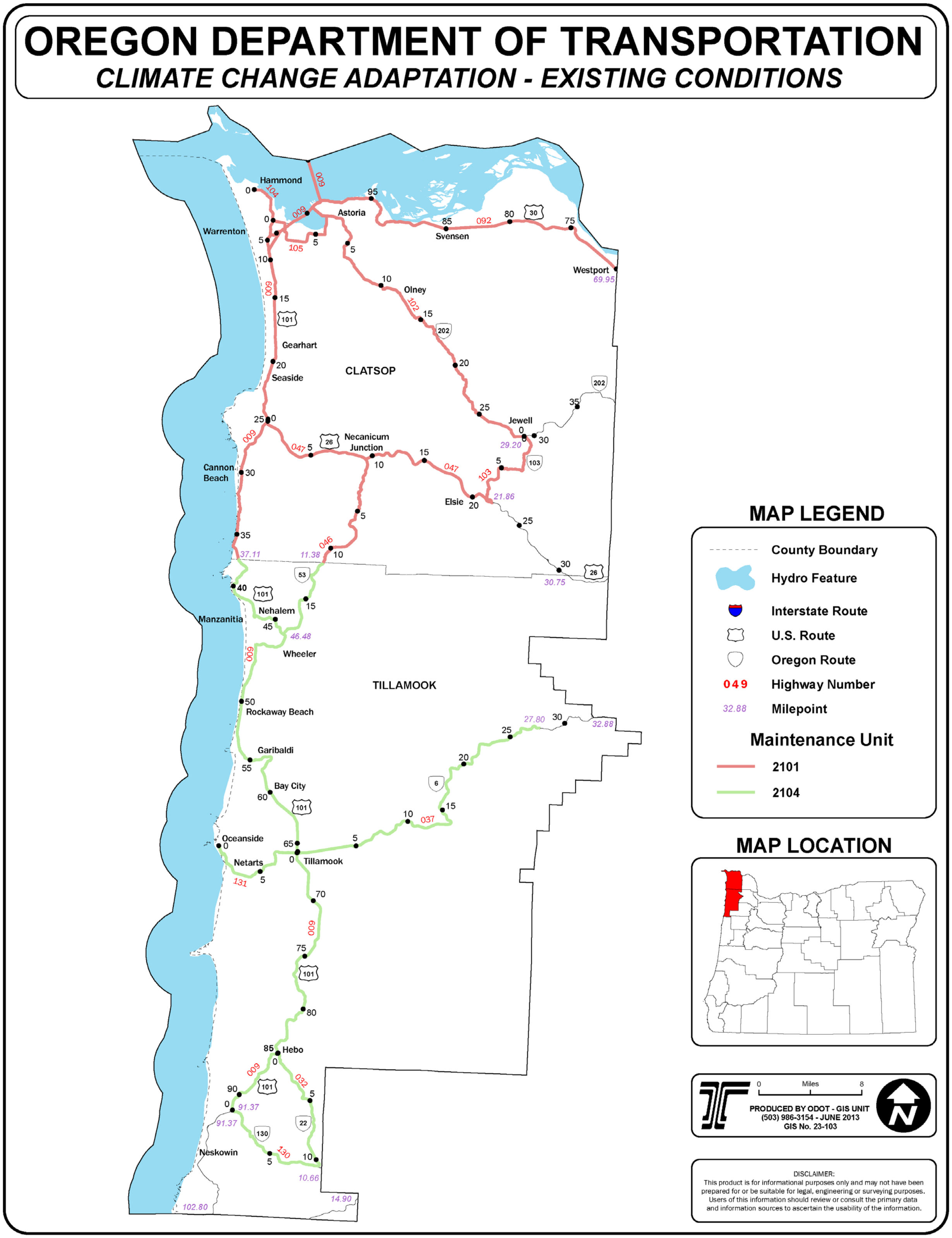
Highway 101 is the primary north-south corridor along the coast, while Highway 30 and 26 provide the primary means of east-west travel. All of ODOT's roadways, bridges and culverts are included in the agency's GIS data for mapping and analysis. Assets were not scanned individually, instead projected climate hazards and potential "high risk sites" were evaluated for their potential impacts to roadway function and travel conditions on a corridor basis. The highway corridors reviewed are outlined in Table 1.

Table 1 – Asset Inventory: ODOT District 1 Highway Corridors

State Highway Route	Beg. MP	End MP	Total Mileage	Route Description
6	0	32.88	32.88	Wilson River Highway- Tillamook to County Line
22	0	10.66	10.66	Three Rivers Highway- Hebo to 130 junction
26	0	34.16	34.16	Sunset Highway- County line to Highway 101
30	69.95	99.34	29.39	Lower Columbia River Highway- Clatsop County line to Astoria
53	0	19.03	19.03	Necanicum Highway- Necanicum Junction to 101
101	4	91.37	87.37	Coast Highway- Astoria to 6 miles south of Hebo
101B	0	7.25	7.25	Coast Highway- 101 Junction to Astoria
103	0	9.02	9.02	Fishhawk Falls- Sunset Highway to Jewell (Highway 202)
104	0	6.03	6.03	Fort Stevens Highway- Hammond to Warrenton
130	0	9.3	9.30	Little Nestucca- Highway 101 to 22 junction
131	0	9.8	9.80	Netarts Highway- Tillamook to Oceanside
202	.18	39.13	38.95	Nehalem Highway- Astoria to Clastsop County Line
Total Highway Mileage			293.84	

[3] State of Oregon Natural Hazards Mitigation Plan (February 2012).

Figure 2 –Adaptation Pilot Study Area



3.2 Climate Data Integration

ODOT researched climate trends and projections and their potential impacts on transportation infrastructure. Climate data was collected from several sources, including downscaled global climate models (GCM), data from regional climate studies and assessments, storm event thresholds tied to ODOT's own maintenance dispatch records, sea level rise projections, coastal erosion rates, and other data where available.[4] A series of GIS data layers for sea level rise were developed in coordination with the Oregon Coastal Management Program.

We used downscaled climate data that were processed at a statewide level and analyzed within regional climate zones. We also used a climate data processing tool to inform our study when looking at specific adaptation sites on the North Coast.

The climate variables reviewed were for temperature (projected minimum and maximum annual average temperature extremes), and precipitation (annual average rainfall trends and extremes). Sea level rise and non-tidal residual wave action (such as storm surge) were also considered as part of the project and are discussed further below.

Downscaled Global Climate Data

GCM data was used to identify potential future climate changes that may impact transportation infrastructure. We were advised by experts at the Oregon Climate Change Research Institute (OCCRI) on best practices and methods for developing climate measures and working with variables within the climate models.

ODOT relied on the Coupled Model Inter-Comparison Project phase 5 (CMIP5) statistically downscaled model ensemble for the Western U.S., acquired through the University of Idaho.[5] The regional downscaled data comprised 14 GCMs.[6] Model files for the daily values of two climate variables (precipitation, maximum near-surface air temperature) were downloaded for analysis. Precipitation events have the most potential for impacts on North Coast highways due to the related hazards, such as flooding, high water, landslides, rock fall, and coastal erosion.

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[4] Data sources include the International Panel on Climate Change (IPCC), the National Research Council (NRC), and the National Oceanic and Atmospheric Administration (NOAA). OCCRI developed regional climate assessments in 2010 and 2013. ODOT's Transportation Operations Center provided incident dispatch records. Data for coastal processes, including extreme value analysis for future sea levels was provided by DOGAMI.

[5] Multivariate Adaptive Constructed Analogs (MACA) Statistical Downscaling Method. University of Idaho.

[6] Global Climate Models used: bcc-csm1-1, BNU-ESM, CanESM2, CNRM-CM5, CSIRO-Mk3-6-0, GFDL-ESM2G, GFDL-ESM2M, HadGEM2-CC, HadGEM2-ES, inmcm4, MIROC5, MIROC-ESM, MIROC-ESM-CHEM, MRI-CGCM3.

Climate data was allocated in the National Oceanic and Atmospheric Administration's (NOAA) regional "climate zones" and then variables were analyzed individually for their potential impacts on the transportation system. Results were processed (in house by ODOT) using the "R" programming language. All of the procedural steps were carried out by five separate scripts.

OCCRI advised ODOT staff to compute the measures for each season and average the seasonal measures over 30-year periods to show the average climate response for the measure. To enable a comparison against past and potential future trends, multiple climate models were downloaded for "mid-range" and "worst-case" emissions scenarios.[7]

Data were downloaded for the following time periods for analysis:

- Historic - (1976-2005)
- Near Term - (2006-2035)
- Long Term - (2036-2065)

Once the average measures were computed for one model, the results were averaged over all models. From these datasets maps and graphs were created to show the difference in average seasonal precipitation and temperature for each of the models and emissions scenarios. Measures were mapped and graphed to present the difference in average seasonal projections over the two (30-year) near and long-term timeframes.

The following measures were computed:

- Average precipitation
- Maximum 1-day precipitation
- Maximum 2-day precipitation
- Maximum 5-day precipitation
- Number of days with maximum temperatures exceeding 100 degrees (Fahrenheit).

Results of the analysis were useful in understanding the magnitude of projected changes relative to the measures, and for comparison with results from other regional climate assessments and studies.

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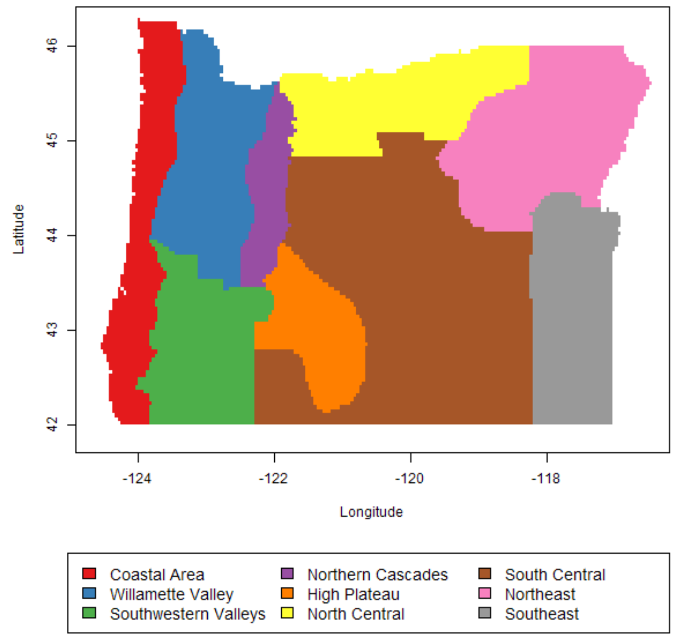
[7] Two emissions scenarios or Representative Concentration Pathways (RCP) were selected for analysis (RCP 4.5 and RCP 8.5). RCPs relate to the radiative forcing at play under the scenario (i.e. difference between solar energy hitting the earth and the amount being radiated back into space). The RCP 8.5 scenario assumes higher radiative forcing, and thus more global warming, due to higher levels of greenhouse gas (GHG) emissions.

Figure 3 –NOAA Climate Divisions



Climate Data Processing Tool

ODOT also used a Climate Data Processing Tool to analyze projected climate impacts at selected sites within a project Study Corridor.[8] An advantage of this tool was the ability to quickly focus downscaled data into a smaller geographic area within a predefined grid and reporting format. In this case we generated two data runs over 12 kilometer square grids covering the five adaptation pilot project sites. We used the CMIP5 climate model ensemble for the analysis with precipitation as our climate variable.

Results from this analysis helped show how "extreme" rainfall events are projected to increase in their frequency and magnitude as compared with historic trends at these locations. This informed our site analysis and benefit-cost assumptions for potential recurring damage and long-term maintenance at the hazard sites.

Sea Level Rise

ODOT used GIS to analyze and map projected sea level rise within the pilot study area. We initially relied on NOAA's "Sea Level and Coastal Flooding Impacts Viewer," an online tool that

[8] The CMIP climate data processing tool is an Excel-based model provided by FHWA that utilizes best available climate model information for use in transportation planning.

allows users to simulate coastal flooding events based on various sea level elevations.[9] This tool was helpful during our Maintenance workshop, since more detailed GIS mapping was not complete at that time. Vulnerable areas subject to coastal flooding or storm surge were identified as "climate hazard sites" by the maintenance crews.

The project team also developed inundation maps to screen coastal highways and determine the extent of potential right-of-way impacts. The primary data layer used for the analysis represents a mid-century sea level rise projection, and includes a locally derived "extreme value analysis" based on a 40-year tide gage time series for Tillamook and Clatsop Counties. This analysis accounts for variations in extreme high tides, storm surge, and other factors that influence high sea levels and coastal flooding. Maps were not generated for the entire coast, instead a GIS tool was used to analyze potential impact areas within the Study Area.

The source for SLR projections was the West Coast study conducted by the National Research Council.[10] The NRC West Coast projections are based on a "mid-range" emissions scenario. ODOT's primary analysis used the high-end of the range for the 2050 projection. This scenario assumes .48 meters (nearly 19-inches) of sea level rise by mid-century. Inundation areas for the year 2100 were also generated in the GIS at select locations.

Table 2 – Projected Sea Level Rise in Oregon

2050 Mid-range	2050 High-range	2100 Mid-range	2100 High-range
17 cm (6.69-inches)	48 cm (18.89-inches)	63 cm (24.8-inches)	143 cm (56.29-inches)

Source: National Research Council, West Coast Report (2012).

ODOT partnered with the Oregon Coastal Management Program and DOGAMI for GIS and data support. More detail on ODOT's approach to mapping sea level rise can be found in Appendix A.

3.3 Existing Assets, Hazards and Conditions

ODOT focused its assessment on state owned highways and included the following spatial data in the project GIS: scour critical bridges, culverts, hydrography, and maintenance facilities. Aerial photos and LiDAR were also available for review of low elevation areas, steep drainages and landslides.[11]

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[9] https://coast.noaa.gov/digitalcoast/tools/slr

[10] Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future (National Research Council, 2012).

[11] **LiDAR** stands for "light detection and ranging." LiDAR is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light.

Natural Hazards

Location and extent of known natural hazards were reviewed as part of the assessment. ODOT reviewed data from its Unstable Slopes Program[12] for which landslide and rock fall locations are mapped. These sites have been assigned hazard ratings of low, medium and high hazard. A Coastal Erosion data layer was obtained from DOGAMI which also includes a four-tiered hazard rating comprising low, medium, high and active hazard zones. ODOT also worked with District 1 maintenance to obtain information and identify hazard areas as part of the local maintenance workshop.

Maintenance Dispatch Records

The project team reviewed and analyzed Transportation Operations Center (TOCS) dispatch center data that was filtered and analyzed for weather-related hazards and incident response calls received by the local maintenance crews. The data reflects over three years (and four winters) worth of dispatch calls and weather warnings—from September 10, 2009 to April 8, 2013.

The data was screened for weather-related incidents on District 1 highways to include:

- Erosion
- Flood
- High Water
- Landslide
- Road Surface Collapse
- Rock Fall
- Debris Flow and Flood Warnings

Thousands of response records were scrubbed so that duplicate entries for a single event were minimized to the extent possible. We ended up with 442 total incidents for both single mile-points and discrete stretches of highway where maintenance crews were active.

Importantly, this data showed the project team when and where maintenance was actively responding to various types of weather related hazards. The results allowed us to produce maps showing areas of recurring hazard activity and "hot spots," particularly for flooding, high water and landslides common on the North Coast.

Weather data from the Western Regional Climate Center was also collected to correspond to specific dates of the various incident response actions. With this information we were able to

[12] The Unstable Slopes Program is a comprehensive database of landslides and rock fall sites along state highways that are ranked for a relative hazard rating and project score.

graph rainfall totals over 24-hours and over 5-day increments that triggered roadway hazards such as high water and rock fall activity.

Current Project Priorities

The Project Team reviewed the region's scoping list for projects programmed in the 2016-18 Statewide Transportation Improvement Program (STIP). There were very few projects that related to the purposes of the assessment and adaptation plan. The Region's geo-hydro unit also made available its Priority Landslides and Rock Fall project list from the draft STIP. Information from this list was incorporated into the GIS for mapping and analysis. Results helped to reinforce locations where individual problem areas were identified through other sources such as dispatch call records and the maintenance workshop.

3.4 Maintenance District Workshop

ODOT conducted a qualitative review of highway system vulnerability. The project team held a workshop with District 1 maintenance crews in Astoria, Oregon. Through a mapping exercise, potential future problem areas were identified for each highway segment. The goal was to capture information about where the most vulnerable assets and risks are located, and rate and prioritize future hazard areas along district highways.

The project team presented information about historic and future climate projections, including the potential for more extreme storm events (rainfall) and an increase in sea level rise by 2050. Key findings and maps from regional climate assessments and model results were presented. The team presented a "web-based" GIS mapping application with existing condition data layers, including locations of known hazards, weather-related incident response, and future sea levels.

The Silverpoint landslide as seen from U.S. 101 south of Cannon Beach.

With this information the crews identified known and probable hazards and hot spots in their areas, and were prompted to consider site exposure, sensitivity and resilience to the climate impacts presented. The resulting "Climate Hazard Sites" were recorded on large wall maps to identify priority sites and risks. The sites were rated for how future climate hazards might impact asset condition and function using a scale presented by the project team. Information was recorded using maps and spreadsheets for hazard locations and descriptions of potential asset conditions and level of disruption.

Asset Condition Ratings

During the maintenance workshop, hazard locations were identified and rated – "Good, Fair, Poor, or Critical"- based on anticipated levels of disruption to the transportation system. A rating system was developed for the exercise and was applied to various sites by the workshop participants.

Highway corridors were later scored and rated using a range of existing conditions data and the results from the maintenance workshop.

Criteria used to identify vulnerability and rate the corridors include:

- TOCS (dispatch records) weather-related hazard incidents
- Unstable slopes (with High Hazard landslide/ rock fall ratings)
- Low-elevation coastal hazards (vulnerable to higher sea levels)
- FEMA 100-year flood zone A
- Region 2 Landslide and Rock fall Priorities
- Number and rating of climate impact hazard sites identified in the maintenance workshop.

Highway corridors were rated with a Low, Medium, High or Extreme rating based on the results of the scoring. Corridors with potential climate hazards deemed "Critical" through the workshop process (i.e., potential for a complete loss or failure of the asset) were ranked and mapped with an "Extreme" vulnerability rating.

Asset data reviewed included maintenance dispatch records, repair frequencies and costs, as-built plans, geology and engineering design reports, historic photos and maps, and regulatory drivers and constraints.

ASSET CONDITION RATINGS AND LEVEL OF DISRUPTION

The following ratings were used during the qualitative assessment process to identify potential asset conditions and levels of disruption under potential future climate conditions.

GOOD

Low Vulnerability – (Full or Slightly Limited Use)
Results in little or negligible impact to assets. Repair of the asset is needed, but can work around it.
Asset has immediate limited use still available.
"Reduced capacity" typically involves:

- less convenient travel
- occasional/ brief lane closures, but roads remain open

FAIR

Medium Vulnerability – (Minor Operational Failure)
Results in minor damage and/ or disruption to asset. Asset would be available after a closure for repair.
A minor and temporary operational failure typically involves:

- temporary road closure, lasting hours to days
- lengthy lane closures (beyond 10 days)

POOR

High Vulnerability – (Major Operational Failure)
Results in major damage and/ or disruption to asset. Asset would be available after a closure for repair.
A major and temporary operational failure typically involves:

- temporary road closure, lasting weeks
- reduced access to destinations served by the asset

CRITICAL

Extreme Vulnerability – (Complete Failure or Loss)
Results in total loss or ruin of asset. Asset would require complete repair or reconstruction, and possibly relocation for a rebuild. A complete and/or catastrophic failure typically involves:

- immediate road closure, lasting months to years
- travel disruptions and rerouting to other roads

3.5 Defining Critical Assets

Critical assets are of utmost importance to a region. Their removal compromises the performance of the entire network, resulting in significant economic or other losses. ODOT relied on its Oregon Highways Seismic Options Report and designated "Lifeline Routes" for this purpose. The Seismic Lifeline Routes study identified and evaluated state highway corridors for vulnerabilities with the goal to build resilience and aid in recovery following a major disaster.[13]

The Lifeline Route project also identified a specific list of highways recommended to make up the Lifeline system, and established a three-tiered system of corridors to help prioritize seismic retrofits and resilience projects on State-owned highways and bridges.[14] The purpose of having three tiers of lifeline routes is to establish guidelines for prioritizing retrofits of highways and bridges with the highest priority roadways being those that provide the most critical linkages necessary to serve the greatest number of residents in the study area, at the lowest investment of time and money. Ideally, vulnerabilities along all three tiers of lifeline routes should be addressed.

ODOT's Bridge section has taken the lead on identifying system vulnerabilities and connecting vulnerable bridges and landslide risks with available funding to increase system resiliency.

The scope of this pilot includes all State highways in the study area (not just Lifeline Routes), with a focus on where these routes are most vulnerable. Ten (10) of the 22 highway segments reviewed for vulnerability are designated Lifeline Routes.

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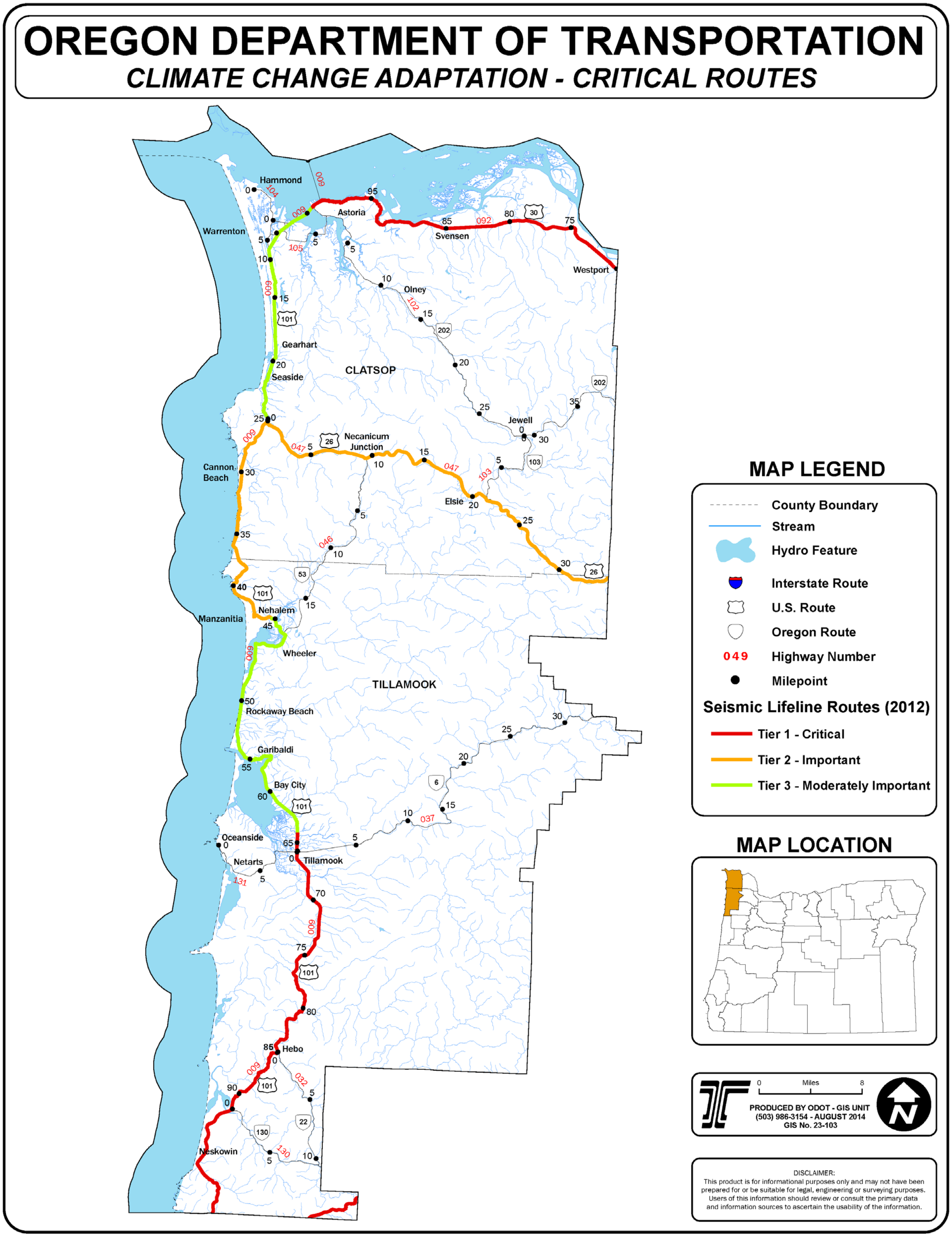
[13] The OSLR study is designed to address Policy 1E, Lifeline Routes, of the 1999 Oregon Highway Plan, which states: "It is the policy of the State of Oregon to provide a secure lifeline network of streets, highways, and bridges to facilitate emergency services response and to support rapid economic recovery after a disaster."

[14] Tier 1 Lifeline Routes are the most-critical highways, providing a backbone system for the parts of the state most vulnerable to a seismic event and for disaster recovery. Tiers 2 and 3 Lifelines are routes that increase the usability of the system and provide additional access, connectivity and redundancy to the Tier 1 Lifeline network.

Figure 4 – Critical Routes



3.6 Selection of Vulnerable Assets to Develop Adaptation Strategies

ODOT selected a highway Study Corridor to help narrow our focus. Once the vulnerability assessment was complete, we were able to make a relative comparison of vulnerability between discrete highway segments within District 1. Selecting a Study Corridor allowed us to prioritize within the region and further screen and prioritize potential adaptation sites at the corridor level. Once sites were selected, adaptation options were developed and a benefit-cost analysis conducted.

Selection Criteria for a Study Corridor

Potential study corridors were prioritized considering the following:

- Rated as "Extremely" vulnerable to future climate impacts based on existing hazards data, climate projections and input from maintenance crews.
- High number of "climate hazard sites" as identified in the July 2013 maintenance workshop.
- Highly vulnerable climate hazard sites with road condition ratings of "Critical" or "Poor" as identified by Maintenance.
- High concentration of weather-related road hazards and maintenance response activities.
- Designated as a critical "Lifeline Route."

Selection Criteria for Adaptation Sites

ODOT's maintenance crews helped to identify many of the region's most vulnerable climate hazard sites. Site selection criteria were also developed to focus on a set of representative site hazards and risks most common for the coastal highway. The project team gathered input on the methods and potential sites from ODOT's Adaptation Work Group. We also toured potential sites with the District maintenance manager and crew members to gain additional background before selecting a final group of sites.

Over a dozen potential adaptation sites within the Study Corridor were screened for:

- <u>Vulnerability and risk.</u> Select sites with a high vulnerability and risk based on current site activity, maintenance records, and past history of storm-related road damage and closures.
- <u>Diversity</u>. Provide for a range of climate hazard impacts to be addressed (e.g., landslide, flooding, storm surge, etc.)

- Feasibility. Adaptation options are scalable to size and magnitude of the problems: information can be made available; the site is not beyond the scope or resources of the pilot project.
- Utility. The site is not already a project or currently scoped for permanent mitigation.
- Replicable. Potential adaptive actions may have long-term application to other comparable sites along the Oregon coast.

As part of the site review process we made a list of key considerations for developing adaptation options, including:

- Scope or potential footprint of the project.
- Climate drivers influencing the site; how climate change projections may drive the problems and potential solutions.
- Number and range of feasible alternatives.
- Level and feasibility of cost-benefit analysis.

Site options reports were prepared keeping future planning, project development and decision-making in mind. We also looked at what critical land use, regulatory and other constraints may affect the various alternatives selected.

3.7 Regulatory Review

ODOT's experience implementing larger coastal hazard mitigation projects is limited, so it's increasingly important for us to understand the scope of the regulatory issues that may drive project decisions as we consider adaptation strategies for coastal highway infrastructure.

The Oregon Coast and surrounding rural lands are subject to standards and statutory requirements related to numerous and complex state and federal programs that often overlap. This includes local development codes that implement the Oregon Statewide Planning Goals. Navigating these regulations in order to pro-actively site, realign or protect facilities for hazards mitigation can be a serious challenge that confronts transportation project delivery.

For this study, ODOT reviewed the regulatory framework that influences our adaptation site options. We reviewed federal, state and local regulations, and reviewed one of ODOT's coastal projects as an adaptation case study. This project (on Highway 101) involved a range of coastal erosion mitigation options, and an eventual decision to realign the highway away from the shoreline and failing embankment. The regulatory hurdles faced and outcomes achieved from this project provide an important example and lessons learned for future coastal adaptation projects. The review includes:

Federal

- Department of Transportation Act
- Land and Water Conservation Fund Act
- Pacific Coast Scenic Byway
- National Environmental Policy Act

State

- Oregon Land Use Planning Program
- Exceptions to State Land Use Goals
- Case Study: ODOT's Beverly Beach/ Spencer Creek Bridge project

Local

- County Land Use Planning Programs

3.8 Identification, Assessment, and Selection of Adaptation Strategies

ODOT relied on materials from many sources to prepare the site adaptation strategies. Maintenance District records were reviewed and site visits conducted in January 2014. Records were researched and reviewed for information about prior construction, maintenance or repair activities at the various sites, as well as data regarding geology, climate and existing hazards. In some instances, historic records regarding prior roadway failures were obtained, such as from scour and landslides. Operations Center dispatch records showing maintenance response activities between September 2009 and April 2013 were also reviewed for proximity of incidents to selected sites.

ODOT has significant institutional experience with the types of hazards addressed by this project, from operations to design and construction. This familiarity extends through all aspects of mitigation and includes identification of appropriate options for specific hazards and methods for assessing the effects, cost-benefit, and lifecycle cost of mitigations. This background, experience, and expertise formed the basis of the methods used in the analysis and selection of options for the five sites considered. Each mitigation and adaptation option considered for this study has a basis in previous design and construction projects completed by the agency to provide a comparable performance history under similar existing conditions.[15]

[15] The study focused on a range of "protection" options as opposed to broader "retreat" scenarios (such as new tunnels, major road realignments), due to their complexity and the magnitude of costs involved. The "retreat option" was deemed infeasible for purposes of our scope and analysis at these locations.

The first steps in this analysis were the evaluation of downscaled climate data and the use of LiDAR datasets to model the existing site conditions, and to provide a graphical representation of the site in cross-section. Climate data was then used along with results of analysis of the maintenance dispatch records and surveys to determine the critical climate drivers affecting each site, with a focus on the projected frequency and magnitude of future climate events. For adaptation strategy selection; the cross-sections of existing terrain and roadway geometry were evaluated with respect to existing slope stability, proximity to bodies of water, and other features affecting current and future performance.

Key features were plotted along with the existing geometry at each site and included projected slide surfaces and other landslide features for the three landslide sites, and embankment locations at the Gallagher Slough site. These projections were based on field measurements and LiDAR data observations. Once complete, the sites were assessed for a range of viable mitigation options based on the previous experiences with projects under similar conditions. A "spectrum" of mitigation options was developed for each site that ranged in cost, effect, and maintenance requirements. Essentially, mitigations with a smaller overall effect on the site have a lower initial cost as expected, but also require more output in terms of maintenance as well as ongoing traffic impact. More positive, permanent mitigation efforts have a higher initial cost but result in less maintenance and disruption to traffic over time.

A portion of the highway shoulder on U.S. 20 collapsed into the Yaquina River, December 2012, about 6 miles west of Eddyville in Lincoln County.

The spectrum of options evaluated resulted in a parametric analysis of adaptation strategies for all sites with each evaluated in terms of existing (static) climate conditions, and projected climate conditions at mid-century. The bounding parameters for mitigation strategies ranged from no initial construction ("Do Nothing") to the most significant construction and engineering (C&E) option with the highest construction cost with a graduated increase of construction effort in the intermediate options. For each level of increasing C&E effort, a corresponding decrease in Operations and Maintenance (O&M) effort was applied based on experience with similar projects in the region. Thus, the first "Do Nothing" parameter would not entail any construction work at a site, but would require ongoing and increasing levels of maintenance to sustain the site in a useable condition (under projected climate conditions), while the final solution would be a large construction project that would reinforce or reconstruct the site to a level of resilience where special ongoing maintenance would not be required.

Once complete, mitigation options were assessed on a cost-benefit and overall lifecycle cost basis. The objective of this assessment was to determine the most feasible adaptation strategy for sites that are similar with respect to the potential effects of climate change. This assessment was used to find the right “balance” between built resilience and maintenance.

ODOT and most other transportation agencies have fiscal constraints that preclude construction projects that would resist the potential conditions that climate change may bring. Agencies also don’t have the capacity to perform the maintenance activities needed to operate their systems on a day-to day basis under these conditions. Road users and the economy dependent on road transportation would not be able to tolerate either condition in their extreme. The concluding option or strategy for each site is then estimated to be that which brings the greatest balance between initial construction effort, maintainability, resilience, and reliability within the existing environmental, engineering, and socioeconomic constraints.

Benefit-Cost and Economic Analyses

Due to similarities between the adaptation sites and selected options, the project team narrowed down the scope of the BCA to two sites, each with a base case and single “permanent fix” to evaluate against it. The base case scenarios were also adjusted by incorporating realistic expectations for the future assuming reasonable and best management practices (under the failure scenario), including any projected changes and the highest net benefits that would reasonably occur in the absence of the adaptation option.

Inclusion of BCA in transportation project assessment requires a substantial amount of detail. Both benefits and costs must be estimated for each year of the analysis period; typically for at least 20 years. In the case of climate adaptation longer analysis periods are needed (we went 30 years into the future). This requires detailed estimation of the timing and level of climate impacts, site specific costs, and effects of base case and adaptation action options.

The benefit components consist primarily of time savings, reductions in vehicle operating cost, and safety improvements (reduction in the number of accidents). The cost component reflects the cost of the adaptation investment or as in the base strategy—repeated repairs.

In order to conduct the analysis, a number of assumptions have to be made. For instance, how frequent are the site failures over time and at what rate (based on climate data) we might expect the number of failures to increase. We also developed a series of engineering, construction and maintenance costs for each option. Another example is the standard assumptions we made relating to household income and wage growth, which impact the value of time savings.

The benefits of adaptation action options are the adverse impacts to be avoided. The more adverse impacts avoided, the greater the benefit. In addition, these impacts must be matched to the corresponding affected populations (group and number affected) to correctly value the benefits.

A slide of mud, trees, rocks and debris covered Oregon Highway 6 about eight miles west of Glenwood on March 26, 2014.

A number of valuation assumptions must also be made and can have significant impact on the BCA outcome. In this case, the BCA values and methods identified in Federal guidance for the most recent round of TIGER Grant applications were used.

If the project will have benefits beyond the end of the analysis period, there can be a residual value which is treated as a separate benefit. This requires assumptions about the useful life of any base case or adaptation option action.

The region being analyzed is sparsely populated and the roadways carry relatively low traffic volumes. Roadway failures are most likely to occur in the November to early April timeframe (i.e. off peak for the coastal region). These facts had significant impact on the analyses.

An important outcome affecting a significant number of years in the base cases for both locations was that at these low traffic volumes a one-lane closure on a two-lane road, less than 0.5 miles in length (with a flagger) results in conditions that are roughly equivalent to free-flow.[16] In other words, small failures that result in closure of one traffic lane would have no significant travel impacts.

For a complete list of assumptions refer to the Adaptation Options Cost Tables (Appendix H) and BCA Assumptions (Appendix I).

Regional Economic Analysis

ODOT's Transportation Planning and Analysis Unit also evaluated potential economic impacts to the region from a long-term closure of Highway 101 (within the Study Corridor) due to a

[16] https://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Work-Zone-Analysis-Manual.pdf, pages 15, 16.

catastrophic roadway failure. The agency's Statewide Integrated Model (SWIM) was used for the analysis.[17]

SWIM supports analysis that accounts for the intricate connections and feedback amongst Oregon's economy, land use, and transportation systems within one dynamic modeling environment. The scenario approach that was used focused on the difference in forecast population and employment for the local and surrounding region for approximately 30 years following the roadway failure.

Several transportation analysis zones were evaluated from the SWIM.[18] For this analysis, average annual population and employment were evaluated for the region to determine the general magnitude and direction of economic impacts. The model study area covers the entire geographic area of the pilot project, and includes six SWIM analysis zones within the region.

[17] The Statewide Integrated Model (SWIM) was used to run a future scenario illustrating impacts of closure on US 101. SWIM supports analysis that accounts for the intricate connections and feedback amongst Oregon's economy, land use, and transportation systems within one dynamic modeling environment. The scenario approach focused on the difference in forecast population and employment for the local and surrounding region for approximately 30 years following the roadway failure.

[18] This model is an average weekday model and does not account specifically for seasonal or weekend travel patterns. Exploring seasonal impacts would require a separate detailed analysis.

4 Findings

4 Findings

Findings from the pilot study will be useful to ODOT now and into the future. This section outlines our findings for:

- Projected climate changes and sea level rise,
- Vulnerabilities and risks from climate impacts,
- Adaptation Strategies at selected sites,
- Benefit-Cost Analysis, and,
- Review of regulatory constraints.

4.1 Projected Climate Change Impacts

There is general consensus among climate scientists that climate and weather patterns are changing and will continue to change this century. ODOT relied on regional climate assessments and downscaled global climate data to understand projected trends and potential climate impacts on the State's transportation network.

Northbound U.S. 101 at Arch Cape tunnel.

ODOT's analysis of annual average temperature and precipitation were consistent with regional climate assessments conducted in Oregon and Pacific Northwest. We also conducted a literature review and conferred with the Oregon Climate Change Research Institute (OCCRI) on our approach, use and interpretation of the data. Key findings from this work include:

- Oregon's North Coast will see a warmer and wetter trend through the end of this century. The North Pacific winter storm track is projected to shift northward, meaning slightly fewer, but more intense storms. Overall, fall and winter seasons will be wetter, spring and summer will be drier in western Oregon.
- Changes in precipitation patterns will lead to changes in stream hydrology and sediment regimes. More frequent and protracted low flow conditions in summer may be experienced, while more intense storm events (peak flows) may lead to greater

frequency and magnitude of flooding, as well as increased stream scour and more frequent debris flows.

- We may experience periodic increases in erosion in steeper areas due to higher peak flows and increased risk of forest fires, corresponding to possible increased sediment deposition in flatter, low elevation areas.
- Oregon will experience more 90-degree days on an annual basis. The number of months of drought (in which precipitation is less than 80 percent of the historical average) is also projected to increase. Increases in periodic vegetation loss are possible due to hotter and drier spring and summer conditions and increased chance of forest fires.[19]
- In the Tillamook Bay watershed, annual mean precipitation is projected to increase between 3 to 5 percent by 2100, (or about 3 to 5 inches). The wettest day of the year is projected to see an increase of between 0.25 and 0.75-inches per event. Days where we receive at least 2-inches of rainfall (over 24 hours) is projected to increase in number, up to 3 additional days per year.[20]
- Locations within the pilot Study Corridor are projected to see nearly three times the number of extreme precipitation events (>2-inches/ 24 hours) occurring by mid-century (2046-2065).[21]

Projecting extreme events comes with higher levels of uncertainty, however more intense fall and winter events are projected by several climate models. Recently, annual precipitation levels have decreased on the coast with more extreme weather events experienced over the last decade.

In summary, the state of climate research is showing that the long-term frequency and magnitude of precipitation events may change overtime and that rain may fall in more concentrated events. These projections point to increasing risks of damage and weather-related road hazards for transportation in the years ahead.

For a complete list of climate data sources and impacts on transportation, refer to the Oregon Climate Data and Trends matrix in Appendix B.

Figures 5 and 6 provide example results of our analysis of statewide climate projections (CMIP5): presenting average seasonal change in winter precipitation over the two (30-year) analysis periods, under two emissions scenarios (RCP 4.5 and 8.5).

[19] Oregon Climate Assessment Report, Oregon Climate Research Institute, 2010.
[20] Climate Change in the Tillamook Bay Watershed, OCCRI, 2013.
[21] Coupled Model Inter-Comparison Project (CMIP5); World Climate Research Program, 2014.

Figure 5 – Winter Change in Average Total Precipitation from Historic Value

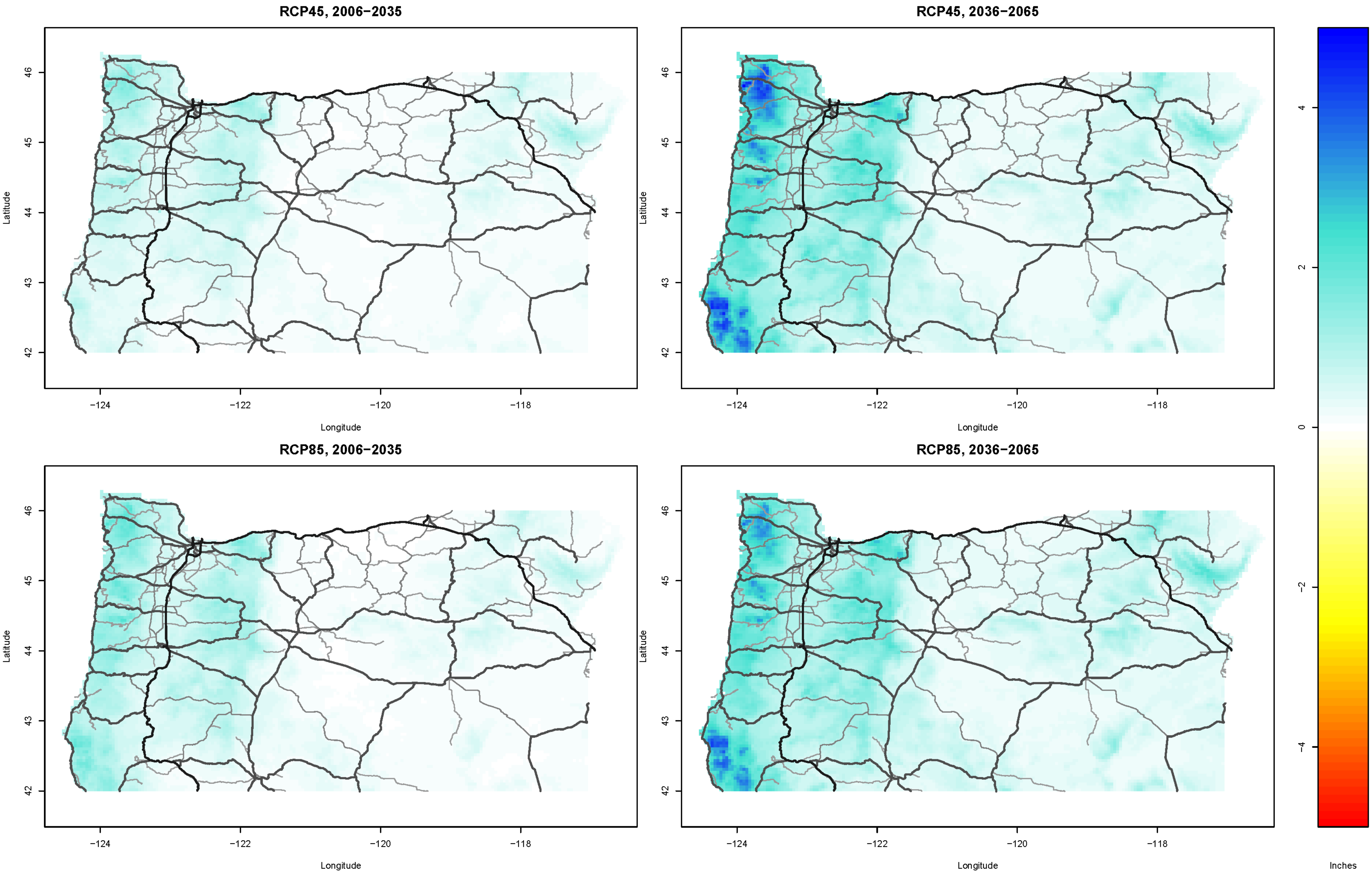


Figure 6 – Winter Average Total Precipitation by Climate Zone

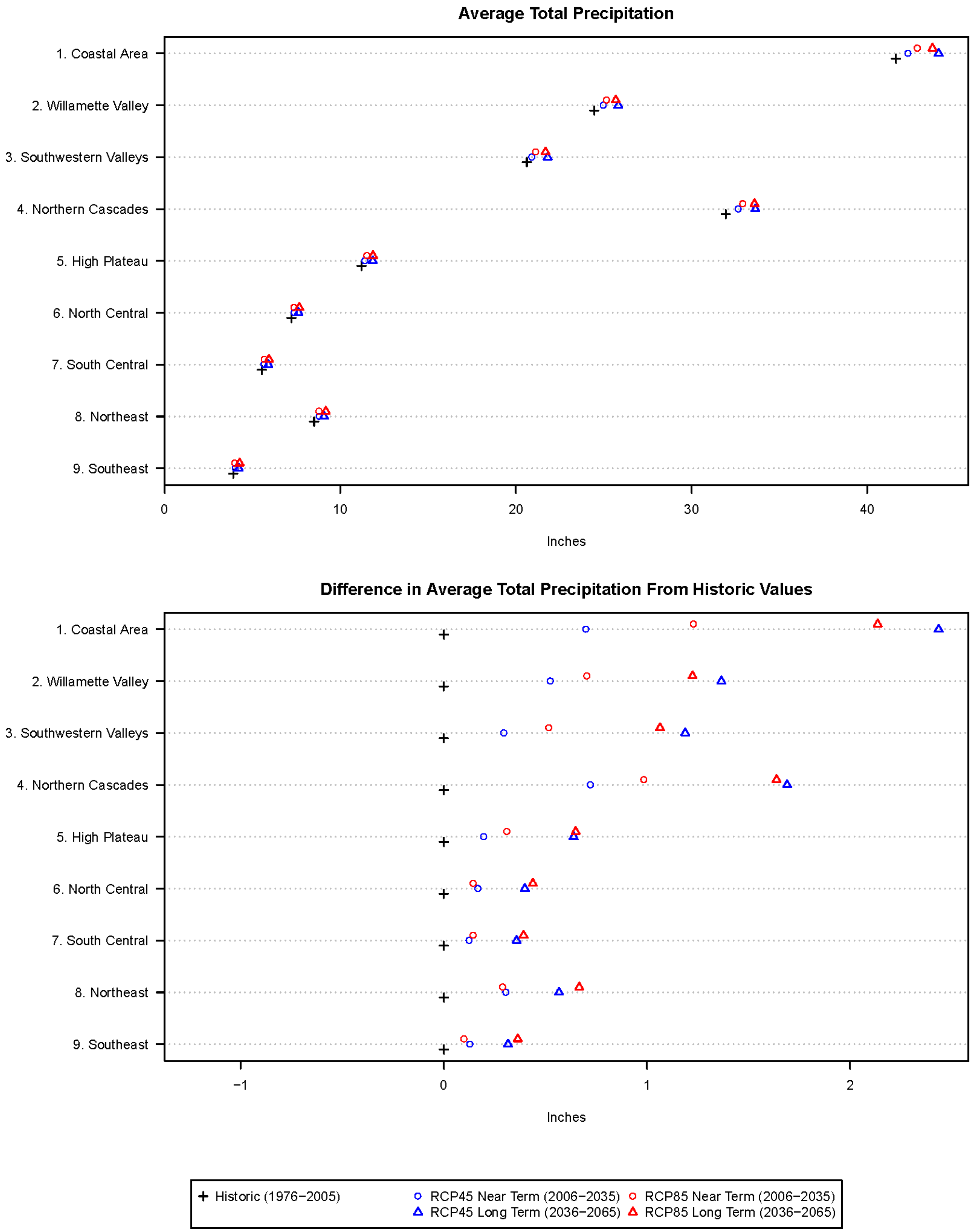


Table 3 is an example CMIP5 data run using the Climate Data Processing Tool, showing precipitation projections for the area between Gallagher Slough and Rockaway Beach. This data reflects the higher emissions "status quo" scenario (RCP 8.5). This analysis shows average total annual rainfall is projected for modest increases by mid-century and then to "level off" off towards mid-century, and for more significant increases in the frequency of "very heavy" and "extremely heavy" rainfall events. These results informed development of our site options, and maintenance cost assumptions.

Table 3 – Results from the Climate Data Processing Tool – Gallagher Slough (RCP 8.5)

	Baseline (1950-1999)	Mid-Century (2046-2065)	End-of-Century (2081-2099)
	Observed Value	Projected Value	Projected Value
Average Total Annual Rainfall	95.0 inches	119.4 inches	117.7 inches
"Very Heavy" 24-hr Precipitation Amount (defined as 95th percentile precipitation)	1.2 inches	1.6 inches	1.6 inches
"Extremely Heavy" 24-hr Precipitation Amount (defined as 99th percentile precipitation)	2.1 inches	2.9 inches	3.0 inches
Average Number of Baseline "Very Heavy" Rainfall Events per Year (1.2 inches in 24 hrs.)	13 times	27 times	28 times
Average Number of Baseline "Extremely Heavy" Rainfall Events per Year (2.1 inches in 24 hrs.)	3 times	10 times	11 times

4.2 Sea Level Rise and Coastal Processes

Global sea levels are rising with near certainty. In some areas on the Oregon coast, geologic activity is pushing the coastline up, accounting for a relatively slower rate of sea level rise compared to other areas globally. However, local relative sea level rise (SLR) is still projected to increase about 24 inches by 2100, compared with 32 inches globally.[22]

Due to the prevalence of sandy beaches and dunes along the Tillamook and Clatsop County coast, coastal erosion and flood hazards will almost certainly increase with rising sea levels. Storm intensity and wave heights have also been increasing over the last several decades, leaving coastal areas vulnerable to flooding and erosion.

[22] Oregon Climate Assessment Report, (Oregon Climate Change Research Institute, 2012).

Beaches and dunes are particularly vulnerable to large storms and high ocean water levels. Along the Tillamook County coast, coastal erosion hazards have been particularly destructive over the past 15 years due to the occurrence of several major storms that have been magnified by El Niño events. Collectively such events have resulted in extensive erosion in several communities, including Rockaway Beach.[23] Along much of the Tillamook County coast this remains the situation with many beaches in a degraded state. Under projected sea level scenarios we will see an increase in the frequency and magnitude of these damaging coastal storms, and coastal infrastructure will be increasingly at risk.

A logjam of driftwood collects in the debris rack at the Crescent Creek outfall adjacent U.S. 101.

ODOT used its GIS to map projected sea levels and screen for potential impacts on the transportation system and identify vulnerable highway corridors. A "hot spots" map was created using a 2050 sea level rise scenario (Figure 7).[24]

This scenario assumes the high end of the range, 48 centimeters (nearly 19-inches) of sea level rise by mid-century.[25] Under this scenario over 15 miles of state highway right-of-way could be potentially impacted by future sea levels, 94 percent of it Tillamook County.

Inundation levels were not fully modeled in the Astoria-Warrenton area or other locations along the Columbia River estuary due to incomplete data. Resolving these data gaps should be a priority moving forward. Further mapping refinements will also be necessary to delineate specific inundation areas for planning purposes, particularly where levees may afford a certain level of protection.

[23] http://www.nanoos.org/home.php

[24] Inundation levels were not fully modeled in the Astoria-Warrenton area or other locations along the Columbia River estuary due to incomplete data.

[25] Sea Level Rise for the Coasts of California, Oregon and Washington: Past, Present, and Future (National Academy of Sciences, 2012).

Table 4 – Sea Level Rise Impacts

(2050 Scenario/High-range)

State Highway	Miles of Impact*
US 101	11.1 miles
OR 53	1.1
OR 130	1.2
OR 131	1.9
	15.3

*Potential inundation of ODOT right-of-way

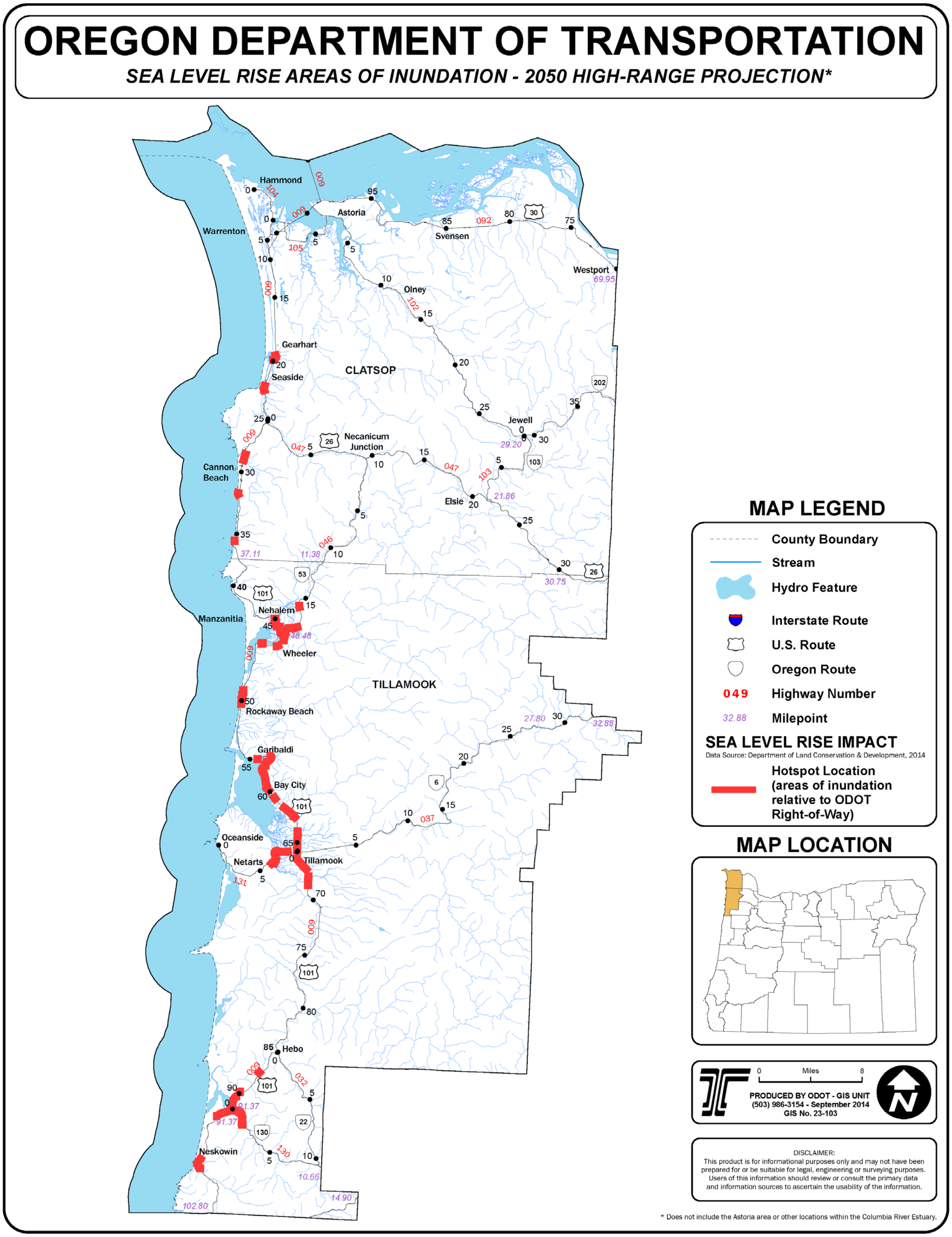
Highway locations most vulnerable to sea level rise were identified in the maintenance workshop and with GIS analysis. The following Study Area locations on US 101 have potential to be impacted by rising seas by 2050:

- Warrenton to Astoria
- Nehalem to Wheeler
- Rockaway Beach
- Garibaldi to Tillamook
- Nestucca Bay

In addition, portions of Highway 202 near Astoria, Highway 53 near Gallagher Slough, Netarts Highway near Tillamook, and Highway 130 near Nestucca Bay, are all at potential risk of sea level rise impacts. Our GIS analysis also shows low lying areas of Highway 30 are vulnerable along the Columbia River (such as near Westport), as well as Highway 104 from Warrenton to Hammond.

Example inundation maps generated by ODOT's GIS team can be found in Appendix D.

Figure 7 – Sea Level Rise Areas of Inundation – 2050 High Range Projection



4.3 Vulnerabilities and Risks to Climate Impacts

ODOT's vulnerability assessment involved the review of maintenance records, regional climate projections, sea level rise maps, and a qualitative workshop with ODOT maintenance crews. Through the workshop, maintenance crews identified potentially high risk hazard sites vulnerable to future climate impacts.

Maintenance Records and Weather-related Hazards

ODOT's Operations and Maintenance Branch provided over three years of maintenance dispatch records from the agency's Transportation Operations Center System (TOCS). These data represent dispatch calls and warnings between September 2009 and April 2013. Data was screened to include weather-related incidents only.

We mapped in our GIS a total of 442 total entries which covered nearly all district highways (see Figure 8 and Appendix E). As was expected, the data show Highway 101 being at the epicenter of weather-hazards activity. High water, landslides and rock falls were the most common hazard types. Other finding from the TOCS data:

- Highway 101 is where a majority of weather-related road hazards occur, with over 218 records, most of these for high water, landslides and rock falls.
- State highway OR 6 and Highway 30 were also active corridors experiencing hazards.
- High water and rock fall were the most common issues requiring a response from Maintenance.
- Flooding issues were concentrated along Highway 30, in Astoria, Gearhart and Seaside, Rockaway Beach, and in Tillamook.
- Landslides and rock falls are commonplace along District 1 highways. These hazards were most heavily concentrated on coastal Hwy 101 between Seaside and Tillamook, and near the Hebo junction. Highways over the coast range, such as OR 6 and Highway 202 are also hot spots for this activity.
- Hot spots locations (areas with multiple incidents at the same mile point) included: Highway 202 south of Astoria, landslides on Highway 6, flooding south of Seaside, rock fall at Neahkahnie Mountain, and in the communities of Rockaway and Garibaldi.
- There were 33 records on OR 6 (through the coast range) related to National Weather Service (NWS) Debris Flow Warnings.
- There were 27 records on Highway 101 related to NWS Flood Warnings.

Figure 8 – Existing Conditions: Weather-Related Road Hazards

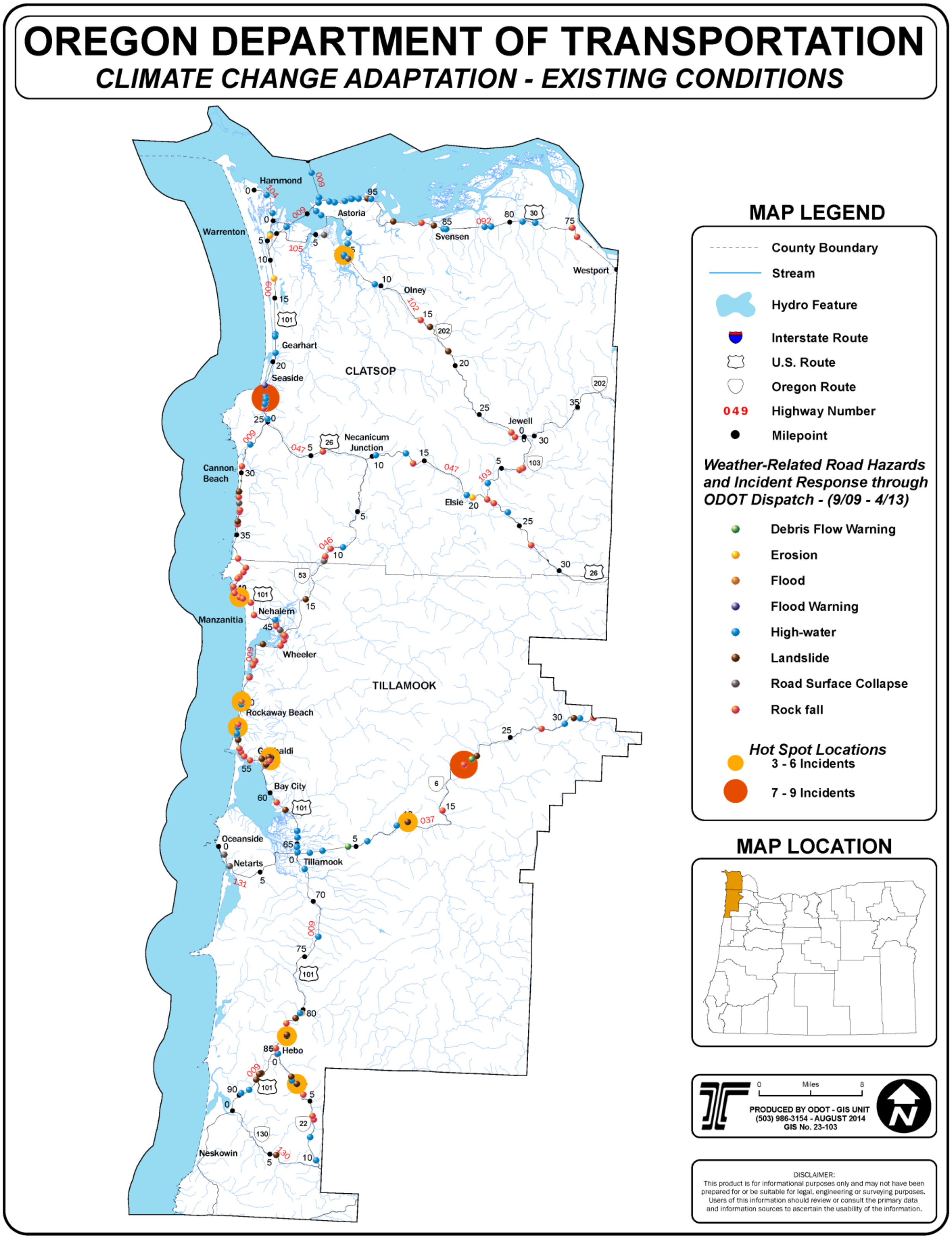
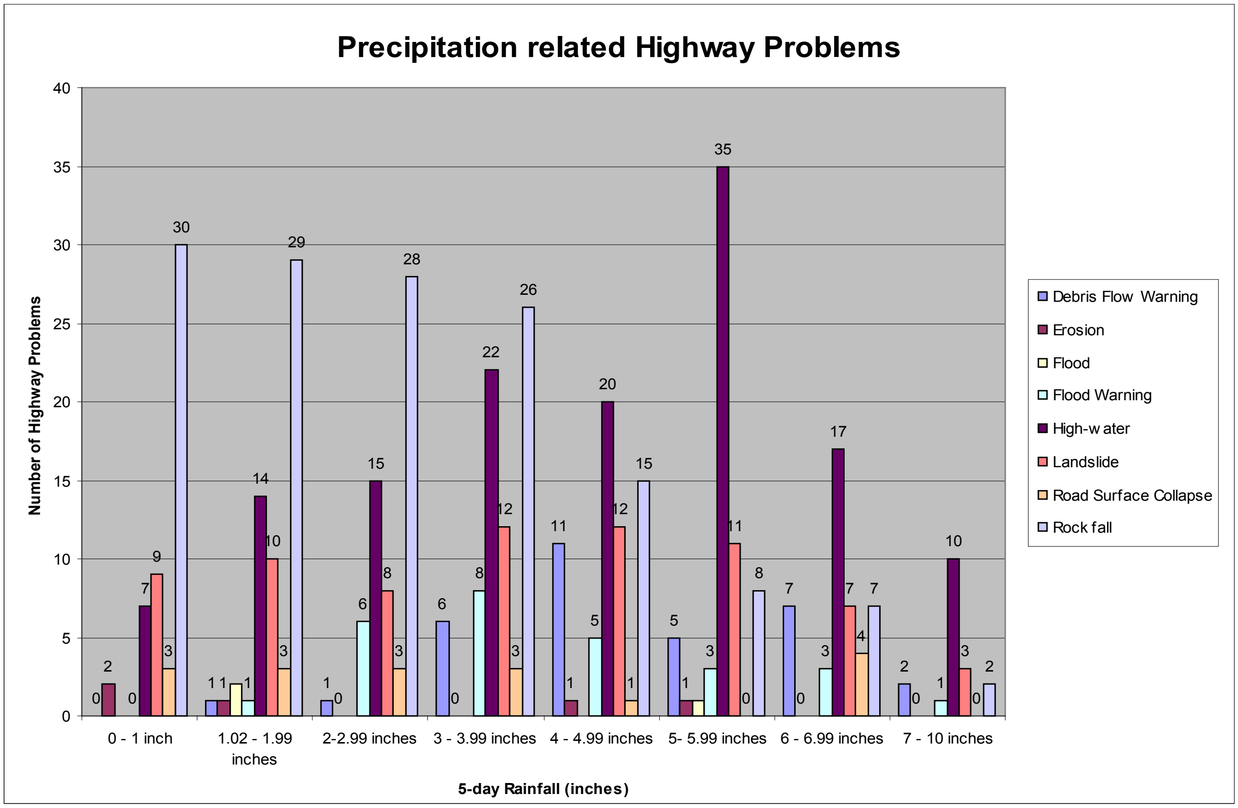


Figure 9 – Precipitation related Highway Problems



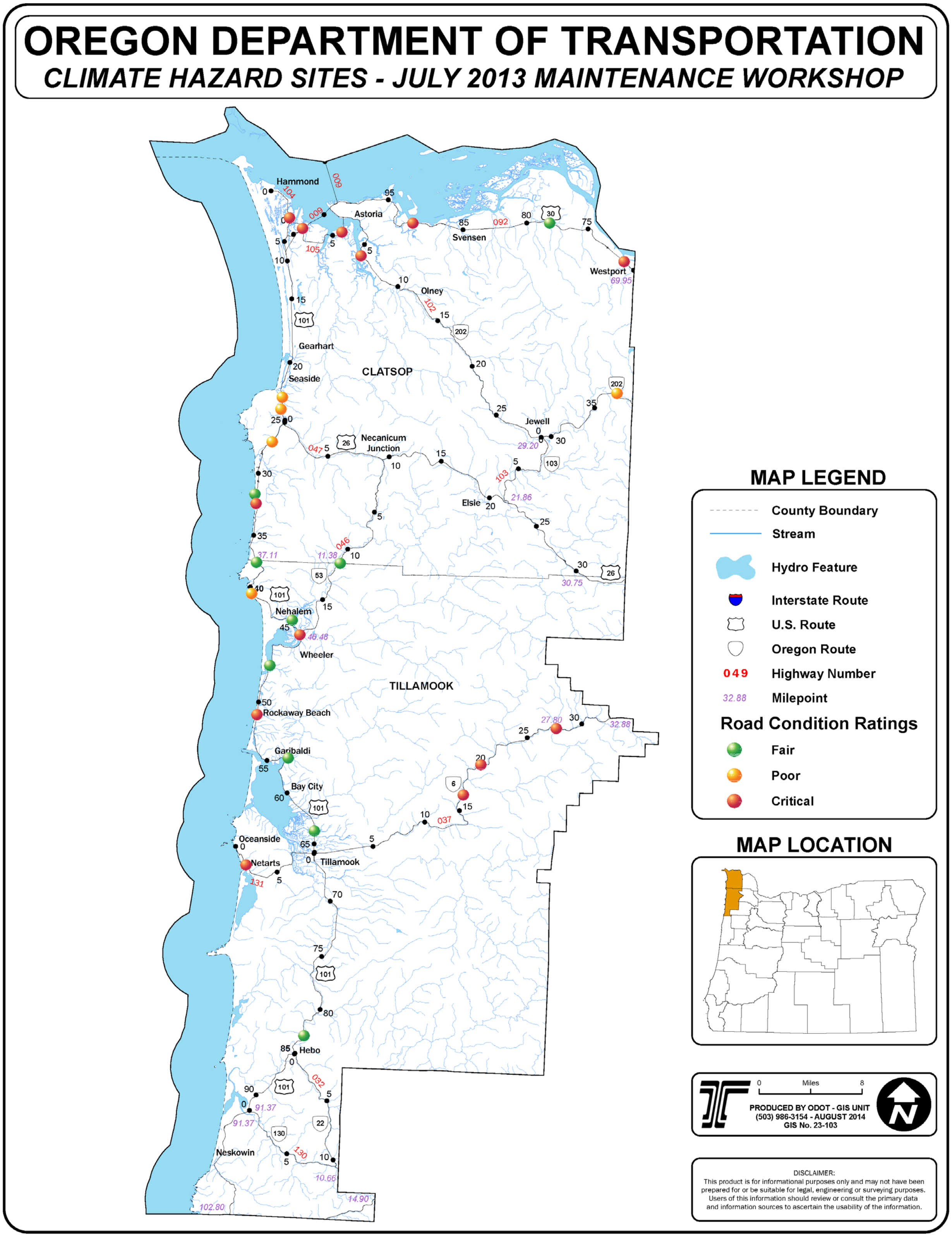
Sources: Western Regional Climate Center (http://www.raws.dri.edu/wraws/orF.html); ODOT Transportation Operations Center System (TOCS), ITS Operations, Salem.

The project team tied specific storm events to the TOCS hazard events. The data shows that 2-inch, 24-hour rainfall events were the most common trigger for hazard activities. A clear majority of hazard activities (high water and landslide events) were logged during winter storms of between 3 and 6-inches of rain over a 5-day period. This is common during multi-day rain events as soils reach their saturation point.

Regional Assessment

ODOT's maintenance workshop helped identify active and potentially high risk hazard sites. Highway corridors were scored and rated using a range of existing hazards data and the results from the workshop. Locations that are currently experiencing problems were identified as likely to get worse with future climate impacts, such as unstable slopes and areas of flooding and coastal erosion. These "Climate Hazard Sites" were mapped and given a hazard rating of Good, Fair, Poor or Critical based on the likely future condition and function of the roadway at the location of the hazards. These sites were recorded and mapped in the ArcGIS.

Figure 10 – Climate Hazard Sites – July 2013 Maintenance Workshop



A summary of maintenance workshop results and the highway condition assessment is located in Appendix G.

Highway corridors were then assessed and rated with a Low, Medium, High or Extreme rating based on the number of impacts and workshop results. Corridors with potential Climate Hazard Sites deemed “Critical” through the workshop process (i.e., potential for a complete loss or failure of the asset) were ranked and mapped with an Extreme Vulnerability rating. A High rating denotes roads where one or two locations may experience more temporary more operational failures; whereas lower ratings indicate corridors that may experience only reduced capacity at potential hazard locations.

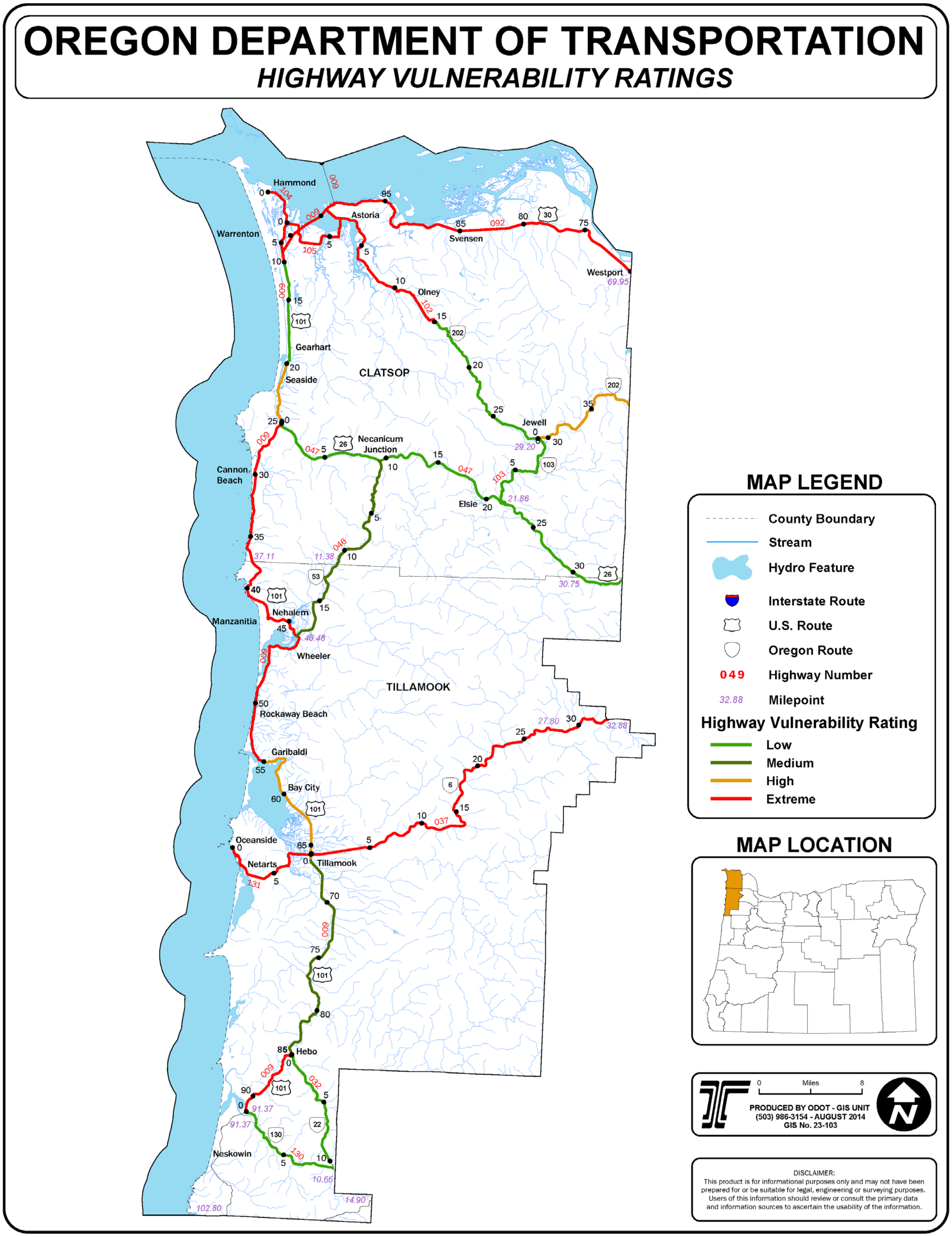
Generally, areas vulnerable to climate change impacts tended to be:

- In the Coast Range (mountainous areas subject to rock fall and landslides),
- Along larger road cuts or fill slopes,
- In low-elevation areas subject to flooding (adjacent to rivers and estuaries); and,
- Coastal areas subject to storm surge and inundation from sea level rise.

The most vulnerable corridors were:

- Highway 30, Astoria to Westport
- The lower elevation (tidally influenced) portions of Highway 202
- Highway 101, in and around Astoria
- Highway 101, from Cannon Beach south to Tillamook, and from Hebo junction to the Nestucca River estuary.
- Netarts highway, from Tillamook to the coast.
- Landslide prone Highway 6 over the coast range.

Figure 11 – Highway Vulnerability Ratings



Vulnerable Lifeline Routes

Many of the region's highways are designated as critical Lifeline Routes, essential for emergency response and economic connectivity between communities that enable recovery from a disaster. These assets are critically important to the study area and their removal would result in significant losses to the communities they serve.

The assessment shows the most vulnerable Tier 1 Lifelines to include the entirety of Highway 30, and Highway 101, from Tillamook south to Nestucca Bay. The other "Extremely" vulnerable Lifeline routes are Highway 101 through the project Study Corridor (Tier 2 and 3) and in Astoria (Tier 3). This assessment provides a relative ranking of priority corridors. Having prioritized corridors will be important as the agency works to identify system vulnerabilities and connect potential resilience projects with available funding.

Table 5 – Vulnerability of Lifeline Routes within the Study Area

Highway	Beg MP	End MP	Lifeline Route (Tier)	Vulnerability Rating	Description	County
30	69.95	99.34	Tier 1	EXTREME	L. Columbia R Hwy- County line to MP 85	Clatsop
101	85	91.37	Tier 1	HIGH	Coast- Hebo to MP 91.37	Tillamook
101	65	85	Tier 1	MEDIUM	Coast- Tillamook to Hebo	Tillamook
101	25	55	Tier 2, 3	EXTREME	Coast- MP 25 to Rockaway Beach	Clatsop, Tillamook
26	0	34.16	Tier 2	LOW	Sunset Hwy- Hwy 101 junction to MP 34.16	Clatsop
101	4	10	Tier 3	EXTREME	Coast- Astoria to MP 10	Clatsop
101	20	25	Tier 3	HIGH	Coast- Seaside to Hwy 26 Junction	Clatsop
101	55	66	Tier 3	HIGH	Coast- Rockaway to Tillamook	Tillamook
101	10	20	Tier 3	LOW	Coast- Warrenton to Seaside	Clatsop

4.4 Defining a Project Study Corridor

The project Study Corridor is about a 25-mile stretch of Highway 101 between Cannon Beach and Rockaway Beach (MP 25-50). This corridor has a wide range of current and potential future hazards susceptible to climate change impacts. The project team engaged ODOT's Adaptation Work Group to define a Study Corridor and select sites for further analysis. The Study Corridor met the following:

- Designated “Extremely” vulnerable through the assessment.
- Critical Assets: Designated Tier 2 and Tier 3 Lifeline Route.
- Contains 11 “climate hazard sites” identified by maintenance crews, including three “Critical” sites, four “Poor,” and four “Fair” condition sites within the 25-mile stretch.
- Over 60 TOCS weather-related road hazard dispatch calls have been responded to in the four year analysis period (2009-2013).
- The area contains 11 landslides and rock falls with a “High Hazard” rating from ODOT’s Unstable Slopes Program.
- Contains DOGAMI designated “Active” and “High” hazard coastal erosion zones in proximity to ODOT highways.
- Three low-elevation roadways confronted with tidal extremes, storm surge and potential sea level rise impacts.
- Contains three (3) Region 2 priority landslide projects (per STIP funding 2016-18).

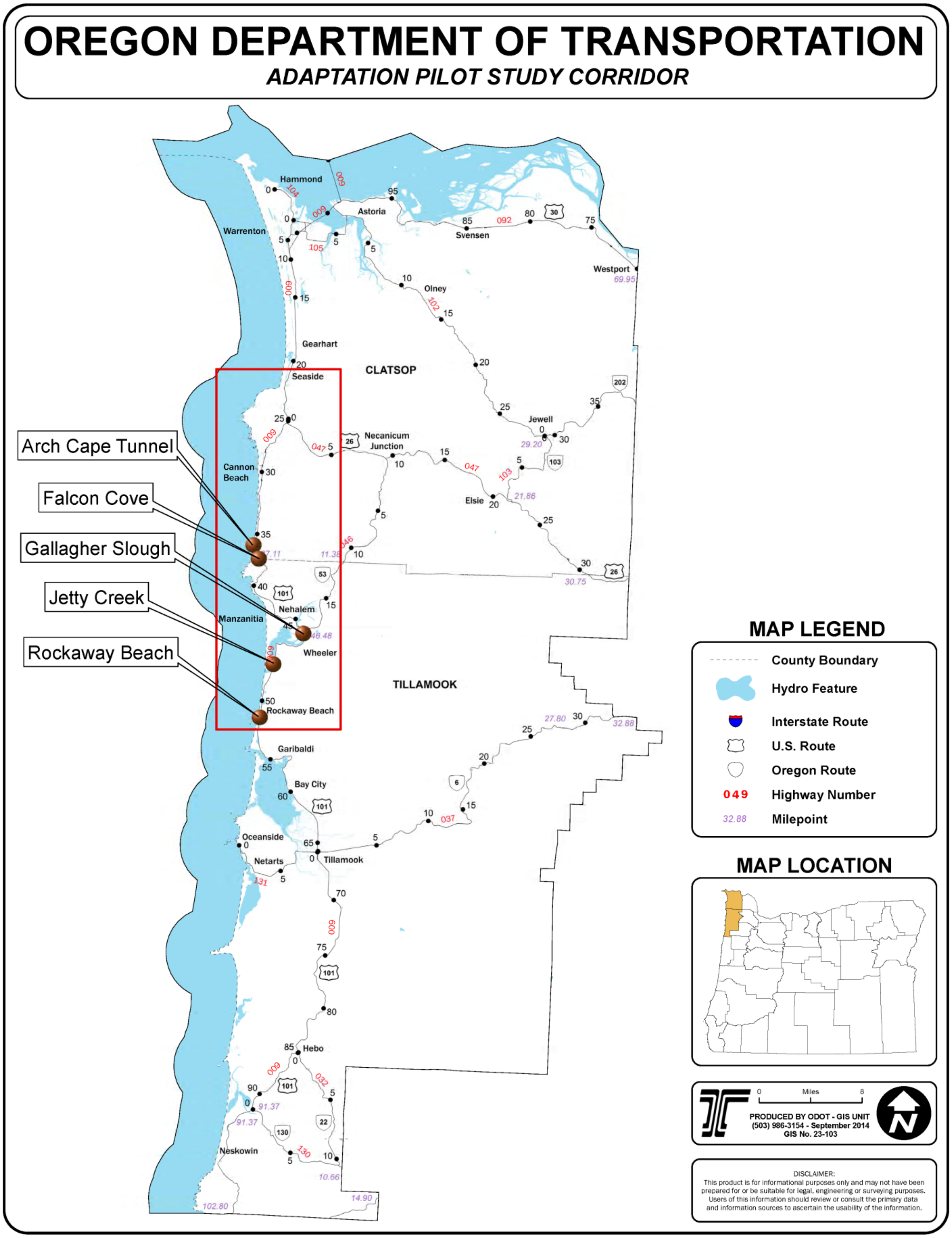
4.5 Selecting Sites with the Study Corridor

The project team initially considered over a dozen sites within the Study Corridor. Nearly all of the sites were identified in the maintenance workshop. The sites were reviewed against screening criteria and sites visits conducted with maintenance staff before final selection. The sites outlined in Table 7 were ultimately selected for additional analysis.

Table 6 – Adaptation Sites within the Study Corridor

Site Name	MP	Workshop Rank	Asset Types	Hazard Types	Climate Stressors
Arch Cape Tunnel	35.96	Critical	Roadway, Tunnel	Landslide, coastal erosion	Precipitation, SLR
Falcon Cove	37.1	Fair	Roadway, Culvert	Fill slope failure	Precipitation
Gallagher Slough	46.45	Critical	Roadway, Bridge	Coastal erosion	SLR, storm surge
Jetty Creek (landslide)	Z-47	Fair	Roadway	Landslide	Precipitation, SLR
Rockaway Beach (Salt Air Creek outlet)	51.31	Critical	Roadway, Culvert	Coastal erosion	SLR, storm surge
Silverpoint (alternate)	31.7	Fair	Roadway, Turnout	Landslide, coastal erosion	Precipitation, SLR
Neahkahnie Mt. (alternate)	40-41	Poor	Roadway, Rock Fall Mitigation	Rock fall	Precipitation

Figure 12 – Adaptation Pilot Study Corridor



4.6 Site-Level Adaptation Strategies

ODOT relied on data and materials from many sources to prepare site options reports. Maintenance District records were reviewed and site visits conducted. Records were reviewed for information about prior construction, maintenance or repair activities at the various sites, including any historic records regarding prior roadway failures. Existing and projected climate data was then combined with standards and guidance to develop reports. Below are site descriptions and adaptation options for the selected sites.

4.7 ARCH CAPE

- Milepoint: 35.9
- Hazards: Landslides, Coastal Erosion
- Climate Drivers: Precipitation, Sea Level Rise, Storm Surge

There are several landslides in the vicinity of Arch Cape (the headland as well as the surrounding community named for this feature). This particular landslide occurs in the southbound lane of US 101 at MP 35.96, approximately 75 feet from the south portal of Arch Cape Tunnel. The roadway at this location spans a transitional cut- fill section where part of the roadway is placed on an excavated portion on its East side with the remaining portion supported on the West side by an embankment. This embankment is situated at the top of a 120-foot bluff and probably comprises the upper 20 to 23-foot section of the bluff. The overall slope of this bluff is about 3/4H:1V with a slightly flatter aspect in the upper embankment section.

This site is currently impacted by a landslide that steadily moves during the wet seasons but is less responsive to specific rainfall events. Movement of a few inches occurs over the course of about seven months every year. This rate of advance doesn't require frequent maintenance until a certain level of deformation occurs, at which point significant work is needed. The position of this landslide with respect to the high bluff and tunnel create specific challenges to the maintenance or potential repair of this site. In this regard, any option for realigning the highway is severely restricted or eliminated. Limited space between the roadway and shoreline further reduce the maintainability of the site and restrict repair options. This site is not unique with respect to its geometric constraints. Similar conditions exist at many sites system-wide with roadways constrained by structures, bordered by high, steep slopes, and underlain by weak materials with precipitation always factoring into slope stability.

Data from the ODOT Unstable Slopes Database indicates that this site experiences some movement every year but doesn't typically need repair more than once in five years due to the slow, constant nature of the landslide. The database information was corroborated by information from Maintenance staff. For this site, “Very Heavy” precipitation events were selected as the primary climate driver for ongoing landslide movement as this site does not appear to have significant movement that can be observationally linked to the more specific storms in the “Extremely Heavy” category. Instead, it moves steadily throughout the October to May wet season at a rate that spans across any measureable event. The frequency of maintenance work currently set at 0.2 times/year (once in five years) was compared to the downscaled data for Mid-Century (2046-2065) which shows an average annual increase in “Very Heavy” events of approximately 24 percent. This rate of increase was applied to the projected future maintenance activity which would increase to 0.25 times per year, or once in four years.

Temporary retaining walls and pavement patches are currently used to maintain the roadway at this location due to the steep, high slope on either side of the highway that preclude a more constant, simple adjustment of grade that can be achieved by the periodic lifts of asphalt concrete. The temporary retaining walls present another complication at the site as they are a feature that must also be replaced on a 12 to 15-year cycle as they are constructed by maintenance forces using materials on hand without a site-specific design, specified materials, or construction methods. These walls also must be replaced due to the likelihood of a second, deeper-seated slide surface in the native materials below the embankment, and because the temporary walls have not been constructed in a way that they would completely retain the upper slide mass.

The view north to Arch Cape tunnel and coastal bluff.

Table 7 – Arch Cape Slide: US 101, MP 35.96

Arch Cape Slide: US 101, MP 35.96					
Adaptation Option	**Description**	**Mitigation Effect**	**Total Construction Cost**	**Annual Maintenance Cost (Current)**	**Annual Maintenance Cost @ 30 Years**
1	Do Nothing	No Effect - Failure continues to SB Lane. Traffic restricted to one-way flagger control for 8-hour period 0.2 times per year	$0	$2,460	$2,740
2	Buttress Primary Slide	Increase Resisting Force on Slide. Continue Maintenance Frequency with increased effort for Buttress Maintenance, Eliminate existing wall and wall Maintenance	$90,914	$1,915	$2,393
3	Buttress Primary Slide, Reinforce Secondary Slide	Increase Resisting Force on Slide. Continue Maintenance Frequency with increased effort for Buttress Maintenance, Eliminate existing wall and wall Maintenance. Reinforce Lower Slide to decrease rate of movement/maintenance requirements	$1,405,713	$968	$1,220
4	Construct MSE Wall, Reinforce Secondary Slide, Protect Slope	Support roadway with retaining wall, stabilize secondary slide with Soil Nails and protect slope face with reinforced Shotcrete. RipRap protection. 50-Year Design Life	$2,925,079	$1,650	$1,650
5	Construct Soldier Pile Wall, Protect Slope	Support roadway with Soldier Pile Wall. Tiebacks support wall and roadway. Secondary Slide is separated from roadway eliminating its effect. RipRap protection. 75-Year Design Life	$3,452,833	$0	$0

Another problem at this site is the susceptibility of the bluff below the highway to wind and wave erosion. Any mitigation taken at the roadway level would ultimately be imperiled by this ongoing process which at this time, proceeds at an unknown rate. Bluff retreat rates are also difficult to determine without an established baseline study to measure this quantity over time. Much research into shoreline migration along the Oregon coast has taken place. Unfortunately, this research has not included an assessment of coastal bluffs or shore cliffs except for specific points outside of the study area. The physical and anecdotal evidence at this site however, suggests that bluff retreat will be an issue for this site by mid-century. At some point, ongoing bluff retreat will completely undermine the roadway at this location. Waves currently impact the lower bluff during higher tides and storms. The bluff face is completely exposed and devoid of vegetation, and material falling from the slope is continually accumulating at the base of the slope until it is transported away by wave erosion. These observations present clear evidence for relatively fast slope retreat, the exact rate of which would require specific survey and analysis of data collected over a period of a few years.

A failing retaining wall on U.S. 101 at the Arch Cape site.

Option 1 – Do Nothing

This is the option for this site where no capital expenditures for construction would be spent. Maintenance work to restore the roadway would be relied upon to keep the roadway in a serviceable condition. As the climate drivers that impact this site increase, so too would the amount of maintenance work required. Without initial capital outlay for construction, there would not be any initial construction work to reduce the amount of maintenance required. This option provides a baseline estimate of the level of service disruption and the cost to maintain the roadway in its present condition for as long as possible. Once the bluff on the ocean side of the highway retreats to the point where the roadway is undermined, routine maintenance will not be able to restore service. For analysis of this option, two retrofits or replacements of the existing walls were considered.

Option 2 – Buttress Primary Slide

This option could be used to reduce the maintenance cost and overall effort by eliminating the temporary retaining walls. The buttress constructed from stone embankment would increase shear resistance of the upper slide by spanning the slide surface with stronger material and providing greater drainage from the landslide. This buttress would also be temporary as it would continue to move along with the underlying slide albeit at a much slower rate. This feature would also eventually be undermined by erosion of the coastal bluff. The benefit of this option is its relative low cost and ease of construction and maintenance as well as increased drainage. Once installed, this feature can be regarded or maintained by subsequent lifts of material as slide movement continues. This type of feature is more accessible for maintenance than the existing temporary walls.

The beach below the steep 100-foot coastal bluff at Arch Cape.

Option 3 – Buttress Primary Slide, Reinforce Secondary Slide

The buttress for the primary slide here would be identical to the buttress for Option 2 with additional support provided by reinforcement of the lower slope to arrest the movement of the underlying landslide. This alternative provides stability to the site by increasing the shear resistance of each slide element; the upper slide by the shear resistance of the buttress material while the lower slide would be reinforced with soil nails, dowels, or some other anchor system depending on the actual materials in the slope. Some ongoing deformation of the roadway would continue after implementation of this alternative but at a considerably diminished rate. This rate of movement would be slow enough that maintenance of the roadway surface would be far less frequent. Minor adjustment of the buttress would also be required on much less frequent interval. Continued erosion of the coastal bluff would impact this site at which point and the roadway and reinforced lower slope would be undercut. The lower slope reinforcement elements would be subject to corrosion that would reduce the design life of this option.

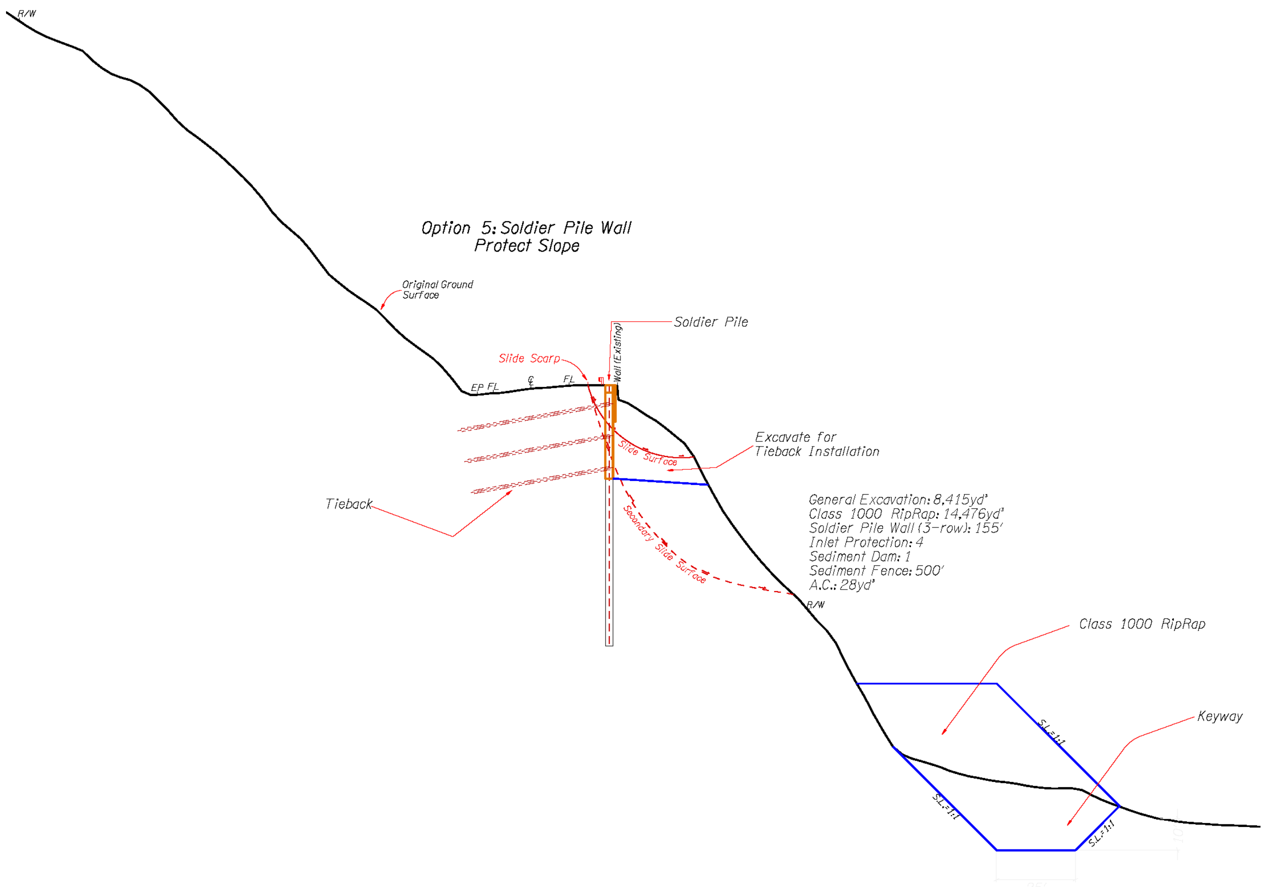
Option 4 – Construct Mechanically Stabilized Earth (MSE) Wall, Reinforce Secondary Slide, Protect Slope

Constructing a retaining wall at the top of the slope would support the roadway by removing most of the existing upper slide and resisting the remaining slide forces by the mass and shear resistance of the wall system. The lower slope would be reinforced and stabilized by the appropriate method for the actual materials encountered (i.e. soil nails, rock bolts, tieback strands, etc.). In addition to the internal reinforcement, the lower slope and reinforcing elements would be protected by an application of shotcrete to protect from erosion of the slope face around the reinforcing elements and corrosion of the elements themselves. The lowest portion of the slope adjacent to the beach would be protected by a riprap or jetty stone revetment to prevent undermining by wave erosion. Some small amounts of deformation at the road level would be expected after construction, thus the MSE retaining wall system was selected for its flexibility and tolerance to variable amounts of deformation. This option would eliminate the need for further maintenance at the road level and subsequently, disruption to traffic. However, the shotcrete would need to be repaired or likely replaced at some point in the design life of this option which is the basis for the remaining maintenance cost.

Option 5 – Construct Soldier Pile Wall, Protect Slope

This option would involve the construction of a soldier pile wall with further support by tieback strands to support the roadway. This structure would be further protected from long-term erosion by a riprap/jetty stone revetment. This structure would include rock-socketed soldier piles that penetrate both slide surfaces with further lateral support provided by tieback strands. The strands would penetrate the slide laterally and also be placed in sufficiently resistant material to provide a bonded zone with enough strength, in conjunction with the soldier piles, to withstand the forces of the landslide once tension is applied. Although deeply placed in resistant material, the structure will need the added shoreline protection for it to accomplish its full design life as the structure could potentially be undermined or exposed to corrosion. All costs related to this option are up front, and design and construction-related. This option would eliminate the need for any further slide-related maintenance at the site.

Figure 13 – Option 5 Conceptual Design for the Arch Cape site



The eroding coastal bluff at Arch Cape tunnel.

4.8 FALCON COVE

- Milepoint: 37.1
- Hazard types: Landslide (fill slope failure)
- Climate Drivers: Precipitation

This site is located on a fill slope at mile point 37.31 on US 101 about six miles North of Manzanita, Oregon. The fill appears to be constructed of locally-derived native material placed at an angle slightly steeper than 2H:1V on both slopes. A 24" diameter Corrugated Metal Pipe (CMP) conducts an unnamed creek through the fill from East to West. This fill experiences significant landslide movement every year during the wet season (October-May) resulting in substantial deformation and differential movement of the roadway that requires work by ODOT maintenance staff to restore the site to a serviceable condition. This site and the fill constructed here is largely representative of numerous comparable sites throughout the Coast Range and the state overall that exhibit similar behavior with respect to their reaction to precipitation and increased groundwater elevations.

Data from the ODOT Unstable Slopes Database indicates that this site experiences significant movement requiring maintenance and repair three times every two years or 1.5 times per year. Three (3) baseline "Extremely Heavy" rainfall events of 2.7"/24 hours are recorded in the climate data each year. This rate of incidence is corroborated by discussions with maintenance staff who observe the damage at the site occurring after every "major storm" or later in the year after two of the "heavier" rainfall events. These observations and measurements have been used to set the current rate of activity used in the analysis of options for the current site conditions. The "Extremely heavy" value from the downscaled data for Mid-

A truck travels southbound on U.S. 101 over the Falcon Cove fill slope.

Century (2046-2065) was used to project potential future rates of activity at the site for the options selected. In this case, the frequency of maintenance activity would increase to 2.5 times per year, or five times every two years.

Table 8 – Falcon Cove Slide: US 101, MP 37.31

Falcon Cove Slide: US 101, MP 37.31					
Adaptation Option	Description	Mitigation Effect	Construction Cost	Annual Maintenance Cost (Current)	Annual Maintenance Cost @ 30 Years
1	Do Nothing	No Effect - Failure continues to NB Lane. Traffic restricted to one-way flagger control for 4-hour period 1.5 times per year	$0	$8,957	$10,509
2	Lightweight Fill	Decrease Driving Force on Slide. Reduces Maintenance Frequency to once in 5 years at current level of effort and closure time. Must be Reconstructed twice in 30 years.	$153,158	$1,194	$1,994
3	Lower Grade	Decrease Driving Force on slide, decrease roadway exposure to slide. Reduces Maintenance Frequency to once in 3 years at reduced level of effort and closure time. Allow 2-way traffic during maintenance.	$232,000	$1,131	$1,889
4	Construct Buttress and Shear Key	Increase Resising Forces against slide, Increase embankment drainage. Reduces Maintenance Frequency to once in 15 years.	$180,350	$376	$628
5	Reconstruct with all-weather material. Resize Pipe.	Removes slide, replaces embankment with resistant material that facilitates drainage. Increases culvert size to address higher streamflow.	$562,097	$0	$0

Option 1 – Do Nothing

For this option, no capital construction would take place. Maintenance work to restore the roadway would be relied upon to keep the roadway in a serviceable condition. The title of this option belies the actual case – Maintenance services would be very busy at the site every wet season. No initial work to reduce the maintenance effort would take place. What this option provides is a baseline estimate of the level of service disruption and the cost to maintain the roadway in its present condition. For the overall analysis of this site, it is assumed that a large enough failure would occur in the next 30 years that reconstruction of the fill would be necessary in any case.

Option 2 – Lightweight Fill

This option's objective would be to reduce the maintenance cost and increase the serviceability by decreasing the rate of movement of the slide. This reduction would be achieved by decreasing the driving forces of the slide mass by removing the preponderance of the soil and replacing it with lightweight fill material. Soil typically has a unit weight ranging from 85 to 115 lbs./ft3. Lightweight materials such as wood chips have a unit weight of approximately 30 lbs./ft3 effectively reducing the driving force of the failing embankment to one third or less of its original. Past experience with construction and maintenance of similar facilities in this environment suggests that this type of fill should be reconstructed every 10 years (+/-) due to internal settlement, decomposition, and wear.

Option 3 – Lower Grade

Similar to Option 2, this alternative reduces the driving forces of the slide and further reduces the rate of movement. This reduction of driving forces is achieved by removing the upper portion of the fill and lowering the grade over the creek. This site's geometry is favorable for this type of mitigation as the corresponding cut slopes would not greatly increase the quantity of earthwork and the fill is located near the crest of the hill. This option not only decreases the driving forces on the slide, but also decreases the area and volume of material affected by the slide. This reduces the overall impact to traffic as well as the quantity of materials needed for repair when movement does occur.

A member of ODOT's project team scrambles up the steep fill slope at Falcon Cove.

Option 4 – Construct Buttress and Shear Key

Constructing a buttress and shear key supports the remaining slide mass and increases the resisting forces against the landslide. Free-draining buttress material also helps decrease the amount of water in the slide mass and fill foundation which further increases the resistance to sliding. For this mitigation, excavation of part of the slide mass and foundation material on the down slope side would be required. This material would then be replaced with specified "stone embankment" material that provides the open drainage and shear strength properties required to stabilize the slide mass. The exact excavation/embankment quantities would have to be determined by a geotechnical investigation prior to construction. For this option, some maintenance at the 15 year point was used for cost analysis however this may be eliminated depending on the type and depth of the actual foundation material. Past experience with similar construction typically requires a minor pavement overlay due to long term foundation settlement if the buttress and shear key are placed on soil materials rather than resistant strata such as bedrock.

Option 5 – Reconstruct with All-Weather Fill, Resize Pipe

For this alternative, the entire fill would be replaced with stone embankment while the culver would be replaced with a newer, larger pipe at a more favorable grade. This option simply replaces the existing fill with material that is strong enough to resist deformation and with enough permeability to prevent the build-up of hydrostatic pressure during the most intense storm events. The embankment would also be placed on a resistant stratum that would also be resistant to local slide movement. The culvert would be sized to accommodate the increased storm intensity projected at the site. This option places all costs up front during construction and should preclude the need for further maintenance apart from routing work on the wearing surface.

4.9 GALLAGHER SLOUGH

- Milepoint: 46.45
- Hazard types: Coastal erosion, roadbed scour
- Climate Drivers: Precipitation, sea level rise and storm surge

This site comprises a lengthy causeway that carries US 101 across the Nehalem River Estuary beginning near the Southeast end of the Nehalem River bridge that terminates at the Gallagher Slough bridge. Gallagher slough is the easternmost drainage from the Nehalem River Estuary while the main branch of the Nehalem River is on the Western side of the Estuary. The Nehalem River Bridge is a high, multi-span bridge capable of passing most river traffic. The Gallagher Slough Bridge is a low, single-span bridge with tide gates. The junction of US 101 and Highway 53 is approximately 100 feet to the southeast of the Gallagher Slough Bridge. The roadway elevation is about 8.5' above MSL in this area with relatively flat slopes in the range of 3H:1V to 4H:1V. The causeway slopes are protected with riprap in most areas on the bay side with larger riprap protection around the wingwalls of Gallagher Slough Bridge.

The elevation, construction, and location of this causeway make it particularly susceptible to flooding, scour, erosion, and embankment failure. These elements are currently factors in the performance of this feature and future climate drivers are expected to worsen these conditions. Higher sea level, greater storm surge, higher wave heights, and more frequent and intense storms will be increasingly detrimental to the causeway as well as the slough bridge. During extreme rainfall events flooding occurs, and water levels reach the edge of the pavement. Small, localized failures also occur periodically in conjunction with these flood events. These failures may be related to the inundation, or they may be related to rapid draw-down failures as floodwaters recede along with the tide.

Although this site isn't currently subject to closure during extreme precipitation events, water levels during those events reaches a the level at which any additional flooding would close the roadway. It is obvious that additional baseline sea level would drive closure of the site during these events, but it is even more significant when considering higher river discharge at this location at the same time. Increased storm surge and wave height also become an important issue since the Nehalem estuary is relatively short and subject to storm surge while wave heights also become a critical issue. In this regard, smaller rainfall events that don't raise the temporary water elevation to a critical height would still impact traffic due to waves running out in the roadway. Wave erosion will also play a substantial role in the performance of the embankment as the riprap currently in place is not sized for wave resistance. Additional discharge through the slough bridge will also affect scour at the foundation and around the wing walls which also may not be sufficiently scour-protected for potential future discharge.

Inspecting the bridge wing wall at Gallagher Slough.

Table 9 – Gallagher Slough: US 101, MP46.5

Gallagher Slough: US 101, MP 46.5					
Adaptation Option	**Description**	**Mitigation Effect**	**Total Construction Cost**	**Annual Maintenance Cost (Current)**	**Annual Maintenance Cost @ 30 Years**
1	Do Nothing	No Effect - Not Currently Affected. Future events coupled with SLR will affect at about year 10	$0	$0	$202,255
2	Armor Existing Roadway	Eliminate vulnerability to most storm damage. Flood events would still inundate the roadway and result in closure during the event but the roadway would stay in place after the event.	$1,412,200	$0	$2,250
3	Elevate Roadway, Armor Slopes, Raise Gallagher Slough Bridge	Eliminate vulnerability to future storm damage. Flood events would not crest above the roadway and it would remain open during storm events.	$7,542,500	$0	$0

Option 1 – Do Nothing

For the current condition, this would be the appropriate choice since extreme rainfall events very infrequently affect the roadway at the present time. However, the downscaled data indicates an over threefold increase in such events that, coupled with projected sea level rise will certainly affect this facility numerous times each year during the October-May wet season. This option would place all future mitigation efforts into the maintenance category. Maintenance would be required for temporary control and direction of traffic during the event several times per year. In addition, minor pavement repair and embankment restoration efforts will also be necessary since the subgrade will experience significant stresses from saturation, piping, and high pore pressures following rapid draw-down. There is also a high likelihood for substantial debris build-up on the roadway during each event.

Option 2 – Protect the Existing Roadway

This option would construct riprap protection along both sides of the causeway to protect the slopes in addition to additional scour protection of the slough bridge. This work would prevent wave erosion and embankment failure by strengthening the existing slopes to the point where they could withstand projected wave energies while providing enough resisting force to prevent slope failure during inundation and rapid draw-down conditions. This option would not prevent road closure during extreme rainfall events. It is intended to withstand these events so that traffic may be immediately restored once the floodwaters recede without significant repair work. Some pavement repair would be necessary as the wearing surface would likely delaminate if strong currents or wave energies are present.

The Nehalem River as seen from U.S. 101 at Gallagher Slough.

Option 3 – Elevate Roadway and Bridge, Armor Slopes

The final alternative for this site would be to armor the existing slopes with riprap, and raise the roadway and bridge elevations to the point where they are above projected flood levels. The elevated roadway section would be constructed from durable material to prevent damage to the pavement section while also being protected by riprapped slopes. The Gallagher Slough Bridge would be elevated to increase its capacity for excess river discharge during and after the flood event. Extra scour protection is included as the bridge would not be widened to reduce discharge velocity. This option would keep the facility open during all storm events and eliminate the need for restorative maintenance after the event. All costs incurred for this option are intended to be taken up by construction of the more resilient facility.

4.10 JETTY CREEK

- Milepoint: Z 47
- Hazard types: Landslide, coastal erosion
- Climate Drivers: Precipitation, sea level rise and storm surge

This slide is located above, and to the East of US 101 at mile point Z47.2, approximately 4 miles (highway distance) south of the community of Wheeler, Oregon and is named for the adjacent creek to the South. The Jetty Creek Slide is a comparatively large landslide that existed here prior to highway construction. Its headscarp lies almost 700 feet to the East in the hillside above the highway, and extends at least to the shore of Nehalem Bay approximately 160 feet to the West of the highway. The toe of the landslide may conceivably be located beneath the bay. An adjacent railroad right-of-way parallels the highway to the West. The location of the highway near the toe of the slope results in a considerable amount of lateral movement in addition to a component of uplift resulting in an actual "hump" in the pavement at the most active portion of the slide. This peculiar deformation in the pavement is an unexpected feature encountered by motorists, and presents a significant hazard. There is discernible lateral deflection in the rails along this section. The impact of the slide on the railroad is unknown since its owner; the Port of Tillamook Bay no longer provides service. A seasonal excursion train uses this section, but any railroad maintenance or observations of ongoing track deformation are unavailable.

This active section of the Jetty Creek landslide is deforming U.S. 101.

This slide is representative of the numerous large, ancient landslides that pervade the Coast Range in Oregon. The origin of this class of landslide has been linked to previous earthquakes originating from the Cascadia Subduction Zone. Once initially activated, these landslides experience episodic movement related to climate events as well as ongoing creep. These landslides tend to have a very complex internal structure: they have a relict geologic structure from pre-deformation, they can have multiple slide surfaces or zones of movement, may have a complex ground and surface water regime, and may also have a post-deformational geologic history. Because of this complexity, these slides tend to be somewhat unpredictable in their impact to the transportation system with respect to climate drivers. In this regard, climate events can result in significant internal deformation that may not translate to displacement of the highway or other structures until a significant time has passed and the specific event can no longer be linked to the specific movement(s). They may also exhibit movement in different areas at different times and at different rates as some portions may at times be more active than others. For this reason, this type of slide is often referred to as a "slide complex" as they often present themselves as a group of smaller landslides or even slides within slides.

The Jetty Creek Slide is actually a modest-sized landslide for this category. The active portion of the slide considered in this analysis is approximately 800 feet wide which is approximately 60% of the total width of the slide while the length is about 850 feet. There appears to be several zones of slide movement in the toe area of the slide near the highway and railroad grades. The most prominent of these emerges below the highway grade and apparently above the railroad. This portion of the slide surface is probably moving along a course defined by part of a circular arc at which point it is moving in an upward direction and creating the distinctive “hump” in the roadway. Some minor horizontal deflection of the rails as well as visible cracking and deformation at the shoreline was observed which are consistent with the development of a pressure ridge in front of the slide toe – a common feature in landslides. The location and geometry of this slide, which is also common to this category, make it particularly susceptible to multiple climate drivers:

- Rainfall – Increased overall precipitation corresponds to a similar increase in seasonal and all-year groundwater elevation. Groundwater elevation above the slide plane is a calculated value that reduces resisting forces, thus decreasing stability.
- Increased Storm Frequency and Intensity – These types of slides tend to experience large pulses of movement in relation to large precipitation events. More frequent storms will result in more episodes of large slide displacements. Higher intensity storms would reasonably be expected to increase the response of the landslide to precipitation events.
- Higher Mean Sea Level (MSL) – Similar to increased rainfall amounts, higher sea level also increases saturation within the lower portions of the landslide. The toe of this landslide is already at or below MSL and increasing this factor increases the pore-water pressure in this portion of the slide. This decreases resisting forces in a very critical part of the slide.
- Increased Storm Surge – Increases in wave erosion at the toe of the slide would remove material mass that provides resistance against sliding.

ODOT crews have installed horizontal drains in this section of the Jetty Creek landslide.

Any of these factors alone would significantly impact this site. All of these climate drivers together, as expected, would have severe consequences that would be difficult to resolve without significant investment.

Unstable Slopes Database information and discussion with Maintenance indicates that this site requires repair work annually. Noticeable deformation occurs in conjunction with the larger storms every year, however due to the nature of the deformation, crews are unable to perform the repair work more frequently. In this regard, the upward component of the slide creates a condition that is not easily or efficiently addressed in smaller increments, requires special equipment and significant repair time. The baseline average of 3 “Extremely Heavy” rainfall events of 2.1“/24 hours that affect this area each year roughly correlate to observed movement. Again, this is difficult to directly link without significant geologic instrumentation and monitoring since the size of the slide itself can conceal internal movements. These observations are the basis of the current rate of activity used in the analysis of options for the current site conditions. The “Extremely Heavy” value from the downscaled data for Mid-Century (2046-2065) was used to project potential future rates of activity at the site for the options selected. For this site, the frequency of maintenance activity would increase to 3.33 times per year or 10 times every three years. In addition to this “routine” slide movement, this site experiences larger incidents at least once every decade. These larger incidents typically occur as rapid movement of material from above the roadway of such volume that the highway is completely buried and out of service for several days until Maintenance forces can clear the materials away.

Landslides of this size are often too costly to mitigate. In practice, alternative methods to slow landslide movements to manageable quantities are selected. These methods are most commonly efforts to improve surface and subsurface drainage as the reduction of pore-water pressures typically have the most immediate impact on landslide stability and are relatively inexpensive, simple, and have the least environmental impact. When it is necessary to repair a slide of this magnitude, the most cost-effective solution usually consists of two or more methods such as drainage coupled with smaller structural solutions or other combinations that help to reduce driving forces while increasing the resisting forces. Singular types of approaches to large landslide repair are most often too costly to consider. In some cases they are impractical while in others they carry too much risk of failure either during construction or by their lack of redundancy as the sole stabilizing measure.

Table 10 – Jetty Creek Slide: US 101, MP Z47.20

Jetty Creek Slide: US 101, MP Z47.20					
Adaptation Option	Description	Mitigation Effect	Total Construction Cost	Annual Maintenance Cost (Current)	Annual Maintenance Cost @ 30 Years
1	Do Nothing	No Effect - Failure continues to deform both lanes. Traffic restricted to one-way flagger control for 8-hour period 1 time per year	$0	$13,732	$45,700
2	Drain and Unload	Decrease reduction of resisting forces by draining groundwater. Reduce driving forces. Reduce maintenance of roadway but introduce minor effort for periodic drain cleaning	$7,882,500	$3,812	$12,700
3	Shear Piles and Drainage	Increase Resisting Force on Slide. Decrease reduction of resisting forces by drainage improvement. Minor Roadway deflection will occur. Drains will require periodic Maintenance.	$16,719,000	$2,059	$6,860
4	Unload, Construct Buttress and Shear Key with Stone Column Support	Reduce driving forces by unloading. Increase resisting forces with Buttress. Depth of slide precludes traditional shear key. Stone columns would be used for shear resistance. Buttress increases shear resistance of stone columns. Very minor deflection of the roadway may continue.	$18,681,000	$530	$1,765
5	Construct Soldier Pile Wall	Increase resisting forces to retain landslide. Very limited maintenance of wall drainage elements.	$20,400,600	$0	$0

Option 1 – Do Nothing

This option assumes that maintenance forces would be able to keep up with increased slide movements on an annual basis, the railroad would continue to not be affected or would remain out of service, and that slide deformation would follow existing patterns. This option places the full burden of mitigation on continuing maintenance efforts with no expenditure for initial construction. This adaptation option is intended to provide a baseline estimate of the level of service disruption and the cost to maintain the roadway in its current condition. Analysis of this site assumes that at least one significant failure would occur that would close the highway and require a significant maintenance intervention to restore service. This effort would be less than a mitigation effort.

Option 2 – Drain and Unload

This relatively easy alternative uses two separate approaches to reduce the driving forces on the slide while at the same time increasing the resisting forces. This combination of effects would slow the rate and magnitude of movement and subsequently reduce the maintenance effort. Unloading the slide would entail removing the upper portion of the landslide by common excavation methods and placing that material outside the slide limits. Each unit of material removed subsequently reduces the driving forces on the slide. Horizontal drains would be installed in boreholes advanced at a slight angle above horizontal to facilitate drainage. Perforated drain pipe is installed in the borehole and sealed in place at the collar location. Groundwater seeps through the perforations and flows down the horizontal drain pipe where it is collected by a manifold system at the outlet and subsequently conducted to nearby streams. Decreasing the pore pressure from groundwater increases the resisting forces in the drained area of the slide. This alternative greatly reduces the annual maintenance activity needed to maintain the roadway geometry which would also periodically affect traffic. The trade-off in maintenance work is with upkeep of the drains themselves. Experience with horizontal drains in this environment has been that they need to be cleaned and jetted every five years to maintain their drainage capacity due to sedimentation, oxidation, and organic growth. This work is relatively inexpensive with minimal traffic impact. Unloading the slide has some drawbacks with respect to environmental impact. In this regard, the visual effect of a large, bare soil/rock exposure is considerable as well as the necessity for effective erosion control to prevent excessive soil loss and reestablishment of native vegetation. The upper portion of the slide has recently been clear cut so the effect on mature timber is minimal.

Option 3 – Shear Piles and Drainage

This is another option to combine methods for the greatest effect on stability. The first part of this approach would be to install the same horizontal drains as Option 2 to improve resisting forces. The second part of this approach would be the installation of shear piles to greatly increase the resisting forces near the toe of the slide. The combined effects of these measures would increase the shear resistance to further movement to the point of only needing very infrequent maintenance of the roadway and periodic drain cleaning. The primary advantages of the shear piles are that their installation has minimal environmental impact while providing significant resistance to sliding. They are installed entirely below ground so that they would not be visible once the construction access is reclaimed. The shear piles themselves are installed in large diameter borings advanced to a specified distance below the slide plan. The piles are then constructed of an H-pile or rebar cage placed at the bottom of the borehole that usually extend to the surface and then encased in concrete or cement grout. One or more rows of shear piles are usually installed depending on the size of the slide, pile diameter, and pile spacing within the row. This option makes construction the predominant adaptation and takes most of the future maintenance work away. This approach also safeguards the slide from most of the effects of rising sea level and toe erosion as it provides shear resistance at the slide surface where the effects of further mass reduction in the toe portion of the slide would be generally negated.

Option 4 – Unload, Construct Buttress and Shear Key with Foundation Support

This is a fairly complex method of slide mitigation with respect to construction sequencing but provides significant future adaptive measures in terms of drainage to reduce the effects of rainfall as well as resistance against sliding even with significant erosion and inundation at the toe. This alternative substantially reduces the driving forces and increases the resisting forces while also increasing subsurface drainage with corresponding reduction in pore water pressure in the lower portion of the slide. The upper portion of the slide would first be removed as in Option 2 to reduce driving forces on the slide while increasing temporary slope stability during subsequent construction of the buttress and shear key. In this case, shear key excavation carries significant risk of failure during construction which can largely be mitigated however large excavations at the toe of any landslide are particularly difficult. Agency experience with this type of construction has shown that 30 feet is about the greatest practical depth of shear key excavation. The projected slide surface at Jetty Creek Slide exceeds this depth. Thus, stone columns were selected as the method to provide shear resistance across the slide surface. The buttress would provide additional resisting force while the mass of the buttress increases the shear resistance of the stone columns. The stone columns would be placed prior to shear key/buttress excavation to provide initial stability. Thus, unloading and shear resistance would already be in place prior to the riskier general excavation of the keyway at the toe of the slide. The buttress constructed of high-permeability stone embankment provides drainage in the basal portion of the slide that would be conducted out of the slide area via a perforated pipe to a nearby drainage similar to the function of the horizontal drain

The Nehalem River estuary as seen just below the Jetty Creek landslide.

manifold. This alternative essentially eliminates future maintenance at the site if coupled with some riprap armoring on between the railroad and the Nehalem Bay shoreline. Very minor deformation of the roadway may continue for a short time after construction but could be of such a small magnitude that it would not necessitate maintenance repair.

Option 5 – Construct Soldier Pile Wall

This option would involve the construction of a soldier pile wall with further support by tieback strands to support the roadway. This structure should be further protected from long-term erosion by a riprap/jetty stone revetment in order to realize its full design life. This structure would include rock-socketed soldier piles that penetrate the slide surface with further lateral support provided by post-tensioned tieback strands. The strands would penetrate the slide laterally and also be placed in sufficiently resistant material to provide a bonded zone with enough strength, in conjunction with the soldier piles, to withstand the forces of the landslide once tension is applied. Although deeply placed in resistant material, the structure will need the added shoreline protection for it to accomplish its full design life as the roadway could potentially be undermined. All costs related to this option are up front, and design and construction-related. This option would eliminate the need for any further slide-related maintenance at the site. Maintenance of wall drainage or ancillary drainage features along the roadway may be necessary in the future. This structure would not address potential instability at the less active Northern portion of the landslide.

4.11 ROCKAWAY BEACH

- Milepoint: 50.78-51.31
- Hazards: Coastal Erosion, Roadbed Scour, Debris
- Climate Drivers: Sea Level Rise, Tidal Extremes, Storm Surge

A double box culvert runs under U.S. 101 at Salt Air Creek, Rockaway Beach.

US 101 runs through the central business district of the city of Rockaway, Oregon, from about MP 50 to 52. Rockaway is primarily a tourist location with a broad sandy beach separated from the town and US 101 by a very small dune field. The town and the highway are low-lying and only a few feet above current sea level in most locations. This site is subject to flooding on a relatively frequent basis with at least one event per year that necessitates road closure and subsequent restoration. Ocean debris deposited on the roadway is a significant issue. This flooding results from the extreme precipitation events as well as storms that produce enough surge to breach the dunes where existing streams drain into the ocean. The storm surge transgresses the stream channels as far as the highway and through the box culverts that carry those streams below US 101.

The debris rack at the Salt Air Creek beach outfall.

Several lakes to the east of the highway also contribute to flooding in this area. These lakes are drained to the ocean by the streams previously mentioned that pass under the highway in 48”-diameter box culverts with the exception of the Lake Lytle outlet that is crossed by a trestle bridge. The area to the east of the city is mountainous with considerable relief and drainage area that feeds these lakes. During extreme precipitation events, discharge from the lakes nearly exceeds the capacity of the box culverts. The large amount of debris deposited in the streams and culverts themselves creates a blockage that results in flooding near the roadway. Thus, the area is subject to ocean flooding and storm surge as well as flooding from the lakes and streams due to extreme precipitation. Debris comes from the eastern drainages as well as the ocean-derived debris.

This site is extremely vulnerable to almost all climate drivers. Increased sea level, grater storm surge, higher wave height, and extreme precipitation events all have a detrimental effect on this location. At this location, the highway is probably less vulnerable than the surrounding community however; it is almost impossible to address the highway vulnerabilities separately. The obvious solutions of moving the highway or elevating it beyond the effects of the climate drivers also remove it from the community it serves directly. Options were developed to analyze the potential effects of some mitigation efforts that could be undertaken to protect the highway, but without a comprehensive strategy for the whole community, these options will be limited in their overall effect.

Table 11 – Rockaway: US 101, MP 49-52

Rockaway: US 101, MP 49 - 52					
Adaptation Option	**Description**	**Mitigation Effect**	**Total Construction Cost**	**Annual Maintenance Cost (Current)**	**Annual Maintenance Cost @ 30 Years**
1	Do Nothing	No Effect - Storm events continue to cause flooding and debris deposition on roadway and roadside drainage.	$0	$3,378	$11,250
2	Construct Ocean Debris Barriers, Widen and Reinforce existing Channels	Eliminate debris deposition on US 101, reduce lake water backup in channels and reduce structure scour.	$447,500	$2,565	$8,550
3	Construct Ocean Debris Barriers, Widen and Reinforce existing Channels, Elevate and Widen Bridges	Eliminate debris deposition on US 101, eliminate lake water backup in channels and eliminate structure scour.	$8,125,300	$0	$0

Option 1 – Do Nothing

Continuing the current efforts to restore service after each event is the most cost-effective short-term strategy. However; with a projected increase of over three times the current number of extreme rainfall events that result in closure, this effort becomes less effective and more costly in the long term. It is also difficult to predict future performance of the facilities affected. At the current time, blockage in the culverts is a manageable issue but the severity of future events may lead to less manageable problems such as scour around and below the culverts as well as deterioration and abrasion from excessive debris.

Option 2 – Construct Ocean Debris Barriers, Channel Reinforcement

This option would reduce the impacts of storm events and reduce the amount of maintenance work needed after those events. For this option, the stream channels from the highway to the sea would be widened and protected with riprap or similar treatment to accommodate higher volumes of storm surge, ease the removal of debris, and protect the stream banks from being undermined. A barrier would also be constructed at the stream mouths to prevent debris from entering the stream channel during events with significant storm surge. Although this option reduces the impact of extreme weather events, substantial maintenance is required to remove debris from the barriers, repair any damage to the barrier from the storm, and remove debris build-up from the channel above and below the box culverts to preserve the effectiveness of these items.

Option 3 – Construct Debris Barriers, Enhance Channels, Replace Structures

The most positive solution with respect to highway resilience would be to perform the work described in Option 2 while replacing the existing box culverts with slightly elevated bridge structures. The vertical alignment of the highway could be minimally raised at these locations with minimal disruption to access. Removing the constriction of the box culverts would allow passage of debris while accommodating greater stream flow during storm events since the small bridge structures would have an opening at least as wide as the existing stream channel. Deep foundations supporting the structure would be placed below scour elevations thus eliminating the need for additional scour protection. With rising sea level, additional aggradation of the stream channel would probably be more of an issue than scour.

Driftwood remains in the ODOT right-of-way from past storm surge events.

4.12 Options Summary

Projected climate change will impact ODOT's maintenance cycles, increase maintenance and operations costs, and affect decisions about when and where to protect or reconstruct roadways. These decisions will be particularly complex along the coastal highways. Sound decisions will rely on the level of condition monitoring and technical data available to inform the timing and scale of adaptation.

An example is the need to capture the data necessary to establish relationships between precipitation, groundwater and slide movement. Observation of site conditions and their relative response to rainfall amount was used for this study. A linear relationship was developed to correlate and project future rainfall events with subsequent maintenance repair activities. The actual relationship between precipitation, groundwater, and slide movement is highly dependent on subsurface conditions and generally follows a geometric curve when the necessary data can be utilized.

More frequent, stronger storms coupled with higher annual rainfall should be expected to greatly increase landslide activity; the rate for which is beyond estimation without a robust subsurface model for any specific storm. What is clear is that this change in climate conditions will have a severely detrimental effect on landslides in the study area. A geometric progression resulting in an order of magnitude increase in maintenance activity would not actually occur as Maintenance personnel would take a more economical, short-term solution such as a temporary closure or detour.

Areas projected to be subject to flooding and storm surge are constrained by the extensive costs and impacts related to potential adaptation options. In many cases, mitigating these climate stressors can be as damaging to a community as the effects of climate change: moving, modifying, or enhancing a facility may be so detrimental to a community that its value is negated. For example, relocating a facility such as Highway 101 out of Rockaway would certainly eliminate the risk to the facility, but would isolate the community. Similarly, raising the grade of the highway at this location would also reduce the risk while impacting the surrounding community by removing access, moving private property, and other direct effects, including environmental impacts.

Considerable efforts are needed to model climate impacts not only on transportation facilities subject to higher sea levels and storm surge, but also on the surrounding communities that rely on the system. In this way, adaptation of the transportation system should take place in conjunction with strategic and local comprehensive planning to fully understand the effects of individual site decisions on the overall community.

4.13 Benefit Cost Analysis (BCA)

This section outlines the findings of the BCA. The two sites selected for BCA were Falcon Cove and Jetty Creek. For a complete list of assumptions see Appendix I.

Falcon Cove Fill Slope Failure

The Falcon Cove site has an average daily traffic (ADT) count of approximately 2,800, of which an estimated 18.4% are trucks. Traffic count growth estimates result in an ADT of 3,700 at year 30. Truck proportions of future traffic volumes are assumed to stay the same.

The base case assumes that the failure continues to the north bound lane at a rate 1.5 times per year initially, increasing to 2.5 times by year 30. A growth trend was used to estimate failure rates for the years in between - meaning it was assumed that failures would occur more frequently in later years. The rates were converted to an estimated whole number of failures per year. Estimated repair and wage cost per failure in current dollars is $6,000.

The analysis period for the adaptation option begins just as Mitigation option 5 is constructed at a current dollar cost of $668,100. As a result there are no failures or related costs.

Since there are no significant travel impacts under the base case scenario, the benefits of the adaptation option are repair costs avoided and differences in residual value of changes to the facilities. The costs of the adaptation option reflect the engineering and construction costs of mitigation option 5. Both benefits and cost are appropriately discounted.

Table 12 – Falcon Cove Benefit Cost Analysis Results

Item	Present Value
Repair Costs Avoided	$253,400
Additional Residual Value	$77,200
Total Benefits	$330,600
Costs	$648,600
Benefit Cost Ratio (B/C)	0.51
Net Present Value (B-C)	($318,000)

Even though the adaptation option results in some costs being avoided and a higher residual value at the end of the analysis period; these benefits are not sufficient to justify the costs associated with the adaptation action. The result is a benefit cost ratio that is 0.51 (less than one) and a negative net present value of -$318,000.

Jetty Creek Landslide

The Jetty Creek site has an average daily traffic (ADT) count of approximately 4,100, of which an estimated 18.5% are trucks. Traffic count growth estimates result in an ADT of 6,000 at year 30. Truck proportions of future traffic volumes are assumed to stay the same.

The base case assumes that failures deform both lanes at a rate of once a year initially, increasing to 3.33 times by year 30. A growth trend was used to estimate failure rates for the years in between - meaning it was assumed that failures would occur more frequently in later years. The rates were converted to an estimated whole number of failures per year. Traffic is restricted to one-way flagger control for an eight hour period when the failures occur. Estimated repair and wage cost per failure in current dollars is $13,700.

The analysis period for the adaption option begins just as Mitigation option 5 is constructed at a current dollar cost of $20,400,600. As a result there are no failures, diversion, deflection, or related costs.

Under the base case scenario, only the full closure for ten months (at year 20) results in significant travel impacts. The benefits of the adaptation option are repair costs avoided, time savings, fuel cost savings, and social cost of carbon avoidance from preventing traffic diversion. The lower ending residual value of the facilities acts as a dis-benefit and is subtracted from the other benefits when determining the total benefit of the adaptation option. The costs of the adaptation option reflect the engineering and construction costs of mitigation option 5. Both benefits and cost are appropriately discounted.

Table 13 – Jetty Creek Benefit Cost Analysis Results

Item	Present Value
Repair Costs Avoided	$10,340,400
Travel Time Savings	$9,007,900
Fuel Cost Savings	$1,361,300
Social Cost of Carbon Savings	$343,300
Reduction in Residual Value	($2,783,600)
Total Benefits	$18,269,300
Costs	$19,806,400
Benefit Cost Ratio (B/C)	0.92
Net Present Value (B-C)	($1,537,100)

Even though the adaptation option results in costs being avoided and savings from avoiding the diversion; these benefits are not sufficient to justify the costs associated with the adaptation action. The result is a benefit cost ratio that is 0.92 (less than one) and a negative net present value of -$1,537,100.

This outcome is in part due to a lower residual value at the end of the analysis period. If a design with the same benefit but a longer useful life could be constructed at the same cost, the outcome might be different. In addition, this analysis assumes no real changes in the value of travel time over a thirty year period. Values of travel time are based in part on wages and household incomes and likely have some sensitivity to real increases in wages and income. How much is sensitivity is unknown, as is whether there will be real income or wage growth over the analysis period (there has not been much if any in the last decade for most people).

Economic Impacts of Road Closures

A major failure on Highway 101 within the study corridor will create immediate impacts to the area. However, this region of the coast is sparsely populated and the roadways carry relatively low traffic volumes. Upon closure, travelers would use alternative routes where available, such as Highway 53, or shift their destinations in response to the change in the highway system. ODOT's statewide model estimates region population and employment growth will be affected to a relatively small degree, and households and jobs would shift to other parts of the region to accommodate the change over time. However, there would be an area in the immediate vicinity of the highway closure that would be affected over the long-term. Over the course of 30 years, population in the area closest to the closure is forecast to be 8 percent lower and employment 20 percent lower. It is important to note that this analysis simulated the average weekday patterns and did not account for seasonal or weekend variation. Exploring seasonal impacts would require further analysis.

4.14 Regulatory Review

The regulatory context for implementing adaptation projects on the Oregon coast is complex. Armoring or realigning transportation facilities can be subject to multiple federal, state and local standards, numerous permit applications, and several different regulatory authorities over many years. The regulatory regimes that manage land uses on the Oregon coast also predate the most current understanding of the risks involved with many coastal hazards.

Adaptation strategies related to more frequent extreme storm events and sea level rise often include protection measures such as revetments and other site hardening measures, and potentially roadway realignment. Identifying preferred alternatives will require balancing the level of risk against the overlapping and sometimes conflicting regulatory requirements that must be navigated in order to implement a solution.

Perhaps the most significant regulations that may restrict the agency's ability to proactively protect coastal infrastructure are section 6(f) of the Land and Water Conservation Fund Act (LWCF)[26], and Goal 18 of the State Land Use Program.

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[26] LWCF funds are often used to acquire or make improvements to parks and recreation areas. Section 6(f) of this act prohibits the conversion of property acquired or developed with these funds for uses other than public outdoor recreation without the approval of the National Park Service (NPS). When acquisition is required, Section 6(f) directs the NPS to assure that replacement lands of at least equal fair market value and of reasonably

The bar is high to meet all of the requirements of a land use exception, adding to research and analysis, engineering and time costs. This tends to put ODOT in a position to select the regulatory path of least resistance which may in some cases result in a less strategic, shorter-term fix.

Many potential adaptation options could require a lengthy Environmental Assessment, or Environmental Impact Statement (if there is a federal nexus), depending on the scope of the project. Even projects fitting a Categorical Exclusion (Class 2) NEPA classification could run into obstacles such as needing Goal exceptions or 6(f) conversion approval from the National Park Service.

Both time and money may weigh against a reroute of a roadway away from a coastal hazard. If a fix is available within existing right of way, the regulatory burden of proof to move to a new route is high. Any of the following options raise one or more barriers to what may be an otherwise less complex and/or less costly (both time and money) mitigation measure:

- Moving a segment of the highway inland into farm or forest land;
- Installing revetments or other barrier protections, like building walls;
- Raising the road surface;
- The need for additional ROW (of any amount no matter how minor)
    - To be acquired from a 6(f) protected park or other recreation property, requiring a conversion;
    - Located on a beach, in a park or recreation area; or
    - In a different land use zone with resource land protections.
    - Blocking a view or otherwise degrading scenic values.

See Appendix J to view the Regulatory Framework and Beverly Beach case study.

Coastal erosion damage along U.S. 101 at Beverly Beach.

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equivalent usefulness and location are provided as a condition of such conversions. Consequently, where conversions of Section 6(f) lands are proposed for highway projects, replacement lands are required.

5

Lessons Learned

5 Lessons Learned

ODOT achieved many objectives and faced several challenges over the course of the pilot. These experiences will help inform ODOT's future efforts to incorporate adaptation into existing programs and decision-making. Many of our challenges concerned data availability, acquisition and interpretation, as well as the process, tools and results for determining costs and benefits of adaptation. We were able to focus our efforts on solutions and alternatives that added value to the project. The following are some of our lessons learned.

5.1 Climate and Hazards Data

ODOT worked with climate data covering the entire State of Oregon. This satisfied the objectives of the north coast pilot study but also addressed other climate regions, which will eventually meet the agency's needs for a broader vulnerability assessment.

We encountered some difficulties processing data from regionally downscaled global climate models. This effort demanded staff resources with highly technical and specialized skills. The process was new to ODOT and involved large amounts of data. There were several weeks of trial and error to download and process it in a useable form. We also had to resolve several data gaps and quality issues with the downloaded model data.

Rock fall site located north of the Jetty Creek landslide complex.

Our original approach was to use ArcGIS with scripting to analyze the data, but it soon became apparent that would take too much time and resources. A very large amount of data had to be processed for each model. The source data for each model are so large that they are provided for 10-year time periods (except for the period from 2000 to 2005). The file size for one 10-year period is almost 3.3 gigabytes. It was decided that the work might be accomplished much more easily and quickly using the R language and environment for statistical computing, especially since an R package is available for reading the climate data into R (ncdf4). Documentation was written up by our analyst since he was retiring and was the only one familiar with the data processing steps taken.

The climate data was processed for statewide application. Not all maps and outputs were able to be scaled specifically to areas within the north coast pilot region due to time and staff limitations. NOAA climate regions are large geographic areas and the coastal region is delineated along the entire length of the Oregon coast, from north to south. There are some distinct climactic differences between the north, central and southern Oregon coast. These broader geographic boundaries tended to dampen out the local distinctions or extremes when averaging results across the coastal zone. In addition, precipitation varies considerably in areas along the coast compared with higher elevations in mountainous Coast Range.

The advantage of having our own dataset for analysis was the ability to compare results with comparable regional analyses done by state climatologists, and the ability to compare relative temperature and precipitation changes projected in the various zones across the state.

Use of the CMIP Climate Data Processing Tool allowed us to quickly concentrate our analysis to the Study Corridor level. The tool allowed us to select a more refined (12 km square) area for analysis over our sites with the advantage of “pre-processed” measures and thresholds specific to that location. For precipitation, the data includes estimates for the projected frequency of larger (extreme) storm events, enabling us to project the magnitude of these threshold events on our project sites. We could compare these data against our baseline storm event “thresholds” that trigger road hazards.

Even with these steps taken, the ability to translate long-term climate projections from global climate models into on-the-ground project level (engineering) decisions remains full of uncertainties.

OCCRI provided invaluable guidance and direction for how to use and interpret climate data. It may have helped the project to have relied even more on OCCRI’s expertise as considerable time was spent processing climate data. However, OCCRI was facing resource constraints and limited availability midway through the project. Regardless, we had the added benefit of referencing several OCCRI studies produced over the course of the pilot, one focused on the Tillamook Bay Watershed which was an excellent source of local information.

Maintenance Records and Workshop

The use of Transportation Operations Center (TOCS) road hazard dispatch data allowed us to map and analyze both the locations where maintenance crews were in the field and the timing and frequency of events. Geospatial mapping of weather-related TOCS data was a first for ODOT, and helped show us weather related hot spots. It was also an effective way to engage maintenance and asset managers about priorities.

A challenge with the TOCs data was the large number of data records. We captured four years of data for the Maintenance District which yielded well over 2,000 records that required further processing. By eliminating redundant entries we were able to pare back the dataset to about 440 incident records.

It would be advantageous to ODOT to have a larger set of TOCS data for analysis which would allow for the screening of more winter weather incidents, geography and trends. If a similar analysis is conducted again we would recommend a decade worth of records be captured, focusing on the rainy season (October through April) in Oregon.

ODOT crews begin work to stabilize a slide on U.S. 101 south of Newport, January 2012.

Agency discussions of projected climate impacts and data gaps were valuable. Having these detailed conversations about climate impacts (and relative risks and priorities) was new for ODOT. We gained a better understanding about the data we have and don't have (but need), including better site condition and costs data from specific storm events. The maintenance dispatch records had limited ability to demonstrate risk levels at our sites. We visited the District 1 office for maintenance records and contacted Region for sources of information regarding maintenance hazards, past project data, and geologic records. We contacted local jurisdictions for information about these sites as well. There was a clear recognition that we need to enhance how we track and record impacts and costs, and further develop our ability to monitor and collect data about these hazards.

Using a maintenance workshop and site visits was the right method for assessing regional vulnerability, since our analysis was based on a qualitative approach. The institutional knowledge from the maintenance crews was important for identifying sites and rating the vulnerability and risk of potential impacts.

Lessons from this initial workshop will help ODOT improve the process and will inform work on future assessments. We have improved our understanding of adaptation planning through this pilot, and will use this experience to "fine tune" our approach. For example, since we now have accurate data layers we can prepare detailed sea level rise maps in advance of a workshop, and generally be more prepared with climate data information and expected outcomes.

Geographic Information Systems (GIS) was an effective tool to collect and share data. The ArcMap (web-based) tool allowed us to manage, store and display different data layers germane to the project. We developed a unique project file that pulled together many existing data sets together for the first time, but also involved the creation of totally new data. Having data in the map tool allowed us to effectively engage and solicit input from District maintenance crews and the Adaptation Work Group.

Sea Level Rise

Mapping sea level rise (SLR) was new to ODOT—and the Oregon Coast. We coordinated with the Department of Land Conservation and Development (DLCD) and other agencies to inform our mapping approach. One of our key objectives was to work in a coordinated way using a consistent set of assumptions as other state agencies. Although we generated our own GIS layers, we later relied exclusively on a DLCD-generated SLR layer for our impact analysis. This layer covered more areas within the estuaries and bays and so was deemed more complete. This mapping exercise provides a high level screen to identify vulnerable highway corridors. Additional mapping refinements will be needed to more accurately delineate inundation areas at specific sites, particularly in areas where levees may afford a certain level of protection. ODOT's effort in this area provides a framework for how to further advance this work.

5.2 Developing Adaptation Strategies

ODOT collected data that informed conceptual level design options at the five adaptation sites. This effort has highlighted data gaps—data that is not readily available or not in a form that can help advance design work or risk assessments. Examples include site specific data regarding bluff erosion rates and shoreline retreat, groundwater and landslide movement data, and timing and elevation of storm surge (in combination with flood events or open ocean wave run-up).

Collecting data that informs risk is difficult, particularly at landslide sites and sites that are impacted by a combination of potential climate impacts. The effects of precipitation levels on landslide activity and effects on toe erosion and groundwater from sea level rise are difficult to determine, yet remain critical engineering information relevant to analyzing landslide risk and potential solutions.

Data specific to coastal erosion rates and shoreline change were difficult to obtain since monitoring was either not conducted at our specific locations, or because flood modeling results were not available or designed to look at our highway locations. ODOT maintenance crews are aware of the locations where high tides and storm surge periodically impacts the roadway, however records about the frequency and magnitude of these events is not readily available. State researchers are monitoring the coast and conducting studies on wave intensity, as well as modeling potential impact areas from extreme coastal events that include wave run-up (Total Water Levels). These results will be valuable to ODOT in the future as we determine adaptation priorities and design strategies to protect infrastructure from coastal storm impacts.

Benefit Cost Analysis

While inclusion of benefit cost analysis (BCA) as an assessment tool was not anticipated in the original scope of the pilot, the project team recognized its potential for helping to compare adaptation options. Given that part of the project goal is development of an assessment process, testing the use of BCA for climate adaptation was also thought to provide value.

Our original intent was to provide benefit cost analyses for each of the five prioritized hazard site locations, and evaluate each of the adaptation options against the "do nothing" base case. However, after looking at the types of hazard issues and strategies, the team found that many of the sites were similar in their costs and outcomes. In addition, in terms of potential traffic impacts, a number of the adaption action options had similar levels of impacts avoided. Therefore the scope of the BCA was narrowed to two sites, each with a base case and single “permanent fix” adaptation option to evaluate against it.

The nature of climate impacts suggest that a corridor approach to benefit-cost may be more appropriate. The existence of viable detour routes was a key factor in determining outcomes. Our analysis shows that there is resiliency within the Study Corridor—however an analysis of multiple catastrophic events (and long-term closures) may yield different results as more than one site is likely to be impacted in a given event. A corridor-scale BCA would need to take into account larger failed sections of roadway (non-free flow conditions) and pay careful attention to design-life values for selected adaptation measures. Constrained truck and freight traffic mobility standards on potential detours, and cost-efficiencies (economies of scale) for contracting and delivering adaptation projects at a larger scale are also factors that have the potential to change the BCA outcomes towards cost-effective results.

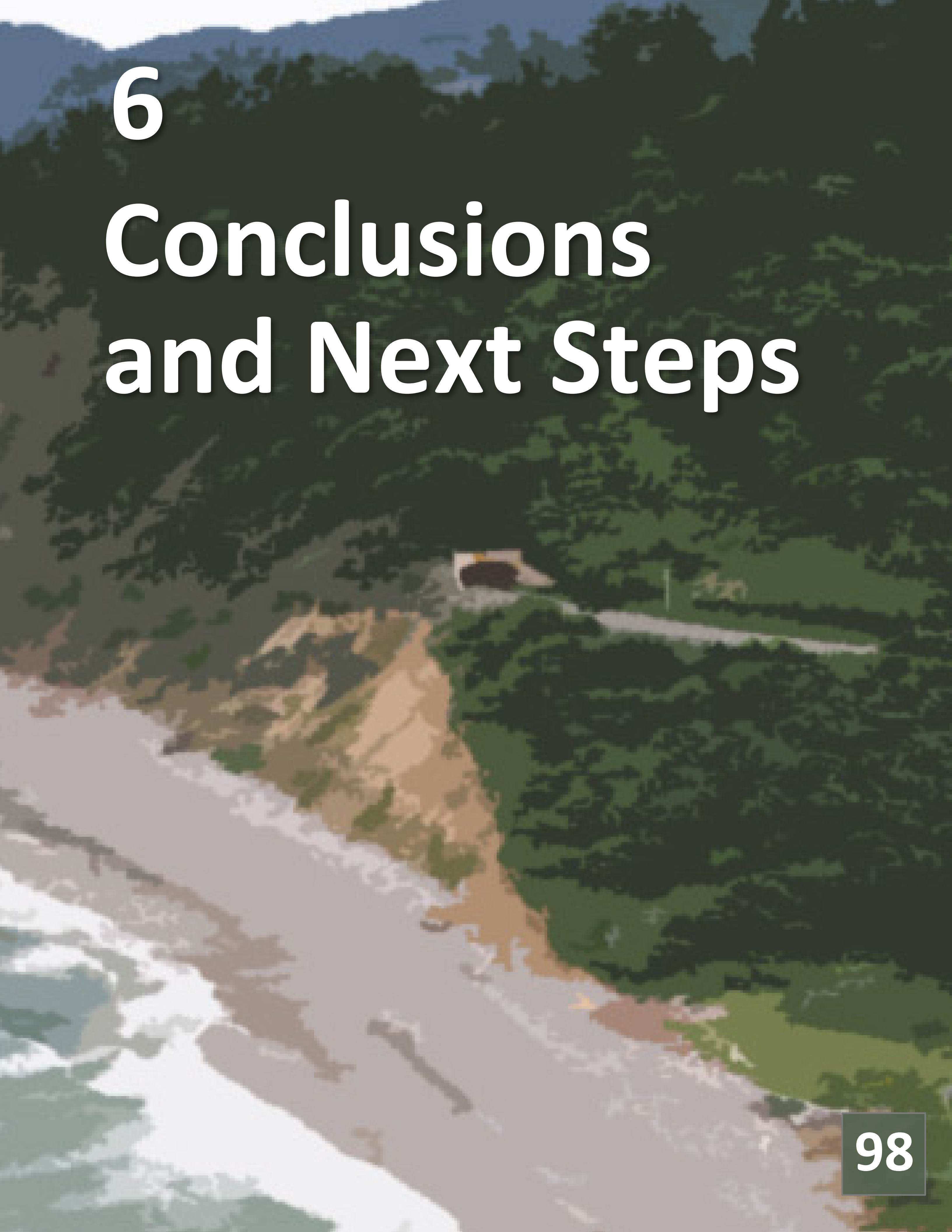
5.3 Key Take-Aways

- Data collection for climate impacts is an on-going process and takes time. Focus on the top priorities and needs first, and use existing data and information wherever possible.
- Use of maintenance-related weather hazards data is effective for identifying “hot spots” and existing hazard areas. Engaging agency management and staff on projected climate impacts is valuable. Use the expertise of maintenance field staff to help identify risks and priorities.
- Data and other institutional information may vary widely in age, quality, extent and scale. Scale becomes a factor between state, region and site-level data needs.

- The challenges and climate data gaps highlight the need for more comprehensive and targeted programs for data collection, monitoring and data management for high risk climate hazard sites.
- Sea level rise mapping provides tangible results and products that can inform project planning and development, however the mapping process is slow, technically challenging and requires inter-agency coordination.
- Benefit-cost and economic impact analyses can provide valuable information, such identifying the importance of viable detour routes in supporting regional resiliency. However, caution should be taken when determining the scale of climate impacts analysis (site vs. corridor-level).

Road surface collapse on OR 255 in Curry County, January 2012.

6 Conclusions and Next Steps



6 Conclusions and Next Steps

ODOT's pilot study has initiated a broader agency discussion on adaptation. Our findings lead us to ask, "What comes next?" ODOT will continue to explore ways to identify and prioritize transportation assets that may be affected by climate change and develop guidance on how best to address these impacts. We will continue to engage management and staff on climate change priorities and develop necessary program or organizational changes. Our accomplishments provide a foundation upon which to build. These potential implementation pathways and priorities are outlined below.

6.1 Key Accomplishments

- Gained a broader understanding of climate risks and impacts on the Oregon coast, and important connections with the agency's seismic resilience planning.
- Used maintenance hazard records as a way to identify and prioritize climate vulnerabilities, and engaged maintenance crews on issues of climate-related road hazards and risks.
- Developed adaptation options and identified gaps in data and historic records- (we found out what we need to know, don't track, or is most difficult to obtain).
- Enhanced coordination between local, state and federal agencies on adaptation, including data sharing and input on a regional adaptation framework for the north coast.
- Made new connections with climate scientists and research specialists for coastal climate impacts.
- Accessed new forms of climate data and management tools, and developed sea level rise GIS layers.
- Used benefit-cost analysis in review of adaptation options.

6.2 Implementation Priorities

ODOT's Adaptation Work Group identified the following priority implementation pathways.

1. Implement a program for data monitoring and research at high-risk sites:
    - A focus of this effort would include risk-based landslide monitoring. We used the pilot study to identify needs and to initiate baseline data collection at the Arch Cape site using ground-based LiDAR. ODOT's goal is to continue annual data collection at this and other sites to proactively inform us of erosion rates and risks to the highway. (See Appendix K for more details).

2. Develop project review guidance using sea level rise GIS mapping:
    - A goal of this effort would be to make the ArcMap GIS tool available to those who need it, such as region planners, technical centers and maintenance. While some mapping refinements are needed, a data layer reflecting a year 2050 sea level rise scenario has been developed.

3. Integrate adaptation and other hazards resilience planning efforts:
    - Investigate opportunities to prioritize adaptation planning in Lifeline Routes most vulnerable to climate impacts—(focus on data monitoring, project development, and funding).

4. Formalize detour routes in priority corridors:
    - Viable detour routes are essential to system resilience; investigate the use the Seismic Lifeline Identification Study as a starting place for this effort.

6.3 Address Information Gaps

- **Standardize records of storm impacts on the transportation system.** ODOT captures much of this information already through the maintenance road hazards dispatch data, however more detail is necessary to better identify vulnerabilities and inform adaptation solutions. Impact data should include:
    - Dates, locations, storm and hazard events and impact details, and,
    - Specific preventative maintenance activities and actions taken to mitigate the impacts.

- The Transportation Operations Center System (TOCS) database could be modified to add fields necessary to capture these new data (post-event). A standardized form could also be produced or a team assigned to record such data when more significant storm events occur. The responsibility to implement these changes could potentially be shared between the agency's Technical Services Branch and the Maintenance Districts.

More than 400 yards of rocks and mud slid onto U.S. 101 south of Port Orford in March 2012.

Standards and guidance would need to be developed for use of any new data collection systems.

- **Collect cost data to inform future Benefit Cost Analyses**. A standardized way of capturing the costs of repair or mitigation of climate-related road hazard impacts should be an agency priority. This data is important to record in a centralized system with the other records noted above, and would inform both project priorities, long-term cost efficiencies and focused engineering solutions.

- **Enhance existing data collection systems.** Hazards records and monitoring field data need to be consistently entered into a database accessible to the agency. The TOCS system, managed by the Maintenance and Operations Branch, is one such system that could be modified to capture additional climate related data and its associate impacts. The Technical Services Branch recently embarked on a comprehensive statewide program to inventory the agency's culverts. The project captures type, size, location and condition– a core set of data essential to manage these assets in a programmatic way and prioritize future retrofits, or changes to maintenance or design standards. The culvert management database could potentially be used to collect adaptation related records for culverts. Technical Services also manages an Unstable Slopes Program and database for rating landslides and rock fall hazards, which could also be a system to capture and assess information related to climate impacts.

- **Implement a program for data monitoring and research at high-risk sites**. Adaptation requires timely and accurate data that relates climate events to site conditions, changes and risk levels. It also requires the ability to relate those specific climate events to specific site response and impact. ODOT needs a coordinated program to assess landslide and erosion risks, and to establish the systems and tools to manage this data. This information can directly lead to clearly defined project priorities and averted risk. Specifically:

    - Better data is needed to relate climate to , groundwater, its effect on landslide movement, coastal erosion rates at the most vulnerable sites

    - Better integration of Region landslide and rockfall assessment and evaluation activities with central asset management efforts.

    - Adaptation design requires that engineers be engaged and comfortable with the methods and uncertainties inherent in climate science. A consistent monitoring program is a pathway for making this a reality.

   - Landslide movement monitoring and flood gauge systems for bridges are good examples of such systems that have been successfully employed.

- **Implement a risk-based landslide monitoring program**: It is technically challenging to relate slide movement directly to rainfall events. This pilot study considered observed site conditions and the relationship between failures and rainfall events, particularly the amount of rainfall preceding landslide failures. Site conditions observations were based on routine, informal examination of the sites by personnel involved in repair work and not through direct measurements which would be required to develop correlations between precipitation amounts and the rate of movement of a particular landslide. ODOT needs to capture the data necessary to establish these relationships between precipitation, groundwater, and slide movement. Such a program will require a stable source of funding that can allow for the development of systems and tools to monitor and warn of hazards at the highest risk sites.

- **Prioritize monitoring sites.** The state's highest risk sites should be prioritized for instrumentation. Data monitoring systems can better quantify risks and hazards, estimate the incidence of hazard events, and help prioritize among potential projects. ODOT's Unstable Slopes Program includes a comprehensive database of landslides and rock falls across the state. While larger and more active slides may have the agency's immediate attention, there are many other locations where additional monitoring could provide vital clues for heading off potentially catastrophic failures in the future. Due to its size and potential to inflict heavy damage, the Jetty Creek slide is an example site from this pilot that is a strong candidate for more intensive monitoring.

- **Build upon prior hazards assessments.** ODOT should utilize previous hazards studies and assessments to prioritize data collection and implement projects. For example, in 2003 the agency screened Highway 101 for vulnerable coastal erosion hot spots. This analysis was done using GIS and aerial photography to identify locations that will eventually require some form of protection (or realignment) and potential regulatory exceptions under state land use Goal 18. A total of 26 areas of concern were identified, 17 in Region 2, and nine in Region 3. The Arch Cape site is included on this list, as was the Silverpoint Slide (an alternate site in this pilot). This body of work provides an important starting point for prioritizing field monitoring, potentially for ground based LiDAR or other methods that can help us better understand erosion rates and sites with the highest risk of failure.

- **Utilize existing LiDAR data and technologies.** All of coastal Oregon has aerial LiDAR coverage, however: very little has been used to identify and evaluate the large, ancient landslides that don't currently affect the highway. The existing ODOT landslide and rockfall data only includes sites that currently affect the roadway. It does not include sites that may be identified only by using this technology. To date, there has not been a comprehensive effort to inventory these sites and evaluate their potential future effect on the transportation system or affected communities. Determining the potential risks presented by these sites with respect to rising sea level and increased rainfall is an essential component to community and infrastructure resilience in areas affected by landslides.

6.4 Integrate Adaptation and Resilience Planning

Adaptation planning has many parallels to hazard mitigation and resilience planning. ODOT's goal is to make clear where these planning efforts can work together and where there are clear distinctions. We need to find ways to ensure that our adaptation work is coordinated with other efforts, provides direction in new areas that need attention, and adds value to existing resilience studies and hazard mitigation plans.

Unlike a seismic event, impacts from climate change may be more localized and the effects felt more gradually over time (such as the case with sea level rise). Some stakeholders may question why we are focusing on long-range climate change impacts within the same timeframe when the Oregon coast faces a considerable risk of a catastrophic seismic event. Regardless of the timeframe, ODOT has a responsibility to plan for and protect public investments in transportation. Planning for resilience to climate impacts and seismic threats within the same priority corridors makes good business sense and meets multiple agency objectives. A clear case should be made that both events can have similar consequences but differ in their timeframe.

The town of Nehalem is engulfed by flood waters, December 2007.
Photo: Gary Braasch

- **Actively Plan for Detour Routes.** Viable detour routes are available along many parts of the Oregon coast and provide a measure of redundancy along the Highway 101 corridor in cases of full closure. Within the pilot Study Corridor, Highway 53 and Miami-Foley road serve as good examples of routes that are used during closure events. ODOT should work to build resiliency in the system by establishing a more formal network of detour routes. The value of detours and redundant routes is recognized in the Seismic Lifeline Routes Identification study, but no findings or recommendations regarding detours were made in this study (as it was focused on state-owned facilities). Existing detour routes or gaps analyses have not been incorporated into hazards mitigation plans to the extent needed to guide system upgrades and improve resilience.

In the pilot area, ODOT has coordinated with local agencies on detours in areas of chronic flooding closures. For example, the agency has agreements with the City of Nehalem when the downtown is flooded for highway traffic to be re-routed onto local side streets, and works with Tillamook County for the use of Miami-Foley Road as an alternate route. These arrangements provide an important template for building a more formal network of safe and reliable alternate routes for the travelling public. This planning would be a comprehensive way to address system resiliency for a range of climate impacts and other natural hazards, such as seismic and tsunami risks.

- **Prioritize corridors to build resilience.** As project funding becomes increasingly competitive, added importance will be placed on having clear project needs and ability to leverage funding opportunities. Prioritizing adaptation mitigation funding within corridors—and project sites within those corridors—could provide additional leverage to the selection process and helps to build resilience at the system-level based on documented vulnerabilities and risks. Identifying vulnerable Lifeline Routes is a step in this direction.

Prioritizing corridors for adaptation runs parallel with ODOT's work to identify retrofit and landslide mitigation priorities on the Lifeline Routes. The Oregon Seismic Lifeline Report developed a GIS based methodology to support prioritization of investments at a corridor level for identified Lifeline Routes. ODOT's Bridge section has taken the lead on identifying system vulnerabilities and connecting potential projects with available funding to increase system resiliency. The same can be done for vulnerable landslide areas and other climate hazard sites in priority corridors. Building resilience within the same corridors can provide funding leverage and serves to meet the same strategic goals and outcomes. Landslides with high hazard ratings present the same risks to the system whether triggered by a seismic event—or from an extreme precipitation event, for example.

A transportation investment package is needed to implement a strategic mitigation program that builds system resilience. Statewide, we would anticipate adaptation projects to vary by corridor and region, but focus particularly on flood hazard areas and unstable slopes as priorities. Similar to the Seismic Lifelines study, the pilot provides some comparative results for the vulnerability of District 1 highways, however does not provide sufficient detail to prioritize actual mitigation projects and options within each corridor. Additional engineering data and evaluation would be necessary to prioritize within the corridors.

6.5 Benefit Cost Analyses

There appears to be real value to including BCAs in climate adaptation project assessments. Comparing the potential value of avoidance of adverse impacts to their cost can provide meaningful information for designers and decision makers. This approach should, however, be one of a number of views provided.

ODOT's general approach could be used for climate adaptation assessments in other parts of the state and by other departments of transportation.

- This suggests transportation agencies, whether at the state or local jurisdiction level, should track costs associated with repairs after extreme weather events, to support this type of analysis, by providing a basis for estimating impacts of future extreme weather events and associated repair costs.
- There may also be benefits to using a corridor approach for this type of analysis (though complicated), given that extreme weather events are unlikely to result in only one site in a hazard area being affected. A more complete assessment of available detours is also appropriate since they provide varied levels of service as alternates to the State highway system.
- If this method is replicated using a site-based approach, it is recommended that sites with unique characteristics or representative impacts be selected.

Cumulative impacts of road closures

The pilot BCA showed that due to lower traffic volumes, remote service areas, viable detours and other factors, significant investments in adaptation projects (within the Study Corridor) may not be cost effective. The analysis also shows that single events do not appear to isolate communities and resilience in the region is largely due to available detour routes. While investing in individual projects may not be cost effective, if we have multiple closures within a corridor during a single event, a similar analysis at the corridor-level might well find a different result for projects analyzed in the aggregate. Larger storm events usually inflict damage across a wide geographic area and transportation impacts are not usually isolated to one site or area, but are spread out regionally. As climate impacts increase in frequency and magnitude, so will the number of sites within increasing effects at each site.

Using a corridor level BCA approach could be a useful strategy to better understand the cumulative effects of weighing potential project costs and benefits. Importantly, these results may help us understand costs—*and value* - of keeping economic and emergency response "Lifelines" open. It is possible for us to find near-term costs for permanent adaptation solutions to be justified, particularly if cost savings are realized and mitigation is implemented prior to catastrophic failures with marked safety and travel flow improvements to the travelling public. As individual projects (or corridors) are analyzed on the Interstate system or in proximity to larger urban areas, the results are also likely to be different as compared with our pilot study. The BCA will remain an important part of ODOT's tool box for understanding costs of adaptation.

6.6 Consider Adaptation in Project Delivery

Utilize mapping and data products. ODOT can begin to incorporate climate related considerations into project evaluations. For example, this pilot study generated new GIS layers for projected sea level rise and coastal inundation under a range of future scenarios. These maps could be prepared into a series coastal "map books" and referenced by the maintenance districts and region planning offices. The online ArcMap tool can also make these data layers more widely available and would promote ease of use and access. These maps could be used during environmental reviews as part of project scoping and development. The Vulnerability Rating maps could be used to identify those higher risk corridors and to potentially help with prioritizing projects, such as along the most vulnerable Lifeline Routes. As discussed earlier, any climate hazards data collection systems should also be made more widely available in order to share information on climate impacts, costs and benefits at key project decision points.

- **Expand and refine sea level rise mapping.** ODOT should work with the OCMP and DOGAMI to generate and update sea level mapping on the north coast, including in areas along the Columbia River Estuary and locations further down the Oregon coast. ODOT should also coordinate with GIS specialists to refine mapping in high priority locations where the extent of inundation may be uncertain due existing levees, tide gates, or hydrologic connections.

6.7 Inter-Agency Coordination

Screen highest-risk sites to lay the groundwork for a programmatic regulatory approach. Selecting a set of high risk sites (such as Arch Cape) as test case examples for how to approach "streamlined" mitigation clearances would be a practical first step. For example, under current state law, ODOT facilities are not considered "development" and so remain ineligible for "grandfathered" repair or improvement of existing engineered shoreline protection. Hardening highway infrastructure along the coast requires a Goal 18 Exception through the Statewide Planning Program.

While a comprehensive programmatic solution may not be possible in the near term, having an understanding of where the highest risk sites are located—and potential steps we can take now to address regulatory priorities in the future would be prudent. A starting point for this work would be to refine the coastal erosion hot spots analysis conducted by ODOT nearly a decade ago. As the climate changes and sea levels rise, this list of sites may be the first to present challenges in the future.

Enhance interagency coordination on infrastructure protection and co-benefit projects. ODOT should prepare for adaptation planning and implementation by working proactively with state and federal agencies. Oregon's land use requirements may raise barriers to proactive, preventive project options along US 101. The regulatory process can weigh heavily in favor of shorter term, limited value solutions and locations compared to potentially longer-term mitigation that could serve multiple purposes, hazards and climate risks (such as flooding, storm surge, and tsunami hazards).

A constructive pathway for ODOT would be to work with the Department of Land Conservation and Development to identify methods to support projects that build resilience in our coastal Lifeline Routes when mitigation investment opportunities arise.

Agency coordination is also needed to identify co-benefit project opportunities and priorities at the landscape scale (such as floodplain restoration or culvert improvements) that can enhance natural resources and protect infrastructure. Pathways for ODOT include interagency meetings on the Adaptation Framework Plan, the state agency Coastal Protection Technical Advisory Committee, and ODOT and Oregon Department of Fish and Wildlife (ODFW) Fish Passage Programs. ODOT can also coordinate with agency efforts to implement the Oregon Resilience Plan, a comprehensive assessment of the resilience of Oregon infrastructure and economy to a major earthquake and tsunami.

In 2013, ODOT partnered with the North Coast Land Conservancy on a floodplain restoration and levee removal project along the Necanicum River. The project has helped to alleviate flood risk on U.S. 101 south of Seaside.

7
Appendices

Appendix A: Sea Level Rise Methodology

Sea Level Rise Methodology

Project Goals:

- Use sea level rise (SLR) maps as a high-level transportation planning tool.
- Map projected mid- to high-range SLR scenarios within the north coast study area.
- Conduct a first order screen of highway infrastructure that may be vulnerable to future inundation or storm surge under the selected scenarios.
- Produce maps and data depicting potential impacts on ODOT‘s operational right-of-way.
- Inform ODOT region, maintenance and asset managers regarding coastal vulnerabilities.
- Provide a template for future coastal mapping products.

What time frames and assumptions are appropriate?

ODOT used timeframes of 2050 and 2100 for its sea level rise mapping and analysis.

As part of its vulnerability assessment, ODOT used climate model projections (for temperature, precipitation) that run out to 2065 and 2100. For sea level rise, the Department of Geology and Mineral Industries (DOGMAI) provided mid- and high range SLR scenarios for 2030, 2050 and 2100. This dataset includes a locally developed methodology specific to Oregon coastal counties that combines a range of tidal values (Extreme Value Analysis) with projected sea level rise.

What specific assumptions are being used? What are the advantages to this approach?

Extreme Value Analysis

An Extreme Value Analysis was undertaken by DOGAMI and Oregon State University as part of its local FEMA flood mapping work. The methods used to perform the Extreme Value Analysis are described in many publications (e.g. Coles, 2001) [1]. Application on the Oregon coast is

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[1] Coles, S., 2001. An introduction to statistical modeling of extreme values. Springer-Verlag, London, 208 pp.

[2] Ruggiero, P., P. D. Komar, and J. C. Allan (2010), Increasing wave heights and extreme value projections: The wave climate of the U.S. Pacific Northwest, Coastal Engineering, 57(5), 539-552.

Allan, J. C., P. Ruggiero, and J. T. Roberts (2012), Coastal Flood Insurance Study, Coos County, Oregon Department of Geology and Mineral Industries, Special Paper 44, Portland, Oregon, 132 pp.

described in Allan et al. (2012) and Ruggiero et al. (2011)[2]. The data presented for Clatsop, Tillamook, and Lincoln County reflects this local FEMA work, which will be published in late 2014.

The Extreme Value Analysis (EVA) is a statistically robust methodology because it calculates the extreme values (10%, 2%, 1% events) based on a complete 40+ year time series of hourly tides, as opposed to doing this deterministically by adding the various contributions and making assumptions about their magnitudes. These data reflect the combined effect of the astronomical tides in addition to seasonal change, El Nino effect (when present) and non-tidal residual (also known as storm surge). Use of the EVA is a defensible methodology since it relies on actual tidal values over a long time period.

For Clatsop and Tillamook Counties, the estimated EVA is as follows:

10% - 3.55 (m)

2% - 3.67 (m)

1% - 3.71 (m)

These values consider only the tides and hence do not reflect any storm wave run-up that occurs out on the open coast during extreme events. This latter process is occurring on top of the tides and can contribute an additional 3 to 4 meters of water level on top of the measured tides. ODOT did not map for these “Total Water Levels” on the open coast.

Sea Level Rise Projections

The source of SLR projections is the 2012 National Research Council (NRC) West Coast report[3]—these projections were derived from global ocean models under an U.N. Intergovernmental Panel on Climate Change (2007) mid-range greenhouse gas emission scenarios, and were sanctioned by the Committee on Sea Level Rise in California, Oregon and Washington, (National Research Council, et. al). The NRC report contains the following projections for the Oregon coast:

2050: -2 - +48 cm (mid-range = +17 cm); mid-range = 6.69-inches, high range = 18.89-inches.

2100: +12 - +143 cm (mid-range = +63 cm); mid-range = 24.8-inches, high range = 56.29-inches.

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[3] Sea Level Rise for the Coasts of California, Oregon, and Washington: Past, Present and Future (National Research Council, 2012).

Methodology

ODOT used the NRC projections to map inundation scenarios for 2050 and 2100.

ODOT relied on the high-range of the combined 2050 SLR and EVA projections to determine transportation impacts under a 2% (50-year) probability of occurrence.

EVA + SLR (at 2% probability)[4]

	Mid-range	**High range**
2050	3.84 m (12.60 ft.)	4.15 m (13.62 ft.)
2100	4.30 m (14.11 ft.)	5.09 m (16.70 ft.)

Sea level rise layers were developed in ODOT's GIS. The GIS analysis involves clipping a Mean Lower Low Water (MLLW) polygon and LiDAR layers to the areas being mapped. The MLLW is the base elevation upon which sea levels and EVA values are added from the selected scenarios. These combined elevations are then matched against the coastal topographic (LiDAR) layer to show newly delineated water levels. Aerial photo layers are used to ensure work is being conducted in areas of interest and that projected areas of inundation make sense on the landscape.

ODOT focused its mapping in the north coast study area. This work is considered a "bath tub" model as the elevations depicted do not account for the specific influence of tide gates, levees or other hydrologic restrictions (or connections) that could change actual inundation areas. Regardless, areas of interest can now be mapped from the GIS as needed to inform planning and show the potential for inundation under selected scenarios.

ODOT's impact analysis (for purposes of the pilot) relied on a GIS layer developed by DLCD's Oregon's Coastal Management Program since it was deemed more complete within bays and estuaries. Projected sea level impacts were not calculated for Astoria or other areas in the Columbia River Estuary due to incomplete data. These areas will be a focus for future mapping efforts.

How is it to be used?

ODOT used the SLR layers to identify areas where right-of-way and highway infrastructure may be potentially impacted in the future. How we present the analysis and results may also provide a template for future SLR mapping work in other areas of the coast.

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[4] Elevations relative to Mean Lower Low Water (MLLW).

During our hazards workshop with Maintenance District 1, crews indicated that coastal highways projected to be inundated should be rated “Critical” from the standpoint of maintaining condition and function. Using GIS to account for these areas under various future climate scenarios will be most useful to the District, as well as regional planners and management teams responsible for setting funding priorities and long-term project decisions.

Appendix B: Oregon Climate Data and Trends Matrix

Oregon Climate Data and Trends Matrix					
Climate Variables	**General Expected Changes**	**Specific Changes**	**Quality of Evidence**	**Impacts on Transportation/ Known Thresholds**	**Sources**
Temperature	Increasing temperatures through the 21st century.	Increase in annual mean air temperature around 0.2 - 1°F per decade.	High. Strong agreement between climate models. The amount of warming depends partly on the rate of future GHG emissions.	Asphalt rutting, bridge expansion, rail buckling. Increasing temperatures won't likely impact transportation in the North Coast pilot area.	Oregon Climate Assessment Report (OCCRI, 2010); CMIP 5 Global Climate Models (IPCC, 2013)
	Hotter summer months and warmer winters on average.	Tillamook Bay is projected to have warmer seasonal averages between 4 and 7 degrees F by 2100.	High. All future GHG emissions scenarios reflect warming trends.	Negligible impact in North Coast pilot area.	Climate Change in the Tillamook Bay Watershed (May 2013)
Temperature Extremes	More days of high heat (temperature events at or >90th percentile).	Oregon will experience more 90-degree days on an annual basis. The hottest day of the year is projected to be warmer by as much as 9-degrees F. (Tillamook Bay)	High. Climate models are in agreement that measures of heat extremes will increase and measures of cold extremes will decrease.	Asphalt rutting, bridge expansion, rail buckling. Temperature extremes may become a factor in eastern Oregon where road pavements are not designed to withstand extreme heat over time.	Climate change in the Tillamook Bay Watershed (OCCRI, 2013); NW Climate Assessment Report (OCCRI, et.al, 2013)
	Prolonged heat waves. Heat waves are very likely to occur more frequently and last longer.	More days with temperatures at or above 100-degrees across the state; between 6 and 13 additional 100+ degree days projected for the central and southeast parts of the state.	High.	Rail tracks can warp with extended periods of 90-degrees+. Road paving is impacted when the Heat Index is expected to be 105-degrees for 3 hours or more with overnight minimums around 80 -degrees or higher.	CMIP 5 GCMs (IPCC, 2013); TRB Research - Weather Thresholds with Implications to US Transportation (2007)
Precipitation	Drier summers. Increased drought conditions.	The multi-model average decrease for summer precipitation is between 14 - 19% by 2100; The number of months of drought (in which precipitation is less than 80% of the historical average) is projected to increase.	Medium. However the most consistent changes in global climate models show a regional warming and drying in the summer months.	Negligible direct impacts. However, extended drought conditions can increase vegetation fuel loading and wildfire risks.	Climate change in the Tillamook Bay Watershed (OCCRI, 2013)

Oregon Climate Data and Trends Matrix					
Climate Variables	**General Expected Changes**	**Specific Changes**	**Quality of Evidence**	**Impacts on Transportation/ Known Thresholds**	**Sources**
	Fall and winter seasons wetter on average.	1) Projected 15 - 30% increase in winter precipitation over 21st century; 2) Annual mean precipitation projected to increase 3 to 5 inches over 21st century; 3) Projected annual average winter increase of >2" of precipitation on the Oregon Coast by 2065 (low & high emission scenarios)	Low. Climate models are inconsistent in regards to overall precipitation trends for the region over the next century.	Increased flooding, erosion and scour can directly impact transportation facilities.	1) Oregon Climate Change Assessment Report (OCCRI, 2010); 2) Climate Change in the Tillamook Bay Watershed (OCCRI, 2013); 3) CMIP 5 GCMs (2013)
Precipitation Extremes	Increase in extreme precipitation events.	Trends in extreme daily precipitation over the 20th century have been ambiguous in Oregon, however there are indications that extreme events (>90th percentile) will increase in this century.	Medium. Future changes in precipitation extremes are more certain than changes in total seasonal precipitation.	Scour at bridges openings, culverts and roadbeds adjacent to waterways subject to flooding. Increase in traffic disruptions and slowdowns. Increased maintenance costs and road closures.	Climate change in the Tillamook Bay Watershed (OCCRI, 2013)
	Increase in maximum 24-hour precipitation events.	1) Days where we receive at least 2-inches of rainfall over 24-hours is projected to increase, up to 3 additional days per year; the wettest day of the year is projected to increase 0.25-0.75 inches per event; 2) The number of days with greater than 1 in (2.5 cm) of precipitation is projected to increase by 13% (± 7%) and the 20-year and 50-year return period extreme precipitation events are projected to increase 10% (-4 to +22%) and 13% (-5 to +28%), respectively, by mid-century.	Medium.	Scour at bridges openings, culverts and roadbeds adjacent to waterways subject to flooding. Increase in traffic disruptions and slowdowns. Increased maintenance costs and road closures.	1) Climate Change in the Tillamook Bay Watershed (OCCRI, May 2013); 2) North American Regional Climate Change Assessment Program- NARCCAP (2013)
	A larger percentage of precipitation has been occurring in the form of intense 1-day events	In the continental U.S., eight of the top 10 years for extreme 1-day precip events have occurred since 1990.	High. Historic data reference consistent with other similar studies.	Scour at bridges openings, culverts and roadbeds adjacent to waterways subject to flooding.	NOAA, 2012. Data set 1910-2011.

Oregon Climate Data and Trends Matrix					
Climate Variables	**General Expected Changes**	**Specific Changes**	**Quality of Evidence**	**Impacts on Transportation/ Known Thresholds**	**Sources**
	Increase in average winter maximum 1-day and 5-day precipitation events.	Projected increase in the average winter maximum 1-day event of >0.25 inches by 2065; Increase in the average maximum 5-day precipitation event of >0.5 inch by 2065; (note: for high and low emission scenarios).	Low.	Highly saturated soils can trigger rock falls/ landslides and contribute to flooding; Maintenance hazard incidents greatly increase with saturated soils prior to >2-in. 24 hr. events.	ODOT analysis of MACA CMIP 5 GCMs (2013)
	Changing frequency of Rain-on-Snow events. Reduced mountain snowpack overtime.	Model research in the Santiam basin suggests the frequency of rain-on-snow events will decrease into the future due to warmer air temperatures and decreasing snowpack. Snowpack in the Northwest is particularly sensitive to warming. By 2050, Cascade snowpack are projected to be less than half of what they were in the 20th century, with lower elevation snowpack being the most vulnerable.	Medium. Modeling the scale and frequency of these events is challenging.	Rain on snow events have caused some of Oregon's worst flood events in modern times. These events can scour out roadways adjacent to mountain rivers and streams and inundate valley lowlands, significantly impacting transportation.	Oregon Climate Assessment Report (2010); Santiam Basin Hydrologic Assessment, Model Uncertainty and Climate Change Effects (OSU, 2013); Climate Impacts on McKenzie River Watershed Snowpack (OSU, 2013)
Sea Level Rise	Global mean sea levels are increasing.	Sea levels are projected to increase by 2-4 feet by 2100. Projected Mean (mean for the A1B scenario), Mid-Range = •2030: +2.7 in. (+/- 2.2 in) •2050: +6.7 in. (+/- 4.1 in) •2100: +24.8 in. (+/- 11.5 in)	High. Over 100 years of historic data exists. It is near certain that global mean sea level will increase.	Highways near the mouth of the Columbia River near Astoria are at risk. Inundation of low-lying secondary transportation routes in many coastal areas of the Northwest will very likely worsen and has the potential to temporarily cut off access to some communities during high tide and storm events.	National Research Council, 2012; IPCC National Academy of Sciences; Climate Change Impact Assessment for Surface Transportation in the Pacific Northwest and Alaska (OTREC, 2011).
	Increase in local relative sea levels.	By the mid-21st century, the rate of sea level rise will exceed vertical land movement on the Oregon Coast (tectonic uplift) causing inundation to low lying areas.	High.	Erosion and flooding impacts in submerged areas.	OCCAR, Climate Change in the Tillamook Bay Watershed (OCCRI, May 2013)

Oregon Climate Data and Trends Matrix					
Climate Variables	**General Expected Changes**	**Specific Changes**	**Quality of Evidence**	**Impacts on Transportation/ Known Thresholds**	**Sources**
Wave Intensity and Coastal Storm Surge	Intensifying wave climate with increasing storms and wave heights.	Analysis of 30-years of data off the Oregon coast show winter wave heights increasing from an estimated 33-feet to as much as 46-feet+.	High. Historic data references. It is uncertain whether current trends will continue into the future.	Increase in coastal erosion and flood risks as beach elevations have been lowered as a result of extreme waves. Many beaches have seen little post-storm recovery in the intervening years.	Oregon State University (Peter Ruggiero, et. al.)
	Increased frequency and magnitude of coastal flooding events.	Storminess and extreme storm events have been increasing, leaving coastal areas vulnerable to flooding and erosion. North Pacific winter storm track is projected to shift northward in the 21st century, meaning slightly fewer, but more intense storms.	High.	Storm surge combined with high tides directly impact low elevation coastal roadways. These impacts will likely be compounded by future sea level rise and associated indundation and coastal erosion.	Oregon Climate Assessment Report (2010)
Wildfires	Wildfire is projected to increase in all Oregon forest types.	Warmer and drier summers leave forests more vulnerable to the stresses from fire danger west of the Cascades. Wildfire in forests east of the Cascades is mainly influenced by vegetation growth in the winters that provides fuel for future fires. Large fires could become more common in western Oregon forests.	Estimate increases in regional forest area burned ranges between 180% and 300% by the end of the century, depending on the climate scenario	Wildfires pose a range of risks to the transportation network, including impacts to regional connectivity and emergency response, and direct damage to signage, pavements and other infrastructure, and can lead to erosion and landslides.	Oregon Climate Assessment Report (2010)

Appendix C: Pilot Data Summary

Pilot Data Summary			
Climate Science Data	**Source**	**Source Date/ Downloaded**	**Data Fields**
Precipitation Levels and Min/Max Seasonal Temps- (30 year averages): (1970-to 2065)	Coupled Model Inter-comparison Project (CMIP5)- World Climate Research Program	1-Nov-2012;	Daily records
Sea Level Rise (2030/ 2050/ 2100)	National Research Council, et. al.; DOGAMI; DLCD Oregon Coastal Management Program.	2012; 2013	Data includes a 1, 2 and 10% probability Extreme Value Analysis using regional tidal data.
ODOT Asset/Project Data	**Source**	**Date Created**	**Data Fields**
Seismic Lifeline Routes	ODOT Data Catalog	2012	Priority Tiers 1, 2, and 3
ODOT Maintenance Facilities	ODOT Data Catalog	2012	
Structurally Deficient Bridges	ODOT Data Catalog	2012	Categories: Bridge Failed, Extensive Scour, Unstable, Stable (needs action)
Culverts and Surface Hydrography	Drainage Facility Management System	2012	Culvert crossing locations and stream systems
STIP Projects 2006-09	ODOT Data Catalog	2006	
STIP Projects 2008-11	ODOT Data Catalog	2008	
Region 2 STIP "150%" Scoping list 2015-18	Region 2 Tech Center - Roadway	2013	OPS- Landslides/ rockfall mitigation; SC- Culvert replacement/ retrofits
Region 2 Draft 2016-18 STIP list	Region 2 Tech Center - Geo/hydro	9/18/2012	R2 Landslide and Rockfall priorities list with scores, Maintenance and Geology
Natural Hazards, Warnings and Incidents	**Source**	**Date Created**	**Data Fields**
Unstable Slopes, Landslides and Rockfalls	ODOT Technical Services Landslides Program	2005	Hazard score ratings of High, Medium and Low
Coastal Erosion	DOGAMI	2011	Rates erosion areas as Low, Medium, High and Active
Transportation Operations Center System (TOCS) - District 1 TOCS Incident by Milepoint and Range	Region 2 TOCS systems	September 10, 2009 - April 8, 2013	Includes: Debris Flow Warnings; Erosion; Flood; Flood Warnings; High Water; Landslide; Road Surface Collapse; Rock Fall
2011 Assessment of Slides, Sinks, Settlements & Rockfall	District 1 Warrenton (2101) and Tillamook Crews (2104)	2011	Internal D1 exercise of priority areas of concern
Storm Event Tracking for January 2012	Maintenance District 1	2012	Reflects storm damage locations and costs from a January 2012 storm on north coast

Appendix D: Sea Level Rise Inundation Maps

Legend

- Highway Tenth Mile Markers
- State Highways
- County
- City Limits

Sea Level Rise Inundation Zone

2050 High-Range Projection

Data Source: Department of Land Conservation & Development, 2014.

1 inch = 178 feet

0 250 500 Feet

DISCLAIMER:
This product is for informational purposes only and may not have been prepared for or be suitable for legal, engineering or surveying purposes. Users of this information should review or consult the primary data and information sources to ascertain the usability of the information.

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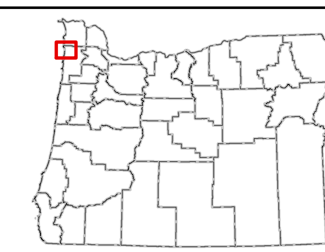

Sea Level Rise Inundation Mapping

Gallagher Slough

Necanicum Highway, Mile Point 19.0

ODOT GIS Unit, 09/10/2014

Legend

- Highway Tenth Mile Markers
- State Highways
- County
- City Limits

Sea Level Rise Inundation Zone

- 2050 High-Range Projection

Data Source: Department of Land Conservation & Development, 2014.

1 inch = 365 feet

0 500 1,000 Feet

DISCLAIMER:
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Sea Level Rise Inundation Mapping

Nestucca Bay

Oregon Coast Highway, Mile Point 90.9 - 92.0 /
Little Nestucca Highway, Mile Point -0.1 - 0.2

ODOT GIS Unit, 09/15/2014

Appendix E: TOCS Maintenance Dispatch Data Table

TOCS Maintenance Dispatch Data Table

Transportation Operations Center System (TOCS) –Maintenance District 1 Dispatch Calls: Weather-related Hazards, Incidents and Warnings
September 10, 2009 – April 8, 2013

Count of Sub-Type	Route													
Sub-Type	OR-103	OR-104	OR-130	OR-131	OR-202	OR-22	OR-47	OR-53	OR-6	US-101	US-101B	US-26	US-30	Grand Total
Debris Flow Warning									33					33
Erosion		1			1					2		1		5
Flood					1					2				3
Flood Warning										27				27
High-water	1	3			10	5	11	1	11	61	2	7	28	140
Landslide	1		1	1	2	3	4	1	12	34		1	12	72
Road Surface Collapse				2	2	1		3		6	1	1	1	17
Rock fall	6				3	3	7	3	17	86		6	14	145
Grand Total	**8**	**4**	**1**	**3**	**19**	**12**	**22**	**8**	**73**	**218**	**3**	**16**	**55**	**442**

Appendix F: Highway Vulnerability Ratings Matrix

Highway Vulnerability Ratings Matrix

Vulnerability Assessment - District 1 Highway Segment Log (Warrenton and Tillamook);														
						CRITICALITY	EXISTING CONDITIONS						MAINTENANCE WORKSHOP	
Highway	State Route ID	BegMP	EndMP	Description	Crew Location	Seismic Lifeline Route (Tier)	TOCS Hazards Incidents (2009-13)	Unstable Slopes (High Hazard)	Low Elevation Coastal Hazards#	FEMA 100-year Flood Zone "A"	Region 2 Landslide Rockfall Priorities	Total	Number of Climate-Impact Hazard Sites + Complete Loss or Failure of Asset (shaded)	Final Asset Condition VULNERABILITY RATING
6	037	0	15	Wilson R.- Tillamook to MP 15	Tillamook		11			3	1	15	multiple	**EXTREME**
6	037	15	32.88	Wilson R.- Hwy 6 to MP 27.8	Tillamook		8	13			17	38	multiple	**EXTREME**
22	032	0	10	Three Rivers- Hebo to Hwy 22	Tillamook		8			3		11		**LOW**
53	046	11.38	19.03	Necanicum- County line to Wheeler	Tillamook		1		3	8	2	14	1	**MEDIUM**
101	009	37.11	55	Coast- Co line to Rockaway Beach	Tillamook	Tier 2, 3	37	7	7	9	11*	71	6	**EXTREME**
101	009	55	66	Coast- Rockaway to Tillamook	Tillamook	Tier 3	15	3	7	8	2*	35	2	**HIGH**
101	009	65	85	Coast- Tillamook to Hebo	Tillamook	Tier 1	11	2		9	2*	24	1	**MEDIUM**
101	009	85	91.37	Coast- Hebo to MP 91.37	Tillamook	Tier 1	11		3	4	1	19		**HIGH**
130	130	0	9.3	L. Nestucca	Tillamook		1		2	3		6		**LOW**
131	131	0	9.08	Netarts	Tillamook		2		4	2		8	1	**EXTREME**

26	047	0	10	Sunset Hwy- 101 to Necanicum Junction	Warrenton	Tier 2	2			5		7		**LOW**
26	047	10	34.16	Sunset Hwy- Necanicum Junct to 34.16	Warrenton	Tier 2	6	1		1	5	13		**LOW**
30	092	69.95	85	L. Columbia R Hwy- County line to MP 85	Warrenton	Tier 1	7	6	1	3	3	20	2	**EXTREME**
30	092	85	99.34	L. Columbia R Hwy- MP 85 to Astoria	Warrenton	Tier 1	14		1	2	3*	20	1	**EXTREME**
53	046	0	11.38	Necanicum Junction to County line	Warrenton		5			1	1	7	1	**MEDIUM**
101	009	4	10	Coast- Astoria to MP 10	Warrenton	Tier 3	1		4	2		7	1	**EXTREME**
101	009	10	20	Coast- Warrenton to MP Seaside	Warrenton	Tier 3	4					4		**LOW**
101	009	20	25	Coast- Seaside to Hwy 26 Junction	Warrenton	Tier 3	6		3	2		11	2	**HIGH**
101	009	25	37.11	Coast- MP 25 to County line	Warrenton	Tier 2	10	4	4	2	2	22	4	**EXTREME**
101B	105	0	7.25	Coast- Hwy 101 junction to Astoria	Warrenton		1		3	3		7	1	**EXTREME**
202	102	0.18	15	Nehalem- Astoria to MP 15	Warrenton		10	2	3	4	5	24	1	**EXTREME**
202	102	15	29.2	Nehalem- MP 15 to Jewell	Warrenton		5	8		1	1	15		**LOW**
202	102	29.2	39.13	Nehalem- Jewell to co. line	Warrenton					9		9	1	**HIGH**
103	103	0	9.02	FishhawkFalls- Sunset Hwy to Jewell	Warrenton		3			7		10		**LOW**
104	104	0	6.03	Fort Stevens	Warrenton		4		2	1		7	1	**EXTREME**

* - Highway segment contains highest priority project based on Region 2 Landslide and Rockfall List (Draft STIP 2016-18).
\# - Number of low elevation highway locations vulnerable to extreme high tides, storm surge and rising seas (GIS analysis).

Appendix G: Maintenance Workshop Results and Site Review Notes

Maintenance Workshop Results and Site Review Notes

(Astoria, OR July 9, 2012)

Highway Condition Assessment

The project team presented information about historic and future climate projections, including the potential for more extreme storm events (rainfall) and an increase in sea level rise (SLR) as high as 5-feet by 2050. This information was the basis for a vulnerability assessment of hazards and hot spots on District highways. Attendees were asked to prioritize locations that would cause the most concern with future travel disruptions using an asset condition rating scale of “Good, Fair, Poor, or Critical.”

Highway 30

- (Critical)- ~MP 90. The huge slide at John Day curves is a major concern since the foot of the slide is down at sea level and susceptible to tidal surge and wave action. SLR could trigger a massive slide and since the highway is perched at this location may not be able to recover.

- (Fair) – There is potential for increased flooding at MP 78.2 near a creek at that location. Slides in this area are increasing with rainfall. There is a similar problem at MP 80 as well.

- (Critical) – MP 70 – 72 the flat into Westport has flooding along tidally influenced Columbia River and there are problems at Plympton Creek. The river waters currently get right up to the edge of the highway. SLR projections will easily put the roadway in this area underwater.

Highway 202

- (Critical)- The dikes at MP 6 is a location adjacent to the inland bay, has been armored, and gets impacted by ocean debris being pushed inland by storm surge. This area will be impacted by SLR through higher storm surge. Highway 202 does not serve many communities, however it provides a back way into Astoria from the south if Highway 101 is shut down near Seaside.

- (Poor/ Critical) - MP 37.5 – The “Motorcycle Slide” east of Jewell is a constant problem and will likely get worse with increased rainfall.

Highway 104

- (Critical) – This is a low area of highway from Warrenton to Hammond. SLR flooding issues would make this section Critical. Drainage issues are already a concern in Warrenton.

Highway 101

- (Critical) - Warrenton to Astoria: The causeway is projected to be compromised by higher sea levels by 2050. Maintenance crews have already been doing erosion repairs along this section of roadway.
- (Critical) - Warrenton to Astoria: (Highway 101B) – This road acts as a detour route for the main Highway 101 causeway and bridge. However, this area is through low lying marsh land and will also be susceptible to SLR flooding. The low elevation area of concern is called Miles Crossing. There are serious access and redundancy issues to Astoria if this area is impassable along with the main Highway 101 crossing.
- (Good) - Warrenton to Seaside: No issues of significance in this stretch of highway.
- (Poor) - South of Seaside to Highway 26 junction: There are issues with tidally influenced flooding and flashy drainage patterns on Beerman Creek and Necanicum River sending water over top and/or eroding the highway. These issues will only get worse in the future. A closer look at where future SLR levels may impact the highway is needed in this area.
- (Fair/ Poor) – There will likely be continued issues with the Cannon Beach Hill slide near MP 27.
- (Fair) – The Silver Point Slide is water driven and located above the road. There is a large viewpoint nearby, so it's possible that this can be used as a detour for drivers to get around larger hazards in the future.
- (Critical) – South Arch Cape Tunnel. MP 32-33. There is currently beach erosion and a large slide in this location that reaches down to the beach. A large future event would render this area impassable. Significant closures have occurred here before.
- (Fair) – There are concerns with the Falcon Cove slide and slides in Oswald State Park MP 37.3 near the county line.
- (Poor) Neahkanie Mountain. MP 40-41. Steep slopes in this area are heavy with large boulders. Rains trigger large rock falls. A slide at this location once closed the highway for months.
- (Good) – Flooding is a current problem in the town of Nehalem, however the road has never been fully closed. Tidally influenced flooding in town is manageable by detouring traffic onto local streets. This will likely be the case even with higher water levels projected with SLR .
- (Critical) - South of Nehalem: There is a bridge south of Nehalem River that crosses Gallagher Slough (MP 46.45) that will likely be impacted by SLR. The highway south of Nehalem generally will be threatened by SLR. More research into this location and SLR projections is needed.
- (Fair) - MP Z-47 – A landslide on a steep hillside in this location could close the road for days. This is near Jetty Creek. The "Fishery Point" slide continues on the southern end at this location.

- (Good) – Wheeler to MP 50- Sunken grades move 2-3” every year. There is continual movement of the road base at this location not directly tied to rain events. The ultimate solution is to move 101 inland.
- (Critical) - Rockaway Beach at MP 51 - 51.3: The highway at Rockaway Creek and Saltwater Creek are impacted by debris washing up from high tides and storm surge. These areas will be impacted from effects of SLR with higher storm surge.
- (Good/ Fair)- There are slide issues at the storage units between Garibaldi and Bay City at MP 56.8
- (Good/ Fair) – Two day closures have happened on the highway north of Tillamook. There is flooding north of town at MP 64 that will get more active. This area will continue to experience flooding and SLR impacts however traffic has a clear detour route via the Wilson River Loop Detour.
- (Fair) – Farmer Creek, MP83: Up to full day road closures have occurred here in the past and will likely again.

Highway 26

- (Good) – The entire route has not seen significant lane closures, with none anticipated under future climate projections. The Elsie Slide (near MP 22) closed lanes but was a one time event.

Highway 6

- (Critical) - Slides from big storms along this stretch may effectively shut down the highway for long periods. Bridges could be lost at MP 27.80 due to narrow openings. Slides are an issue at several locations and culverts are generally undersized. The area at MP 5 to county line was closed for over a month in the 90’s.

Highway 53

- (Fair) – The “County Line Slide” has had issues during heavy rainfall events. Highway 53 acts as a detour route for connections between Tillamook and Seaside when landslides or other road closures occur on Highway 101 from Cannon Beach to Nehalem.

Highway 131

- (Critical)- Netarts Highway: There was a recent 2 to 3 month closure at this location as the road is built on sand and with heavy rainfall the road failed. Addressing a long term fix at this location will likely be a low priority however since it’s a dead end to a small number of homes at Oceanside.

Potential Adaptation Sites– Site Review Notes- Initial Site Visit (September 17, 2013) and Site Tour with Maintenance (October 30, 2013; underlined).

The following sites on Highway 101 were identified in the maintenance workshop and largely satisfy the site selection criteria. Further review of these and potentially other sites is necessary before work commences on individual sites.

- ✓ **Cannon Beach Hill - Landslide — MP 27 (Poor)**
  - This site could not be located after several passes through, likely a MP mix-up
  - Since maintenance rated as "Poor" we will need to coordinate with them on where this is and nature of problem
  - The site was not identified as part of the Oct. 30 site tour.

- ✓ **Silverpoint Slide - Landslide– MP 31.7 (Fair)**
  - Large slide area with movement apparent above and below highway
  - Last major event was in the 1960's
  - Large turnout area on the coast side is showing pavement cracks and slumping in several areas
  - Past mitigation includes drainage trench on slope and K-rail barriers along highway frontage
  - Possible coastal erosion drivers from beach level below slide needs further investigation
  - "Fair" rating due to use wide RW and turnouts to keep traffic moving in case of an event
  - Dave Neys noted he could provide maintenance costs (per response) associated with this slide. Photos may also be available.
  - Long –term risks associated with future SLR and coastal erosion at the site was not something the maintenance district had considered at this site.
  - 1984-85 was when the site was last active.

- ✓ **Hug Point – Fill Failure – 33.6 (not rated by District)**
  - Similar to Falcon Cove fill failure site with active slumping of SB lane
  - Steeper drop off to creek below, no coastal influence
  - Site of a recent culvert replacement project
  - Road fill support unaddressed
  - A failing culvert due to high flows and road collapse is what triggered replacement.

- ✓ **Arch Cape Tunnel - Beach Erosion/ Landslide — MP 32-33 (Critical)**
  - South of the tunnel
  - Southbound lane slumping, defective retaining wall support is failing
  - Impacts to guardrail and pavement condition
  - Larger slide movement towards coastal bluff

- Highway is approx. 20-30 feet from a sheer cliff's edge, straight drop to beach
- Coastal erosion is a factor at the site (need to understand nature and extent)
- Increasing SLR and wave action will continue to erode bluff towards roadway
- Slide appears localized (below roadway)
- Few options to realign highway as site is very close to tunnel opening
- Dave notes that aerial photos were taken at this location. Steve Carter (now retired) had initiated helicopter fly over of the site (~2010), and flagged this location as one to carefully monitor.
- Maintenance says the guardrail was planned to be shifted in to minimize the shoulder width and would include a new retaining wall. (It does not appear to be a current or priority project).
- DOGAMI erosion monitoring and profile data may be available for the beach and bluff.
- If highway is at risk, could armoring of the bluff below be a potential option (with Goal Exception/ OPRD permit?).

✓ Falcon Cove Slide - Landslide – MP37.3 (Fair)

- Site of a fill failure that was initially difficult to spot
- A recent asphalt paving job is already showing signs of movement, slumping in SB lane
- Maintenance input is needed on recent activity at this site
- 24" concrete culvert appears undersized for drainage, recently flagged for survey
- Data on site history and basin hydrology needed
- The last pavement overlay at this location was in 2012.
- It was determined that an earlier fill failure at this location was actually up the road to the north, and included tiered rock embankment support.
- We can contact Warrenton office for more information about the risks and status of this site.
- Regular overlays at fill slope failures can be expensive ($30,000 per overlay) at the Hwy 202 site.
- Dave noted this does not appear to be a priority site from a risk standpoint.

✓ Neahkanie Mountain - Rock Fall – MP 40-41 (Poor)

- Last big event in 1992 closed the road
- More recent mitigation of rock cliff faces includes scaling, tie rods and large sections of high strength wire mesh
- Very few areas with fall out zones
- Some evidence of recent rock fall activity; several sections remain unprotected
- Need to check in with maintenance on status and drivers at site
- Screens were installed in 2002.
- New screen has been identified as a need; Maintenance was unaware of failing tie back plates.
- Region Tech Center will help choose new mitigation options going forward.

- It was recognized there are very limited options for how to address this site as part of the pilot project.

✓ Nehalem Flooding/ High water– MP 45 (Fair)

- Nehalem landslide just south of town appears stable since drainage improvements
- Site not likely to be driven by increasing sea level rise
- Due to length of exposed area, high tides and sea level rise will be a challenge to mitigation along the water's edge
- Potential opportunity for a formalized detour routing either within or around the town.
- ODOT has an agreement with the city for managing detour through town. There is apparently also a southerly route to get to 101 that goes SW around the downtown for when access through downtown is not feasible.
- Shirley Kalkhoven (Nehalem Mayor, ACT Chair) knows the detour options well and details of agreements.
- The Miami-Foley Road route is also an important detour for when 101 is closed on points south of town. There is also an agreement between ODOT and Tillamook Co. for management of this as a detour.

✓ Gallagher Slough - Tidal surge/ sea level rise– MP 46.45 (Critical)

- Bridge with tide gate at this location
- Low area of highway along the bay (roadway appears less than 6' from high tides)
- Evidence of driftwood apparent higher up on bridge wing walls
- Some erosion below roadbed at high tide level
- Not clear how flood gate is managed or may drive conditions at opening
- Future SLR elevations will likely scour roadbed in this section
- At high tides there is already water very close to pavement edge at this location.
- The bridges and roadway were elevated some time ago to deal with tidal surge issues.
- Besides rip rap protection or other armoring, elevating the roadway further in this location may be a future option.

✓ Jetty Creek – Landslide- MP Z-46.99- 47.2 (Fair)

- Rock falls and landslide reviewed, sites part of a larger slide complex
- Road section is site of temporary safety signage due to slumping roadway
- Limited shoulder for material fallout
- Slide has had horizontal drainage pipes set in the slope, including two piezometers and an inclinometer on the downhill side across the road in front of the railroad track
- Subsurface data may be available from Region, is this project in scoping?
- Railroad is on the coastal side of the road and the estuary is not far below the rail line
- Possible that higher groundwater levels from SLR could impact the slide complex
- There is active clear cut logging above the site

- The slide is pushing up and under 101 to the point of causing a dangerous road drop for larger vehicles. The railroad tracks below appear to be unaffected by these forces.
- Realignment options are the ultimate solution, but not a good option in this location due to the mountainous location. The road takes you into Garibaldi and tourists prefer to be near the beach and scenic points.
- Bernie at Region geo-hydro is POC for data, history, options for realignment and details of current scoping.
- The project scope does not include any funds for a more permanent fix since the mountain is moving rapidly in this location.
- Horizontal drains have been installed within the last 5 years.

✓ Rockaway Beach - Storm surge/ sea level rise– MP 51-51.3 (Critical)

Rockaway 1- Lake Lytle outlet:

- The Lytle Lake outfall (Br. 02349) was reviewed and has a large driftwood racking system. Logs have been cut and piled up to allow flow to beach. The railroad bridge provides additional rack and protection of the ODOT structure. No scour or impacts apparent.
- Maintenance indicates that the City of Rockaway maintains the wood debris at the outlet.

Rockaway 2- Rockaway Creek outlet:

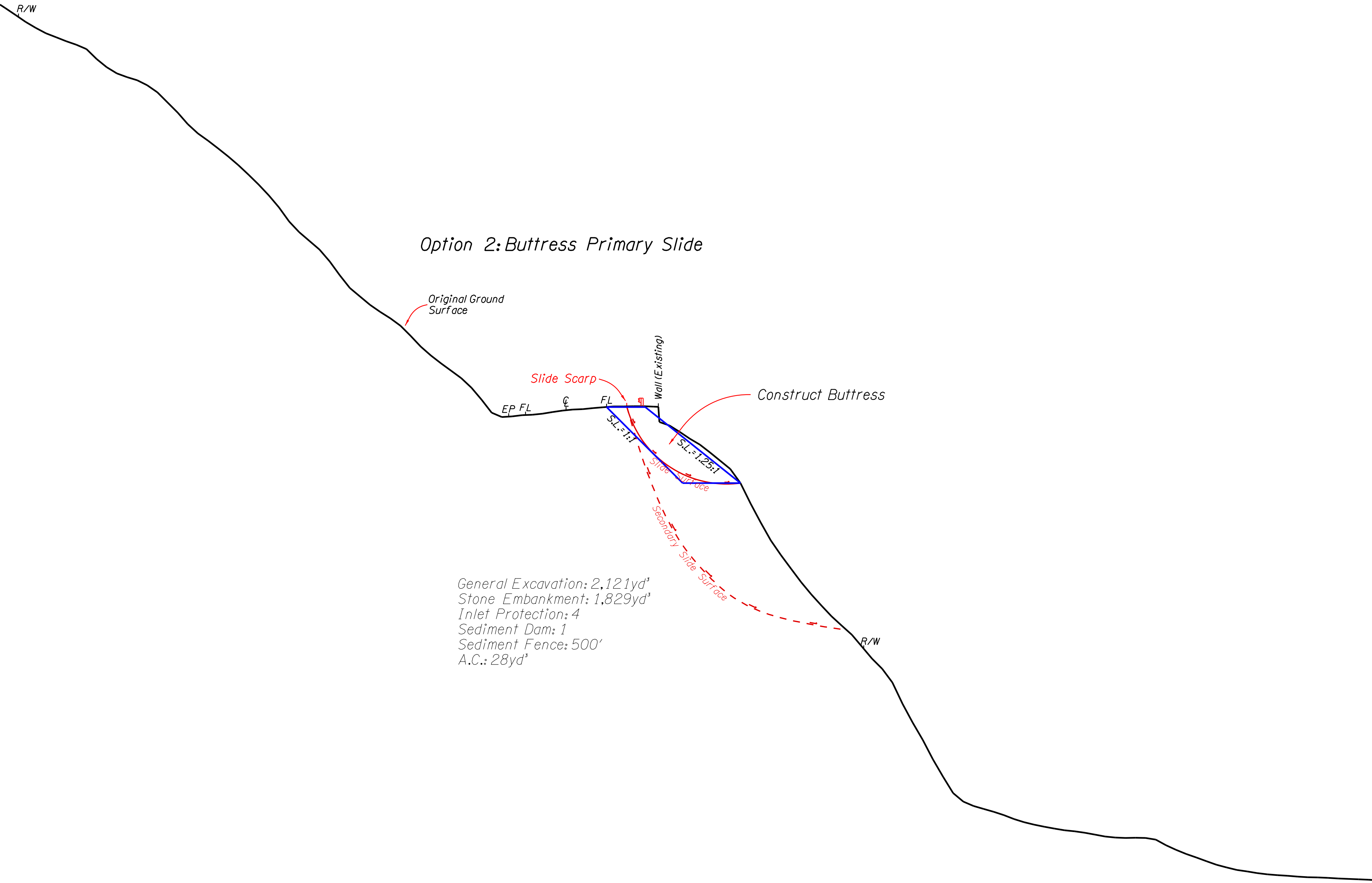
- The creek outfall at Nehalem Avenue was reviewed during the 10/30 site tour. Rip rap revetment at the outlet location near the beach is undersized, not complete and provides inadequate protection against storm surge. Large logs placed across the creek at that location are not cabled down or otherwise secured.
- Maintenance indicates that during storm surge that sea water and debris have been sent over the highway at this location and into the businesses on the east side of the road.

Rockaway 3- Salt Air Creek outlet:

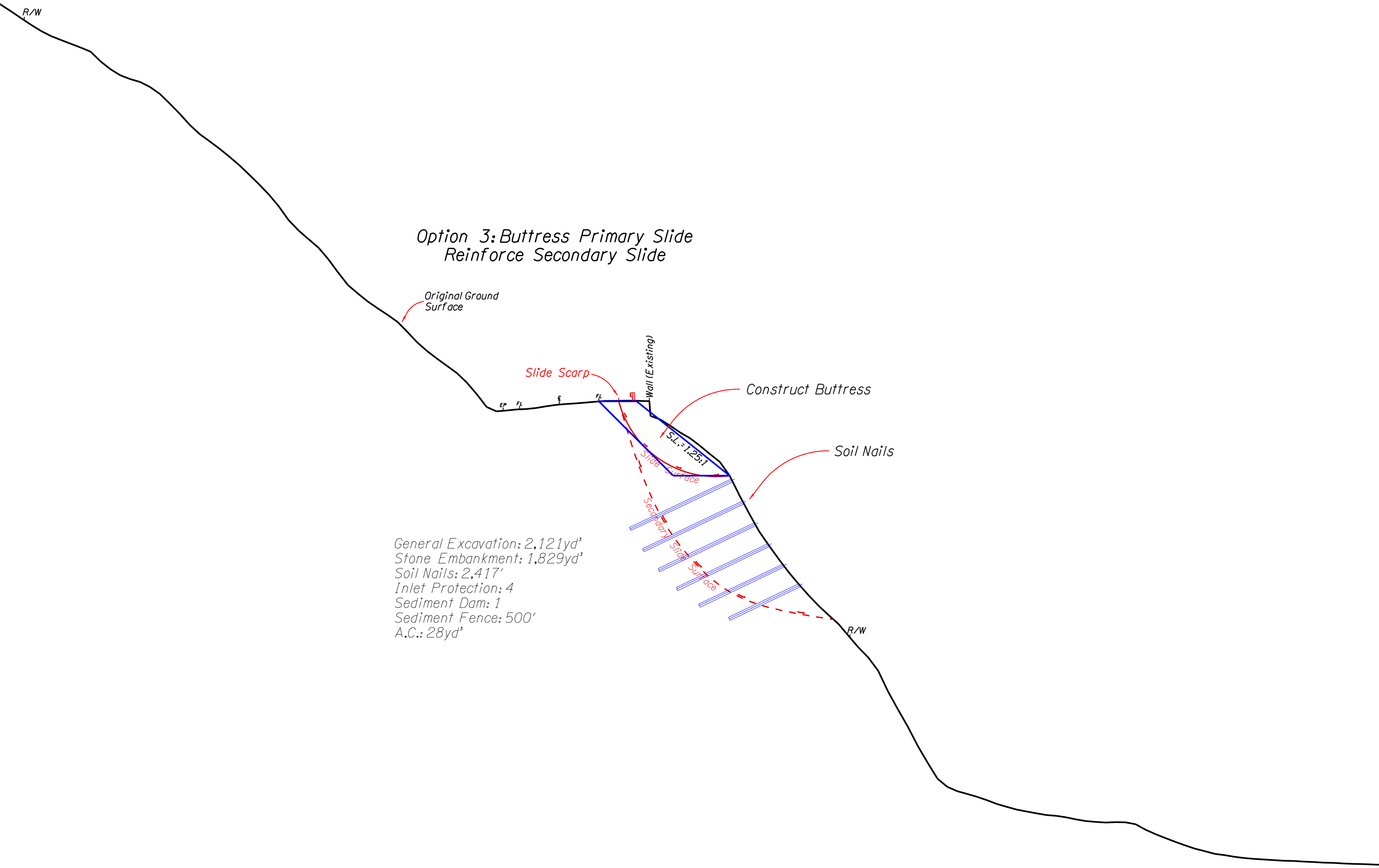
- Large pieces of driftwood have been deposited on the ODOT RW at the Clear Lake outfall (box culvert crossing between 5th and 6th streets)
- The creek out fall from the highway to the beach has been recently cleaned out and reinforced with small rock
- A steel pile storm surge debris rack has been built at dune edge and creek outfall to beach and “reinforced” with logs; appears part of a larger coastal protection effort using logs (not rock)
- Timing and effectiveness of the rack installation needs to be investigated.
- Maintenance indicates the city maintains the rack and could provide more information on history of site and role. Contractor’s name responsible is named Sheldon.
- Maintenance estimates they have not had storm surge issues on the highway for about 10 years.

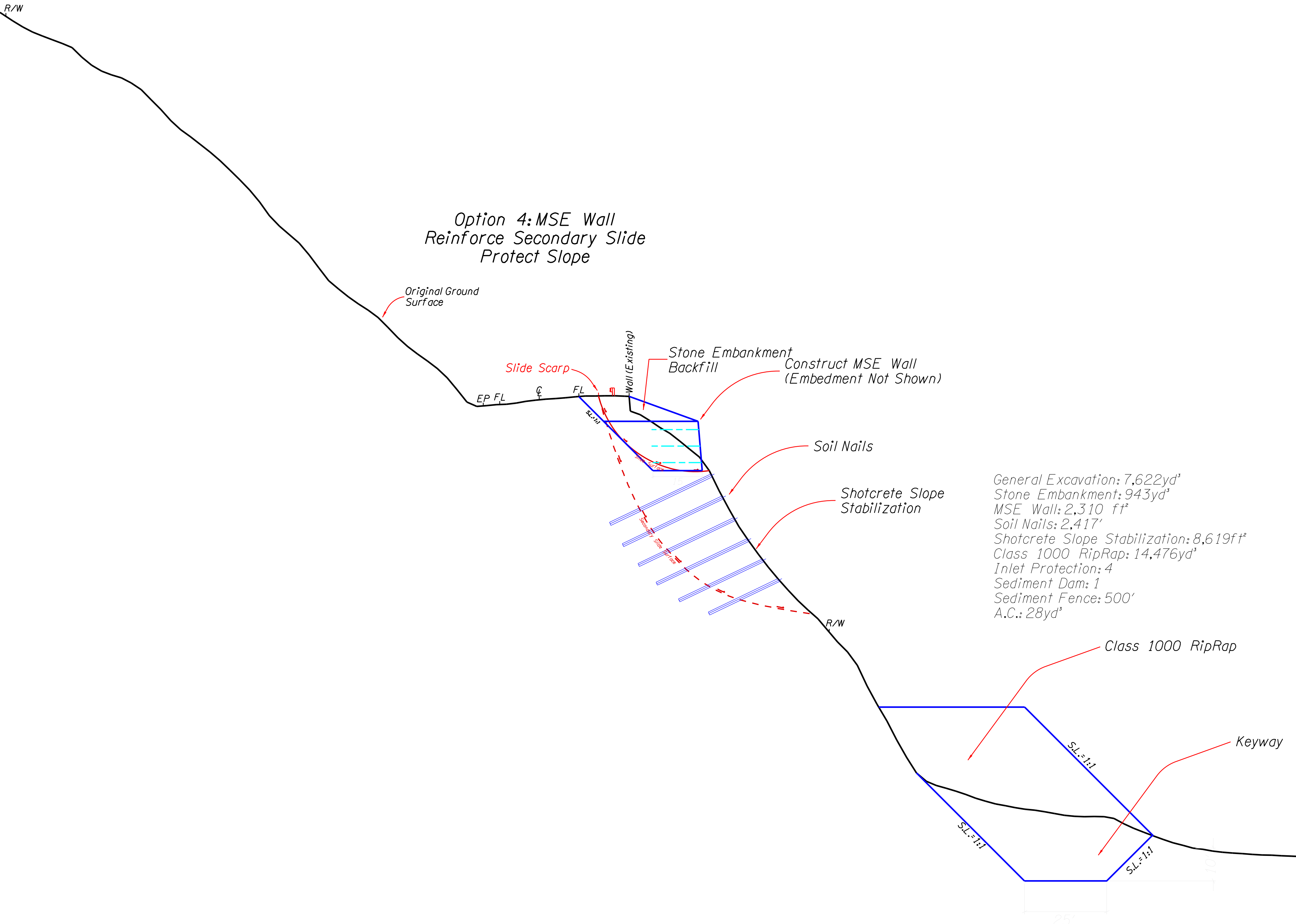
Appendix H: Adaptation Options Cost Tables and Conceptual Designs

Arch Cape Slide: US 101, MP 35.96															
Mitigation Option	**Description**	**Mitigation Effect**	**PE&CE Cost**	**R/W Take (ft^2)**	**Construction Cost**	**Total Construction Cost**	**Construction Time**	**Construction Reoccurrence in 30 years**	**Annual Maintenance Cost (Current)**	**Current Maintenance Frequency (Repairs/Year)**	**Maintenance Closure Time (Current)**	**Annual Maintenance Cost @ 30 Years**	**Maintenance Frequency @ 30 Years (Repairs/Year)**	**Maintenance Closure Time (30 years)**
1	Do Nothing	No Effect - Failure continues to SB Lane. Traffic restricted to one-way flagger control for 8-hour period 0.2 times per year	$0	0	$0	$0	0	0	$2,460	0.2	8 Hours	$2,740	0.25	8 Hours
2	Buttress Primary Slide	Increase Resisting Force on Slide. Continue Maintenance Frequency with increased effort for Buttress Maintenance, Eliminate existing wall and wall Maintenance	$14,664	0	$76,250	$90,914	1 week	0	$1,915	0.2	8 Hours	$2,393	0.25	8 Hours
3	Buttress Primary Slide, Reinforce Secondary Slide	Increase Resisting Force on Slide. Continue Maintenance Frequency with increased effort for Buttress Maintenance, Eliminate existing wall and wall Maintenance. Reinforce Lower Slide to decrease rate of movement/maintenance requirements	$226,728	0	$1,178,985	$1,405,713	4 weeks	0	$968	0.067	8 Hours	$1,220	0.08	8 Hours
4	Construct MSE Wall, Reinforce Secondary Slide, Protect Slope	Support roadway with retaining wall, stabilize secondary slide with Soil Nails and protect slope face with reinforced Shotcrete. RipRap protection. 50-Year Design Life	$462,829	13,485	$2,462,250	$2,925,079	10 weeks	0	$1,650	0.067	0	$1,650	0.067	0
5	Construct Soldier Pile Wall, Protect Slope	Support roadway with Soldier Pile Wall. Tiebacks support wall and roadway. Secondary Slide is separated from roadway eliminating it's effect. RipRap protection. 75-Year Design Life	$546,333	13,485	$2,906,500	$3,452,833	10 weeks	0	$0	0	0	$0	0	0

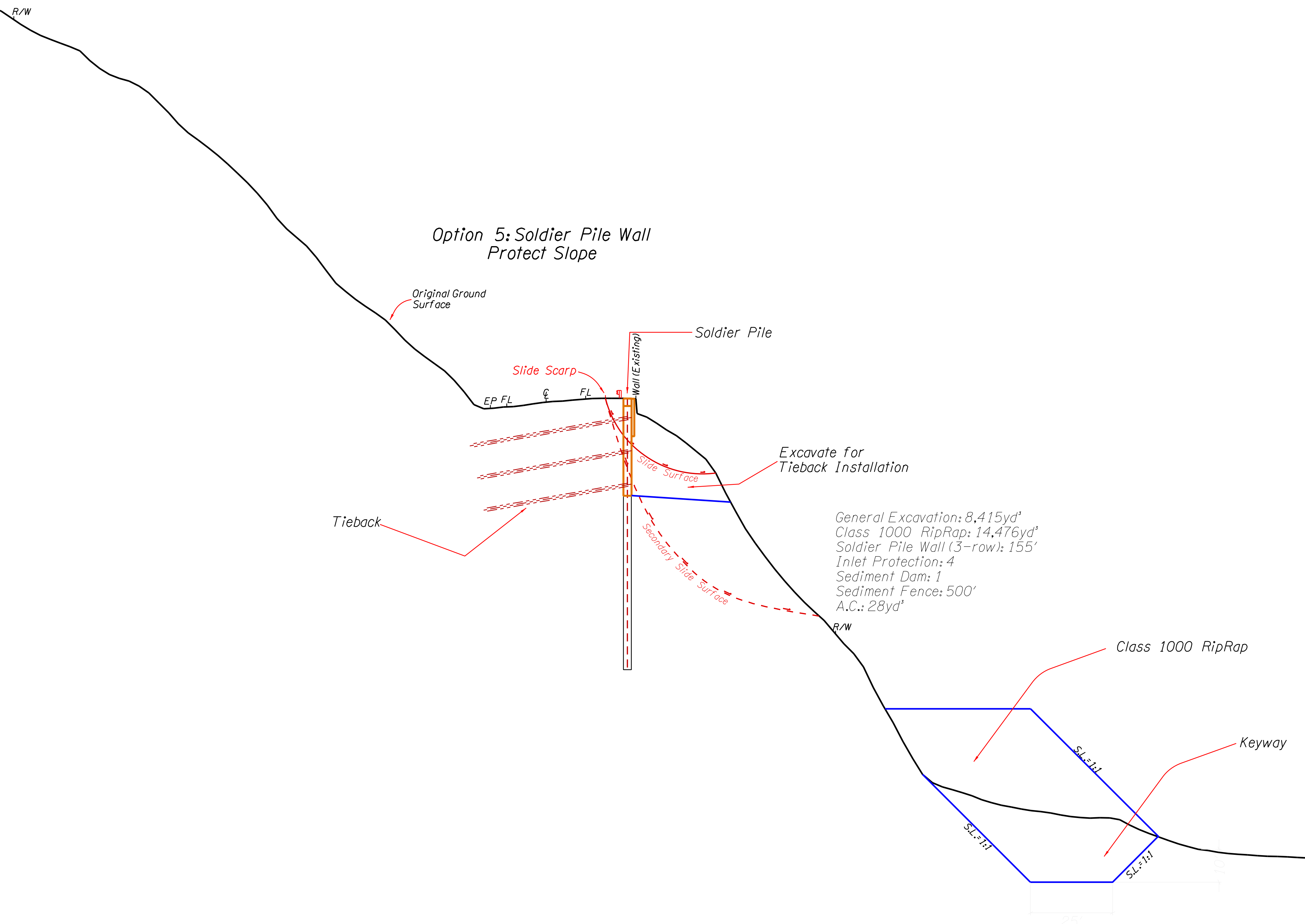

R/W
Option 2: Buttress Primary Slide
Original Ground Surface
Slide Scarp
Wall (Existing)
Construct Buttress
EP
FL
℄
FL
S.L.=1:1
S.L.=1.25:1
Slide Surface
Secondary Slide Surface
General Excavation: 2,121yd³
Stone Embankment: 1,829yd³
Inlet Protection: 4
Sediment Dam: 1
Sediment Fence: 500'
A.C.: 28yd³
R/W

Option 3: Buttress Primary Slide
Reinforce Secondary Slide





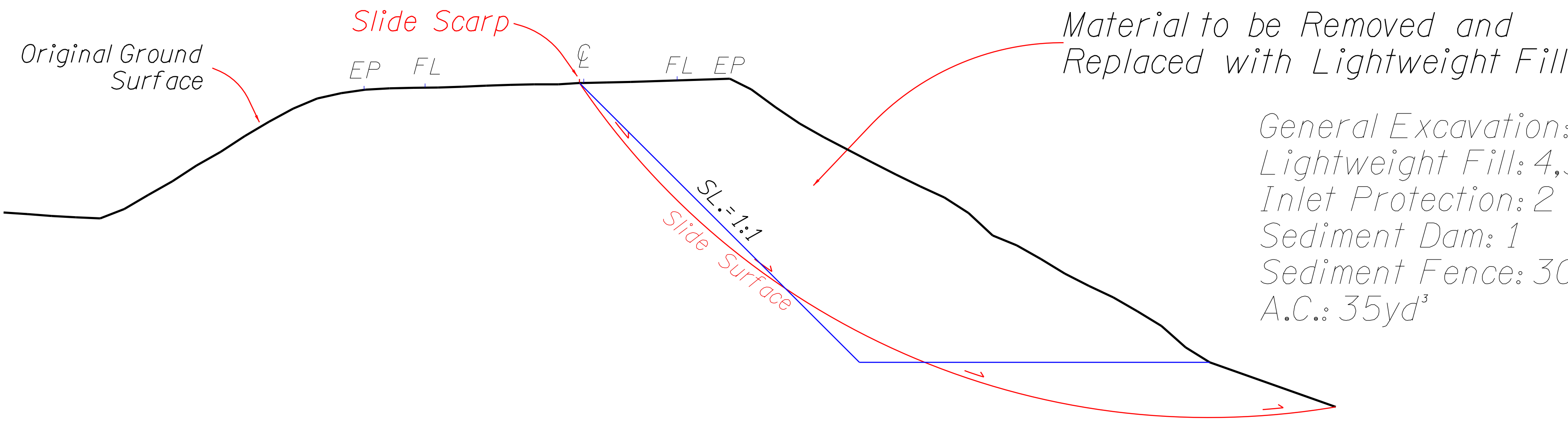
Option 4: MSE Wall
Reinforce Secondary Slide
Protect Slope
R/W
Original Ground Surface
Slide Scarp
EP
FL
℄
FL
Wall (Existing)
Stone Embankment Backfill
Construct MSE Wall (Embedment Not Shown)
Soil Nails
Shotcrete Slope Stabilization
R/W
General Excavation: 7,622yd³
Stone Embankment: 943yd³
MSE Wall: 2,310 ft²
Soil Nails: 2,417'
Shotcrete Slope Stabilization: 8,619ft²
Class 1000 RipRap: 14,476yd³
Inlet Protection: 4
Sediment Dam: 1
Sediment Fence: 500'
A.C.: 28yd³
Class 1000 RipRap
Keyway
S.L.=1:1
S.L.=1:1
S.L.=1:1



R/W
Option 5: Soldier Pile Wall
Protect Slope
Original Ground Surface
Soldier Pile
Wall (Existing)
Slide Scarp
EP FL
FL
Slide Surface
Excavate for Tieback Installation
Tieback
Secondary Slide Surface
General Excavation: 8,415yd³
Class 1000 RipRap: 14,476yd³
Soldier Pile Wall (3-row): 155'
Inlet Protection: 4
Sediment Dam: 1
Sediment Fence: 500'
A.C.: 28yd³
R/W
Class 1000 RipRap
Keyway
S.L.=1:1
S.L.=1:1
S.L.=1:1

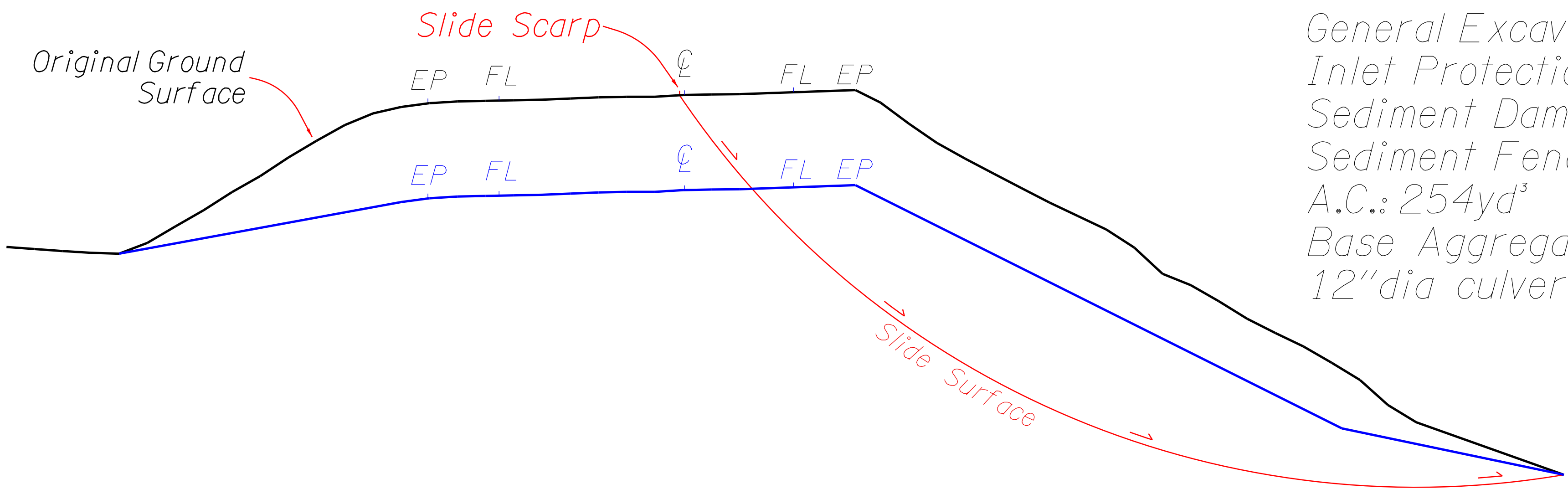
Falcon Cove Slide: US 101, MP 37.31													
Mitigation Option	**Description**	**Mitigation Effect**	**PE&CE Cost**	**R/W Take (ft^2)**	**Construction Cost**	**Construction Time**	**Construction Reoccurrence in 30 years**	**Annual Maintenance Cost (Current)**	**Current Maintenance Frequency (Repairs/Year)**	**Maintenance Closure Time (Current)**	**Annual Maintenance Cost @ 30 Years**	**Maintenance Frequency @ 30 Years (Repairs/Year)**	**Maintenance Closure Time (30 years)**
1	Do Nothing	No Effect - Failure continues to NB Lane. Traffic restricted to one-way flagger control for 4-hour period 1.5 times per year.	$0	0	$0	0	0	$8,957	1.5	8 Hours	$10,509	2.5	8 Hours
2	Lightweight Fill	Decrease Driving Force on Slide. Reduces Maintenance Frequency to once in 5 years at current level of effort and closure time. Must be Reconstructed twice in 30 years.	$29,453	0	$153,158	2 weeks	2	$1,194	0.2	8 Hours	$1,994	0.33	8 Hours
3	Lower Grade	Decrease Driving Force on slide, decrease roadway exposure to slide. Reduces Maintenance Frequency to once in 3 years at reduced level of effort and closure time. Allow 2-way traffic during maintenance.	$44,615	Easement to Adjust Approaches	$232,000	4 weeks	0	$1,131	0.33	6 Hours	$1,889	0.55	6 Hours
4	Construct Buttress and Shear Key	Increase Resising Forces against slide, Increase embankment drainage. Reduces Maintenance Frequency to once in 15 years.	$32,200	583	$180,350	1.5 weeks	0	$376	0.067	8 Hours	$628	0.11	8 Hours
5	Reconstruct with all-weather material. Resize Pipe.	Removes slide, replaces embankment with resistant material that facilitates drainage. Increases culvert size to address higher streamflow.	$106,000	1,436	$562,097	4 weeks	0	$0	0	0	$0	0	0

Option 2: Remove and Replace with Lightweight Fill



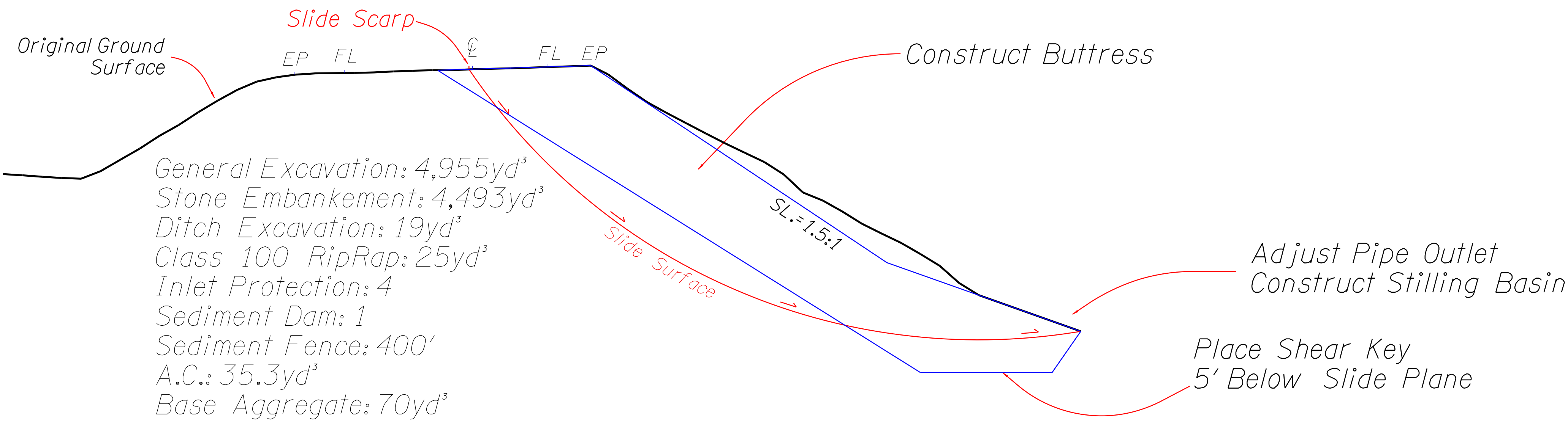
General Excavation: 4,311yd³
Lightweight Fill: 4,311yd³
Inlet Protection: 2
Sediment Dam: 1
Sediment Fence: 300'
A.C.: 35yd³

Option 3: Lower Grade, Adjust Geometry



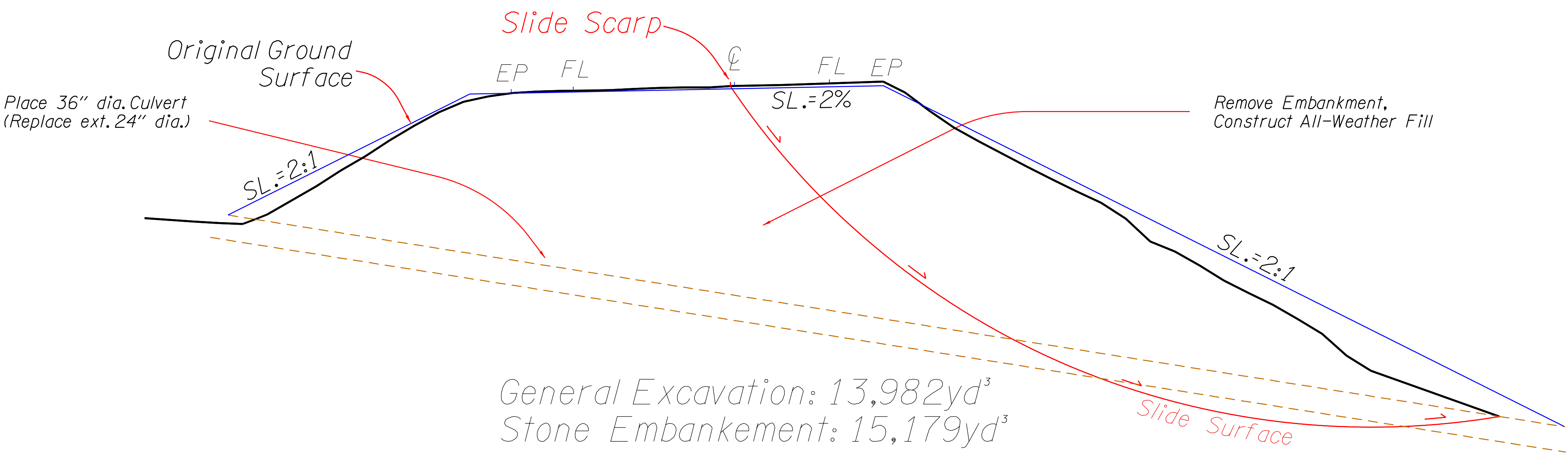
General Excavation: 9,467yd³
Inlet Protection: 8
Sediment Dam: 2
Sediment Fence: 1000'
A.C.: 254yd³
Base Aggregate: 510yd³
12"dia culvert@Approach: 40'

Option 4: Construct Buttress and Shear Key



General Excavation: 4,955yd³
Stone Embankement: 4,493yd³
Ditch Excavation: 19yd³
Class 100 RipRap: 25yd³
Inlet Protection: 4
Sediment Dam: 1
Sediment Fence: 400'
A.C.: 35.3yd³
Base Aggregate: 70yd³
R/W: 583ft²

Option 5: Remove and Replace with All-Weather Fill Material. Resize and Realign Pipe



General Excavation: 13,982yd³

Stone Embankement: 15,179yd³

Inlet Protection: 4

Sediment Dam: 2

Sediment Fence: 600'

36"dia Culvert@10'Depth: 166'

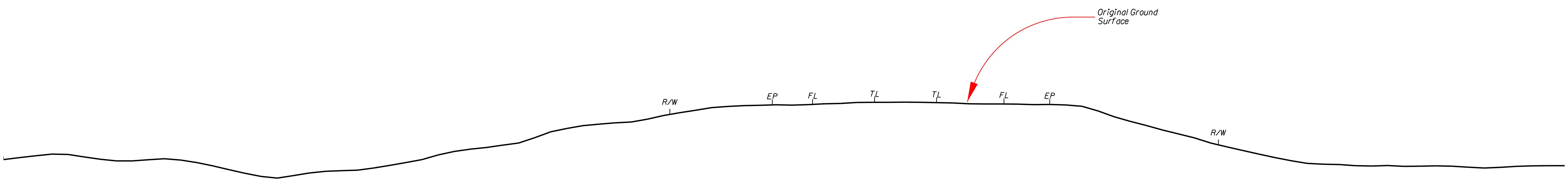
A.C.: 130yd³

Base Aggregate: 260yd³

R/W: 1,436ft²

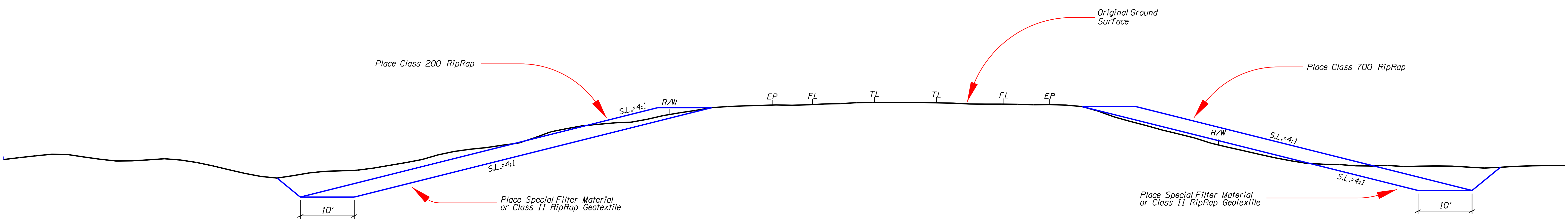
Gallagher Slough: US 101, MP 46.5														
Mitigation Option	**Description**	**Mitigation Effect**	**PE&CE Cost**	**R/W Take (ft^2)**	**Construction Cost**	**Total Construction Cost**	**Construction Time**	**Construction Reoccurrence in 30 years**	**Annual Maintenance Cost (Current)**	**Current Maintenance Frequency (Repairs/Year)**	**Maintenance Closure Time (Current)**	**Annual Maintenance Cost @ 30 Years**	**Maintenance Frequency @ 30 Years (Repairs/Year)**	**Maintenance Closure Time (30 years)**
1	Do Nothing	No Effect - Not Currently Affected. Future events coupled with SLR will affect at about year 10	$0	0	$0	$0	0	0	$0	0	0	$202,255	5	24 Hours
2	Armor Existing Roadway	Eliminate vulnerability to most storm damage. Flood events would still innundate the roadway and result in closure during the event but the roadway would stay in place after the event.	$235,500	175,700	$1,176,700	$1,412,200	8 weeks	0	$0	0	0 Hours	$2,250	0.03	8 Hours
3	Elevate Roadway, Armor Slopes, Raise Gallagher Slough Bridge	Eliminate vulnerability to foreseable storm damage. Flood events would not crest above the roadway and it would remain open during storm events.	$1,077,500	142,702	$6,465,000	$7,542,500	12 weeks	0	$0	0	0 Hours	$0	0	0 Hours

Option 1: Do Nothing



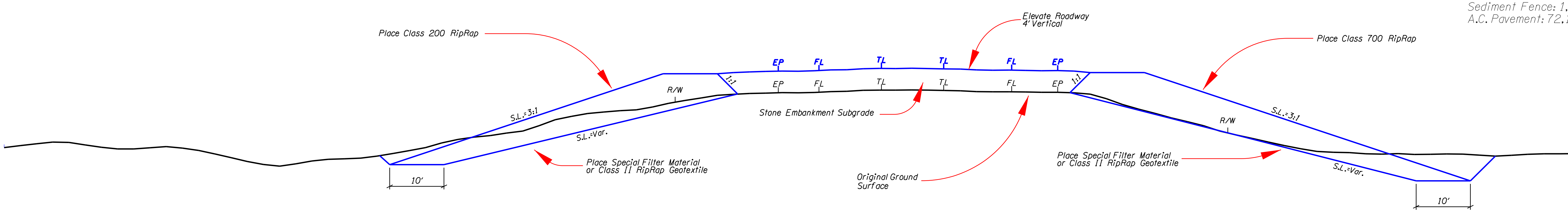
Option 2: Protect Existing Roadway

General Excavation: 17,063yd^3
Class 700 RipRap: 8,093yd^3
Class 200 RipRap: 8,602yd3
Inlet Protection: 8
Sediment Fence: 1,800'



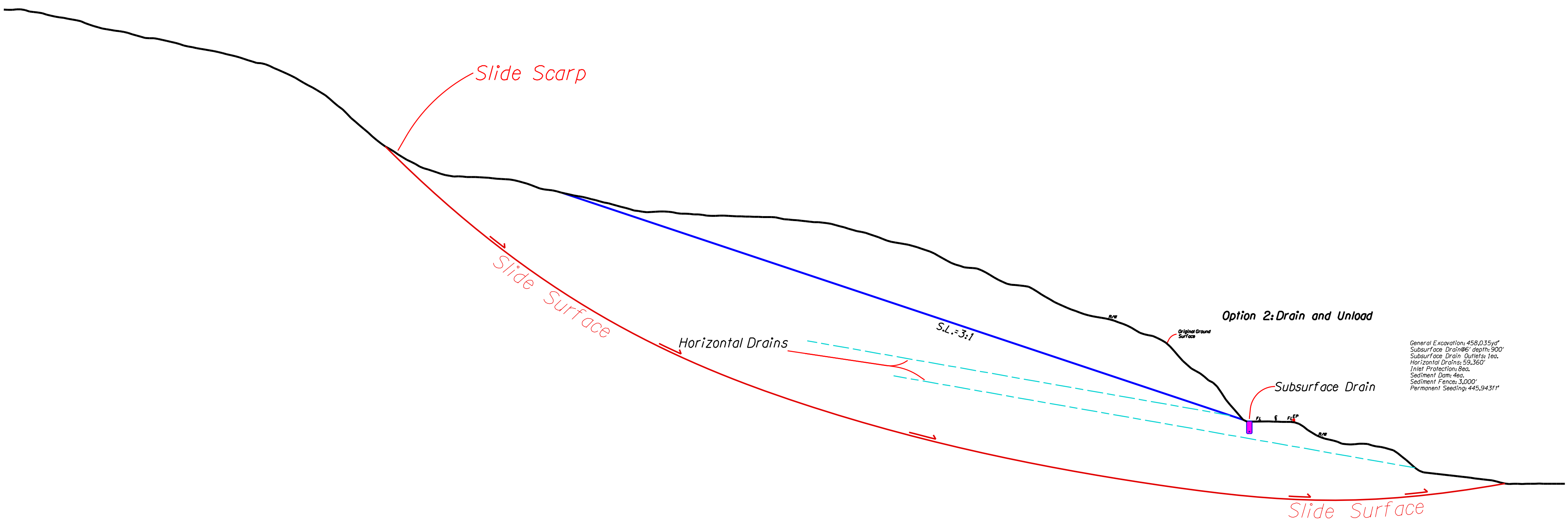
Option 3: Elevate and Protect Roadway

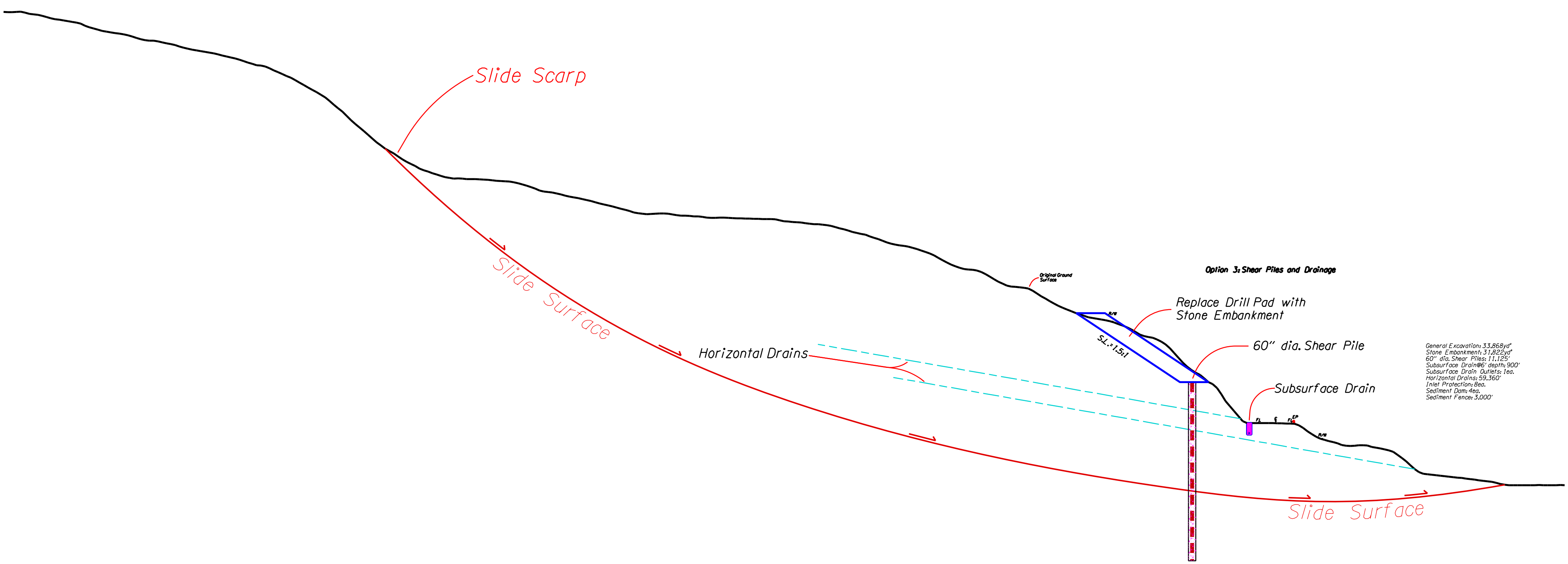
General Excavation: 14,738 yd^3
Class 700 RipRap: 17,750 yd^3
Class 200 RipRap: 15,231 yd^3
Stone Embankement: 13,415 yd^3
Inlet Protection: 8
Sediment Fence: 1,800'
A.C. Pavement: 72,100 ft^2



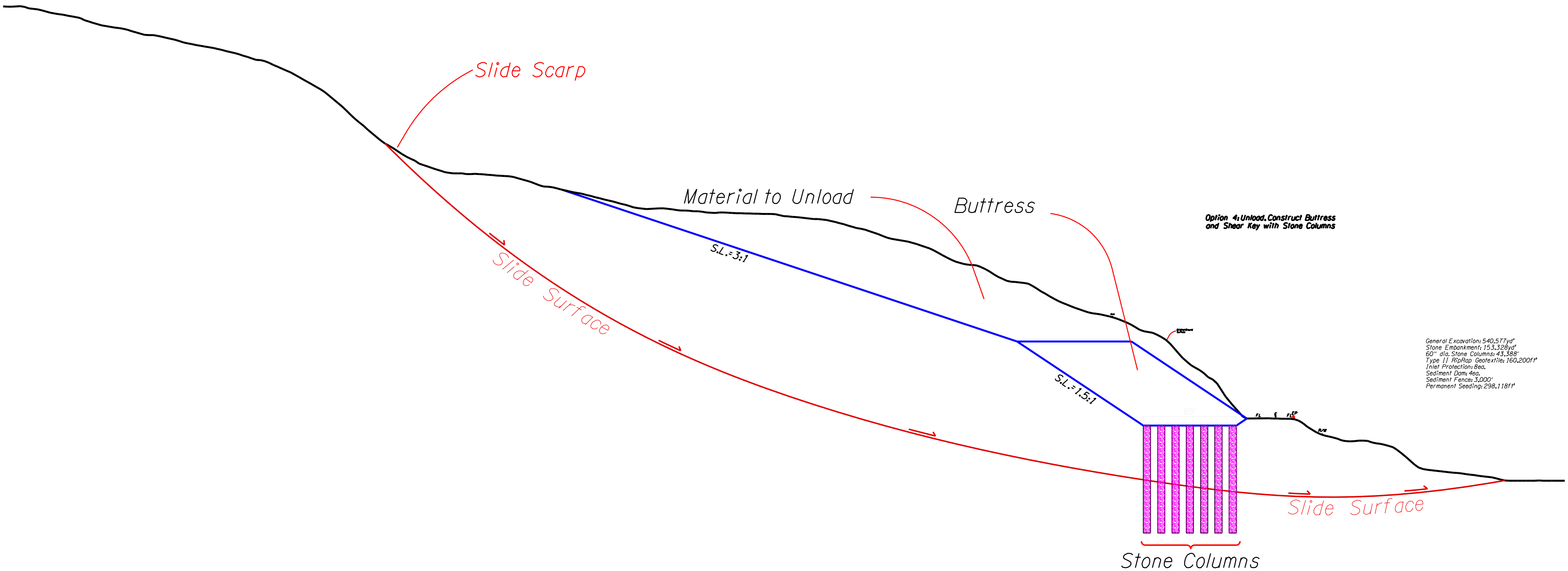
Jetty Creek Slide: US 101, MP Z47.20

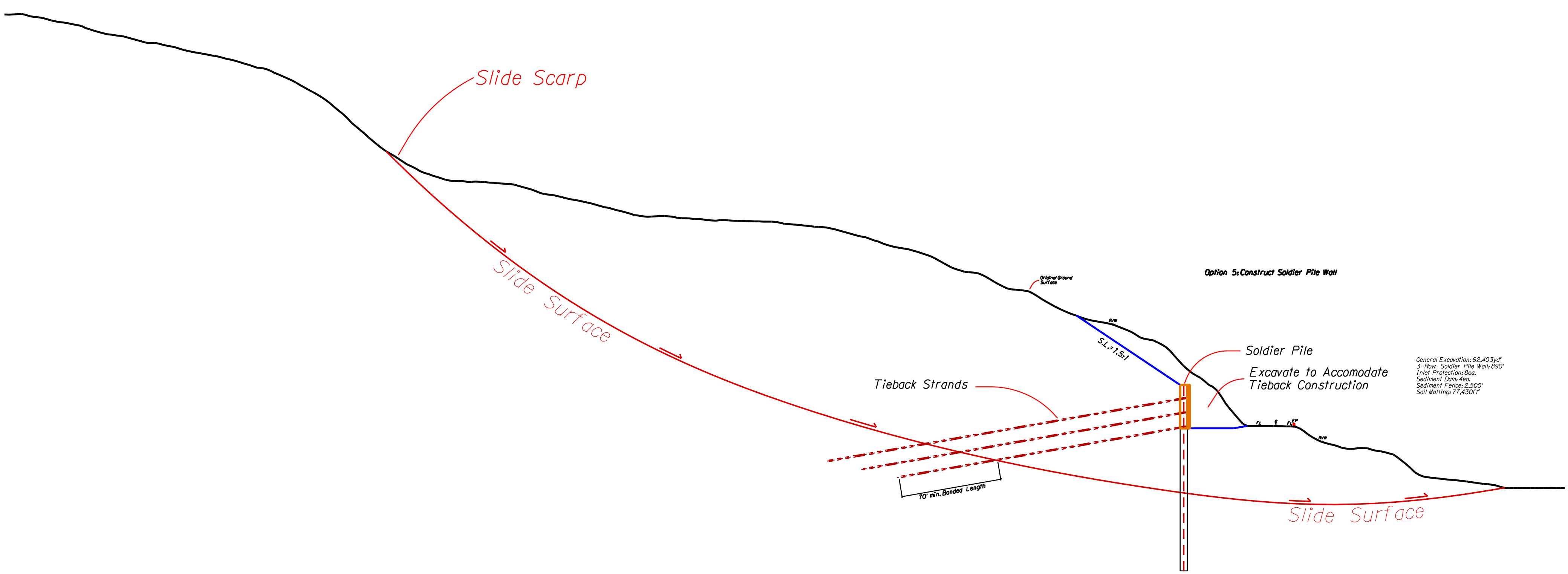
Mitigation Option	Description	Mitigation Effect	PE&CE Cost	R/W Take (ft^2)	Construction Cost	Total Construction Cost	Construction Time	Construction Reoccurrence in 30 years	Annual Maintenance Cost (Current)	Current Maintenance Frequency (Repairs/Year)	Maintenance Closure Time (Current)	Annual Maintenance Cost @ 30 Years	Maintenance Frequency @ 30 Years (Repairs/Year)	Maintenance Closure Time (30 years)
1	Do Nothing	No Effect - Failure continues to deform both lanes. Traffic restricted to one-way flagger control for 8-hour period 1 time per year	$0	0	$0	$0	0	0	$13,732	1	16 Hours	$45,700	3.33	16 Hours
2	Drain and Unload	Decrease reduction of resisting forces by draining groundwater. Reduce driving forces. Reduce maintenance of roadway but introduce minor effort for periodic drain cleaning	$1,051,000	346,210	$6,831,500	$7,882,500	8 weeks	0	$3,812	0.2	16 Hours	$12,700	0.67	16 Hours
3	Shear Piles and Drainage	Increase Resisting Force on Slide. Decrease reduction of resisting forces by drainage improvement. Minor Roadway deflection will occur. Drains will require periodic Maintenance.	$2,229,200	0	$14,489,800	$16,719,000	10 weeks	0	$2,059	0.2	8 Hours	$6,860	0.67	8 Hours
4	Unload, Construct Buttress and Shear Key with Stone Column Support	Reduce driving forces by unloading. Increase resisting forces with Buttress. Depth of slide precludes traditional shear key. Stone columns would be used for shear resistance. Buttress increases shear resistance of stone columns. Very minor deflection of the roadway may continue.	$2,490,800	346,210	$16,190,200	$18,681,000	12 weeks	0	$530	0.05	8 Hours	$1,765	0.167	8 Hours
5	Construct Soldier Pile Wall	Increase resisting forces to retain landslide. Very limited maintenance of wall drainage elements.	$2,720,000	23,245	$17,680,600	$20,400,600	14 weeks	0	$0	0	0	$0	0	0


Slide Scarp
Slide Surface
Horizontal Drains
S.L.=3:1
R/W
Original Ground Surface
Option 2: Drain and Unload
Subsurface Drain
FL
FL
EP
R/W
Slide Surface
General Excavation: 458,035yd³
Subsurface Drain@6' depth: 900'
Subsurface Drain Outlets: 1ea.
Horizontal Drains: 59,360'
Inlet Protection: 8ea.
Sediment Dam: 4ea.
Sediment Fence: 3,000'
Permanent Seeding: 445,943ft²



Option 3: Shear Piles and Drainage
Slide Scarp
Slide Surface
Original Ground Surface
R/W
Replace Drill Pad with Stone Embankment
S.L.=1.5:1
60" dia. Shear Pile
Horizontal Drains
Subsurface Drain
Slide Surface
General Excavation: 33,868yd³
Stone Embankment: 31,822yd³
60" dia. Shear Piles: 11,125'
Subsurface Drain@6' depth: 900'
Subsurface Drain Outlets: 1ea.
Horizontal Drains: 59,360'
Inlet Protection: 8ea.
Sediment Dam: 4ea.
Sediment Fence: 3,000'


Option 4: Unload, Construct Buttress
and Shear Key with Stone Columns
Slide Scarp
Material to Unload
Buttress
S.L.=3:1
S.L.=1.5:1
Slide Surface
Slide Surface
Stone Columns
General Excavation: 540,577yd³
Stone Embankment: 153,328yd³
60" dia. Stone Columns: 43,388'
Type II RipRap Geotextile: 160,200ft²
Inlet Protection: 8ea.
Sediment Dam: 4ea.
Sediment Fence: 3,000'
Permanent Seeding: 298,118ft²



Option 5: Construct Soldier Pile Wall
Slide Scarp
Slide Surface
Original Ground Surface
R/W
S.L.=1.5:1
Soldier Pile
Excavate to Accomodate Tieback Construction
Tieback Strands
70' min. Bonded Length
FL
FL
EP
R/W
Slide Surface
General Excavation: 62,403yd³
3-Row Soldier Pile Wall: 890'
Inlet Protection: 8ea.
Sediment Dam: 4ea.
Sediment Fence: 2,500'
Soil Matting: 77,430ft²

Rockaway: US 101, MP 49 - 52															
Mitigation Option	**Description**	**Mitigation Effect**	**PE&CE Cost**	**R/W Take (ft^2)**	**Construction Cost**	**Total Construction Cost**	**Construction Time**	**Construction Reoccurrence in 30 years**	**Annual Maintenance Cost (Current)**	**Current Maintenance Frequency (Repairs/Year)**	**Maintenance Closure Time (Current)**	**Annual Maintenance Cost @ 30 Years**	**Maintenance Frequency @ 30 Years (Repairs/Year)**	**Maintenance Closure Time (30 years)**
1	Do Nothing	No Effect - Storm events continue to cause flooding and debris deposition on roadway and roadside drainage.	$0	0	$0	$0	0	0	$3,378	1	8 Hours	$11,250	3.33	30 Hours
2	Construct Ocean Debris Barriers, Widen and Reinforce existing Channels	Eliminate debris deposition on US 101, reduce lake water backup in channels and reduce structure scour.	$74,500	0	$373,000	$447,500	4 weeks	0	$2,565	1	8 Hours	$8,550	3.33	24 Hours
3	Construct Ocean Debris Barriers, Widen and Reinforce existing Channels, Elevate and Widen Bridges	Eliminate debris deposition on US 101, eliminate lake water backup in channels and eliminate structure scour.	$159,300	0	$7,966,000	$8,125,300	24 weeks	0	$0	0	0 Hours	$0	0	0 Hours

Appendix I: Benefit Cost Analysis Assumptions

Benefit-Cost Analysis Assumptions

The two sites selected for BCA were Falcon Cove and Jetty Creek. This section outlines key assumptions used in the analyses done for these sites.

Falcon Cove

The Falcon Cove site has an average daily traffic (ADT) count of approximately 2,800, of which an estimated 18.4% are trucks. Traffic count growth estimates result in an ADT of 3,700 at year 30. Truck proportions of future traffic volumes are assumed to stay the same.

Base case assumptions include:

- Failure continues to the north bound lane at a rate 1.5 times per year initially, increasing to 2.5 times by year 30. A growth trend was used to estimate failure rates for the years in between - meaning it was assumed that failures would occur more frequently in later years. The rates were converted to an estimated whole number of failures per year. Estimated repair and wage cost per failure in current dollars is $6,000.
- Low traffic volumes on the facility mean that the failures (which result in a single lane closure with a flagger) are roughly equivalent to free-flow and have no significant travel impacts.
- At year 15, an event based catastrophic failure results in mitigation option 4 level repairs at a total current dollar cost of $212,600.
- One lane remains open after the failure and during construction. Since it has been determined that one lane open at this location is roughly equivalent to free-flow, there are no significant travel impacts.
- Mitigation option 4 results in less frequent failures - essentially one more at year 25 at a slightly lower cost of $5,600 in current dollars.
- Mitigation option 4 has a 75 year useful life of which 60 years will remain at the end of the analysis period.
- The discount rate is set at 3%. This reflects that costs and benefits are valued differently over time.

Adaptation option assumptions include:

- The analysis period begins just as Mitigation option 5 is constructed at a current dollar cost of $668,100. As a result there are no failures or related costs.
- Mitigation option 5 has a useful life of 75 years of which 45 remain at the end of the analysis period.
- The discount rate is set at 3%. This reflects that costs and benefits are valued differently over time.

Jetty Creek

The Jetty Creek site has an average daily traffic (ADT) count of approximately 4,100, of which an estimated 18.5% are trucks. Traffic count growth estimates result in an ADT of 6,000 at year 30. Truck proportions of future traffic volumes are assumed to stay the same.

Base case assumptions include:

- Failures deform both lanes at a rate of once a year initially, increasing to 3.33 times by year 30. A growth trend was used to estimate failure rates for the years in between - meaning it was assumed that failures would occur more frequently in later years. The rates were converted to an estimated whole number of failures per year. Traffic is restricted to one-way flagger control for an eight hour period when the failures occur. Estimated repair and wage cost per failure in current dollars is $13,700.
- Low traffic volumes on the facility mean that the failures (which result in a single lane closure with a flagger) are roughly equivalent to free-flow and have no significant travel impacts.
- At year 20, an event based catastrophic failure results in closure and diversion of traffic to Miami Foley Road (a county facility). The closure occurs in November and lasts for ten months (seven due to winter weather and three for construction). It is assumed that freight trucks can use this facility effectively (this has not been evaluated).
- The diversion adds an average of 10 miles of travel per vehicle and 20 minutes of travel for all users. Forecast levels of usage are matched to corresponding year. Changes in time and distance of travel result in additional travel time costs, fuel costs, and the social cost of carbon from emissions. This impacts intercity truck, business, and personal travel.
- The repair is mitigation option 4 at a total cost in (in current dollars) of $18,681,000. The repair results in less frequent minor deflection - essentially one more minor event at year 27 at a slightly lower cost of $10,600 in current dollars.
- Mitigation option 4 has a 75 year useful life of which 65 years will remain at the end of the analysis period.
- The discount rate is set at 3%. This reflects that costs and benefits are valued differently over time.

Adaptation option assumptions include:

- The analysis period begins just as Mitigation option 5 is constructed at a current dollar cost of $20,400,600. As a result there are no failures, diversion, deflection, or related costs.
- Avoidance of diversion results in time savings, fuel cost savings, and emissions avoidance.
- Mitigation option 5 has a useful life of 50 years of which 20 remain at the end of the analysis period.
- The discount rate is set at 3%. This reflects that costs and benefits are valued differently over time.

Item	Assumed Value	Notes
Travel time value per person hour in 2014 dollars	$20.61	Based on vehicle class distribution and the intercity all-purpose surface mode and truck drivers surface mode values provided in the *TIGER Benefit-Cost Analysis (BCA) Resource Guide*, inflated to 2014 dollars.
Persons per vehicle	1.20	Based on vehicle class distribution and vehicle occupancies used in the "The Value of Travel-Time: Estimates of the Hourly Value of Time for Vehicles in Oregon 2011".
Metric tons CO2/gallon of motor fuel	0.009148	Based on vehicle class distribution and CO2 volumes per gallon of gasoline and diesel identified in Table 2. Carbon Dioxide Emission Factors for Transportation Fuels, Voluntary Reporting of Greenhouse Gases Program Fuel Emission Coefficients, Energy Information Administration.
Social cost of carbon per unit metric ton of carbon dioxide in year 20 in depreciated $2014 dollars	$63.00	*TIGER Benefit-Cost Analysis (BCA) Resource Guide*, Updated 3/28/14. Values provided in the original table are whole 2007 dollars per unit metric ton of carbon dioxide and include a 3% depreciation rate. For this analysis the dollar values were inflated to June 2014 dollars using the Bureau of Labor Statistics Consumer Price Index (All Urban Consumers U.S. City Average).
Vehicle fuel efficiency in year 20	33.09 mpg	Based on vehicle class distribution and the reference case fuel efficiencies identified for on the road cars and light trucks combined and freight trucks in the Annual Energy Outlook 2014, Energy Information Administration.
Fuel price per gallon in year 20 in 2014 dollars	$4.13	Based on vehicle class distribution and the reference case fuel prices identified for sales weighted average price for gasoline (including Federal, State, and local taxes) and diesel fuel for on-road use (including only Federal and State taxes) in the Annual Energy Outlook 2014, Energy Information Administration.

Appendix J: Coastal Regulatory Review

Coastal Regulatory Review

Climate Change Hazard Mitigation
Regulatory Framework for Coastal Mitigations

Background

In considering best practices for mitigating risks to highway infrastructure from rising sea levels, increasing number and intensity of storm events and other natural hazards related to climate change, it is important to understand the variety of regulatory issues that will affect project decisions. In Oregon the state land use planning program adds an additional set of considerations related to balancing environmental, economic, social and energy issues that are related to land use changes.

The original Oregon coastal highway was located on the beaches wherever that was practical. In fact, one original justification for designating the beaches public was to provide a transportation corridor. When major improvements to the highway were constructed in the nineteen thirties, the historic bridges of the corridor were built and the right of way moved away from the beaches, but often just beyond known active dune areas.

The knowledge of natural hazard risks for the coast highway was limited for most of its history. The only clue to seismic and tsunami risks until quite recently was the Native American story of cataclysmic events that occurred in 1700, prior to European exploration and settlement. Climate change is also just emerging as a hazard that can be modelled and predicted based on reliable evidence.

Significant segments of US 101 are sited in high risk areas for the effects of both Cascadia subduction zone events and sea level rise related to climate change. The regulatory regimes that manage land uses on the Oregon coast also predate the most current understanding of the risks of such events. As discussed further below, navigating the current regulatory land use process in order to site facilities pro-actively for hazard mitigation on US 101 will be challenging.

Programs Setting Standards for Road Projects on the Oregon Coast

The Oregon Coast and other rural lands are subject to standards and statutory requirements related to numerous state and federal programs that often overlap, and to local development codes that implement the Oregon Statewide Planning Goals. The programs that are relevant include, but may not be limited to:

- Oregon Statewide Planning Goals and applicable City and/or County comprehensive plans and land development codes
- Department of Transportation Act (DOT Act) of 1966 - Section 4(f)
- Land and Water Conservation Fund (LWCF) Act of 1965 - Section 6(f)
- Pacific Coast Scenic Byway Designation

- State and Federal Wetlands Regulations
- National Environmental Policy Act (NEPA)
  - Endangered Species Act
  - The Clean Air and Clean Water Acts
  - Social Impacts, Civil Rights, and Environmental Justice
  - National Historic Preservation Act (NHPA) - Section 106 (Historic and Archaeological Resources)
  - Many other federal and state regulations and local requirements

Agencies that May be Involved in Road Siting Decisions on the Oregon Coast

- **Local City or County** (sometime both in unincorporated areas of urban growth boundaries) (application review process for land use changes, enforcement of environmental protection and development goals that apply)
- **Department of Land Conservation and Development** (advisory on land use process, may appeal a local decision)
- **Land Use Board of Appeals** (appeals of land use decisions brought by public and private parties after local appeals are exhausted)
- **Department of Transportation** (highway design standards, NEPA reviews of proposed projects as part of project development and project management)
- **Federal Highway Administration (FHWA)** (administrative oversight of state Scenic Byways , Section 4(f), and NEPA compliance for highway projects)
- **Oregon Parks and Recreation Department** (protection of park lands and recreational functions for state and federal grant-assisted properties, jurisdiction over ocean shore area pursuant to ORS 390.605 et. al.)
- **National Park Service** (federal regulatory oversight of state and local recreation lands and sites assisted with grants from the Land and Water Conservation Fund)
- **Department of State Lands** (state regulation of wetlands / estuaries, waters of the state, some state owned lands)
- **U.S. Army Corps of Engineers** (federal regulation of estuaries / wetlands, structures in riverine, wetland and coastal areas; development and construction of mitigation systems and/or structures)
- **U.S. Environmental Protection Agency** (regulatory framework and oversight of NEPA process in highway project development)

Oregon Land Use Planning Program

The **Oregon Statewide Planning Goals**[1] are the state framework for land use planning that is implemented by cities and counties. The Goals, related to natural resources and geographic system

[1] https://www.oregon.gov/LCD/Pages/goals.aspx#Statewide_Planning_Goals

characteristics, are primarily standards of protection. Goals 3 (agriculture) and 4 (forest land) which apply to most privately owned rural land statewide, are intended to both protect natural resources and support their economic use; land uses, including transportation facilities, have to be listed as allowed or permitted uses to be permitted on Goal 3 or 4 lands without taking an Exception. The statewide planning program provides a foundation for land use planning to address a broad suite of public policy objectives which at times are in conflict with each other. The Exceptions process which establishes a process for amending a local comprehensive to allow land use not otherwise in compliance with the statewide goals is set out in Goal 2 and in OAR 660 Division 4.

ODOT makes many decisions related to land use including adopting statewide transportation plans and plan amendments and processing state highway approach permits. ODOT's State Agency Coordination Agreement[2] establishes the relationships between ODOT and DLCD programs and sets out procedural requirements related primarily to Goal 1: Public Involvement.

Location decisions for new or modified roadways are subject to land use administrative rules and statutes that allow some transportation uses outright, permit others conditionally and in other cases require exceptions to one or more land use goals. Consequently, an ODOT project that requires local government approval may be subject to appeal to LUBA.

(ODOT also has a stakeholder right to appeal local land use decisions that do not meet local code provisions or that result in long range or facility plans that are not consistent with state transportation plans though exercise of that appeal right is rare.)

Several Goals may apply to coastal area land use decisions:

- Goal 2. LAND USE PLANNING outlines the basic procedures of Oregon's statewide planning program which include provisions for taking an Exception to a state goal under certain circumstances.
- Goal 3. AGRICULTURAL LANDS requires protection of agriculturally zoned lands for agriculture, open space and forest uses by maintaining large lot sizes and limiting uses that do not support or preserve those values.
- Goal 4 FOREST LANDS requires protection of forest zoned lands for commercial forest, woodlot, open space and agricultural uses by maintaining large lot sizes and limiting uses that do not support or preserve those values.
- Goal 5 OPEN SPACES, SCENIC AND HISTORIC AREAS AND NATURAL RESOURCES covers more than a dozen natural and cultural resources such as wildlife habitats and wetlands. Each resource is inventoried and evaluated. Significant resources or sites have to be managed in one of three ways: preserve it, allow proposed uses that conflict with it, or find a balance between the resource and the conflicting uses.

[2] OAR 731-015: https://secure.sos.state.or.us/oard/displayDivisionRules.action?selectedDivision=3275

- Goal 7. AREAS SUBJECT TO NATURAL DISASTERS AND HAZARDS deals with local government oversight of development in places subject to natural hazards such as floods or landslides.
- Goal 12. TRANSPORTATION is to "To provide and encourage a safe, convenient and economic transportation system. State and local jurisdictions are required to plan for transportation facilities and services sufficient meet their constituents' needs over time, including identifying funding.
- Goal 16. ESTUARINE RESOURCES requires LCDC to classify Oregon's 22 major estuaries in four categories: natural, conservation, shallow-draft development, and deep-draft development and requires local comprehensive plans to divide each estuary into "management units and prescribe the types of land uses and activities that are permissible in those "management units."
- Goal 17. COASTAL SHORELANDS defines a planning area bounded by the ocean beaches on the west and the coast highway (State Route 101) on the east and directs local governments to inventory specified resources within this area. Based on this inventory, the goal requires local comprehensive plans to specify how certain types of land and resources there are to be managed, such as major marshes or sites best suited for port facilities (reserved for "water-dependent" or "water related" uses).
- Goal 18. BEACHES AND DUNES requires local comprehensive plans to prohibit most development on beaches, active foredunes, and certain other dune forms, but allows some other types of development that meet key criteria. The goal also deals with dune grading, groundwater drawdown in dunal aquifers, and the breaching of foredunes.

  An important aspect of this goal is that it grandfathers "development" that was in place on January 1, 1977, allowing rip-rap or other engineered stabilization of dunes, etc. only for those developments in place on that date. While conventional wisdom is that a highway meets the definition of "development," the legislative history for the Goal and rules does not clearly support that conclusion, and it is settled law that ODOT facilities are not "development" for the purpose of the Goal. Consequently, hardening a bank on the coast west of US 101 to reinforce the highway right of way requires an Exception to Goal 18.
- Goal 19. OCEAN RESOURCES aims "to conserve the long-term values, benefits, and natural resources of the nearshore ocean and the continental shelf," dealing with matters such as dumping of dredge spoils and discharging of waste products into the open sea. Goal 19 applies primarily to the decisions and actions of state agencies, not cities and counties.

EXCEPTIONS:

Goal 2, Part II identifies the allowable bases for approval of an Exception[3].

A local government may adopt an exception to a goal when:

[3] OAR 660-0040-0020

(a) The land subject to the exception is physically developed to the extent that it is no longer available for uses allowed by the applicable goal;

(b) The land subject to the exception is irrevocably committed to uses not allowed by the applicable goal because existing adjacent uses and other relevant factors make uses allowed by the applicable goal impracticable; or

(c) The following standards are met:

(1) Reasons justify why the state policy embodied in the applicable goals should not apply;

(2) Areas which do not require a new exception cannot reasonably accommodate the use;

(3) The long-term environmental, economic, social and energy consequences resulting from the use of the proposed site with measures designed to reduce adverse impacts are not significantly more adverse than would typically result from the same proposal being located in areas requiring a goal exception other than the proposed site; and

(4) The proposed uses are compatible[4] with other adjacent uses or will be so rendered through measures designed to reduce adverse impacts.

Applying section (c), the "reasons exception" criteria, is the approach most likely to work to get approval of an Exception to a Goal or Goals for a climate change mitigation project.

One or more resource land goals will apply to most existing or potential transportation corridors along US 101. Coastal urban land areas may be affected by any or all of Goals 5, 7, 16, 17 and 18. Rural lands that are not developed will have primarily Goal 3 (Agriculture) or 4 (Forest) designations and may be subject to one or more of Goals 16, 17 and 18. Approval of an Exception will require findings to satisfy all of section (c) for each Goal that applies.

There is no specific provision that reducing hazards related to climate change, rising sea levels and increased frequency and intensity of storm events (or earthquake or tsunami) has any particular weight in justifying a "reasons" exception, but, arguably, those concerns do constitute a defensible "reason." However, the bar is high to meet all of the requirements of an exception, adding to research and analysis, engineering and time costs. This tends to put ODOT in a position to select the regulatory path of least resistance which will sometimes result in a less strategic, shorter term fix.

AREAS SUBJECT TO NATURAL HAZARDS:

Local government planning for natural hazards (Goal 7) is implemented by adopting comprehensive plan elements related to:

". . . floods (coastal and riverine), landslides, earthquakes and related hazards, tsunamis, coastal erosion, and wildfires. Local governments may identify and plan for other natural hazards."

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[4] Compatible, as used in subparagraph (4) is not intended as an absolute term meaning no interference or adverse impacts of any type with adjacent uses.

While climate change is not identified separately as a hazard, the list of hazards that must be considered covers the bases of hazards likely to be exacerbated by climate change. And local jurisdictions have the option to plan for climate change impacts as a context for land use decision making in affected areas. The first Implementation section of Goal 7 requires that the local government:

> *"3. Adopt or amend, as necessary, based on the evaluation of risk, plan policies and implementing measures consistent with the following principles:*
>
> > *a. avoiding development in hazard areas where the risk to people and property cannot be mitigated; and*
> >
> > *b. prohibiting the siting of essential facilities, major structures, hazardous facilities and special occupancy structures, as defined in the state building code (ORS 455.447(1) (a)(b)(c) and (e)), in identified hazard areas, where the risk to public safety cannot be mitigated, unless an essential facility is needed within a hazard area in order to provide essential emergency response services in a timely manner."*

Paragraph (b) appears to provide support in principle for moving a lifeline highway out of a sea level rise or coastal erosion hazard area, but lifeline highways are not specifically included in the referenced definition of essential facilities or major structures.

Another climate change adaptation project, sponsored by DLCD, is currently under way. This pilot program will explore ways to support local efforts to mitigate climate change impacts through the land use planning process at the local community level. The effort will likely result in guidance for natural hazards planning for climate change impacts, and may discover a need for goal and/or rule amendments to better support facility siting away from coastal hazards that are forecast to be exacerbated by climate change.

County Land Use Planning Programs

Both Clatsop and Tillamook Counties have included beach and dune protection, erosion and landslide hazard mitigation, and geo-technical review of proposed development within hazard areas in their comprehensive plans and zoning codes.

Clatsop County has designated Geological Hazard Overlay Districts (GHOD), which are based on maps provided by DOGAMI. Tillamook County has a "Beach and Dune" overlay zone that applies limitations and site development standards to vulnerable soil and slope areas, also relying on geo-technical studies by applicants to identify site specific issues. Both counties identify hazard areas based on U.S. Soil Conservation Service soil mapping done in the seventies and geo-technical reports developed by developers / owners on a case-by-case basis to assess hazards and make site specific conditions and recommendations.

Clatsop County Zoning

County Planning Maps, the Geologic Hazards District development code chapter and the Southwest Coastal Area Plan were reviewed. There are, no doubt, other parts of the County's plan and code that would apply to land use applications along US 101.

In Clatsop County 90% of the land area is forest land, zoned for forest use or mixed forest/agriculture. The soil classes are not typically favorable for agricultural uses except pasture and woodlands.

The Southwest Coastal Area Plan includes the pilot study sites in Clatsop County. The zoning districts along US 101 outside of incorporated and exception areas (areas found by the county to be built and committed to nonresource uses through a formal exceptions planning and zoning process) are almost entirely Recreation Management, Agriculture Forest and Forest-80 (80 acre minimum lot size).

Pursuant to development code section 4.040 Geologic Hazards District, the county plan identifies and the code regulates the Bluff Edge along the coast, and Erosion and Slide areas. A Geologic Hazard Permit requires a geotechnical report that the county reviews for onsite risks and offsite impacts. Regulatory Slide Areas comprise about half of the land area in the Southwest Coastal Area. The designated Ross Slide Areas occur along the coastal bluffs in the Southwest Coastal Area crossing or in close proximity to US 101 near most if not all of the pilot study sites in Clatsop County.

Clatsop County Geo-hazard Review Process

Transportation projects in Clatsop County usually require a Development Permit. They may also require a Conditional Use Permit, depending on how the land the project traverses is zoned.

If a transportation project (or any other development proposal) is within a GHOD, the County requires the applicant to provide a Preliminary Geological Hazard Report. There is a fee charged for the County to review the report in addition to the fee for the Development Permit and Conditional Use Permit (if required).

If the Preliminary Geological Hazard Report indicates more detail is required to make a determination, the County requires the applicant to provide a formal Geological Hazard Report. There is a basic fee for hazard report review and additional fees may apply if the County needs to hire a professional geologist or engineer to review the report.

Tillamook County Zoning

The county development code was reviewed for applicable provisions. Tillamook does not currently have its plan maps posted on-line. The county manages the hazards of interest through the Beach and Dune Overlay Zone whose boundaries are based on an SCS (NRCS) 1975 soil survey of beaches and dunes. Regulatory hazards include landslides, mudflow areas, ocean front on bluffs where erosion, etc. are recognized, Brallier peat soils, and other locally known hazards. The local goals and objectives for beach and dune protection are in the Goal 18 element of the comprehensive plan.

The development code has specific standards and limitations on "beachfront protective structures":

SECTION 3.085: BEACH AND DUNE OVERLAY ZONE (BD)

4. Beachfront Protective Structures:

(A)(4)(b) Beachfront protective structures (riprap and other revetments) shall be allowed only in Developed Beachfront Areas and Foredune Management Areas, where "development" existed as of January 1, 1977, or where beachfront protective structures are authorized by an Exception to Goal 18; and

(d) Beachfront protective structures located seaward of the state beach zone line (ORS 390.770) are subject to the review and approval of the State Parks and Recreation Division. Because of some concurrent jurisdiction with the Division of State Land, the Parks Division includes the Division of State Lands in such beach permit reviews.

County Decision Authority and Appeals

In addition to reviewing and processing applications for specific land use proposals, each county is the decision authority for review and approval of Exceptions applications within their boundaries. Processing an Exception application can be time consuming and expensive to complete; Exceptions cases are may be appealed locally and to the Oregon Land Use Board of Appeals. Neighbors and other constituencies for the resources affected can be particularly concerned about Exceptions to the basic land use goals. Though ODOT projects along the coast are typically approved without appeals, the possibility of appeals based on any of the findings offered as part of an exception application increases the perceived risk to the Agency, particularly considering the time and expense required to develop a comprehensive case for an exception to the land use goals.

Department of Transportation Act (DOT Act) of 1966 - Section 4(f)

The U.S. Department of Transportation (DOT) was established by an act of Congress, signed into law by President Lyndon B. Johnson on October 15, 1966. The department's first official day of operation was April 1, 1967.

Mission: The mission of the Department of Transportation, a cabinet-level executive department of the United States government, is to develop and coordinate policies that will provide an efficient and economical national transportation system, with due regard for need, the environment, and the national defense. It is the primary agency in the federal government with the responsibility for shaping and administering policies and programs to protect and enhance the safety, adequacy, and efficiency of the transportation system and services.

Section 4(f) of that Act stipulates that the Federal Highway Administration (FHWA) and other DOT agencies cannot approve the use of land from publicly owned parks, recreational areas, wildlife and waterfowl refuges, or public and private historical sites unless the following conditions are met:

- There is no feasible and prudent alternative to the use of land.
- The action includes all possible planning to minimize harm to the property resulting from use.

Consequently, these limitations apply if any FHWA funding is used to develop or construct a highway project. While the state goals discussed above make it very challenging to move the highway right of way out of an existing corridor, this regulation makes it challenging to increase or do a minor realignment of the footprint of a facility in an existing corridor if it affects any of the listed recreational and preservation land uses. However, Section 4(f) does allow for negligible or “de minimis” takings of land if those acquisitions fit certain criteria.

Land and Water Conservation Fund Act, Section 6(f)

(Federal funds) The LWCF Act specifies that property purchased or developed with LWC Funds may not be converted to any use other than public outdoor recreational uses, so that potentially converted lands may have to be replaced with suitable lands of at least equal fair market value (FMV) and similar recreation values. Early consultation and coordination with the local park or recreation agency with jurisdiction over the impacted property, Oregon Parks and Recreation Department (OPRD), and National Park Service (NPS) is required to determine whether any potential conversion of protected lands may occur as a result of any development, including highway projects. ODOT consults first with the local jurisdiction, and then with OPRD who in turn will consult with NPS to determine section 6(f) applicability to any coastal highway improvement and/or realignment project. Section 6(f) applies regardless of highway project funding source.

Ensuring compliance with LWCF Act requirements requires verifying which properties have received federal assistance through the granting of LWCF funds. The verification process is the first step ODOT takes in the consultation process with the local jurisdiction and OPRD.

Following is a list of potential parks and recreation/historic areas and landmarks that may have stringent development or acquisition constraints and “anti-conversion” protections placed on them due to state and/or federal grant assistance that has been applied to those properties, including but not limited to LWCF funds. The list of properties in general is from the north end to the south end of the study area (note: the bolded sites are more likely to have “anti-conversion” protections on them; this list is not necessarily exhaustive and should be explored in more detail through the above-mentioned consultation and coordination process with the local jurisdiction and OPRD as highway development projects would become more imminent in the future):

- Cartwright Park
- Seaside Golf Course
- Seltzer Park
- Klootchy Creek County Park
- CZ Picnic Ground
- **Evergreen Cemetery**
- **Ecola State Park**
- Sea Ranch RV Park
- **John Yeon State Natural Site**
- Lea Shirley Park
- **Haystack Hill State Park**
- **Tolovana Beach Wayside**
- **Arcadia Beach State Park**

- **Hug Point State Park**
- Manzanita City Park
- Hallensted Park
- **Oswald West State Park**
- Nehalem City Park
- **Nehalem Bay State Park**
- **Manhattan Beach State Park**
- **Twin Rocks County Park**
- **Barview County Park**
- **Barview Jetty County Park**

These recreation and/or historic sites—especially those in bold font—may be protected from development for purposes other than recreation. If developments, including highway construction, are proposed adjacent to or within the boundaries of these sites by any private or government entity, including any permanent or temporary rights-of-way or construction easements, consultation with OPRD Grants Program Managers would need to be initiated and proper processes followed to comply with any development restrictions. In some cases, consultation and ensuing processes could be lengthy, complex, and costly and some sites may require acquisition of suitable replacement property as compensation for development impacts. It is highly recommended to consult with the local jurisdiction and OPRD early if development on protected sites cannot be avoided.

If any ROW were needed for any of the planning scenarios/solutions for mitigating climate change impacts, if the ROW (of any amount no matter how minor) were needed to be acquired from protected site, it would require a “conversion” process to be completed which requires ODOT to purchase replacement property and perform NEPA and federal appraisals of both the conversion property and the replacement property. This process can take anywhere from 1-3 years, and can cost several thousands of dollars for the process work (staff time, appraisal costs, etc.) and may not include the cost of the replacement land, which is based upon the federally appraised fair market value of the conversion (i.e., the ROW from the project would need from within the park’s protected boundaries).

Pacific Coast Scenic Byway

The Scenic Byway / All American Road designation is intended to preserve scenic values along U.S. 101. The basic requirements for scenic byways are:

- Bridge design and vegetation management must consider scenic byway criteria / standards – impacts of the work on the scenic values that support the byway designation.
- Rock walls: Match materials, extend where reinforcing re: slides, etc.
- Bridges and appurtenant structures: frequent inspections, repair rather than replace if possible (spalled concrete, etc.), bridge colors, design enhancements for new bridges,
- Bypasses – if needed to maintain safety – scenic bridge may be maintained for limited use.

The pilot project area overlaps two scenic byway regions: All of US 101 in Oregon is designated the Pacific Coast Scenic Byway, an Oregon Scenic Byway and an All American Road under the National Scenic Byways Program (U.S. Department of Transportation, Federal Highway Administration)

- The pilot project study area begins within the southern edge of the Cannon Region of the byway, which includes Silver Point and Arch Cape: http://www.oczma.org/pdfs/PCSBP%20Chapter%205-Clatsop%20_%20Cannon%20Region%20Plan.pdf
- The rest of the sites to the south are in the Nehalem Region: http://www.oczma.org/pdfs/PCSBC%20Chapter%205-Nehalem,Tillamook,Nestucca.pdf

The federal Scenic Byways program was created by ISTEA: 23 U.S.C. 101 Section 1047(g) *"The Secretary shall not make a grant under this section for any project which would not protect the scenic, historic, recreational, cultural, natural, and archeological integrity of the highway and adjacent area. . . "*

TEA-21 amended the US Code to include a National Scenic Byways Program, making the program permanent. (The original program sunsetted at the end of ISTEA)[5]

State and Federal Wetlands

Regulatory wetlands, by Army Corps of Engineers' definition, include artificially created wetlands/ponds, intermittent streams, perennial streams, estuaries and beaches. All of these types of wetlands can be found in Oregon coastal areas.

Projects that damage or remove wetlands have to comply with state and federal wetlands protection regulations. The existence of wetlands on a proposed development site creates location, design, engineering and logistics concerns that are routine aspects of ODOT project development. The applicable regulations require minimizing and mitigating impacts and replacing wetlands that will no longer be functional once the project is built.

National Environmental Policy Act (NEPA)

NEPA, signed into law by President Richard Nixon on January 1, 1970, set up procedural requirements for any federal, state, or local jurisdiction project that involves federal funding, work performed by the federal government, or permits issued by a federal agency. All projects with a federal "nexus" (as described above) require a proper NEPA classification determination and NEPA approval (in ODOT's case, by FHWA or FTA/FRA as the case may be) of the demonstrated classification. Most of these projects fit a Class 2 category, requiring demonstration and documentation through the various applicable state and federal regulations that environmental impacts will not be significant. Some federalized projects require preparation of an environmental assessment (EA) and/or environmental impact statement (EIS) if impacts are determined to be significant (40 CFR 1508.27). All NEPA classes of

[5] Scenic America webpage, "Reports"
http://www.scenic.org/resources/studies-and-reports

actions (CE, EA, and EIS documents) contain statements of the effects of a proposed project on a broad range of applicable environmental resources including social, economic, cultural, and natural resources..

The NEPA process is an ingrained part of the project development process at ODOT for all state and local agency sponsored transportation projects funded with FHWA, FTA (transit), or FRA (rail) funds. It provides the framework for identifying all of the relevant social, economic, cultural, and natural resources that may exist within and/or adjacent to a proposed project's footprint and study area. Any potential impacts to existing resources would be analyzed and mitigation measures applied as required by the myriad of statutory and regulatory process and permitting requirements.

For ODOT (state and local) projects, NEPA applies to all classes of USDOT federal actions including Class 1 (requiring preparation of an EIS), Class 2 or categorical exclusion (excluded from preparation of an EA or an EIS), and Class 3 (requiring preparation of an EA). The specific NEPA process and documentation requirements differ slightly between the USDOT federal agencies, with a vast majority of ODOT's (state and local) federal actions being funded by FHWA. More FTA and FRA projects are on the horizon however.

CASE STUDY: Beverly Beach / Spencer Creek Bridge[6]

PROBLEM: Spencer Creek Bridge was built in 1947. Corrosion of reinforcing steel had caused significant damage to the bridge when this project was started. Spalling[7] of concrete under the bridge was occurring. Damage was severe enough that the bridge was put under a posted load limit of 27 tons in 1995, causing many large trucks to take a long detour. Repairs were done in 1997 to keep traffic moving, but deterioration continued.

In addition to the problems with the aging bridge, coastal erosion and related slides in the weak mudstone forming the beach cliff west of the highway and south of the bridge are active hazards threatening the base of the highway.

The geology exposed in the beach cliff south of Spencer Creek includes fill material placed for the south bridge abutment, Pleistocene and younger marine terrace deposits and colluvial soil and interbedded sandstone and fossiliferous mudstone of the Miocene-age Astoria Formation which dips out of slope to the west-southwest between 15 and 20 degrees along this stretch of the coast. The material above the Astoria Formation is weaker mudstone. A recent DOGAMI publication shows the entire highway reach from Wade Creek north approximately 1000 meters (about .6 miles) being a "potentially active complex landslide."

SITE DESCRIPTION: The highway in this area is located between the Beverly Beach rural residential community (RRC) and the Otter Creek RRC. East of the highway on Spencer Creek is Beverly Beach State Park. Wade Creek is between Spencer Creek and Newport (which is about 7 miles south of Spencer

[6] Primary Sources: Spencer Creek Bridge Conceptual Alternatives Report and Appendices and Spencer Creek Bridge, Appendices to Reconnaissance Report (ODOT, FHWA, U.S. Army Corps of Engineers)
[7] Breaking or crumbling of concrete from a reinforced structure or structural element such as a bridge pier

Creek); Johnson Creek and an unnamed creek are located north of Spencer Creek in the same littoral zone. Zoning in the area is a mix of Rural Residential (large lot, single family), Public Facility (schools, government, parks, etc.), Retail Commercial, and Timber Conservation which is the majority designation outside of developed areas.

ODOT Proposed Alternatives

ODOT, FHWA and the U.S. Army Corps of Engineers considered a wide range of potential solutions to address the replacement or rehabilitation of the Spencer Creek Bridge and to provide a stable roadway at the approaches of the bridge.

The Conceptual Alternatives Report identified 9 alternatives. The 5 alternatives further reviewed in the Reconnaissance Report included:

- Alternative B: New, wider bridge and approaches at the same centerline location. Would require repair of existing embankment failures and shoreline erosion protection.
- Alternative D: Shift the highway to the east and do all widening on the east side to minimize impacts to the beach. Requires shoreline erosion protection and removal of as many as 17 houses, park restrooms and part of the day-use parking area. Also requires either moving the cut slope south of the bridge to the east or construction of a retaining wall to protect remaining homes.
- Alternative F: Would move US 101 about 50 feet inland between Wade Creek and Spencer Creek and use the existing sea cliff as the barrier to shoreline erosion. Would relocate part of Beverly Drive in Beverly Beach; requires removal of an existing store and Laundromat, park restrooms and large part of the day use parking lot plus cut slope or retaining wall protections for nearby homes as in Alternative D.
- Alternative G: Similar to Alternative F, but keeps alignment of US 101 more or less parallel to Beverly Drive.
- Alternative I: Would move the US 101 alignment east of Beverly Beach State Park and reconnect to US 101 south of the community of Beverly Beach and near Otter Rock to the north. New road access would be necessary for the community of Beverly Beach, would increase park traffic on Beverly Beach Road, but would avoid direct impacts to the beach area, the park and homes and businesses. On the other hand it would impact large areas of forest land and possibly a variety of habitat areas. No shoreline erosion control would be required.

Spencer Creek Regulatory Issues

This site and the work needed to protect the function of the bridge and the highway are a good case study for the Climate Change Adaptation pilot project because many of the potential regulatory hurdles described above are in play. The ones specific to locational decisions are:

- Oregon Land Use Planning Goals and applicable City and/or County land development codes
- Department of Transportation Act (DOT Act) of 1966 - Section 4(f)
- Land and Water Conservation Fund (LWCF) Act - Section 6(f)

- Scenic Byway designation

Land Use Planning Goal 18 protects beaches and dunes. Hardening the bank west of the highway would require an exception to Goal 18. Moving the alignment away from the beach to the east, beyond Beverly Beach State Park, would require an Exception to Goal 4 – Forest Lands and possibly an Exception to Goal 18 for any transitional areas still within the purview of Goal 18. Other locational or natural resource issues might trigger other Exceptions or Goal 5 review and conditions.

Land use impacts vary by alternative. Impacts of the alternatives were assessed based on the size of the area impacted, impacts to protected resources, and the number of existing uses that would be displaced.

> *"Oregon land use law gives priority to alternatives that do not require goal exceptions. Of the five alternatives, only F and G would not require a Goal Exception. Consequently, before any of the other alternatives could be approved, alternative F and G would have to be shown as not able to reasonably accommodate the identified needs of the project, before a goal exception would be allowed to permit any of the other project alternatives."*[8]

Beverly Beach State Park and the beach itself are subject to Department of Transportation Act section 4(f). A project using FHWA funds cannot use land from publicly owned parks, recreational areas, wildlife and waterfowl refuges, or public and private historical sites unless the following conditions are met:

- There is no feasible and prudent alternative to the use of land.
- The action includes all possible planning to minimize harm to the property resulting from use.

Consequently, all alternatives have to be weighed against these criteria.

Beverly Beach State Park is a Land and Water Conservation Fund federally assisted site. LWCF dollars were used for acquisition or development of some or all of the area of that park. Consequently, no portion of the park within the protected 6(f) boundaries can be converted to a non-recreation use without replacing the lost recreation and economic values with property deemed suitable by OPRD and NPS.

The Scenic Byway Designation has local and state constituents with an interest in any highway reconfiguration that changes or reduces scenic values. Moving a highway out of sight of the beach is a significant change to the scenic qualities of the highway.

How ODOT Addressed Mitigation of the Landslide Risks to US 101 at Spencer Creek

When the need to repair or replace the bridge (circa 1995) and the eminent risks of beach erosion and landslides to the highway became a priority, a lot of time and effort was invested in identifying solutions and resolving regulatory issues.

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[8] Reconnaissance Study Report, Appendix C, Environmental Memorandum, page C-23

TIME LINE:

Emergency Temporary Bridge Installed	Sept. 1999
Created Coastal Protection Technical Advisory Committee	April 2001
ODOT Studied methods to stabilize roadbed with rip rap or other armoring techniques.[9]	2001-2006
ODOT Conceptual Alternatives Report	July 2002
U.S. Army Corps of Engineers Reconnaissance Report & Appendices	June 2003
Spencer Creek EIS	March 2006
Permanent Bridge Replacement (Shifted 50 feet east)	2008
Extended 101 Realignment	Not in Scope

U.S. Army Corps of Engineers' Reconnaissance Study Report

To maintain the highway in its current alignment, some sort of engineered solution for the coastal erosion and landslide problem would be necessary. The Corps study found that, on 5-10 year intervals of occurrence, the landslide conditions were triggered or exacerbated as follows:

> *"The primary causes of erosion were found to be high precipitation events initiating landsliding or slumping along the sea cliff and episodic severe storm events involving elevated water levels and large wave heights, often associated with El Nino events."*
>
> *. . .*
>
> *"The primary coastal engineering issues are as follows:*
>
> - *Sediment-starved littoral cell*[10]
> - *Low sand volume in profile, particularly above the MHHW line (material not available to adjust during storm to buffer shoreline)*
> - *Low elevation of bluff/beach intersection (frequent and significant energy impact)*
> - *Geologically vulnerable bluff slope*
> - *Wave-focusing by offshore reefs (increased wave energy, sediment redistribution)*
> - *Recent (10-20 year increase in storm climate (El Nino, La Nina, storms impacting wave energy, longshore and cross-shore transport)*
> - *Loss of recreational beach area."*

The Corps proposed a variety of alternatives or combinations of alternatives for hardening or protecting the bluffs below the highway, including revetments (hardening the toe of the bluff), rock seawall at the toe of the bluff or at mid-beach, beach nourishment with sediment to improve resilience, cobble beach fill, constructed near shore rock reefs and near shore sediment placement. Most of these alternatives

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[9] Norman Rauscher – Correspondence dated 03/13/2012

[10] A littoral cell is a more or less contained area of beach that shares the same system of sediment deposition and beach replenishment. In this littoral cell, beach sand is not being replenished at an optimal rate, reducing the resistance of the beach to high water and heavy sea events.

would reduce the extent of the beach and/or change its character, so 4(f) issues would arise in implementation.

Construction and maintenance costs of the Corps alternatives were estimated and varied widely. Maintenance intervals varied from yearly to 25 years.

Department of Transportation Act (DOT Act) of 1966, Section 4(f) Impacts

Beverly Beach State Park is one of the most popular parks in Oregon. Recreational opportunities include walking, hiking and running; picnicking; flying kites; agate, rock, shell, and driftwood collection; fossil exploration; whale and marine mammal watching; clam digging and surfing. Impacts of engineered mitigations would include:

- Revetment or Seawall at Bluff Toe: would reduce shell, rock and fossil collecting without limiting other activities significantly. Wall climbing might occur.
- Seawall at Mid-beach: Would preclude most beach use except at low tide.
- Submerged Nearshore Rock Reef: Virtually no impact on beach use except possible visual impact and adverse surfing conditions; the reef would change the way waves break on the beach and create a barrier.
- Cobble Beach Fill: Would change the character of the beach materials, hindering many activities.
- Beach Nourishment (same size sediment): Would enhance beach in long term, but would hinder many collecting activities after fresh applications (anticipated to be needed every five years).
- Beach Nourishment (medium or coarse materials): Would not affect most activities; might change appearance and could adversely impact razor clams long term.
- Submerged Nearshore Sediment Berm or Nearshore Dredged Material Placement: Would not have immediate impacts on beach but would have impacts similar to the beach nourishment approaches as wave action redistributed materials, and depending upon the type of material used for the berm.

Bridge Replacement Alternatives

Land use impacts vary by alternative. Impacts of the alternatives were assessed based on the size of the area impacted, impacts to protected resources, and the number of existing uses that would be displaced.

> *"Oregon land use law gives priority to alternatives that do not require goal exceptions. Of the five alternatives, only F and G would not require a Goal Exception. Consequently, before any of the other alternatives could be approved, alternative F and G would have to be shown as not able to reasonably accommodate the identified needs of the project, before a goal exception would be allowed to permit any of the other project alternatives."*[11]

[11] Reconnaissance Study Report, Appendix C, Environmental Memorandum, page C-23

Conclusions:

Alternatives to mitigate coastal hazards related to sea level rise and more frequent or more extreme storm events are likely to include measures like abutments and other site hardening measures, and/or rerouting US 101 in some areas. Identifying a preferred alternative will require balancing the size of the risk against the overlapping and sometimes conflicting regulatory issues discussed here. Many of the potential solutions for mitigation could require lengthy EA or EIS processes (if there is a federal nexus) depending on the scope of the resultant project. Even a project fitting a Categorical Exclusion (Class 2) NEPA classification could run into obstacles such as needing Goal exceptions or 6(f) conversion approval from NPS.

Both time and money may weigh against a reroute of a roadway away from a coastal hazard. If a fix is available within existing right of way, the regulatory burden of proof to move to a new route is high. Any of the following options raise one or more barriers to what may be an otherwise less complex and/or less costly (both time and money) mitigation measure:

- Moving a segment of the highway inland into farm or forest land;
- Installing barrier protection like building walls;
- Raising the road surface;
- The need for additional ROW (of any amount no matter how minor)
    - To be acquired from a 6(f) protected park or other recreation property, requiring a conversion;
    - Located on a beach, in a park or recreation area; or
    - In a different land use zone with resource land protections.
- Blocking a view or otherwise degrading scenic values.

The Oregon Land Use Planning program may raise barriers to pro-active, preventive alternatives in some cases. As observed in the case study above, the exceptions process can weigh heavily in favor of shorter term, limited value fixes in or very near higher risk locations compared to potentially longer term hazard mitigation that could serve multiple purposes for climate risks, flooding related to rainfall events and high seas, and tsunami hazards. One constructive follow-up activity to the pilot project would be working with DLCD to identify methods to support projects that get coastal lifelines out of harm's way when mitigation investment opportunities arise.

Appendix K: Monitoring of Shore Cliff Retreat using Terrestrial LiDAR

Monitoring of Shore Cliff Retreat using Terrestrial Light Detection and Ranging (LiDAR)

Coastal bluff and shore cliff erosion is a significant concern not only to the Oregon Department of Transportation, but to other infrastructure owner-operators and as private property owners along the Pacific Coastline. Shore cliff erosion is a coastal process that is particularly sensitive to the prospective climate drivers. Sea-level rise, storm frequency and intensity, wave height and incidence, and rainfall amounts all influence coastal bluff erosion and retreat. The rate at which coastal bluffs retreat is also directly proportional to these climate change effects. Infrastructure is by necessity, located at the tops of coastal bluffs, and is commonly subject to disruption as coastal bluffs fail and subsequently undermine roadways, utility lines, or fixed structures. Coastal bluff erosion is a well-defined process but information regarding the actual rate of retreat has not been effectively studied in the past.

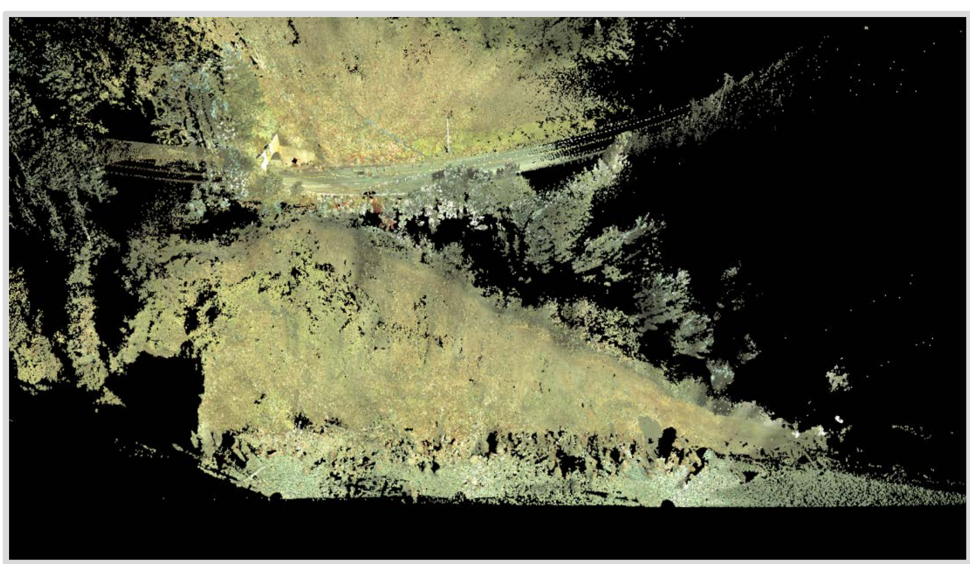
The steep terrain and underlying geology of the Oregon Coast generally precludes relocating infrastructure while environmental constraints greatly inhibit efforts to protect shorelines that fall outside statewide land use goals. In most cases, State highways are not protected by land-use goals and shoreline protection structures are forbidden. These issues highlight the need to assess coastal bluff retreat in terms of both magnitude and rate of retreat. This knowledge would allow the Agency to make decisions regarding when particular segments of the highway would be affected by coastal erosion and when necessary steps must be taken to protect it. The magnitude of bluff retreat is also important to determine as it is a critical factor in determining what measures must be taken to protect a particular element of the highway. This information is also important with respect to justifying exceptions to land use goals and other environmental exemptions when proposing construction projects to protect infrastructure.

Of particular concern on the Oregon coast is the existence of landslides immediately above, within, or otherwise included in a coastal bluff. Not only is coastal bluff erosion on its own is a significant concern; it also severely affects pre-existing landslides, some of which are very large. In their most simple sense, landslides occur when their driving forces exceed their resisting forces. Most of the resisting forces are mobilized in the lower, or “toe” portions of the slide mass. As the toe of the slide erodes, the resisting forces decrease, and at some point enough resistance will be removed that failure will occur. Coastal bluffs can either support the toe of the slide, or buttress an upslope slide. Erosion rate and magnitude can be used as an input for stability analysis. This data can be used to determine the effect of erosion on the overall slide stability and later to evaluate the most effective mitigation method(s).

For the current project, the Arch Cape site is an example of an existing landslide within the coastal bluff where further erosion will undermine the slide itself. The alternate Silver Point Slide is a case where the existing coastal bluff buttresses a large upslope landslide. As this bluff erodes, lateral support of the landslide decreases and ultimately, a larger, deeper slide surface will develop that will eventually have a greater effect on the highway.

Terrestrial laser scanning (TLS) provides the appropriate technology for rapid 3-dimensional data acquisition using Light Detection and Ranging (LiDAR) to map, visualize, measure, and understand the processes caused by coastal bluff erosion. LiDAR data can be used to rapidly survey a site or region repeatedly for change analysis and quantification. LiDAR data provides a "point cloud" of data in 3-space with a very high resolution and precision. The equipment reads a return from the laser reflected from the ground surface to establish a point with x, y, and z coordinates. Subsequent scans from the established baseline scan locations are used to measure differences between coordinates that define differences in slope morphology. These differences between scan coordinates are used to develop rates of change that can then be used to project the actual times at which potential impacts may register, whether actual pavement undermining or removal of buttress support.

The primary advantage of TLS is that it provides a fixed location in space that is captured digitally. All subsequent measurements are based on this highly precise location that is free of the distortions and uncertainties present in standard photogrammetric methods. All features at a site can be measured without fixed points which themselves would be subject to displacement by slope movement or incidental contact. An additional benefit of TLS is that every laser reflection point produces specific color returns in the Red, Blue, and Green (RGB) spectrum that can provide an actual image of any site. The image below is the scanned topography of the Arch Cape site from the baseline survey with color enhancement based on the accompanying RGB returns.



Arch Cape Baseline Scan

This figure illustrates another advantage of digital topography: The scanning instrument is located on a fixed tripod at a limited number of locations on the ground surface and once complete, the image can be rotated along any axis. This image has been rotated and zoomed about the X-axis to give the appearance of an aerial image. Note that the tunnel liner appears in this image since the overlying ground surface can be removed digitally.

A series of annual TLS data set acquisitions are proposed for the Arch Cape and Silver Point sites. These datasets would provide a measurement from the baseline that would be used to determine an annual difference between the initial and each subsequent scan interval. These surveys would be used to project the rate of slope retreat and determine which areas of the slope are the most susceptible to erosion. This information would in turn be used to predict the actual time when impact to the roadway would be expected as well as to evaluate the locations and methods to protect the slope. Subsequent images would be enhanced to indicate areas and magnitudes of retreat or advance to facilitate rapid assessment of changes as well as to quantify movement visually. The rates of erosion would also be used to model the many other sites with similar conditions with respect to site geometry and underlying geology that exist along the Oregon coastline.