Historic Columbia River Highway

Rockfall Hazard Study

January 2013

HISTORIC COLUMBIA RIVER HIGHWAY ROCKFALL HAZARD STUDY

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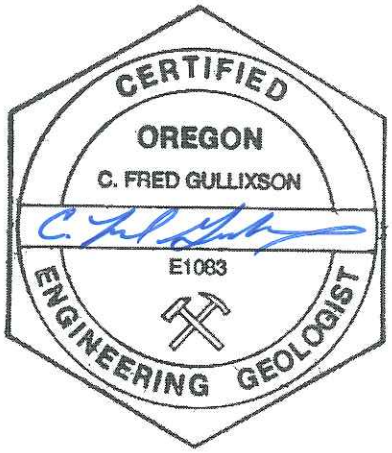
 Renews: December 31, 2014	 Renewal Date: November 30, 2013
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1 Purpose and Scope

At the request of of the Oregon Department of Transportation's Columbia River Gorge Liaison, the Region 1 Geo/Hydro/HazMat Unit evaluated and conducted preliminary analyses of rockfall hazards along the proposed alignment for the Historic Columbia River Highway (HCRH) State Trail. The proposed HCRH State Trail will be a paved recreational Multi-use (bicycle and pedestrian) trail extending from Troutdale, Oregon to The Dalles, Oregon. The trail will share some sections of the HCRH that are still under traffic, reoccupy abandoned sections of the old HCRH and establish new alignments between existing sections.

This study focused on an 8-mile section of the trail alignment between Wyeth and Hood River, approximately mile points 52 to 58 (Figure 1-1). Specifically, this study examined those segments of proposed alignment that are located immediately adjacent to existing rock or talus slopes, where trail design will require consideration of rock slope performance and hazard. These alignment segments all lay within existing rockfall catchment areas along the eastbound lanes of I-84. This study does not include trail locations off of I-84, where the trail alignment can be shifted away from the rock slopes. For this study, we followed the existing guidelines of the Oregon Department of Transportation (ODOT), the Columbia River Gorge National Scenic Area (CRGNSA), and the HCRH Advisory Committee. We assumed that the standard trail geometry is a 12-foot wide paved trail with 2-ft wide shoulders, for a total width of 16 feet.

This report provides scoping-level, conceptual rockfall mitigation alternatives and cost estimates for 9 hazardous slopes. The slopes discussed in this report are recommended for rockfall mitigation (as described herein) and should be addressed in future work. Further investigation, analysis, and design work will be required to develop final mitigation methods and in the development of construction plans, specifications and estimates.

Work for this study included field assessment, rockfall modeling, and conceptual mitigation design on the selected slopes. Slope number, alignment stationing, and associated landmarks are shown on Table 1 and in Figures A-1 through A-11. Rockfall slopes were numbered sequentially starting from the west end of the study area, near Wyeth, Oregon at Shellrock Mountain (Site 1). Figures A-1 through A-11 include aerial photographs and LiDAR-based slope maps of the proposed alignment, showing the location of all slopes included in this study.

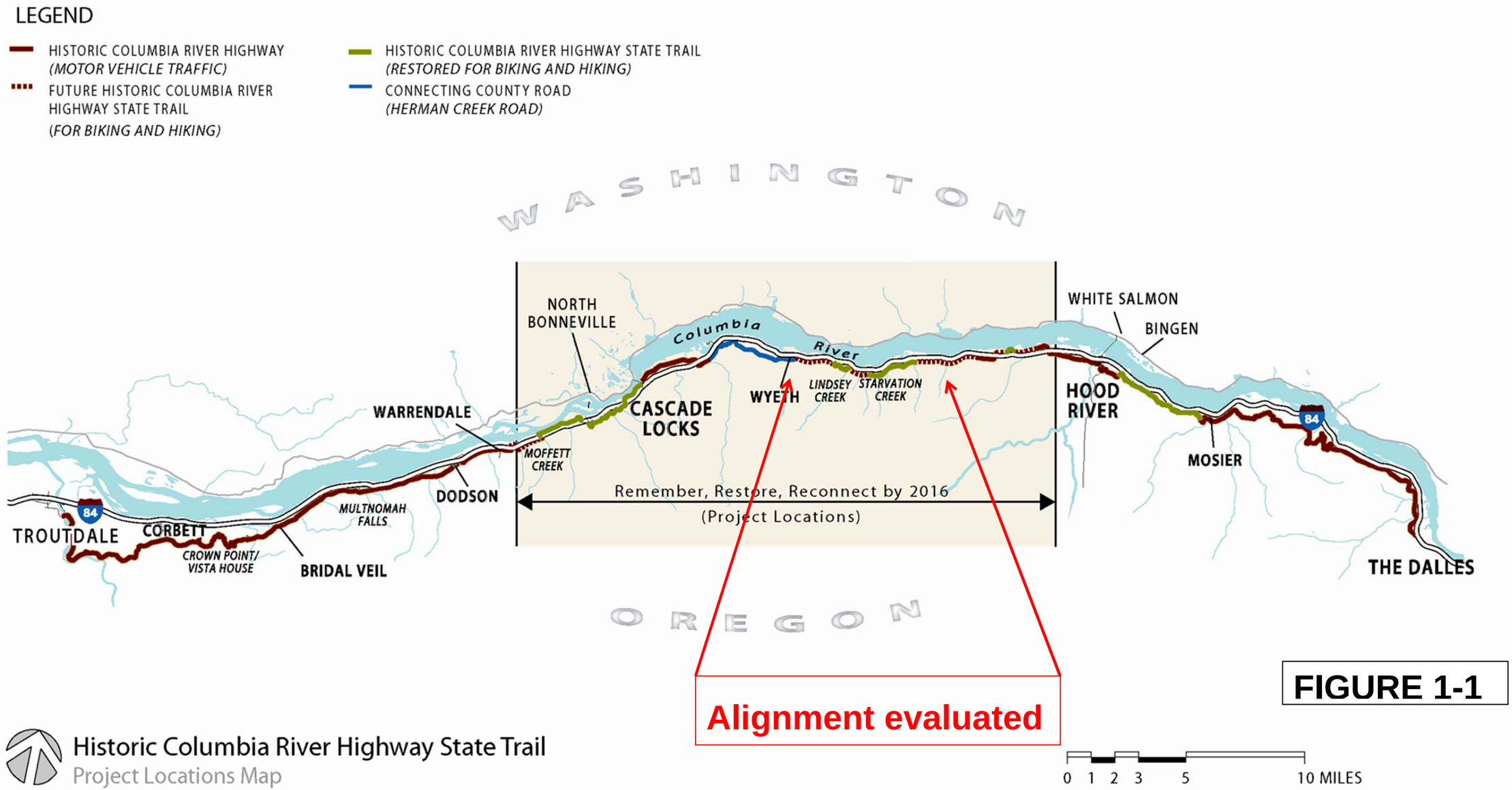
LEGEND
HISTORIC COLUMBIA RIVER HIGHWAY (MOTOR VEHICLE TRAFFIC)
FUTURE HISTORIC COLUMBIA RIVER HIGHWAY STATE TRAIL (FOR BIKING AND HIKING)
HISTORIC COLUMBIA RIVER HIGHWAY STATE TRAIL (RESTORED FOR BIKING AND HIKING)
CONNECTING COUNTY ROAD (HERMAN CREEK ROAD)
WASHINGTON
OREGON
Columbia River
NORTH BONNEVILLE
WARRENDALE
DODSON
MOFFETT CREEK
CASCADE LOCKS
WYETH
LINDSEY CREEK
STARVATION CREEK
WHITE SALMON
BINGEN
HOOD RIVER
MOSIER
THE DALLES
TROUTDALE
CORBETT
CROWN POINT/ VISTA HOUSE
BRIDAL VEIL
MULTNOMAH FALLS
84
Remember, Restore, Reconnect by 2016
(Project Locations)
Alignment evaluated
FIGURE 1-1
Historic Columbia River Highway State Trail
Project Locations Map
0 1 2 3 5 10 MILES

Table 1. Summary of Site Locations.

Site	Station (start)	Station (end)	Landmark	Approx. EB I-84 Milepoint	Location re: I-84 EB
1	63+00	91+00	Shellrock Mountain.	52.20	8 ft above EoP
2	106+00	109+00	East of Summit Creek, behind existing concrete bin wall.	53.00	25 ft south of EoP
3	323+00	325+00	East of Viento trailhead.	56.57	Shoulder
4	331+00	334+00		56.70	Shoulder
5	340+00	342+00		56.84	Shoulder
6	348+00	354+00		57.00	Shoulder
7	373+00	384+00	Cliffs west of Perham Creek.	57.50	Shoulder
8	398+00	404+00	Cliffs west of Mitchell Creek.	57.94	Shoulder
9	412+00	413+00	Cliff east of Mitchell Creek.	58.12	Shoulder

2 Background Information

In 1989 ODOT completed an evaluation of cut slopes and rockfall hazards in this area of the I-84 Corridor in the Columbia River Gorge. ODOT also evaluated the I-84 corridor using the Rockfall Hazard Rating System in 1991. At this time ODOT's Unstable Slope Program identifies two sites on I-84 within the project limits that are rated in Region 1's Top 200 Hazard Slopes, at mileposts 55.32 (#96) and 55.47 (#131). Although these locations are along I-84, the trail alignment in this vicinity is not at the shoulder so they are not relevant to this study. Ongoing maintenance of rock slopes has occurred in this corridor by ODOT under the supervision and direction of ODOT's engineering geologists and geotechnical engineers, in response to rockfall occurrences along I-84 and the HCRH. Approximately $90,000 was spent between 2010-2012 by ODOT Maintenance to repair and mitigate rockfall that occurred in the corridor. Rockfall mitigation measures, such as high energy catchment fences, have been implemented at various locations within the Columbia River Gorge National Scenic Area, as needed. Additionally, rockfall mitigation has been incorporated into design of HCRH State Trail projects over the past 20 years including at the Mosier Twin Tunnels in 1997, at the Oneonta Gorge Tunnel in 2007 and at McCord Creek in 2012.

3 Standards of Practice for Rock Slope Hazard Evaluation, Design, and Mitigation

The standard of practice for highway rock slope design evaluation and mitigation in the U.S. is guided by the Rockfall Hazard Rating System (ODOT/FHWA 1989), the Rockfall Catchment Area Design Guide (ODOT/FHWA 2002) Rock Slopes Reference Manual (FHWA, 1998) and the Colorado Rockfall Simulation Program (CRSP) (1990).

The Rockfall Hazard Rating System (RHRS) was developed by ODOT in collaboration with FHWA to provide a consistent tool for evaluating the rockfall hazard of existing slopes. The RHRS uses slope, catchment, roadway and traffic characteristics to develop a numerical score that can be used to compare rock slopes for prioritization.

The Rockfall Catchment Area Design (RCAD) Guide was developed by ODOT in collaboration with the Federal Highway Administration (FHWA) to update previous Ritchie ditch design guidelines (1963). A typical Ritchie Ditch catchment area geometry is shown in figure 3-1.

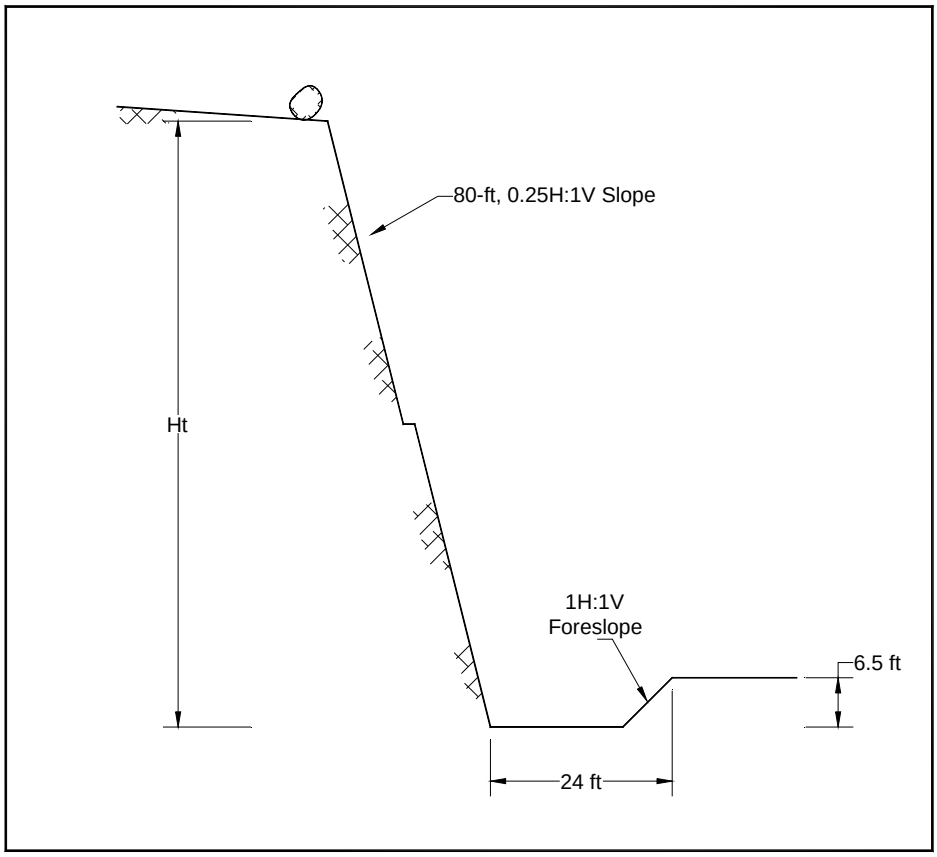

Figure 3-1. Typical Ritchie catchment area geometry

This paper summarizes a research project that investigated how slope, catchment area geometry and rockfall properties affected rockfall retention at the toe of varying slopes and developed updated guidelines for catchment design. Typical RCAD catchment area geometries are shown in Figure 3-2. The RCAD study showed that the most effective and economical catchment area was a single-slope configuration with an angle of 4H:1V. This slope is considered recoverable (an errant vehicle can return to the roadway). Steeper slopes or Ritchie configurations can provide better rockfall containment, but would require guardrail or barrier to separate traffic from the unrecoverable slope.

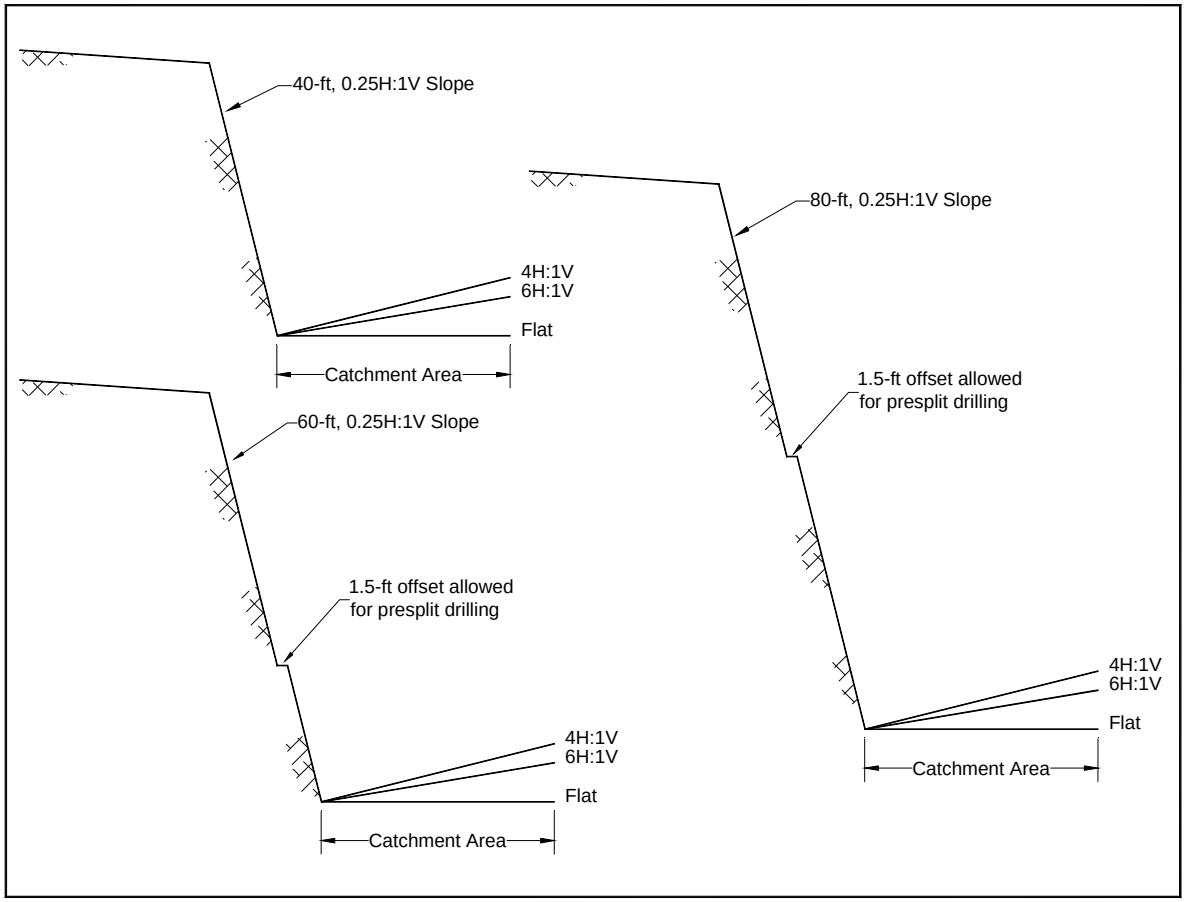

Figure 3-2. Typical RCAD catchment geometries

Rockfall Simulation Programs simulate rocks rolling down a slope, predict the statistical distribution of speeds and bounce height, and use existing slope geometry and rock properties to predict the trajectory and kinetics of rock impact and subsequent "roll out". These tools are also used to evaluate the effectiveness of mitigation alternatives. The two most commonly used programs are the Colorado Rockfall Simulation Program (CRSP) and ROCFALL (RocScience).

Additionally, the British Columbia Ministry of Transportation and Highway, British Columbia published a Technical Bulletin on the subject of rock slope design in 2002, which provides guidelines for preliminary and conceptual rock slope design for highways, and outlines recommended conceptual catchment ditch width and depth based on rock slope heights.

At this time, ODOT uses the RCAD Guide for catchment area design and as a preliminary evaluation tool for existing catchment areas. Rock slope performance is evaluated using the Colorado Rockfall Simulation Program (CRSP) or ROCFALL and Rock Slopes is used as a guide for rock slope design. ODOT has adopted catchment area design criteria (ODOT GDM, 2012) of 99% retention of impacting rocks and 90% retention of rolling rocks. However, based on a conversation with the ODOT Unstable Slopes Program manager, ODOT will soon increase the standard to 95% for retention of rolling rock.

These evaluation methods and design criteria are the standard of practice for assessing rockfall hazard and evaluating and designing mitigation alternatives along Oregon highways. For non-highway roads and trails rock slope design standards (and guidelines) are poorly defined.

There are no established design guidelines for rockfall mitigation along pedestrian or bicycle trails. While FHWA, the National Park Service and the Rails-to-Trails Conservancy provide various guidelines for designing and constructing shared-use trails, none of these organizations provides guidance on mitigating rockfall hazards on trails.

While the standard of practice for mitigating rockfall in high risk locations is well defined, in many sections of the existing Historic Columbia River Highway and HCRH State Trail, road and trail users are in close proximity to active rock slopes with limited or under-designed catchment areas. However, for the design of new trail alignment, ODOT aims to design and construct the trail to meet a clear standard for rockfall protection, as described in the following sections.

4 Design Criteria for Rockfall Mitigation

Based on discussion with HCRH stakeholders, including ODOT, US Forest Service, Oregon State Parks, and the Federal Highway Administration (FHWA) Western Federal Lands Highway Division (WFLHD), we identified four primary design considerations for rockfall hazard mitigation: Safety to the Travelling Public, Operations (cost of maintenance), Aesthetics within the Columbia River Gorge National Scenic Area, and Cost of Construction. While all of these factors should be considered during design, ODOT identified the following design criteria priorities, and considered them throughout the evaluation of rockfall hazards and development of recommended mitigation.

- **Safety (Risk):** Maintaining or improving existing catchment effectiveness for I-84 and recommending mitigation that protects the trail from falling rock impacts.
- **Operations (Maintenance):** Recommending measures that require the least maintenance for long-term serviceability and that achieve roadway and trail safety.
- **Aesthetics:** Recommending mitigation measures with the least impact to the existing visual conditions within the I-84 corridor.
- **Construction Cost:** Recommending the simplest, most cost-effective method to achieve the above criteria.

In general, safety and operations are complimentary: the safer solutions will likely require the less maintenance. But, the safest, most easily maintained mitigations may be expensive or significantly impact corridor aesthetics. The following design guidelines and site specific mitigation options attempt to balance all these factors.

5 Recommended Rockfall Catchment Design Guidelines for the HCRH State Trail

Safety is the primary factor influencing these design guidelines. Rockfall risk to trail users is considerably different than risk to highway drivers. High traffic volumes on the highway generally increase the exposure to rockfall. Falling rock can be life-threatening to drivers, cyclists and pedestrians. For a fast moving vehicle, rock debris on the roadway can be a substantial hazard. For a slower moving pedestrian or cyclist, avoiding debris on the trail is substantially easier and safer. However, large or high-velocity rocks rolling across the trail could be a significant hazard.

Operations (Maintenance) is another significant factor. A scattering of rock on the trail would have a small effect on the overall serviceability of the trail. However, if the volume of accumulated rock is sufficient to partially or completely block the trail, the user experience would be adversely affected. Also, rocks rolling across the trail or debris clean-up could damage the trail surface. Frequent maintenance to remove rockfall debris would constitute a significant funding and manpower commitment.

With these factors in mind, we recommend designing all new trail segments to protect trail users from 99% of rock impacts and to provide catchment for 90% of rock roll-out. This recommendation assumes a single-slope (RCAD) geometry with a slope angle of 2H:1V or flatter.

6 Types of Mitigation

The rockfall mitigation options considered for this study include trail realignment to avoid rockfall areas; catchment (slope excavation); scaling; draped mesh; and rockfall fences and barriers. General descriptions with advantages and disadvantages to each option are provided below.

Slope reinforcement using rock bolts requires site-specific determination of the rock structure and strength. This level of analysis was outside the scope of this study, but rock bolts should be considered an option during design.

Trail Realignment

Avoidance is the best measure with regard to rockfall, and realigning the trail away from rock slopes will achieve both the aesthetic and safety goals of this project. In some areas realignment may not be an option due to the adjacent highway or other existing features. Reducing the trail width may provide the same benefit in sections where space is restricted.

Scaling

As a rock slope ages, the outer face of the slope can be affected by freeze thaw cycles, seepage, root wedging, wind levering, and temperature fluctuations. These actions often result in loosening of the rock face and generation of rockfall. Removal of the loosened rock using scaling methods is often an economical option for reducing the potential for rockfall. Scaling can be conducted mechanically, using a long reach excavator. Scaling is often conducted by crews rappelling the slope or working from high-lift equipment and clearing loose rock and debris by hand Scaling is an inexpensive mitigation measure, but it is temporary and must be repeated periodically to maintain the benefit. The aesthetic impact of scaling is small because it makes only small changes to the existing slope surface. Removal of trees from the slope face during scaling will reduce root wedging and wind levering.

Rockfall fences and barriers

Rockfall fences and barriers are designed to absorb energy from rolling or bouncing rocks with the goal of retaining the rock and debris. The key elements to consider when designing rock fences and barriers are bounce height and velocity. The bounce height and velocity are determined using rockfall modeling software and are used along with rock mass condition to determine the appropriate fence height and strength. Fences and barriers have a moderate to high cost and will alter the visual appearance of a site. Fence and barrier materials can typically be coated to match the coloring of the underlying or adjacent rock.

Draped mesh-Pinned mesh

Draped mesh is high strength mesh, often resembling chain link, anchored at the top of a rock slope and draped down the face. This type of mitigation allows rock to roll down the rock face, but keeps the rock close to the slope and reduces the rolling velocity. Draped mesh is not anchored at the bottom and the rockfall debris moves down the slope in a controlled manner and is deposited in the ditch below.

Pinned mesh is similar to draped mesh except that the mesh is held tight to the face by a pattern of anchors. Pinned mesh holds loose rock in place and can be designed to provide some slope reinforcement. Draped mesh is relatively economical, but requires regular ditch maintenance. Pinned mesh is costly. Both mesh-types significantly alter the visual appearance of the slope, but can be color coated to match the local rock conditions. All mesh requires periodic inspection and maintenance.

Catchment

Broad ditches, excavated at the toe of rock slopes, are a common rockfall mitigation measure. Catchment areas are often constructed with flat bottoms but research over the past decade has shown that catchment areas constructed with a foreslope will dramatically reduce roll out. Catchment areas can be further enhanced by deepening the catchment relative to the trail and by placing soft soil or loose crushed rock in the ditch bottom and on the foreslope. Loose material acts as a dampening blanket to absorb energy from the impact of the rock and to reduce bounce and roll out. To construct a catchment area below an existing slope generally requires significant excavation of the slope, but catchment areas do not significantly alter the visual appearance of existing slopes and are cost-effective when space is available for adequate ditch excavation. Catchment areas are typically included as part of new rock slope design. Catchment areas require periodic inspection and maintenance to remove debris.

7 Field Investigation

Field investigation consisted of several phases of visual reconnaissance of the alignment in July and August 2012. The field work consisted of visually assessing site conditions and determining the rock slope characteristics at each site. Rock slope characteristics include rock mass structure, orientation of discontinuities, condition of discontinuities, failure mode(s), degree of weathering, block size, primary source zones, slope benching, and evidence of recent rock fall. The most critical sections of the slope were identified and slope parameters were recorded for rock simulation modeling.

Field investigation was completed from the road and shoulder. Photographs were taken at each rock slope. Slope measurements were collected primarily using a laser range finder and measurements at the road level were collected using a measuring tape. Slope angles were measured using a clinometer. Detailed discontinuity measurements and stereonet (kinematic) analyses were not completed for this study.

8 Analysis of Rockfall Risk

At all the sites we evaluated, the rockfall risk to the existing highway is low because the existing catchment areas and rockfall mitigation features are functioning as intended. Because the proposed trail segments necessarily lie within the existing catchment areas, we anticipated that

the paved trail may reduce the roadway protection effectiveness of the catchment areas while exposing trail users to a significant rockfall hazard. This geometry was an immediate concern. The intention of this study was to provide rock slope recommendations that would not increase the risk to the existing highway, and would also be low risk for trail users. We considered different risk levels and alternatives such as closing the trail during high risk seasons or providing rockfall warning signs. Ultimately we determined that designing the trail for year-round use and optimal safety was our top priority and approached rockfall analyses with the design criteria of providing 99% containment of rockfall impact along the proposed trail alignment and 90% containment of rolling rock. The following sections of this report explain the site specific rockfall analyses and recommended mitigation to meet this criteria.

Rockfall modeling was completed for all analyzed slopes using the computer simulation program ROCFALL (RocScience, 2000). ROCFALL is a statistical analysis program designed to assist with a risk assessment of rock slopes and evaluation of mitigation measures.

Modeling was completed to analyze rockfall behavior rolling and falling down the slope. The models predict rockfall velocity, energy, bounce height, bounce location, and roll out distance. This information was used during the rock slope evaluation to better understand falling rock behavior at each site and to help determine the appropriate mitigation measure(s). The location of the cross sections used for modeling was selected during field work at the most critical locations, often corresponding to the highest point in the slope, areas where the slope angle or existing catchment geometry changed significantly, or locations where active rockfall was observed. Cross section geometry was developed using a hand-held, computing laser rangefinder. Other input parameters, including source zones, block size, shape, surface roughness, and friction coefficients, were based on field observations. Program input parameters are provided in the appendix.

Initially, two slope geometries were modeled for each rockfall site. The first model represents the existing slope and catchment geometry (Figure 8-1). This was done to calibrate the input parameters to the observed rockfall conditions. The calibrated input parameters were then used in all subsequent simulations. Each simulation was run repeatedly using 500 rocks. A final run of 10,000 rocks was used as a check.

The second geometry modeled modified slope and catchment area geometry, adding a trail prism and concrete barrier (Figure 8-2). The trail prism represents the width and depth of the trail foundation and pavement. We used a 16-ft-wide trail prism, which is consistent with the HCRH Trail Guidelines for a preferred 12-ft-wide paved trail with 2-ft-wide shoulders. We modified the trail prism width to a total of 12-ft-wide in some locations where the existing and available width between the highway and rock slope is less than 16-ft-wide. In all cases, concrete barrier was positioned at the existing edge of pavement, assuming no reduction of the highway paved shoulder width.

The modified models were used to determine if rockfall mitigation was necessary. If the model showed less than 1% of rocks impacting the trail and less than 10% of rolling rocks reached the trail, the rockfall hazard was considered acceptable and no further modeling or analysis was needed (Figure 8-3). At sites 2, 4 and 5, less than 1% of rocks impacted the trail prism and less than 10% of rocks rolled to the trail. At these locations no rock slope mitigation is required for trail construction. At sites 8 and 9, the trail requires narrowing to 12-ft-wide to fit existing geometry (width between highway shoulder and rock slope), but less than 1% of rocks impacted the narrowed trail prism and less than 10% of rocks rolled to the trail. For the remaining rockfall sites (Sites 1, 3, 6, and 7) additional models, with mitigation options added, were evaluated to

determine the most appropriate mitigation type for each specific site (Figure 8-4). This was an iterative process, testing both the type and geometry of mitigation measures.

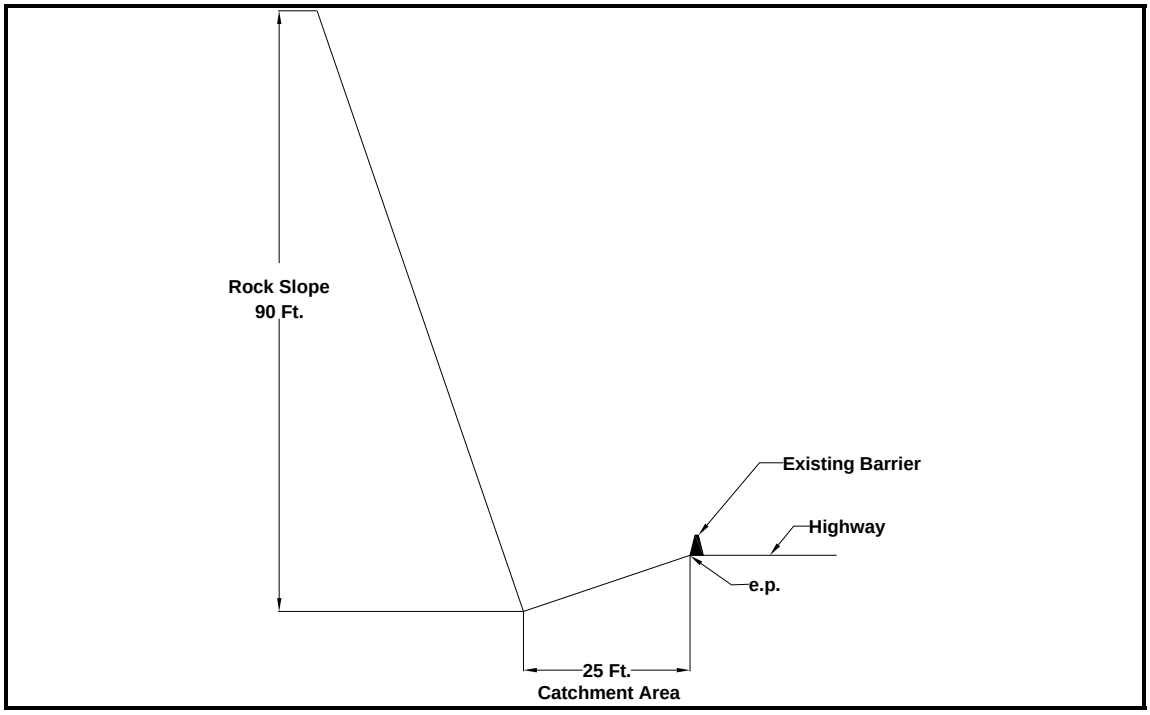

Figure 8-1. Existing Slope Geometry

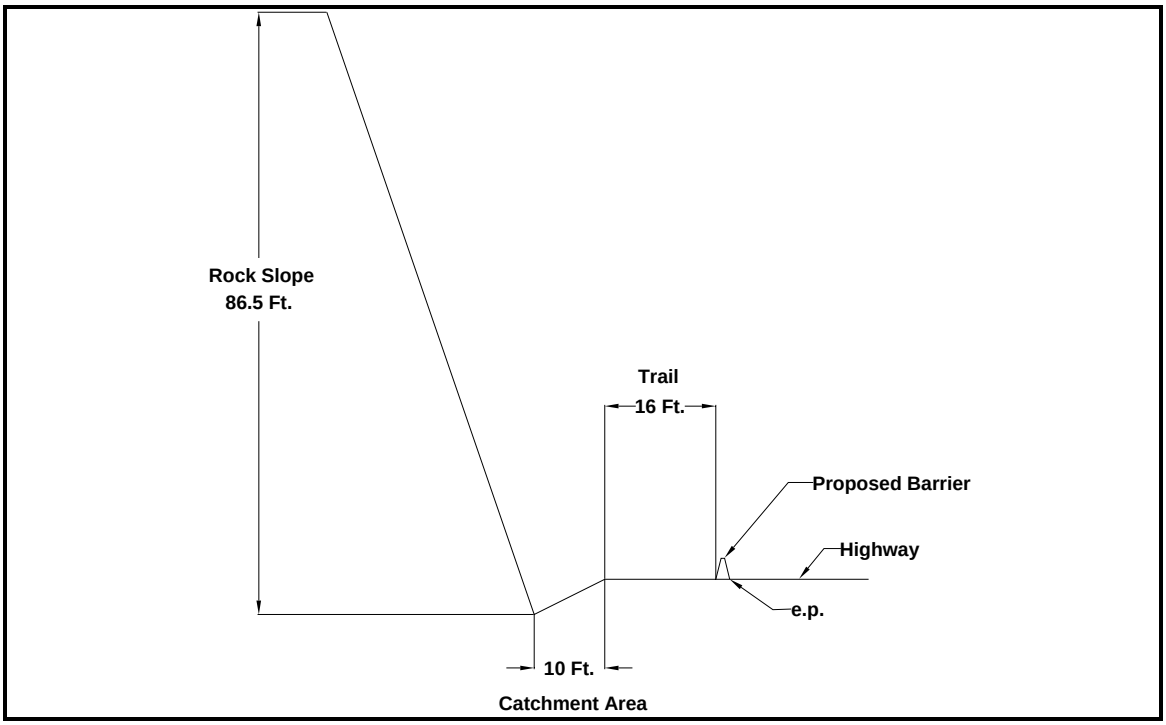

Figure 8-2. Proposed Slope Geometry

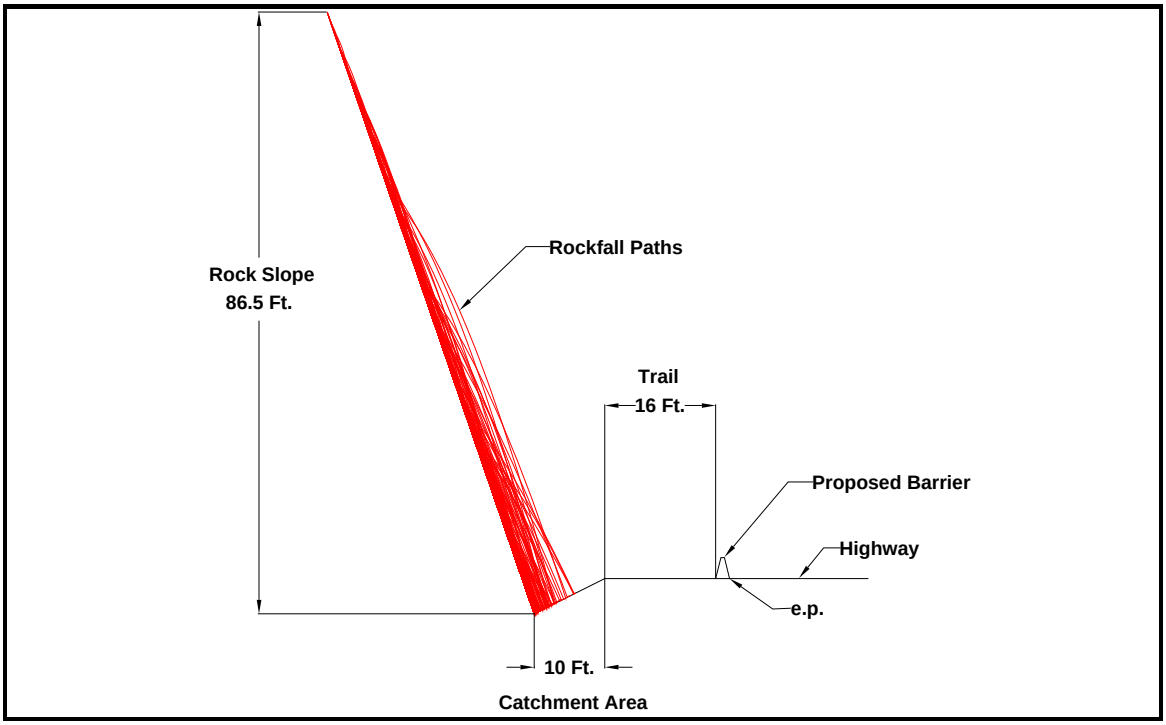

Figure 8-3. Rockfall Analysis: No Impact to Trail

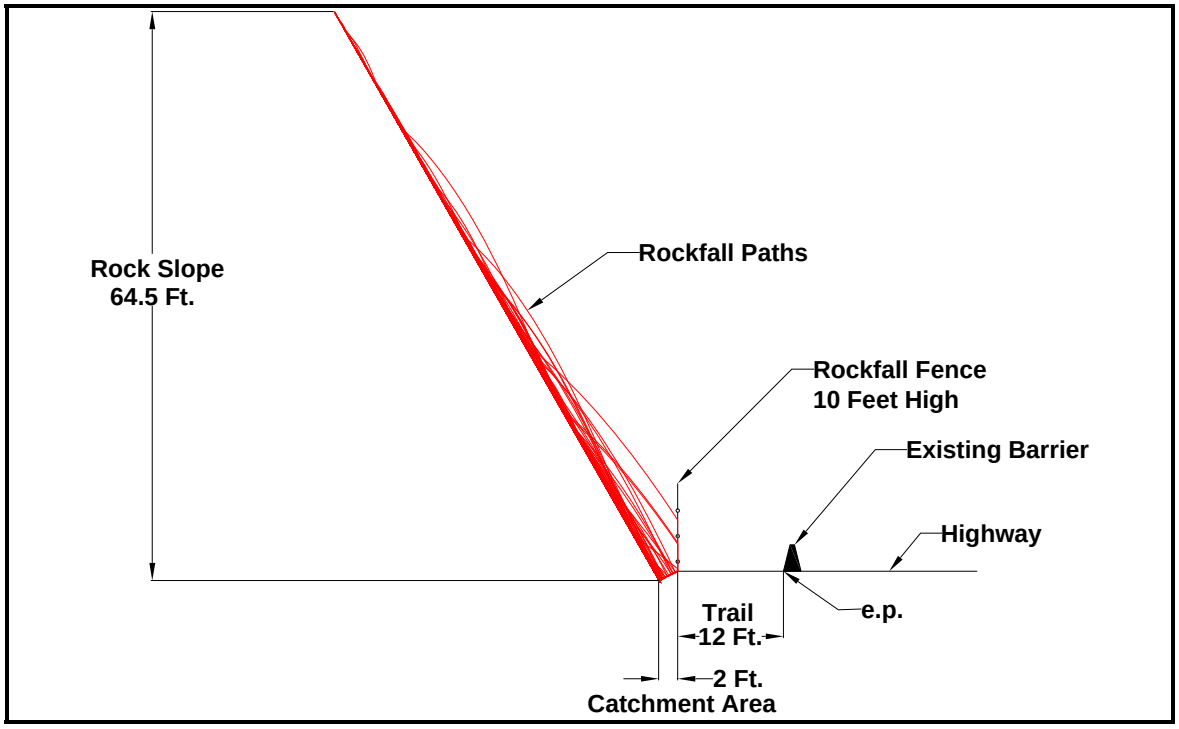

Figure 8-4. Rockfall Analysis: Rockfall Fence and Narrow Trail

Model Limitations

The reliability of rockfall modeling and prediction of rockfall behavior is dependent upon the accuracy of the modeled slope geometry This study relied on a limited number of field-developed cross sections, derived using a hand-held laser rangefinder. This method to develop site specific models was appropriate for this preliminary evaluation, but more thorough, surveyed cross-sections will be necessary for design development.

9 Site Specific Analyses and Recommendations

This section describes the existing site conditions, site-specific rockfall modeling, recommended mitigation measures, and preliminary cost estimates for mitigation of Sites 1 through 9. Figures showing the modeled slope cross-sections are provided for each Site (except Site 1). Table 2 provides a summary of all sites, site conditions and cost estimates as well. The recommended mitigation measures all assume that the catchment areas will be constructed with a dampening blanket of uncompacted soil or shoulder aggregate.

Table 2

Summary of Recommended Rock Slope Mitigation, Wyeth to Mitchell Point, Oregon

Site #	Landmark	Slope Type	Slope Height	Slope Angle	Recommended Trail Width	Recommended Mitigation	Item	Quantity	Unit Price	Cost	Total at Site
1	Shellrock Mountain	Talus	>400 ft	45 degrees	16-ft-wide	Trail to extend across top of existing metal bin wall. Will require moving/replacing existing cable-mesh catchment fence upslope of the trail.	10-ft-tall ring-net/cable-fence	24,000 SQ FT	$60 / SQ FT	$ 1,440,000.00	$ 1,440,000.00
-	Trail meander. Historic pavement	Talus	Not measured	45 degrees	16-ft-wide	Pull trail away from toe of slope. Do not remove existing trees at toe (catching talus debris).	N/A	N/A	N/A	N/A	$ -
2	East of Summit Creek, location of the existing concrete bin wall	Rock slope	40 ft	75 degrees	16-ft-wide	No mitigation is needed.	N/A	N/A	N/A	N/A	$ 30,000.00
			80 ft			Trail should be raised by 9-ft behind and up to top of bin wall to avoid rockfall impact.	Embankment construction	4,000 CU YD	$7.50 / CU YD	$ 30,000.00	
3	East of Viento trailhead	Rockfall	250 ft	55 - 65 degrees	16-ft-wide	Excavate slope	Excavation	11,000 CU YD	$14 / CU YD	$ 154,000.00	$ 202,459.00
							Perimeter Controlled Blast Holes	5,302 LF	$4.50/LF	$ 23,859.00	
							Rock Staining	26,400 SQ FT	$1.00/SQ FT	$ 24,600.00	
4		Rockfall	200 ft	70 degrees	16-ft-wide	No mitigation is needed.	N/A	N/A	N/A	N/A	$ -
-	Trail meander. Historic pavement.	Talus	Not measured	45 degrees	16-ft-wide	Pull trail away from toe of slope. Do not remove existing trees at toe (catching talus debris).	N/A	N/A	N/A	N/A	$ -

continued on next page

Table 2 (continued)

Summary of Recommended Rock Slope Mitigation, Wyeth to Mitchell Point, Oregon

Site #	Landmark	Slope Type	Slope Height	Slope Angle	Recommended Trail Width	Recommended Mitigation	Item	Quantity	Unit Price	Cost	Total at Site
5		Rockfall	15 to 60 ft	60 degrees	16-ft-wide	No mitigation is needed.	N/A	N/A	N/A	N/A	$ -
-	Trail meander. Historic pavement.	Talus	Not measured	45 degrees	16-ft-wide	Pull trail away from toe of slope.	N/A	N/A	N/A	N/A	$ -
6		Rockfall	75 to 100 ft	60 to 75 degrees	12-ft-wide	10-ft-tall protective fence.	10-ft-tall fence	5,800 SQ FT	$31 / SQ FT	$ 180,000.00	$ 180,000.00
7	Cliffs west of Perham Creek.	Rockfall	100 to 150 ft	65 to 75 degrees	16-ft-wide	Excavate slope using controlled blasting to provide adequate catchment and trail width, improve surface of rock slope.	Excavation	221,700 CU YD	$14 / CU YD	$ 3,103,800.00	$ 3,555,400.00
							Perimeter controlled blasting	66,800 LF	$4.50 / LF	$ 300,600.00	
							Rock Staining	151,000 SQ FT	$1.00/SQ FT	$ 151,000.00	
-	Trail meander. Historic pavement.	Rockfall	Not measured	Not measured	16-ft-wide	Pull trail away from toe of slope.	N/A	N/A	N/A	N/A	$ -
-	Trail meander.	Talus	Not measured	Not measured	16-ft-wide	Pull trail away from toe of slope.	N/A	N/A	N/A	N/A	$ -
-	Trail meander.	Rockfall	Not measured	Not measured	16-ft-wide	Pull trail away from toe of slope.	N/A	N/A	N/A	N/A	$ -

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Table 2 (continued)

Summary of Recommended Rock Slope Mitigation, Wyeth to Mitchell Point, Oregon

Site #	Landmark	Slope Type	Slope Height	Slope Angle	Recommended Trail Width	Recommended Mitigation	Item	Quantity	Unit Price	Cost	Total at Site
8	Cliffs west of Mitchell Creek.	Rockfall	25 to 50 ft	68 degrees	12-ft-wide	Narrow trail to fit existing space.	N/A	N/A	N/A	N/A	$ -
9	Cliff east of Mitchell Creek.	Rockfall	30 ft	75 degrees	12-ft-wide	Narrow trail to fit existing space.	N/A	N/A	N/A	N/A	$ -
										TOTAL	**$ 5,407,859.00**

This does not include any contingency.
This does not include minor surface scaling at all sites.
This does not include traffic control / staging required to complete rock slope work.

Site 1 – Shell Rock Mountain **(Mile Post 52.2 to 52.7)**

Site Description

Shellrock Mountain is an igneous intrusion (Tolan and Beeson, 1984), younger than surrounding Columbia River Basalt. The surface slopes of Shellrock Mountain are active talus composed of loose, angular basalt. Existing rockfall protection for I-84 is composed of a metal bin wall topped with a cable-mesh rock protection fence. The proposed trail alignment crosses the active talus about 10 ft above I-84. In this area the proposed trail alignment lies behind the existing cable-mesh rock protection fence, within the active rockfall catchment area for the existing talus slope.

Figure 9-1. Site 1: Existing catchment area, bin wall, and cable-mesh fence

Recommended Mitigation

To protect the trail from active talus, we recommend that a ring-net/cable-mesh rockfall protection fence should be constructed along the south edge (upslope) of the trail alignment. Following the construction of this rockfall protection fence, we recommend removal of the existing rockfall protection fence.

Estimated Cost for Mitigation Measure

This estimate does not include construction costs of traffic control, trail construction, hand rail, or other items not specifically associated with rockfall mitigation measures.

Item	Quantity	Unit Price	Cost
10-ft-tall ring-net/cable- mesh fence	24,000 SQ FT	$60 / SQ FT	$ 1,440,000.00

Site 2 – East of Summit Creek (Mile Post 52.96 to 53.15)

Site Description

East of Summit Creek the proposed trail alignment passes between an existing concrete bin wall and a near vertical basalt cliff that more than 200 feet tall. The rock slope is benched at a height of about 70 ft. The cliff benching and bin wall construction were completed in the mid-1980s following a multiple fatality accident caused by a rockfall originating from this location. Gabion baskets were constructed on the lower bench to provide additional catchment and protection for the upper slope. The concrete bin wall is about 10-ft-tall and about 600-ft-long. Between Stations 106+00 to 109+00, the rock slope is about 70 feet high, 4V:1H, with a catchment width of 30 feet. From Station 109+00 to 112+00, the slope height reduces to 45 feet; the slope angle is about 3V:1H, and the catchment width narrows to 17 feet.

Rock debris was observed in the catchment area behind the bin wall and the bin wall shows damage that may be from rock impacts, especially at the east end of the wall.

Figure 9-3. Site 2: Existing catchment area behind bin wall.

Description of Rockfall Analysis

An analysis of the existing and proposed geometry and field observations between Stations 106+00 and 109+00 indicates less than 1% impact and 10% roll-out occurs within the proposed trail footprint. No mitigation is necessary in that section. From field observation between Station 109+00 to 112+00 and computer analysis of the existing and proposed geometry, more than 1% rock impact is observed within the proposed trail footprint.

Recommended Mitigation

At this location we considered the following mitigation options: narrowing trail, draped mesh, rockfall protection fence, and raising the grade of the trail. To protect the trail from impact, we recommend elevating the trail about 9 ft above the existing surface. This proposed design is shown in Figure 9-3. The catchment area includes an impact dampening blanket of loose soil or gravel. Note that one of the 500 simulated rocks (0.2%) impacted high up in the catchment area and rolled across the trail. The stability of the proposed embankment or existing bin wall has not been investigated.

Estimated Cost for Mitigation Measure

This estimate does not include construction costs of traffic control, trail construction, hand rail, or other items not specifically associated with rockfall mitigation measures.

Item	Quantity	Unit Price	Cost
Raise trail with constructed embankment	4,000 CU YD	$7.50/CU YD	$ 30,000.00

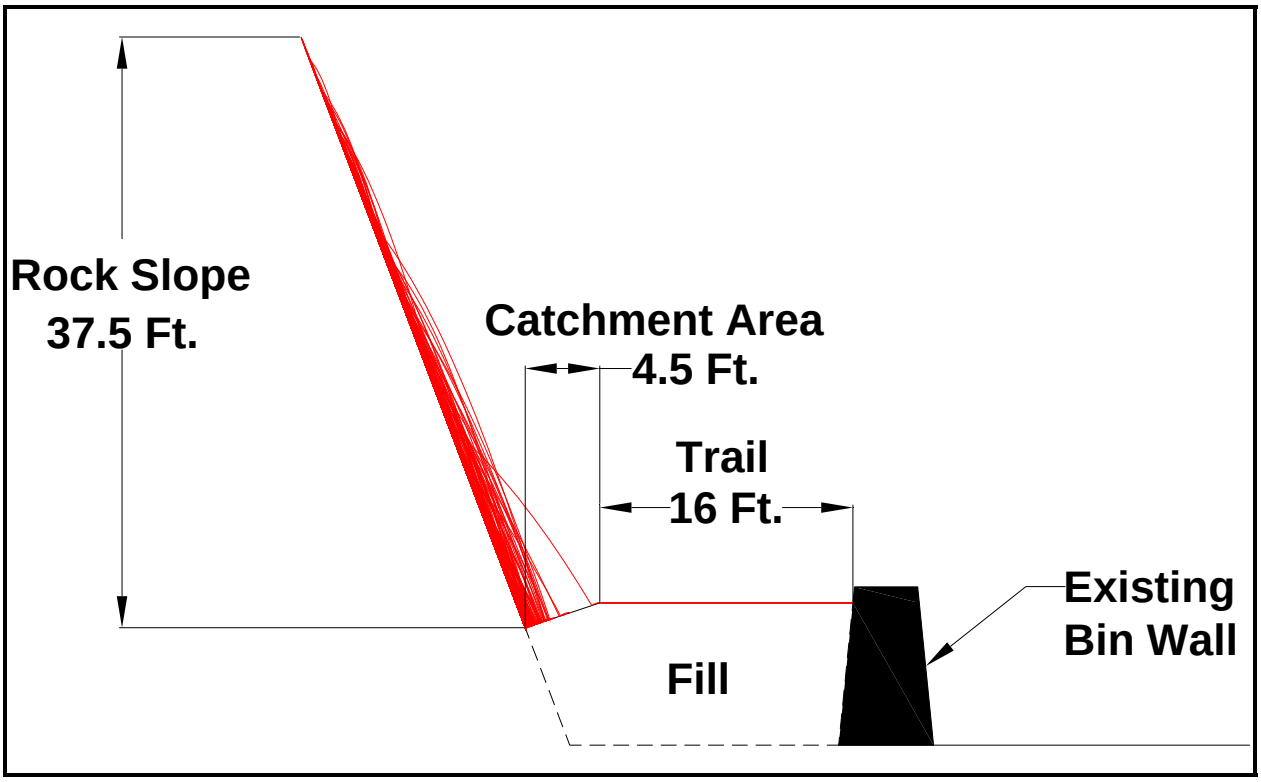

Figure 9-3. Site 2: Rockfall Analysis and Proposed Mitigation

Site 3 – East of Viento Trailhead **(Mile Post 56.55 to 56.6)**

Site Description

At this location the trail alignment is located off the highway shoulder at the toe of an existing 60 degree rock slope. The rock slope is up to about 230-ft-tall and has two benches, at heights of about 40- and 90-ft-tall. The existing catchment area is 37-ft-wide (from behind the existing barrier to the toe of the slope) with a 7-ft-deep, 15-ft-wide ditch at the toe.

Figure 9-4. Site 3: Existing catchment area and lower rock slope

Figure 9-5. Site 3: Rock slope benches

Description of Rockfall Analysis

An analysis of the existing and proposed geometry and field observations indicate that mitigation is necessary. The analysis of the proposed geometry indicates that some rock would impact on the trail surface, bounce across the shoulder barrier and come to rest in the eastbound travelled way. Mitigation options considered are a rockfall protection fence, pinned mesh, and rock excavation to increase the catchment area. The rockfall protection fence and pinned mesh are excluded due to high cost and visual impact.

Recommended Mitigation

To protect the trail from impact, we recommend that the lower half of the slope be excavated. The proposed design, shown in Figure 9-5, shows a catchment area width of 69 feet, a 100-foot high excavated slope with an angle of 4V:1H. This recommendation assumes some removal of blast-hole traces (half-casts) and rock staining.

Estimated Cost for Mitigation Measure

This estimate does not include construction costs of traffic control, trail construction, hand rail, or other items not specifically associated with rockfall mitigation measures.

Item	Quantity	Unit Price	Cost
Rock excavation	11,000 CU YD	$14/CU YD	$ 154,000.00
Perimeter Controlled Blast Holes	5,302 LF	$4.50 / LF	$ 23,859.00
Rock Staining	26,400 SQ. FT	$1/SQ. FT	$ 26,400.00
		TOTAL COST FOR SITE 3 =	**$ 204,259.00**

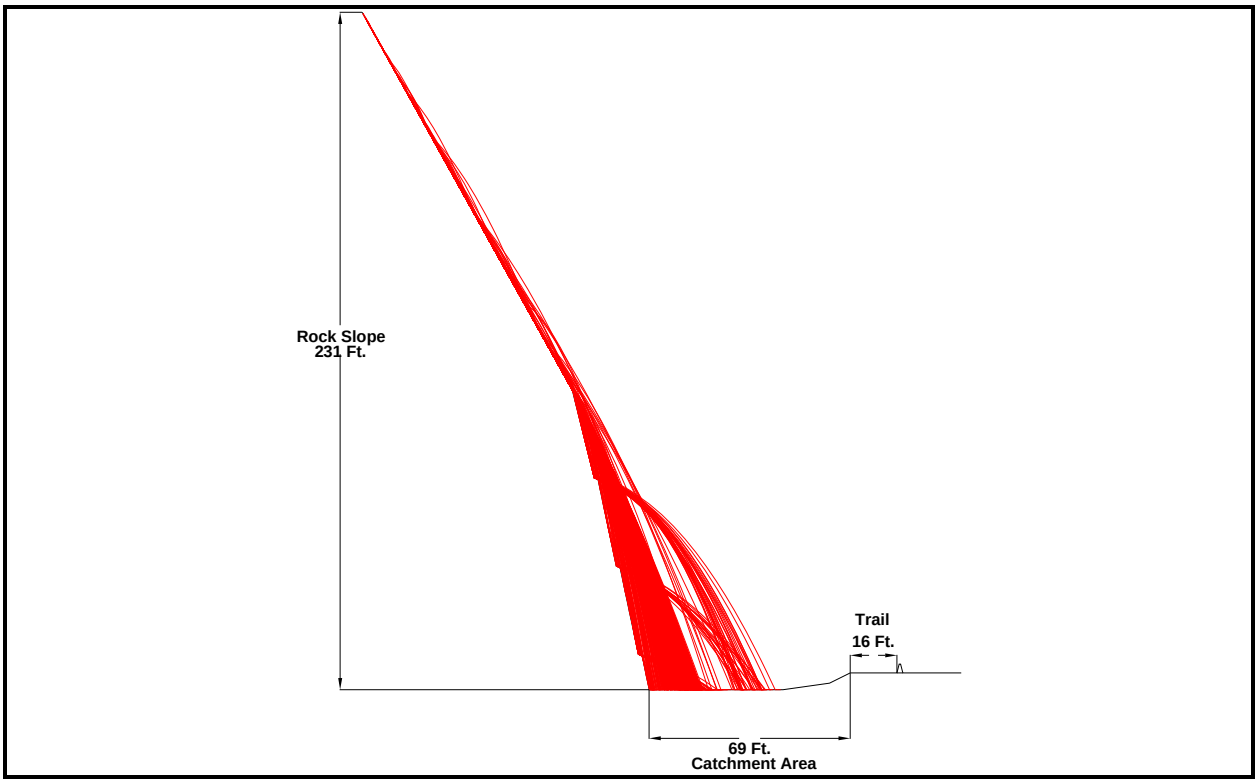

Figure 9-6. Site 3: Rockfall Analysis and Proposed Mitigation

Site 4 **(Mile Post 56.66 to 57.73)**

Site Description

At this location the trail alignment is located off the highway shoulder at the toe of an existing 70 degree, 100-ft-tall rock slope.

At the time of reconnaissance, we observed freshly impacted, 8- to 12-in-diameter cobbles scattered in the existing catchment area, that appear to originate from the middle to top of the slope at the soil-rock contact where the rock slope is over steepened. Rockfall debris is scattered across the catchment area, and has impacted the back of the existing concrete barrier. The existing catchment area is 27-ft-wide (from behind the existing barrier to the toe of the slope) with a 5-ft-deep, 10-ft-wide ditch at the toe.

Figure 9-7. Site 4. Existing Catchment Area.

Description of Rockfall Analysis

An analysis of the existing and proposed geometry and field observations indicate that mitigation is not needed (Figure 9-8).

Recommended Mitigation

No mitigation is necessary. Construct catchment area with a dampening blanket of loose soil or gravel.

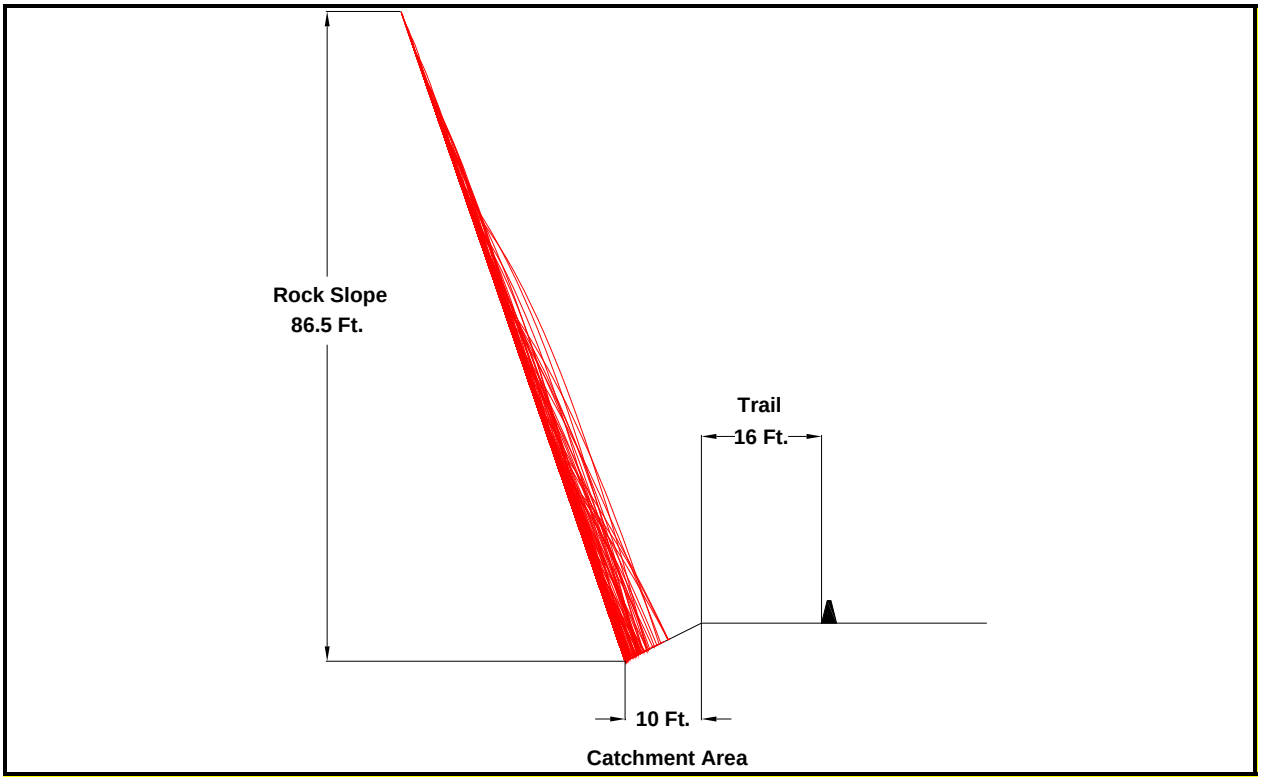

Figure 9-8. Site 4: Rockfall Analysis: No Mitigation

Site 5 **(Mile Post 56.8 to 56.85)**

Site Description

At this location the trail alignment is located off the highway shoulder at the toe of an existing 60 degree, 80-ft-tall rock slope.

This basalt slope is partially vegetated with small fir trees and shrubs. The existing catchment area is 25-ft-wide (from behind the existing barrier to the toe of the slope) with a 5-ft-deep, 10-ft-wide ditch at the toe. There is no indication of recent rockfall in the catchment area.

Figure 9-9. Site 5: Existing Catchment area

Description of Rockfall Analysis

An analysis of the existing and proposed geometry and field observations indicate that mitigation is not needed (Figure 9-10).

Recommended Mitigation

No mitigation is necessary. Construct catchment area with a dampening blanket of loose soil or gravel.

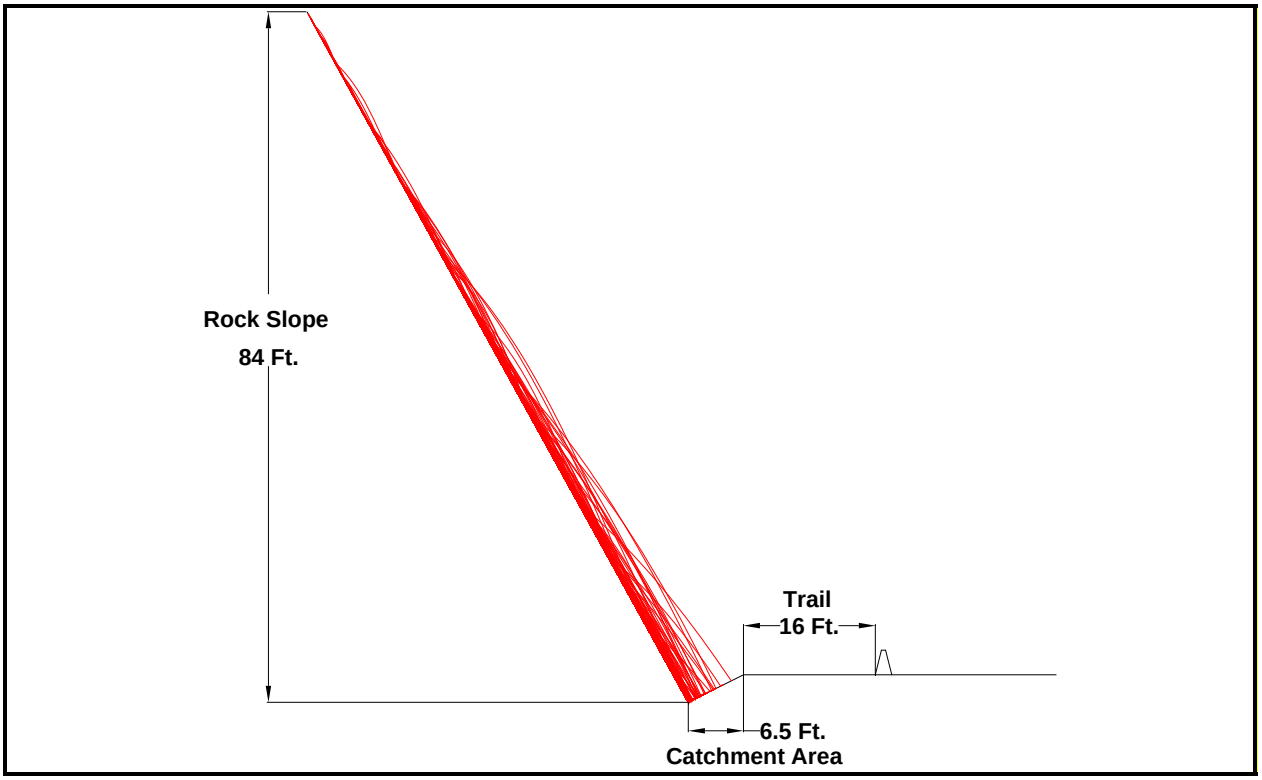

Figure 9-10. Site 5: Rockfall Analysis: No Mitigation

Site 6 **(Mile Post 56.98 to 57.02)**

Site Description

At this location the trail alignment is located off the highway shoulder at the toe of an existing 60 to 70 degree, 50- to 70-ft-tall rock slope. The east end of the rock slope is active, with fresh rockfall debris observed in the catchment area. The existing catchment area is 14-ft-wide (from behind the existing barrier to the toe of the slope) with a 2-ft-deep, 2-ft-wide ditch at the toe.

Figure 9-11. Site 6: Existing Catchment area

Description of Rockfall Analysis

An analysis of the existing and proposed geometry and field observations indicate that mitigation is necessary to protect the trail from rock impacts. Slope excavation, pinned mesh, draped mesh and a rockfall protection fence were the mitigation options considered. All the options except slope excavation include a 12-foot wide trail. Slope excavation and the mesh options are not recommended based on cost and visual impacts.

Recommended Mitigation

To protect the trail from impact, we recommend a 10-foot high x 580-foot long rockfall protection fence and a 12-foot wide trail. This combination leaves a 2-foot to 3.5-foot wide catchment area. This catchment area will be difficult to maintain, but the frequency of rockfall appears low and maintenance should only be necessary occasionally.

Estimated Cost for Mitigation Measure

This estimate does not include construction costs of traffic control, trail construction, hand rail, or other items not specifically associated with rockfall mitigation measures.

Item	Quantity	Unit Price	Cost
Rockfall Protection Fence	5,800 SQ FT	$31 / SQ FT	$ 180,000

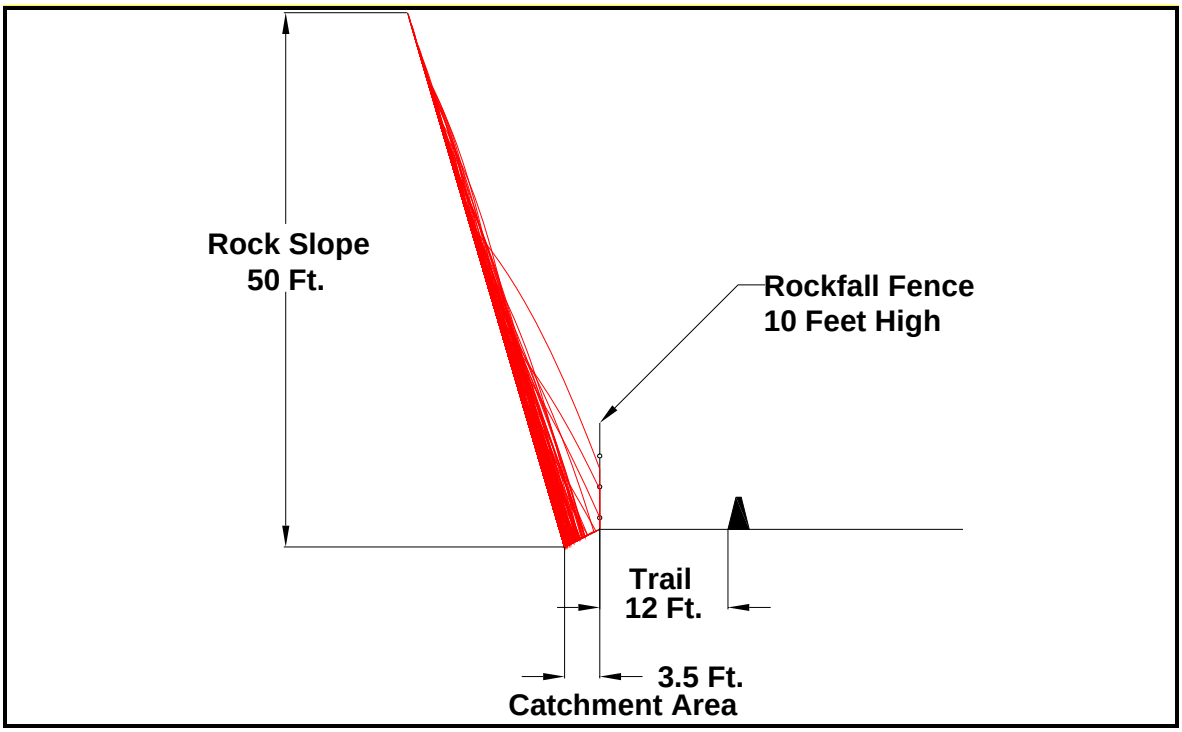

Figure 9-12. Site 6: Rockfall Analysis: Rockfall Protection Fence

Site 7 – Cliffs west of Perham Creek (Mile Post 57.34 to 57.6)

Site Description

At this location the trail alignment is located off the highway shoulder at the toe of an existing 70 degree, 220-ft-tall rock slope. The existing rock slope has up to four narrow benches and is composed of closely jointed and fractured basalt. The rock slope is highly active and the existing catchment area contains continuous piles of rock debris 2- to 12-ft-wide. The

catchment area is up to 25-ft-wide (from behind the existing concrete barrier to the toe of the slope, with a 5ft-deep, 5-ft-wide ditch at the toe of slope.

Figure 9-13. Site 7. Existing catchment area

Figure 9-14. Site 7: Upper rock slope

Description of Rockfall Analysis

An analysis of the existing and proposed geometry and field observations indicate that mitigation is necessary. The analysis of the existing geometry shows that most rock is contained in the catchment area. However, much of the rock derived from the upper slope launches from one of the benches and impacts close to the barrier. A small number of rocks cross the barrier and come to rest in the highway. The analysis of the proposed geometry indicates that much of the rockfall impacts on the trail surface. Some of the rocks bounce across the shoulder barrier and come to rest in the highway. Without a significant mitigation effort, the trail could not be safely located in the existing catchment area. Mitigation options considered are a 20 to 30-foot high rockfall protection fence, pinned mesh covering the entire slope, and rock excavation to increase the catchment area. The rockfall protection fence and pinned mesh are excluded due to visual impact to the I-84 corridor and National Scenic Area.

Recommended Mitigation

To protect the trail from impact, we recommend slope excavation. Slope excavation has about the same cost as pinned mesh and ultimately will have less visual impact than a tall rock fence or the existing slope covered with pinned mesh. The proposed design, shown in Figure 9-14, is a 220-foot high excavated slope with a slope angle of 4V:1H and a 75-foot wide catchment area. This recommendation assumes some removal of blast-hole traces (half-casts) and rock staining.

During design, some or all of the following techniques should be explored to help mitigate the visual impact of the new slope. All of these options will increase the volume/cost of the excavation.

- The horizontal alignment of the slope can be varied to interrupt the horizontal linearity of the slope. Use the design catchment area width as the minimum setback.
- The slope angle of each lift can be varied to break up the plane of the cut slope. This option may require a wider catchment area.
- The cut slope can be designed with one or more wide benches, although, our initial modeling indicates a significantly wider catchment area would be necessary.

Estimated Cost for Mitigation Measure

This estimate does not include construction costs of traffic control, trail construction, hand rail, or other items not specifically associated with rockfall mitigation measures.

Item	**Quantity**	**Unit Price**	**Cost**
Rock excavation	221,000 CU YD	$14/CU YD	$ 3,103,00.00
Perimeter Controlled Blast Holes	66,800 LF	$4.50 / LF	$ 300,600.00
Rock Staining	151,000 SQ. FT	$1/SQ. FT	$ 151,000.00
TOTAL COST FOR SITE 7 =			**$ 3,555,400.00**

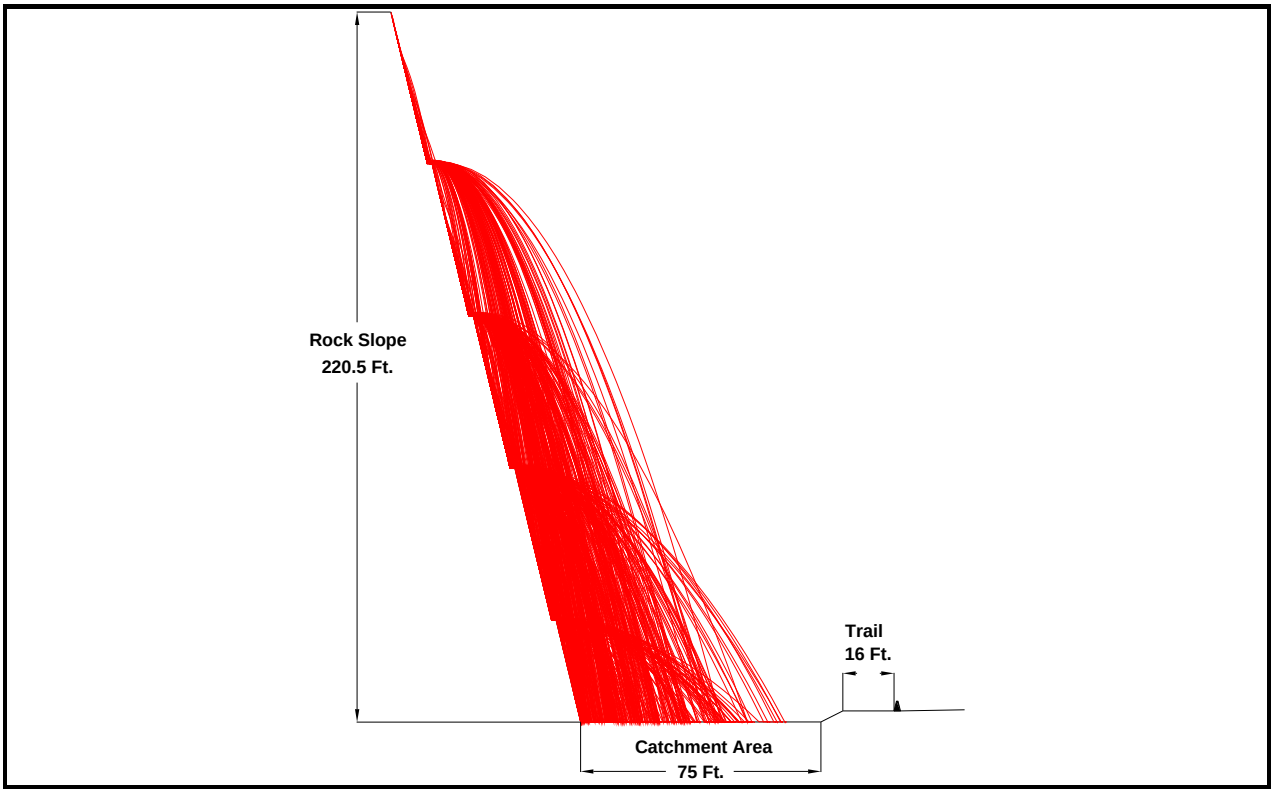

Figure 9-15. Site 7: Rockfall Analysis: Slope Excavation

Site 8 – Cliffs west of Mitchell Creek (Mile Post 57.86 to 57.95)

Site Description

At this location the trail alignment is located off the highway shoulder at the toe of an existing 70 degree, 70-ft-tall rock slope. The catchment area is 15 feet wide and 5 feet deep, separated from the highway by concrete barrier. The existing rock slope has a weathered basalt horizon at the top of slope. The material is undermined and raveling to toe. The rock slope is densely vegetated in some areas and is highly active in other areas with rockfall debris partially to fully filling the catchment area, allowing rocks to bounce or roll out and impact the back of the barrier.

Figure 9-16. Site 8: Existing catchment area

Figure 9-17. Site 8: Rock slope

Description of Rockfall Analysis

The existing catchment geometry requires that the trail at this location be constructed 12-ft-wide to fit in the existing space between the highway shoulder and rock slope. Analysis of this proposed geometry (Figure 9-18) indicates that rockfall will not impact the trail, so no further analysis or mitigation is needed.

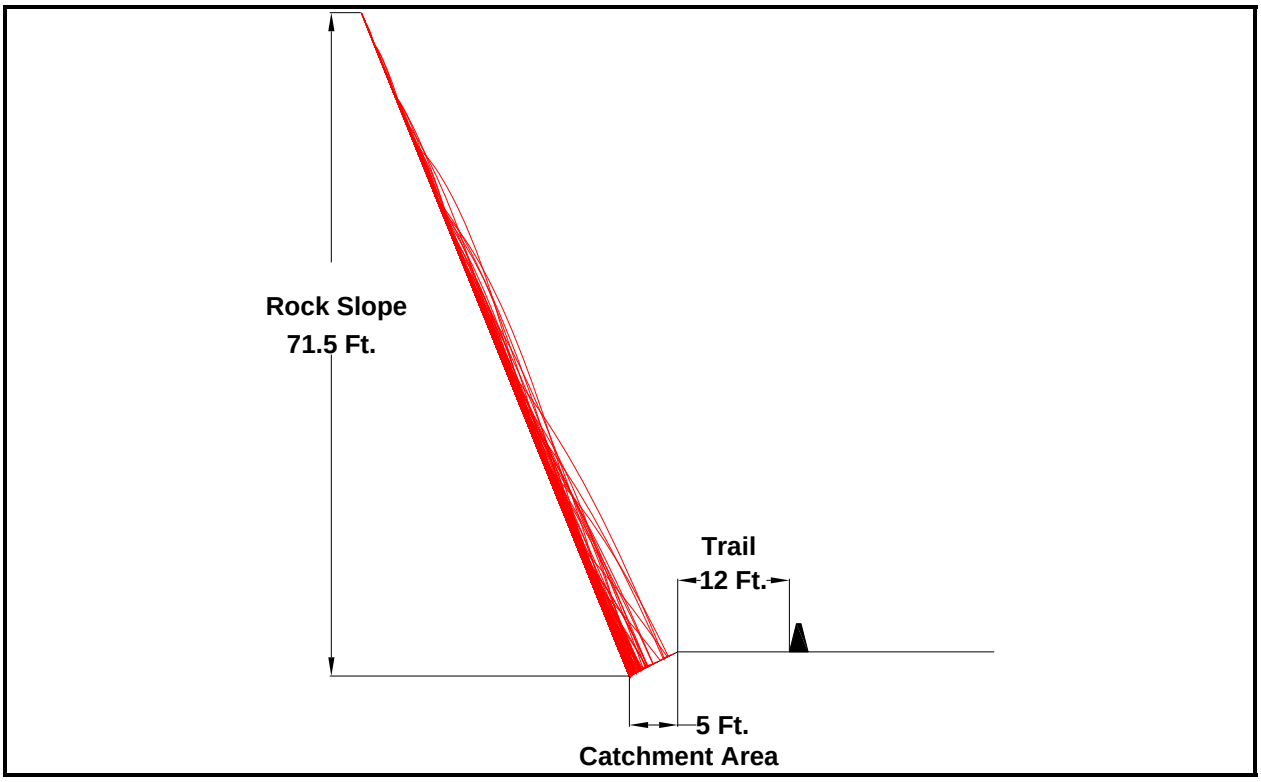

Figure 9-18. Site 8: Rockfall Analysis: Narrow Trail

Site 9 – Cliff east of Mitchell Creek (Mile Post 58.1 to 58.12)

Site Description

At this location the trail alignment is located off the highway shoulder at the toe of a 30-foot high, 75 degree slope. The existing catchment area is 22 feet wide. The slope is massive basalt overlain by cobble conglomerate. There is very little rockfall debris in the catchment area.

Figure 9-19. Site 9: Existing catchment area

Description of Rockfall Analysis

The existing catchment geometry (Figure 9-20) indicated that no rockfall will impact the trail and no further analysis is needed. The catchment area should be constructed with a dampening blanket of loose soil or gravel.

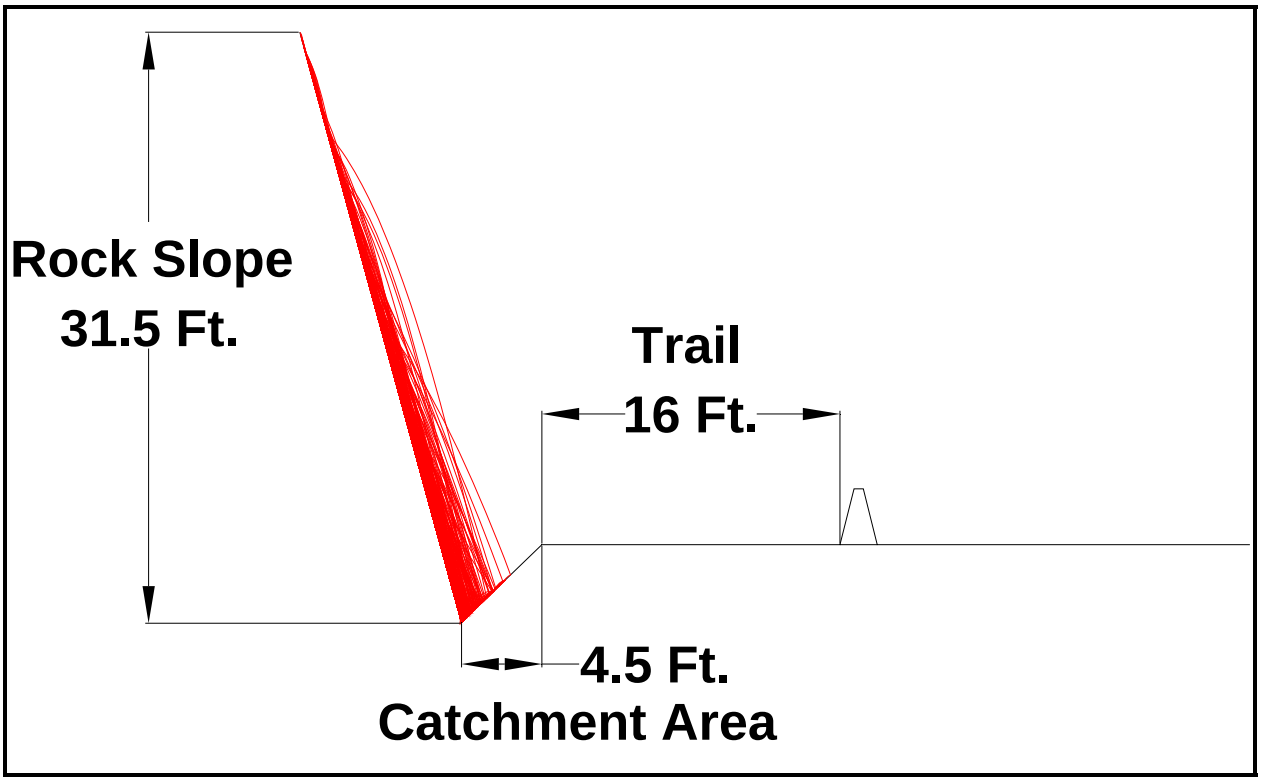

Figure 9-20. Site 9: Rockfall Analysis: No Mitigation

10 Next steps

This study was completed to provide preliminary recommendations and scoping-level cost estimates for rockfall mitigation for the proposed HCRH State Trail alignment between Wyeth and Mitchell Point (Mile Post 52.2 to 57.7), Oregon. This study focused on evaluating portions of the proposed alignment that are located on the shoulder of Interstate I-84 eastbound, between the highway shoulder and existing, active rock slopes. Nine individual rockfall sites were recognized in this project area and evaluated for recommended mitigation.

As part of this study ODOT established design criteria for rockfall hazard mitigation along the proposed trail and performed rockfall analyses and developed recommendations based on the criteria, as follows (and previously described in Section 4):

- **Safety (Risk):** Maintaining or improving existing catchment effectiveness for I-84 and recommending mitigation that protects the trail from falling rock impacts.

- **Operations (Maintenance):** Recommending measures that require the least maintenance for long-term serviceability and that achieve roadway and trail safety.
- **Aesthetics:** Recommending mitigation measures with the least impact to the existing visual conditions within the I-84 corridor.
- **Construction Cost:** Recommending the simplest, most cost-effective method to achieve the above criteria.

Following this study, we understand that design and construction of the next portions of HCRH State Trail will be managed and administered by the Federal Highway Administration (FHWA), Western Federal Lands Highway Division (WFLHD) and consultant designed. We understand that the recommendations and cost estimates developed in this study will be utilized by the future design team; however additional site specific analyses will be necessary to complete design for construction plans and specifications for the project. As a stakeholder, ODOT should participate in technical review of upcoming designs and in future discussions of rockfall mitigation along the proposed alignment.

We recommend that the above criteria be used for this next phase of design and for all future HCRH State Trail design. Furthermore, we recommend that these design criteria be incorporated into the next version of "The Historic Columbia River Highway State Trail Guidelines".

11 References

Rockfall Catchment Area Design Guide, Final Report (SPR-3(032), Oregon Department of Transportation, FHWA-IR-RD-02-04, January 2002.

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Geotechnical Design Manual (GDM), Oregon Department of Transportation, 2012

I-84 Corridor Strategy: A Vision and Design Guidelines for Interstate 84 in the Columbia River Gorge National Scenic Area, FHWA, et al, 2005

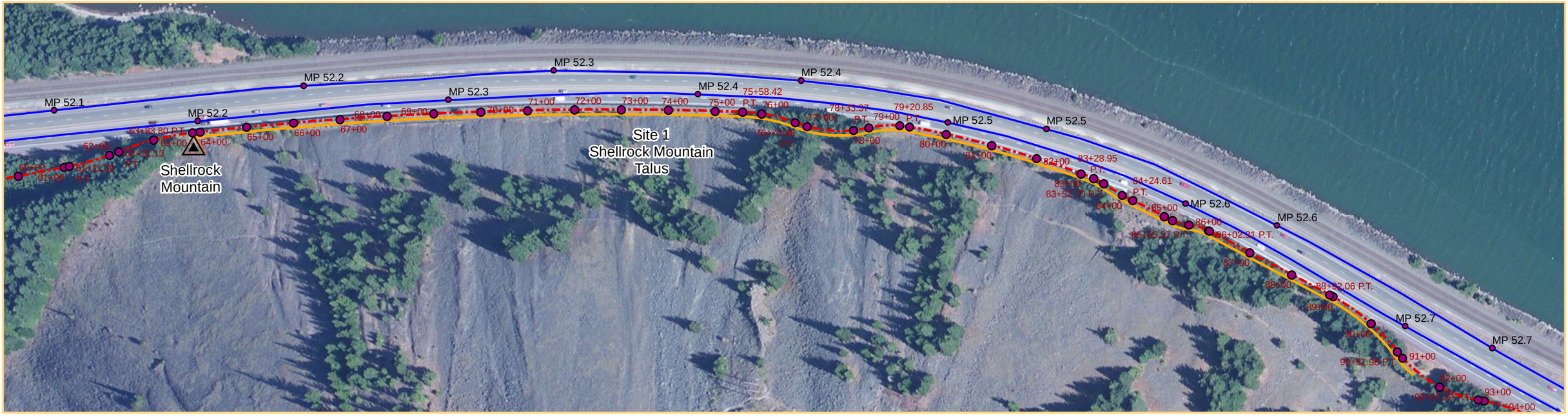
12 Appendix

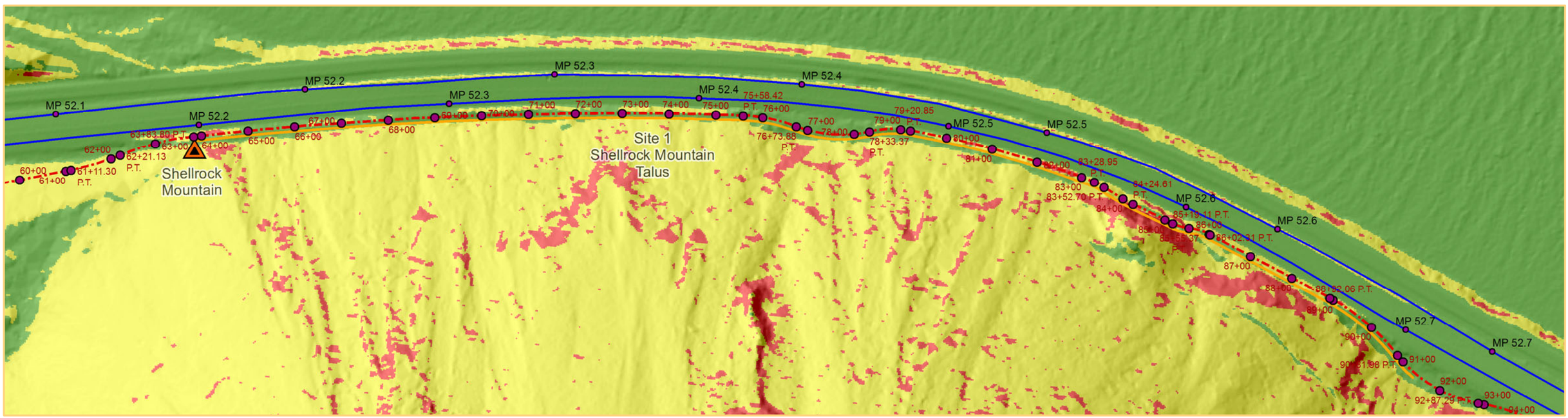
Alignment Maps

Glossary of Terms

ROCFALL Program Input Data

Alignment Maps





- Tenth Mile Marker
- Trail Engineering Station
- Landmark

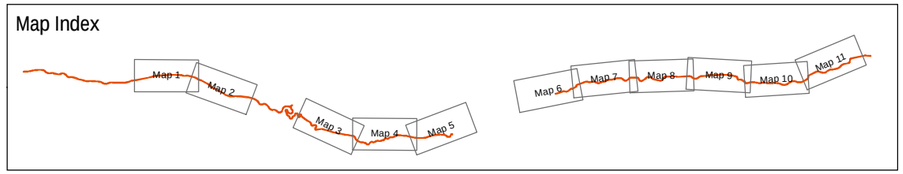
- Rockfall Section
- Proposed Trail
- Highway
- Stream

Slope in Degrees

- 0 - 20
- 20 - 40
- > 40

Data Sources:
Rockfall Locations and Landmarks provided by the Oregon Department of Transportation
Slope data derived from Lidar data provided by the Department of Geology and Mineral Industries (DOGAMI)

Map Index



1 inch = 208 feet

0 50 100 200 Feet

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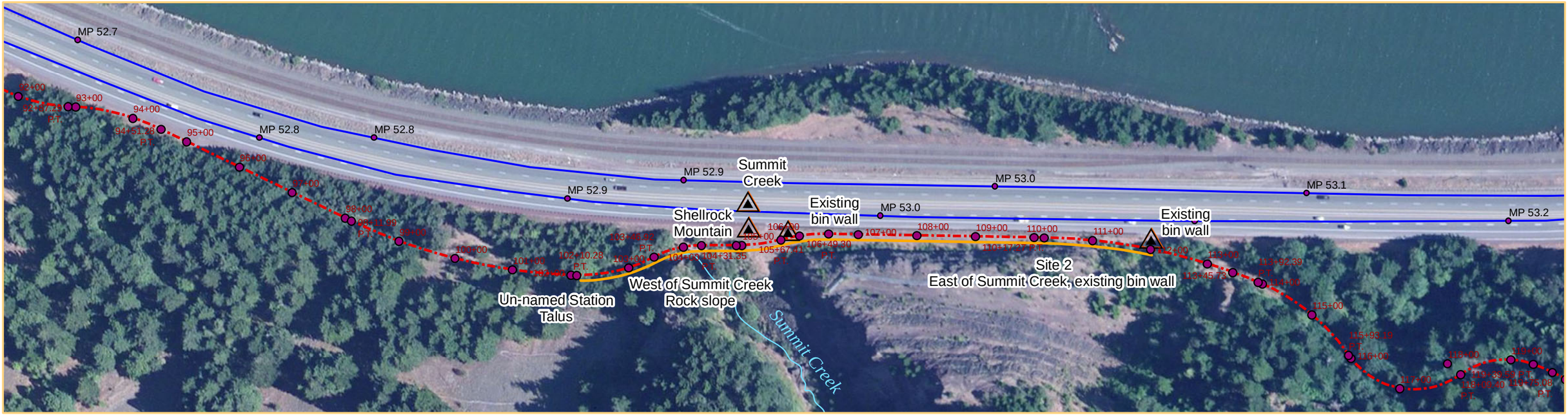
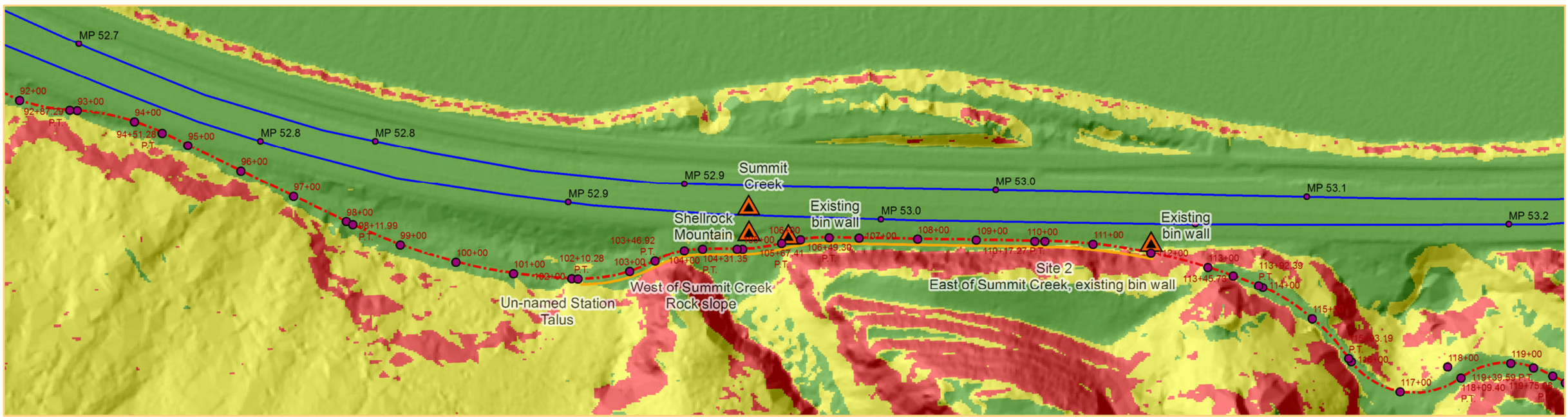
Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 1

Wyeth to Hood River Master Plan
Hood River County, Oregon





Tenth Mile Marker
Trail Engineering Station
Landmark

Rockfall Section
Proposed Trail
Highway
Stream

Slope in Degrees

0 - 20
20 - 40
> 40

Data Sources:
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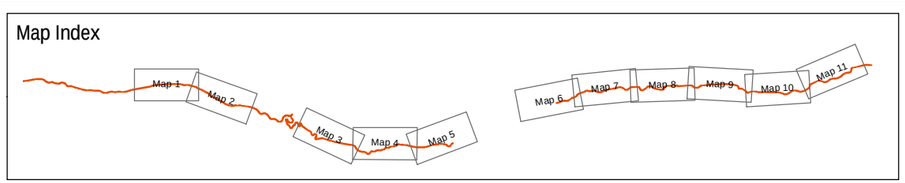

1 inch = 167 feet

0 50 100 200 Feet

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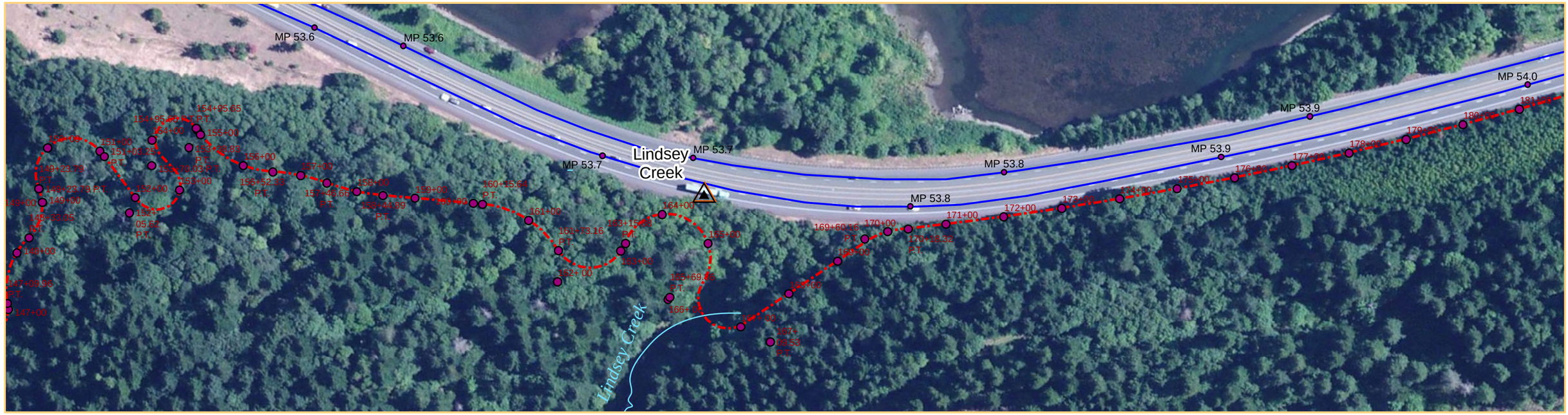
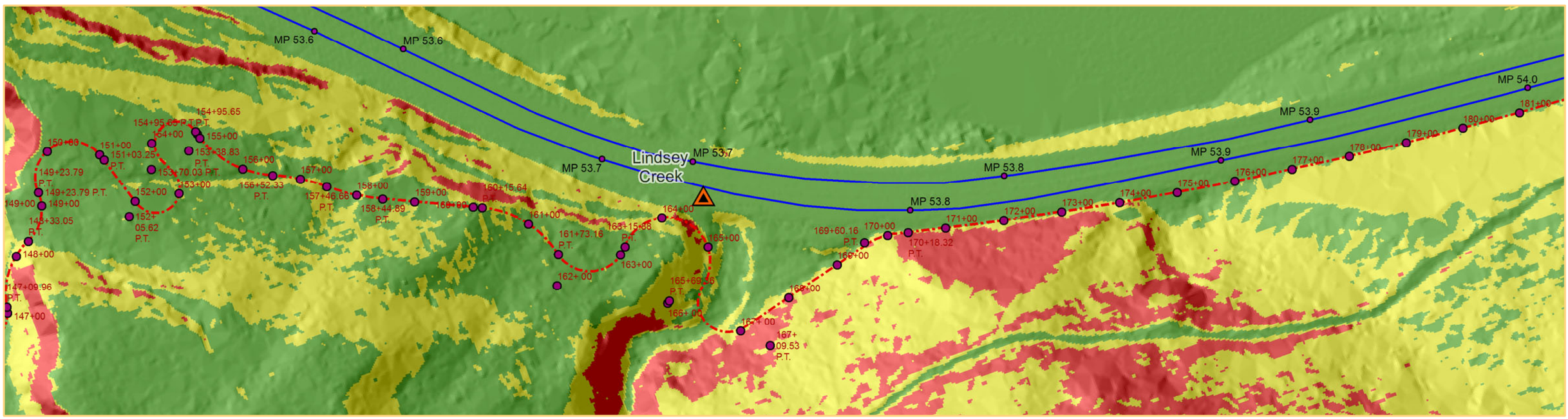
Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 2

Wyeth to Hood River Master Plan
Hood River County, Oregon





Tenth Mile Marker
Trail Engineering Station
Landmark

Rockfall Section
Proposed Trail
Highway
Stream

Slope in Degrees

0 - 20
20 - 40
> 40

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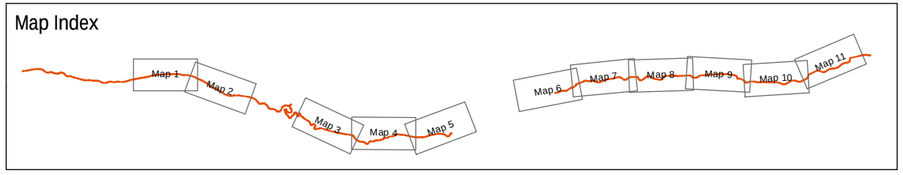

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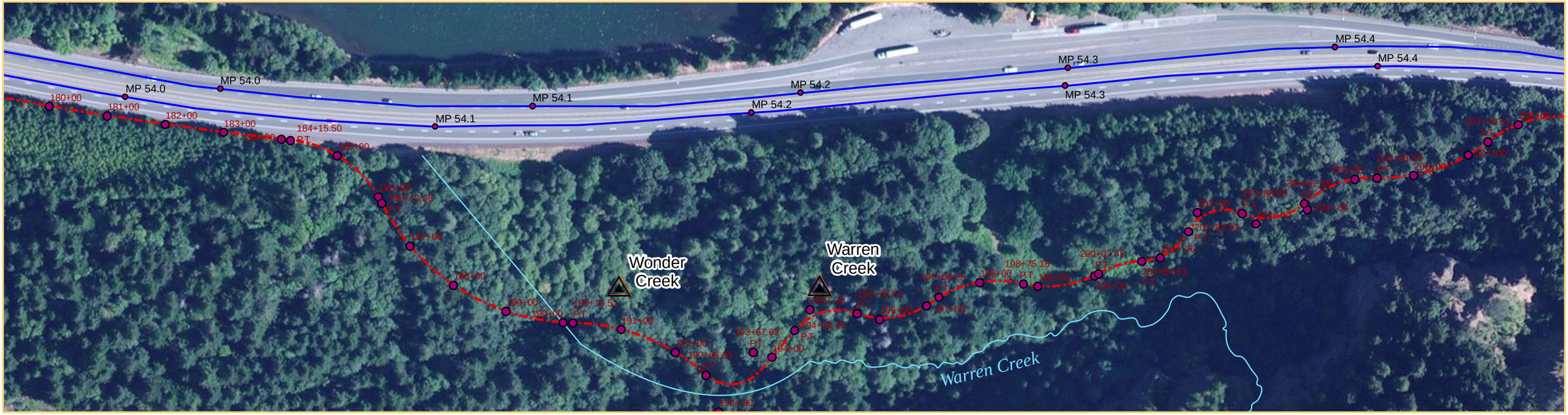
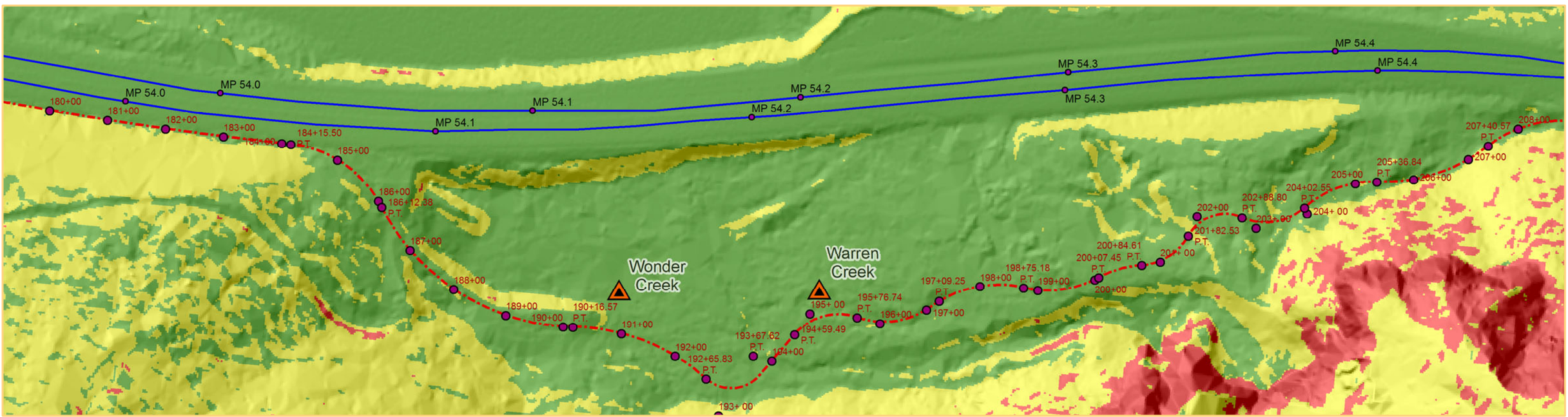
Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 3

Wyeth to Hood River Master Plan
Hood River County, Oregon





Tenth Mile Marker
Trail Engineering Station
Landmark

Rockfall Section
Proposed Trail
Highway
Stream

Slope in Degrees

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20 - 40
> 40

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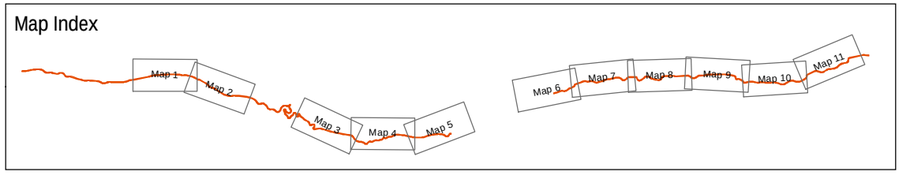

1 inch = 167 feet

0 50 100 200 Feet

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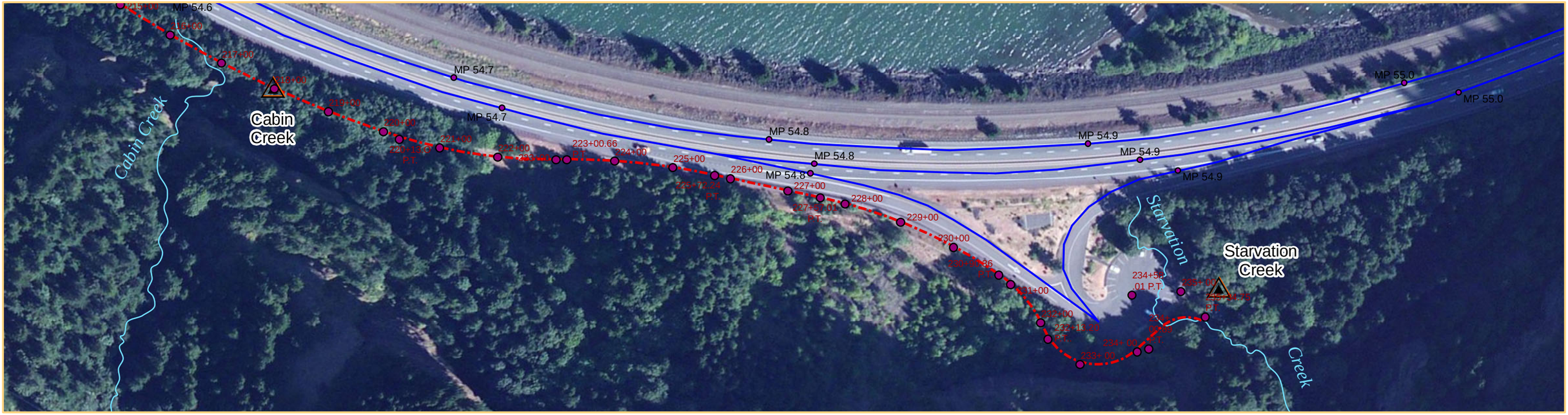
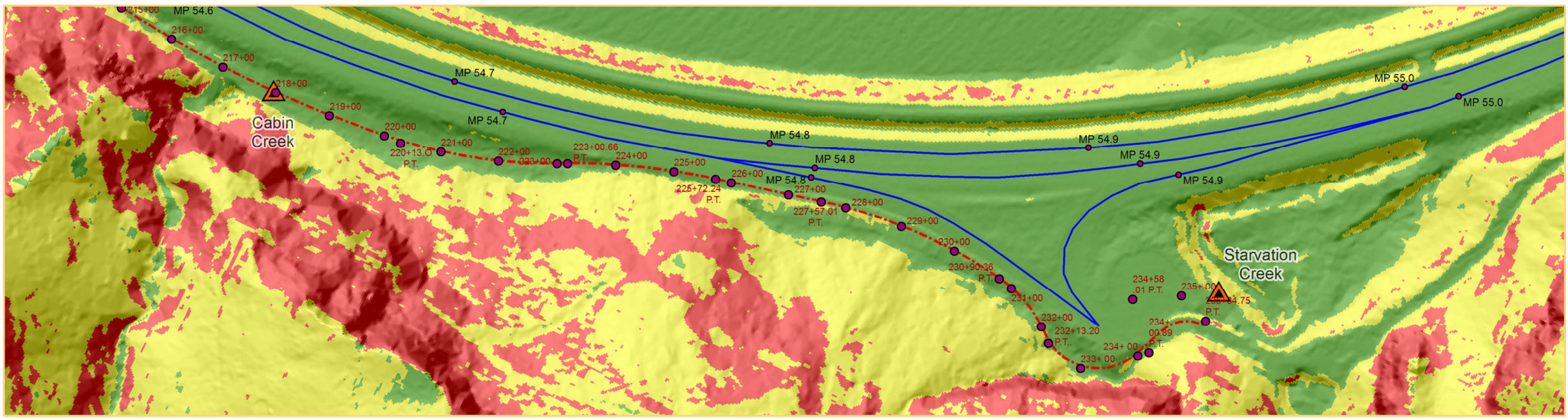
Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 4

Wyeth to Hood River Master Plan
Hood River County, Oregon





Tenth Mile Marker

Trail Engineering Station

Landmark

Rockfall Section

Proposed Trail

Highway

Stream

Slope in Degrees

0 - 20

20 - 40

> 40

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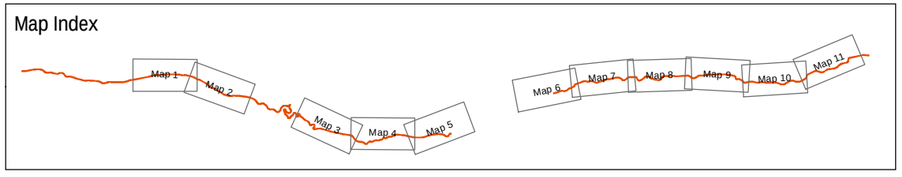
Slope data derived from Lidar data provided by the Department of Geology and Mineral Industries (DOGAMI)

Map Index



1 inch = 167 feet

0 50 100 200 Feet

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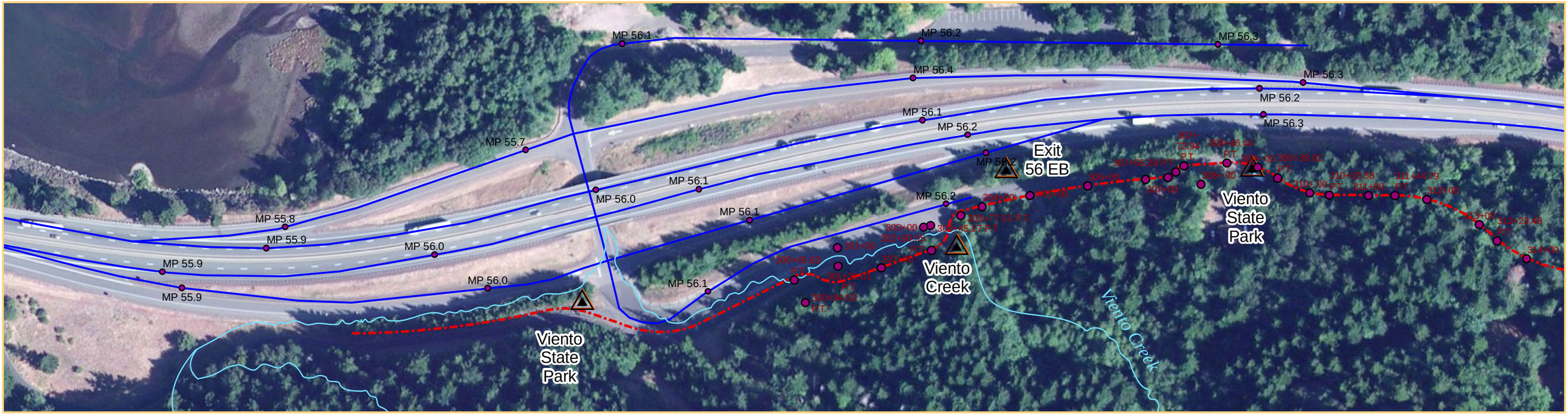
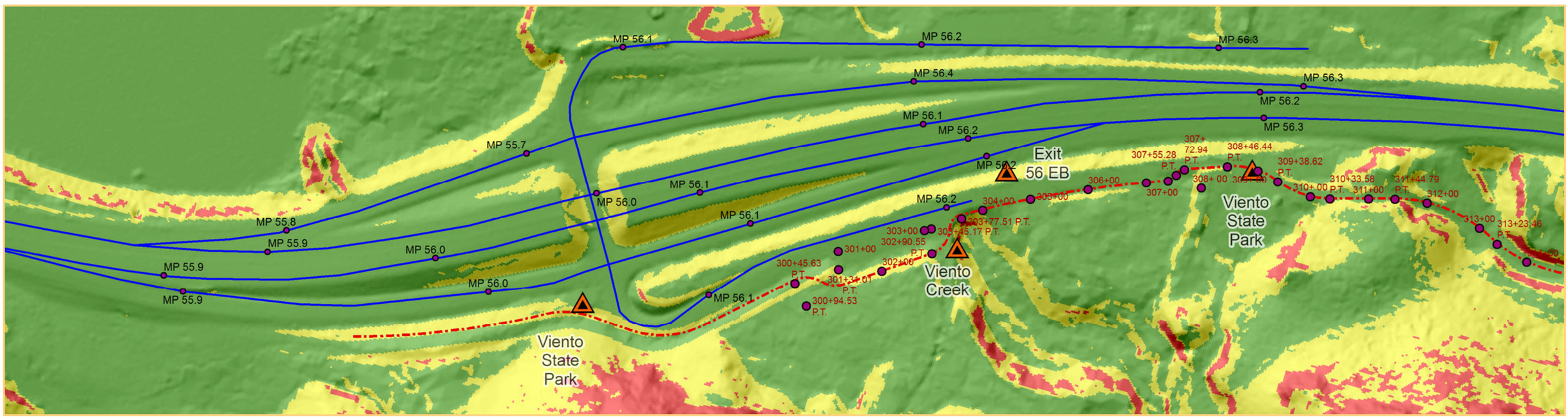
Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 5

Wyeth to Hood River Master Plan
Hood River County, Oregon





Tenth Mile Marker

Trail Engineering Station

Landmark

Rockfall Section

Proposed Trail

Highway

Stream

Slope in Degrees

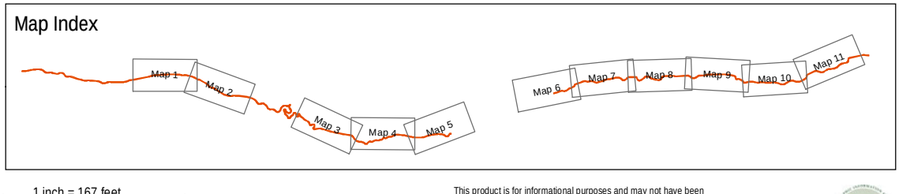
0 - 20

20 - 40

> 40

Data Sources:
Rockfall Locations and Landmarks provided by the Oregon Department of Transportation
Slope data derived from Lidar data provided by the Department of Geology and Mineral Industries (DOGAMI)

Map Index



1 inch = 167 feet

0 50 100 200 Feet

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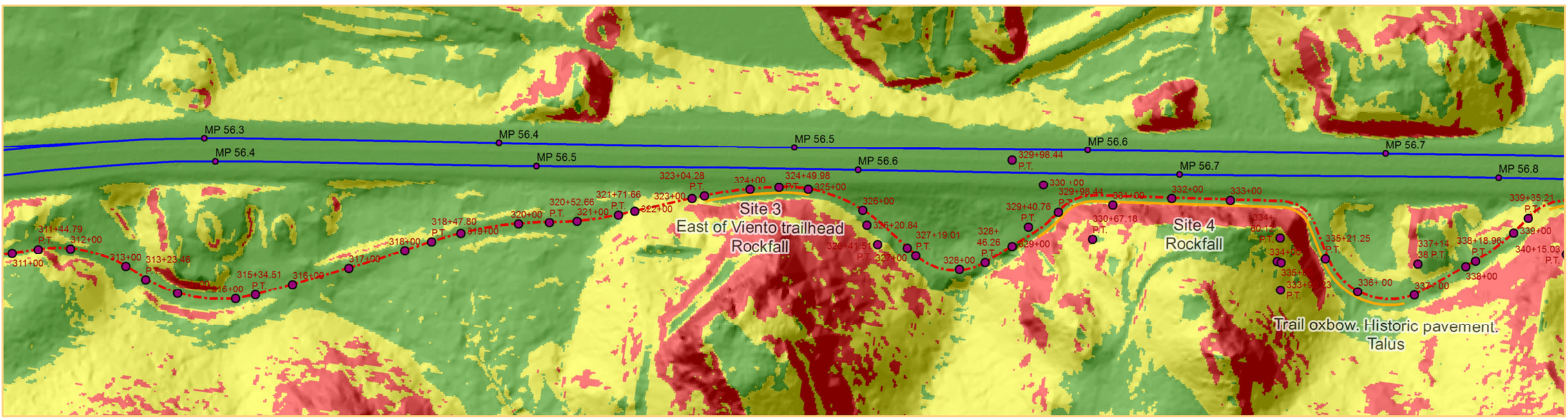
Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 6

Wyeth to Hood River Master Plan
Hood River County, Oregon



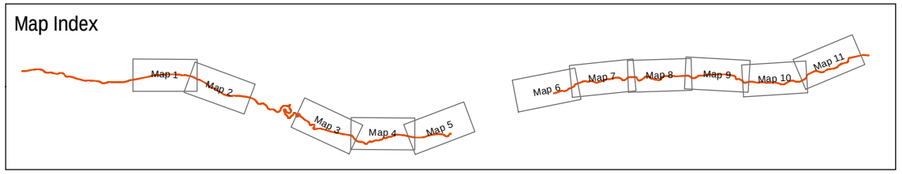
Tenth Mile Marker
Trail Engineering Station
Landmark

Rockfall Section
Proposed Trail
Highway
Stream

Slope in Degrees
0 - 20
20 - 40
> 40

Data Sources:
Rockfall Locations and Landmarks provided by the Oregon Department of Transportation
Slope data derived from Lidar data provided by the Department of Geology and Mineral Industries (DOGAMI)

Map Index



1 inch = 167 feet
0 50 100 200 Feet

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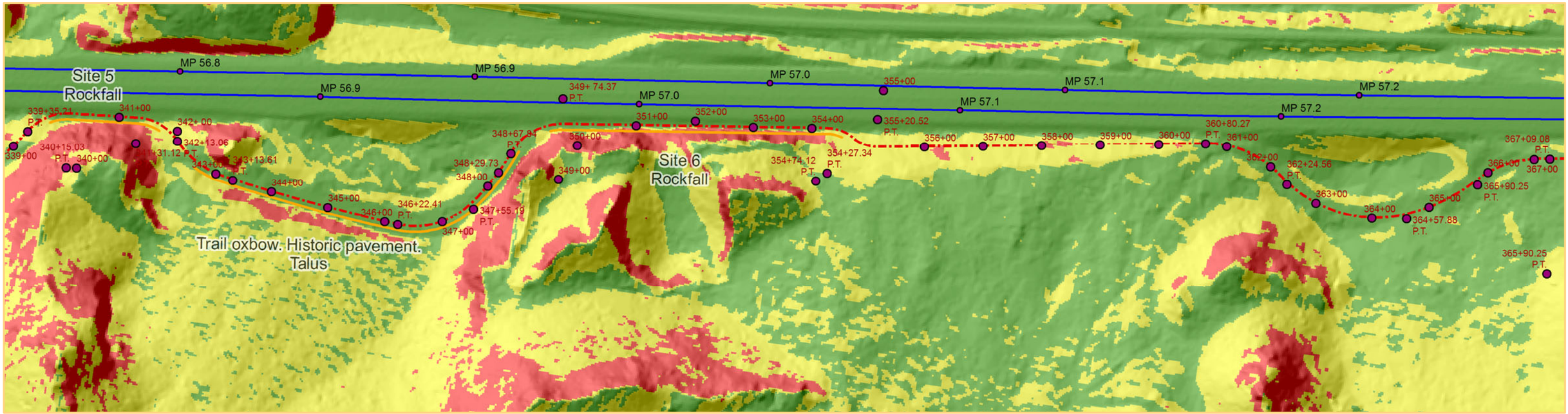
Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 7

Wyeth to Hood River Master Plan
Hood River County, Oregon



Tenth Mile Marker
Trail Engineering Station
Landmark

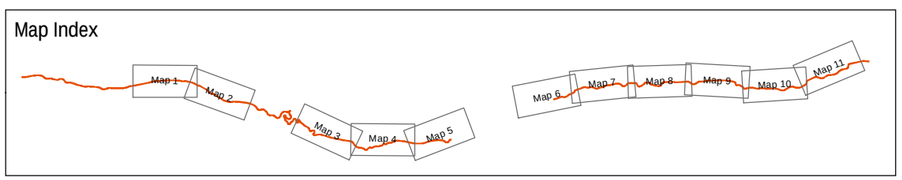
Rockfall Section
Proposed Trail
Highway
Stream

Slope in Degrees

0 - 20
20 - 40
> 40

Data Sources:
Rockfall Locations and Landmarks provided by the Oregon Department of Transportation
Slope data derived from Lidar data provided by the Department of Geology and Mineral Industries (DOGAMI)

Map Index



1 inch = 167 feet

0 50 100 200 Feet

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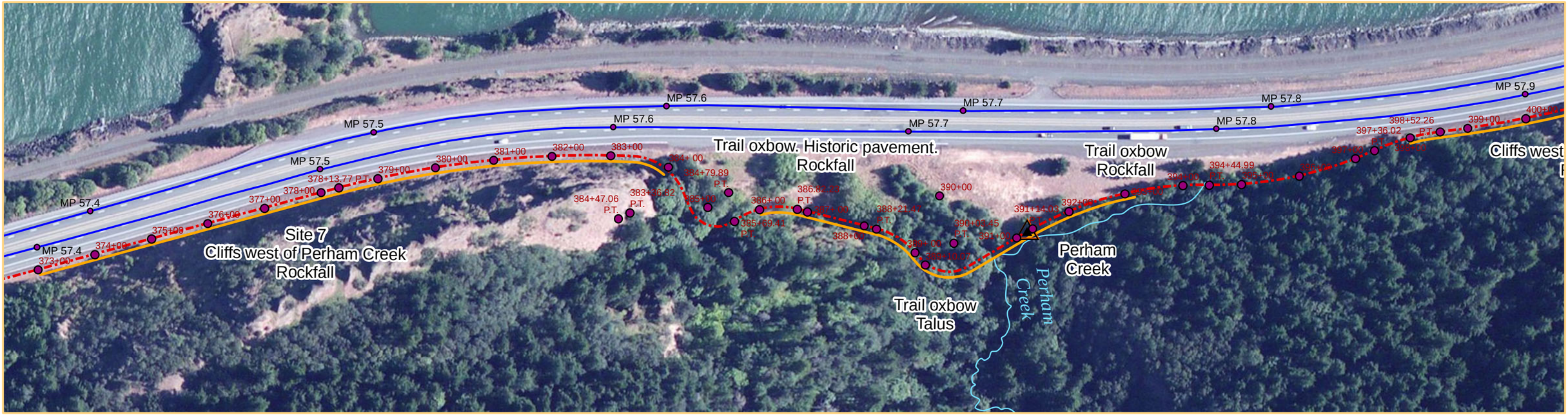
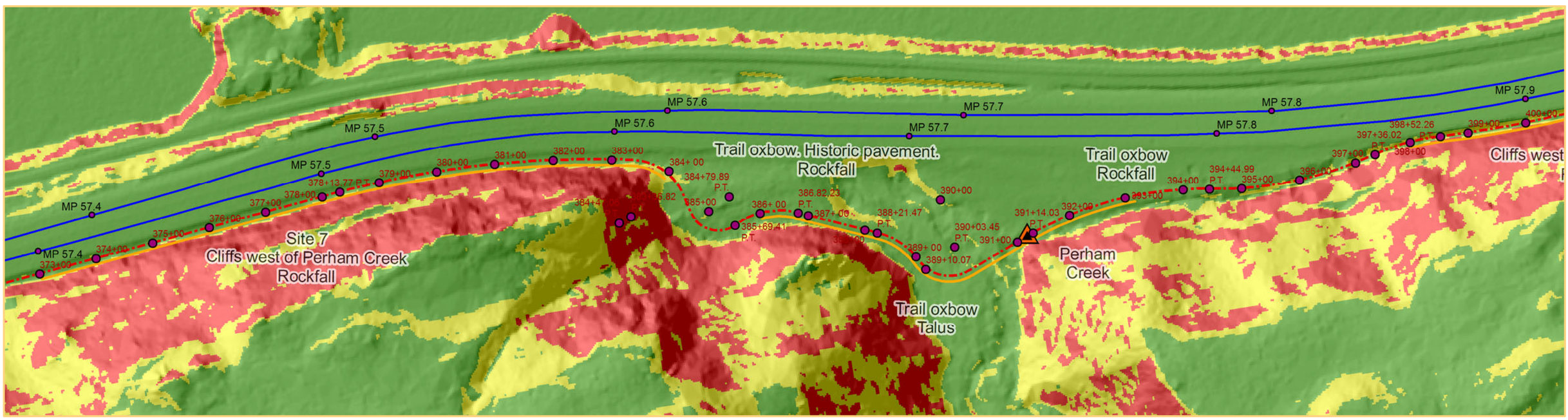
Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 8

Wyeth to Hood River Master Plan
Hood River County, Oregon





Tenth Mile Marker
Trail Engineering Station
Landmark

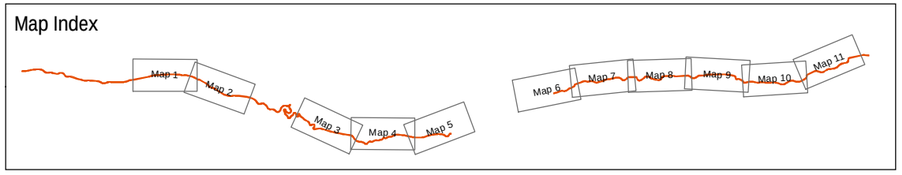
Rockfall Section
Proposed Trail
Highway
Stream

Slope in Degrees

0 - 20
20 - 40
> 40

Data Sources:
Rockfall Locations and Landmarks provided by the Oregon Department of Transportation
Slope data derived from Lidar data provided by the Department of Geology and Mineral Industries (DOGAMI)

Map Index



1 inch = 167 feet

0 50 100 200 Feet

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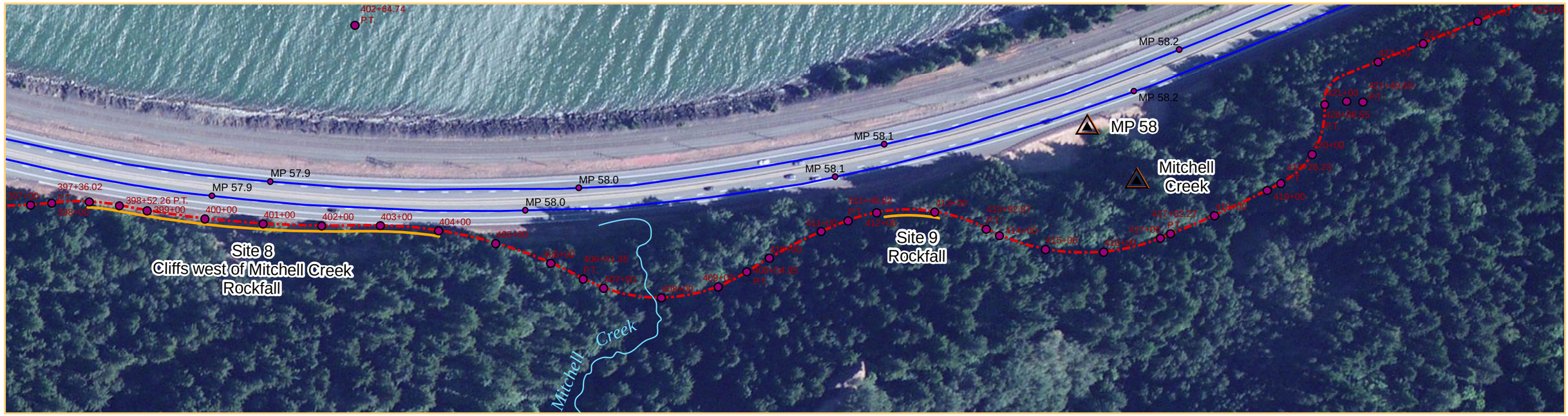
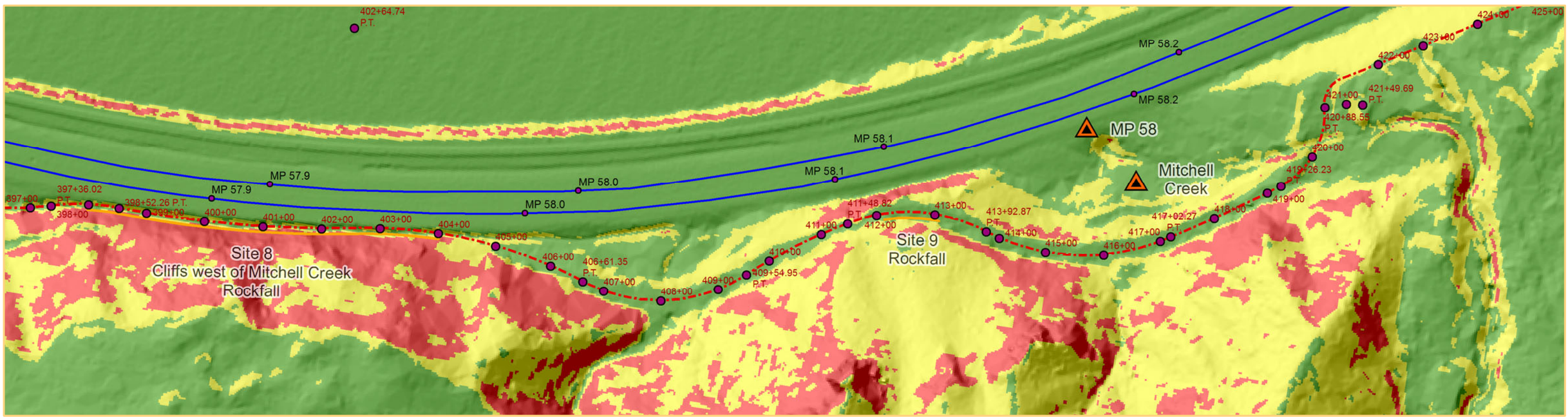
Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 9

Wyeth to Hood River Master Plan
Hood River County, Oregon





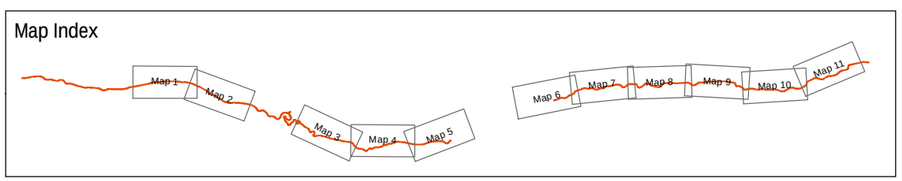
Tenth Mile Marker
Trail Engineering Station
Landmark

Rockfall Section
Proposed Trail
Highway
Stream

Slope in Degrees
0 - 20
20 - 40
> 40

Data Sources:
Rockfall Locations and Landmarks provided by the Oregon Department of Transportation
Slope data derived from Lidar data provided by the Department of Geology and Mineral Industries (DOGAMI)

Map Index



1 inch = 167 feet
0 50 100 200 Feet

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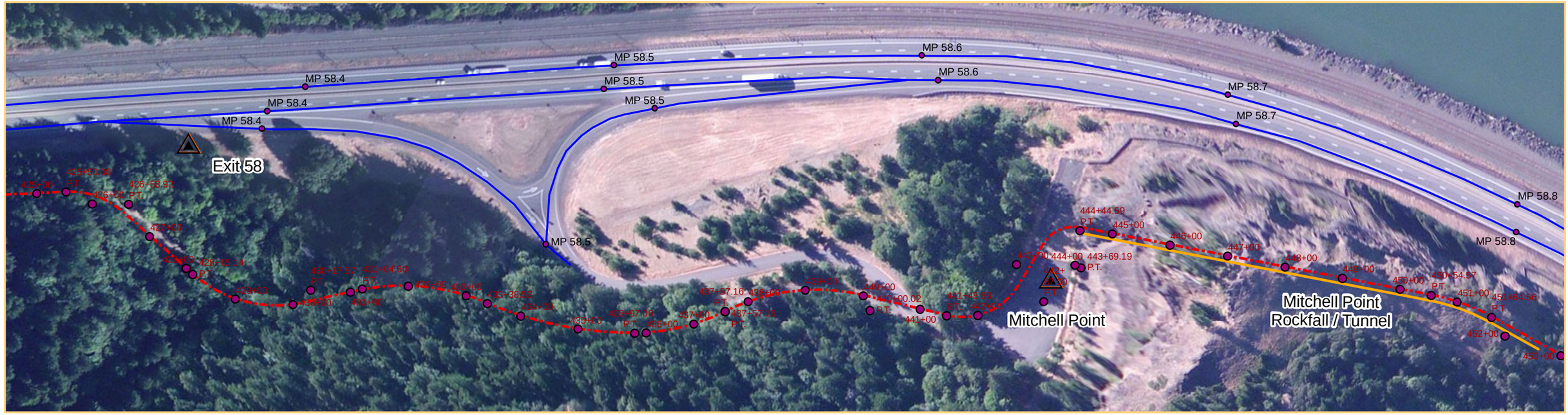
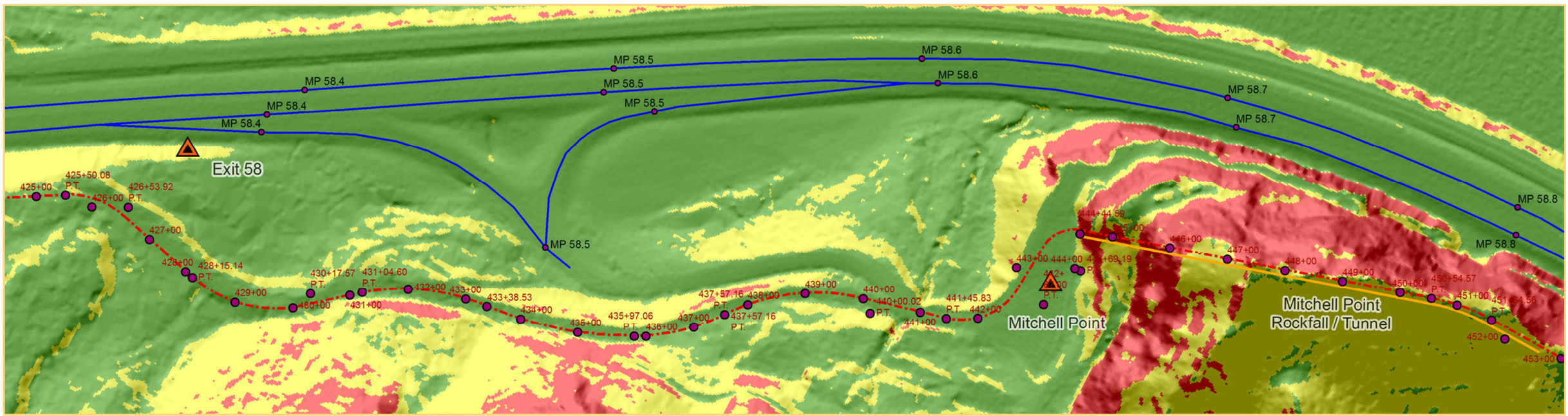
Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 10

Wyeth to Hood River Master Plan
Hood River County, Oregon





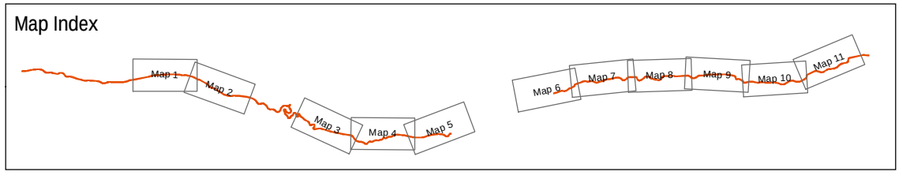
- Tenth Mile Marker
- Trail Engineering Station
- Landmark
- Rockfall Section
- Proposed Trail
- Highway
- Stream

Slope in Degrees

- 0 - 20
- 20 - 40
- > 40

Data Sources:
Rockfall Locations and Landmarks provided by the Oregon Department of Transportation
Slope data derived from Lidar data provided by the Department of Geology and Mineral Industries (DOGAMI)

Map Index



1 inch = 167 feet

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Historic Columbia River Highway (HCRH) Potential Rock-Fall Locations

Map 11

Wyeth to Hood River Master Plan
Hood River County, Oregon

Glossary of Terms

Catchment Area – The area between the roadway edge of pavement and the base (toe) of a rock cut slope used to restrict rockfalls from the roadway. The term is synonymous with ditch, rock fallout area, rockfall ditch, rockfall catch ditch, and catch ditch.

Catchment Area Width – The horizontal distance between the roadway edge of pavement and the base (toe) of a rock cut slope.

Controlled Blasting – Special blasting procedures, such as presplitting and cushion blasting, used to minimize blast damage to the final walls of rock slope excavations. Significantly reduces long-term rockfall compared to use of uncontrolled blasting methods.

CRSP – Acronym for the computerized Colorado Rockfall Simulation Program, which is used to model rockfall trajectories and energies based on known slope shapes and estimated properties.

Ditch – Synonymous with catchment area.

Foreslope – The portion of the roadway prism inclined downward from the edge of pavement toward the base of a cut or roadside ditch.

Perimeter Controlled Blast Holes – A row of closely spaced, lightly loaded blast holes drilled along the rock slope final excavation line and detonated at least 25 milliseconds before the production blast holes. .

Ritchie Ditch – Rockfall catchment area (ditch) configuration and dimensions obtained from an empirical table developed by Washington State Department of Highways Geologist Arthur M. Ritchie in 1963.

Rockfall – The movement of rock from a slope that is so steep the rock continues to move down slope. The movement may be by free falling, bouncing, rolling or sliding.

Roll Out – The furthest slope distance from the toe of the rock cut slope attained by a falling rock.

Root Wedging – Inflation of a rock slope due to the growth of tree roots into joints or cracks. A common cause of rockfall from older, poorly maintained slopes.

Wind Levering – Inflation of a rock slope due to the wind-driven back and forth motion of trees. A common cause of rockfall from older, poorly maintained slopes.

ROCFALL Program Input Data

The following are the input variables used in the statistical analysis/modeling program ROCFALL. The variables fall into three categories: Program settings, Seeder variables and Material settings. For a thorough explanation of the variables, please refer to the ROCFALL User's Guide and Advanced Tutorial.

Project Settings

The following variables were changed from the program defaults.

- Rock Density – 175 lb./cu. ft.
- Consider Angular Velocity
- Friction Angle from Material Editor
- Rn – Scaled by velocity

Line Seeder

- Initial x Velocity – 0.75 ft./sec., 0.15 std. dev.
- Initial y Velocity – 0.00 ft./sec., 0.00 std. dev.
- Rock Mass – 50 lb., 3 std. dev.
- Initial Angular Velocity - 0.00 ft./sec., 0.00 std. dev.

Material Properties

```
*****************ROCFALL MATERIAL FILE*****************
* File Version
1
* All lines beginning with an * are treated as comments
*
* Each Material is a set of 4 lines
* line 1 is the material name
* line 2 is the color (3 RGB components each 0->255)
* line 3 is RN(mean), RN(std dev), RT(mean), RT(std dev)
* line 4 is PHI(mean), PHI(std dev), ROUGHNESS(std dev)
*
* Number of Materials
```

8

Clean hard bedrock [default]

128 128 128

0.53 0.04 0.99 0.04

30 2 5

Asphalt [default]

0 0 255

0.4 0.04 0.9 0.04

0 0 0

Bedrock outcrops [default]

192 192 192

0.35 0.04 0.85 0.04

30 2 0

Talus Cover [default]

255 104 32

0.3 0.04 0.82 0.04

35 2 0

Talus with vegetation [default]

192 220 192

0.32 0.04 0.8 0.04

30 2 0

Soil with vegetation [default]

0 255 0

0.1 0.04 0.5 0.04

40 2 2

Concrete

0 0 0

0.48 0.19 0.53 0.17

40 2 0

Clean freshly shot rock

210	180	140	
0.53	0.04	0.99	0.04
30	2	3	