Attachment 1

Geomorphic and Hydraulic Memorandum

TECHNICAL MEMORANDUM

To: Mara Krinke
David Evans and Associates, Inc.

From: Tim Abbe, PhD, PEG
Shawn Higgins
Steve Winter

Date: April 29, 2016

Re: Lolo Pass Road Access Alternatives Study
Additional Geomorphic and Hydraulic Assessment of the Barlow Trail Alignment
PRELIMINARY REVIEW DRAFT

PROJECT BACKGROUND

Natural Systems Design, Inc. (NSD) prepared this memorandum to provide our geomorphic and hydraulic assessment of an alternative road alignment for Lolo Pass Road near Zigzag in Clackamas County, Oregon. Clackamas County is committed to improving reliable access to Lolo Pass Road and bridge upstream of the Zigzag River Confluence, and has teamed with the Federal Highway Administration in an effort to rebuild the bridge in place, rebuild it in a safer location, and move the road as needed.

To support this work, NSD previously developed a broader assessment of geomorphic conditions in this portion of the Sandy River described in our report *Geomorphic and Hydraulic Assessment of the Sandy River for the Lolo Pass Road Access Alternatives Study* dated September 23, 2015. This memorandum builds on this previous work, adding our assessment of a new alternative developed by the project team. The reader is directed to the September 2015 report for a full description of the geomorphic context for this reach of the Sandy River.

The new alternative considered in this memorandum aligns a new section of Lolo Pass Road along an existing section of Barlow Trail road lying west of Clear Creek. This alternative includes two new bridge crossings; one over the mainstem Sandy River downstream of the confluence with Clear Creek near river mile 43.55, and one over Clear Creek.

There are two potential locations for the bridge over Clear Creek – Option 1 is approximately 1,700 feet, and Option 2 is approximately 3,300 feet upstream of the Sandy River confluence (Figures 1-3). These options are discussed separately below, though they share many common elements.

The key considerations being addressed with this project include the following:

1. Identify geomorphic processes operating at both bridge sites.

2. Assess the potential for existing and future channel migration and avulsion to negatively affect the bridge at both sites.

3. Evaluate flood surface elevations associated with the 100-year storm event (1% annual chance) at both sites under both existing and possible future conditions.

SUMMARY OF GEOMORPHIC HAZARDS

As discussed in detail in NSD's September 2015 report, the Sandy River presents a significant risk of channel migration throughout this project reach. The river has moved through past bridge and road alignments here, and is still adjusting to past eruptive episodes from Mt. Hood. No alternatives considered here will be completely outside the Channel Migration Zone (CMZ) as mapped by NSD.

The magnitude of risk for channel migration generally varies by the type of landform and proximity to the main channel and historical channel alignments. Our assessment of geomorphic risk is keyed to the road and bridge crossing locations' relationship to landforms present throughout the valley. The primary landforms present through the project reach include (from lowest to highest in elevation relative to the river):

1. Active channels of Sandy River and Clear Creek.

2. Alluvial terraces consisting of sediments reworked by the river. There are multiple elevations associated with the alluvial terrace but they are generally within 10 vertical feet of the active channel.

3. Lahar terraces composed of Old Maid lahar deposits. This surface lies on the order of 10 to over 25 feet above the adjacent main channel.

4. Surrounding hillsides typically composed of volcanic rocks.

It is important to note that any of the terraces and the hillsides in this reach can be influenced by channel migration. There is a progressive reduction in risk as you move up onto the higher alluvial terrace and lahar terraces and give the active channel more space.

The new Barlow Trail alternative is aligned along the toe slope of the steep slope extending approximately 600 vertical feet up to Crutcher Bench. The hillslope is mapped as tertiary volcaniclastic rocks and has is approximately 60% slope. This hillslope presents a geomorphic risk to hillslope processes, as there is visual evidence of recent, at least surficial slides and the hillslope is mapped as having 'moderate' and 'high' susceptibility to land sliding in the DOGAMI Statewide Landslide Information Layer for Oregon (accessed online April 2016).

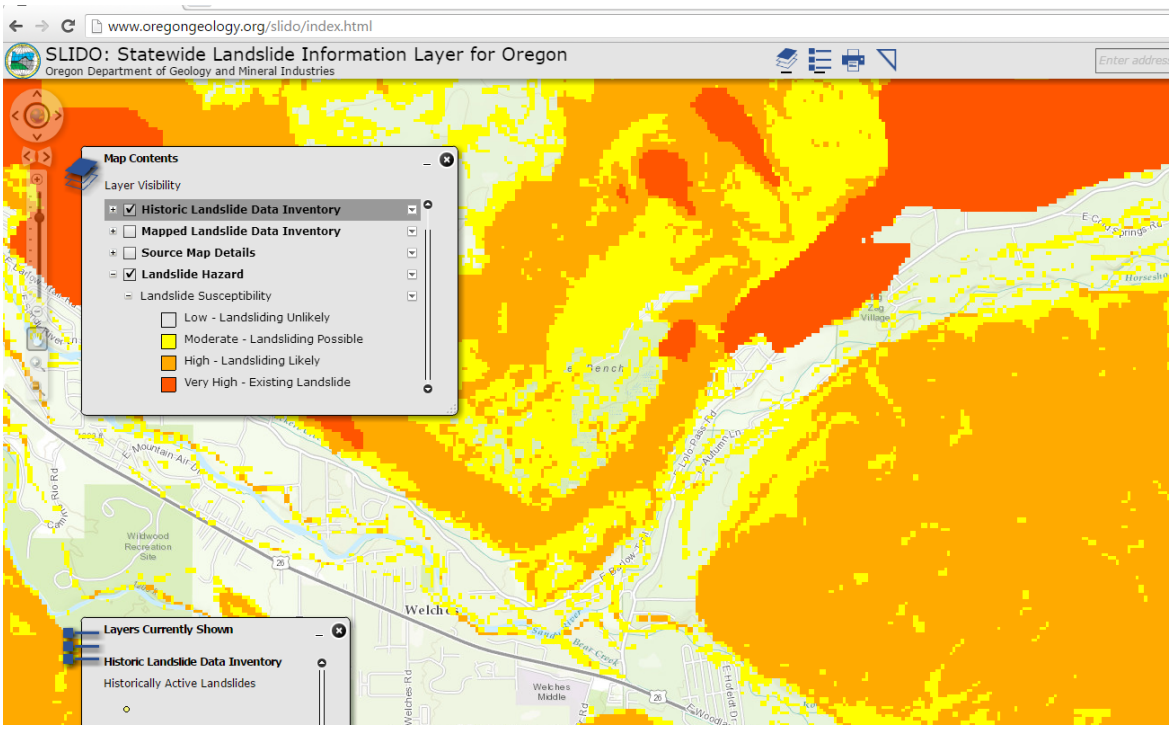

Figure 1. Screen capture from DOGAMI SLIDO layer.

Therefore, the Barlow Trail alignment is exposed to risks due to land sliding. However, much of the hillslope is composed of volcanic rocks, so geotechnical measures (e.g., blasting) could establish a higher road alignment that would have minimal exposure to channel migration.

BARLOW TRAIL ALIGNMENT SEGMENTS

The Barlow Trail alignment for Lolo Pass Road includes five general segments. Each segment is described in Table 1 and 2, representing the two Clear Creek crossing options (see Figures 1 -3).

Table 1. Barlow Trail Alternative Road Segments Option 1: Downstream Clear Creek Bridge

SEGMENT NUMBER	DESCRIPTION	NOTES
1	The downstream mainstem bridge and approaches.	This crossing is the most straightforward segment. This would include a longer span over a single thread channel that could span from higher lahar terrace to the west and the highest alluvial terrace to the east (approximately 340 feet). Approaches would need to be modified for design speed curves.
2	Align Lolo Pass Road along Current E Barlow Trail Road	The E. Barlow Trail Road lies typically on the Old Maid Terrace along the valley wall. It would need to be improved to a higher design speed, which we assume will include widening.
3	Clear Creek Crossing and approaches	A second bridge will be required to cross Clear Creek. The downstream option would be on the order of 360 LF
4	Lolo Pass Road transition to higher terrace	With the downstream bridge option, an approximately 1,250 LF segment of Lolo Pass Road would be relocated to a higher alluvial terrace to set back from the river. With the upstream bridge option Lolo Pass road
5	Higher Terrace	Approximately 1,600 LF of Lolo Pass Road would be relocated to remain on the higher lahar terrace.

Table 2. Barlow Trail Alternative Road Segments
Option 2: Upstream Clear Creek Bridge Option

SEGMENT NUMBER	DESCRIPTION	NOTES
1	The downstream mainstem bridge and approaches.	This crossing is the most straightforward segment. This would include a longer span over a single thread channel that could span from higher lahar terrace to the west and the highest alluvial terrace to the east (approximately 340 feet). Approaches would need to be modified for design speed curves.
2	Align Lolo Pass Road along Current E Barlow Trail Road	The E. Barlow Trail Road lies typically on the Old Maid Terrace along the valley wall. It would need to be improved to a higher design speed, which we assume will include widening.
3	North of the existing Barlow Trail Road alignment	The major decision point is if EBTR can be extended upstream on the terrace, moving the bridge crossing point to where the road can traverse directly to the higher lahar terrace.
4	Clear Creek Crossing and approaches	A second bridge will be required to cross Clear Creek. The upstream option would on the order of 460 LF.
5	Higher Terrace	Approximately 1,600 LF of Lolo Pass Road would be relocated to remain on the higher lahar terrace.

HYDRAULIC REVIEW

Each of the three potential bridge locations was reviewed to assess potential influence of the bridge on flood flows, and consider the general hydraulic characteristics of each crossing. This review is intended to develop preliminary recommendations regarding span width, low chord elevation, and the potential for scour. At each location, the potential for systemic channel aggradation was assessed.

For the Sandy River, NSD used the DOGAMI HEC-RAS model, as described in our September 2015 report. For Clear Creek, we do not have an HEC-RAS model developed. NSD used the 2016 Preliminary floodplain mapping (DOGAMI, in prep) as a basis for flood elevation and used WinXSPRO to assess hydraulic conditions at the two potential Clear Creek bridge crossings. Sections were cut at each location using the 2011 LiDAR data as the source of topographic information. The hydraulic review for Clear Creek is substantially less detailed than for the Sandy River.

SANDY RIVER METHODS AND RESULTS

For the Barlow Alternative Sandy River crossing, the existing HEC-RAS was modified to remove the existing Lolo Pass Road bridge and add a new bridge at approximately river mile 43.55. The initial bridge geometry was estimated using the elevations of adjacent terraces to determine how a span that would not interact with the 1% annual chance flow scour potential interact with flood flows to develop a minimum low chord elevation for the bridge. The initial hydraulic result is shown below in Figure 2 for both aggraded and ungraded conditions.

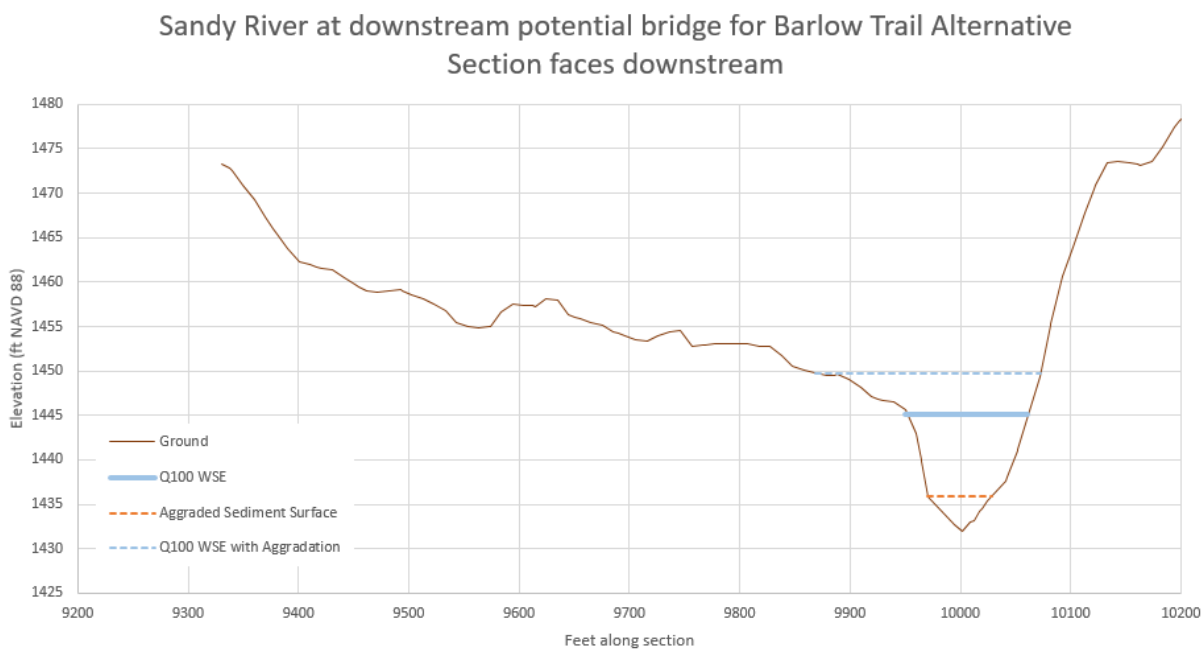

Figure 2. HEC-RAS cross section at the potential Sandy River crossing downstream of the confluence with Clear Creek.

The modeled 1 percent annual chance water level from the model is 1,445.1 feet, which is in agreement with the Preliminary FIRM maps. Channel velocities through the bridge sections are comparable with adjacent sections and lower than up and downstream sections (Figure 3).

Profile Output Table - Six XS Bridge

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HEC-RAS Plan: bart1 River: sandyriver8 Reach: 2 Profile: Q100

Reach	River Sta	Profile	E.G. Elev	W.S. Elev	Crit W.S.	Frctn Loss	C & E Loss	Top Width	Q Left	Q Channel	Q Right	Vel Chnl
			(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(cfs)	(cfs)	(cfs)	(ft/s)
2	58000	Q100	1454.44	1450.27	1450.27	4.75	0.32	88.55	10.36	10877.93	11.71	16.40
2	57787	Q100	1448.97	1445.86	1444.99	0.76	0.00	102.68	30.07	10844.22	25.71	14.19
2	57737 BR U	Q100	1448.21	1445.10	1444.25	0.85	0.00	102.71	30.14	10844.07	25.79	14.18
2	57737 BR D	Q100	1447.36	1444.26	1443.41	0.28	0.00	102.80	30.41	10843.52	26.07	14.15
2	57687	Q100	1447.07	1443.98	1443.08	5.26	0.08	102.86	30.58	10843.17	26.25	14.14
2	57385 CJ	Q100	1441.72	1438.91	1437.97	3.97	0.21	120.10	1.30	10869.82	28.88	13.48

Figure 3. Six Bridge cross section output from RAS model with summary hydraulic information

3 feet were added to the BFE to develop a minimum low chord elevation at 1448.1 feet in elevation. The minimum low chord elevation would intersect the midslope position on the western bank and would intersect the alluvial terrace on the eastern bank. Both locations, and particularly the eastern alluvial terrace are highly susceptible to channel migration, therefore a longer span is recommended for this location.

The potential for flood stage to increase due to systemic channel aggradation was investigated by adding 6 feet of sediment to the bed throughout the model using the 'fixed sediment elevation' tool in RAS. This depth is measured from the thalweg so results in approximately 4 feet of aggradation across the bed through the project reach and re-running the model. The aggradation scenario resulted in a 1% annual water surface of 1449.7 feet, approximately 4.6 feet higher than the unaggraded state (Figure 3).

Therefore, a low chord elevation that accounts for both aggradation and allows for debris passage would be 1,453 feet. This elevation intersects a higher portion of the alluvial terrace, but is still relatively low and exposed to channel migration. We recommend that a similar width to the replacement option (400 feet) be pursued here to reduce exposure to lateral migration. We presume that a sloped structure will be required to intersect the higher western terrace; we only reviewed minimum elevations here, so higher low chord elevations due to slope are acceptable.

CLEAR CREEK METHODS AND RESULTS

For Clear Creek, the Preliminary Flood Insurance Study (Draft 2016) indicates that the 1% annual chance flow is 1,705 cfs. Channel cross sections based on 2011 LiDAR were entered into WinXSPRO and roughness values were estimated then iterated to develop a wetted width near the 1 percent annual flow that was comparable to the width of the floodplain shown on the Preliminary FRIM Panels (41005C0402E and 41005C0406E). The resulting hydraulic assumptions and calculated characteristics are shown in Table 3.

Table 3. Cross-sectional analysis results for Clear Creek bridge locations

BRIDGE ALTERNATIVE	SLOPE (FEET/FEET)	N	Q (CFS)	DEPTH (FEET)	WETTED WIDTH (FEET)	VELOCITY (FEET/S)	SHEAR (LBS/FEET^2)
1. Downstream	0.017	0.040	1,711	4.74	49.3	10.5	3.4
2. Upstream	0.017	0.050	1718	5.0	73.8	7.9	3.1

The water surface elevations from the WinXSPRO assessments are comparable to the Base Flood Elevations (BFEs) reported on the PFIRMs. These elevations match within 2.0 feet, which is generally reasonable given the error in LiDAR for the channel bottom and the estimates of BFEs, which require interpolation between data points on the PFIRMs. The agreement is better for the

upstream cross-section, as the bed elevation of the downstream cross-section based on 2011 is higher than the bed shown on the FEMA profiles.

Both crossings have a relatively confined flowpath at higher flow, which is consistent with the preliminary flood mapping. Both locations are similar hydraulically; the upstream location is less confined, with an overbank bench on river left that results in lower overall velocity and associated shear stress.

Clear Creek Span Width and Height

It appears feasible to install bridges for Clear Creek that will span the regulatory floodplain with a low chord elevation that provides some factor of safety in the case of potential channel aggradation. However, the landings on the river left (eastern) bank will be exposed to potential scour, which should be considered in structure design.

Clear Creek is relatively confined between the valley toeslope and the higher terrace. At the downstream location a span width of approximately 100 feet would allow for the structure to span from the toeslope to the terrace. This span width would exceed the regulatory floodplain in this location. The minimum low chord elevation at the downstream crossing to consider would be 1483 feet (BFE + 3 feet). The adjacent higher terrace is at elevation 1,488 feet which. Please note that these span lengths were developed using perpendicular alignments; if the structure is skewed, the overall length will need to be increased to preserve the perpendicular span lengths discussed here.

The downstream bridge location was also tested to determine the potential impacts of channel aggradation. The existing bed was brought up by 4 feet and the procedure was re-ran. The resulting stage was similar to the scale of the bed adjustment, adding an additional 0.5 feet to the resulting water depth. Therefore, an additional 4.5 feet of clearance could be necessary to accommodate aggradation. BFE + 4.5 feet in this location is approximately 1484.5 so BFE + 7.5 = 1487.5 feet.

At the upstream location, if the bridge is to span between the toe slope and the high terrace, the minimum span width would be approximately 300 feet. If this option is selected then the low chord elevation would be near 1518 feet elevation, approximately 15 feet above the 1% annual chance floodplain. The lowest elevation to consider would be BFE + 3 feet = 1,506 feet.

The WinXSPRO upstream section was modified to aggrade the bed by 4 feet to test the response in this reach. The resulting water depth scaled to the bed adjustment and was 3.2 feet higher than the existing condition result, so adding 4 feet to account for aggradation should be sufficient in this reach. Therefore, the low chord elevation that would allow for channel aggradation would be (BFE + 3 feet + 4feet) = 1,510 feet elevation.

Bridge Summary

Key bridge parameters are included below in Table 4 for the potential crossing locations.

Table 4. Bridge parameters to meet hydraulic and geomorphic objectives

PARAMETER	CLEAR CREEK DOWNSTREAM BRIDGE LOCATION	CLEAR CREEK UPSTREAM BRIDGE LOCATION	SANDY RIVER AT RM 44.55
Minimum Span Width to stay outside of floodplain	100 feet	150 feet	230 feet
Span Width that reduces exposure to lateral migration	175 feet	300 feet	400 feet
Minimum low chord elevation (BFE + 3 feet)	1,483 feet	1506 feet	1448.1 feet
Low Chord Elevation that includes aggradation (Aggraded BFE + 3 feet)	1,487.5 feet	1,510 feet	1,453 feet

GEOMORPHIC REVIEW

NSD reviewed each element of the road alignments and assessed each element's setting and exposure to geomorphic hazards. These results are summarized below.

Table 5. Qualitative geomorphic assessment of E. Barlow Trail Road Alternative Option 1 – Downstream Clear Creek Crossing

ALIGNMENT SEGMENT	DESCRIPTION	GEOMORPHIC SETTING	GEOMORPHIC RISK ELEMENTS	DESIGN CONSIDERATIONS	SUMMARY
Downstream Crossing (common to both options)	New bridge over the mainstem Sandy River Downstream of the Clear Creek confluence with associated road approaches.	• River right abutment will be on higher Old Maid lahar deposits, river left abutment will be on lower terrace • Within CMZ	• Abutment sour • Channel migration into of high terrace • Channel migration within alluvial terrace	• Locate crossing downstream of confluence. • Locate river left abutment as high on alluvial terrace as possible. • Provide scour mitigation for both abutments.	Crossing location is at a narrow section of the valley and is comparable to other alternatives.
Existing E. Barlow Trail Rd Alignment (common to both options)	Road modifications to increase level of service of existing road.	• Old Maid lahar deposits • Moving north increasing influence of steep (~60% slope) hillside mapped as Tertiary volcaniclastic. Evidence of recent failures. • Within CMZ	• Channel migration into high lahar terrace • Hillslope failures	• May require geotechnical stabilization of hillslope • May require bank protection along Clear Creek bank	For the most part minimizes exposure to channel migration by staying on higher terrace, but increases exposure to hillslope processes

ALIGNMENT SEGMENT	DESCRIPTION	GEOMORPHIC SETTING	GEOMORPHIC RISK ELEMENTS	DESIGN CONSIDERATIONS	SUMMARY
New Bridge Over Clear Creek	Bridge over Clear Creek between valley toe slope and lower alluvial terrace	• Old Maid lahar deposits • Moving north increasing influence of steep (~60% slope) hillside mapped as Tertiary volcaniclastic. • Alluvial deposits • Within CMZ	• Clear Creek channel migration into high lahar terrace • Hillslope failures • Sandy River migration into alluvial terrace	• May require geotechnical stabilization of hillslope • Locate river left abutment as high on the alluvial terrace as possible. • Provide scour mitigation for both abutments	Bridge landing to the east will be in alluvial sediments between the Sandy River and Clear Creek.
New Road Alignment – Alluvial Terrace	Move Lolo Pass Road generally NW to higher alluvial terrace and up to lahar terrace	• Alluvial sediments • Within CMZ	• Channel migration into alluvial terrace (either Clear Creek or Sandy)	• Align road to highest portion of terrace • Include revetment or other scour protection from mainstem Sandy River	This section of road will reduce risk over existing conditions by relocating higher, but will still be on the alluvial terrace.
New Road Alignment – High Terrace (common to both options)	Move Lolo Pass Road generally NW to higher alluvial terrace and up to lahar terrace	• Old Maid lahar deposits • Within CMZ	• Channel migration into lahar terrace	• Set back from edge of terrace	This section of road will reduce risk over existing conditions by relocating to the higher terrace.

Table 6. Qualitative geomorphic assessment of E. Barlow Trail Road Alternative Option 2

ALIGNMENT SEGMENT	DESCRIPTION	GEOMORPHIC SETTING	GEOMORPHIC RISK ELEMENTS	DESIGN CONSIDERATIONS	SUMMARY
Downstream Crossing (common to both options)	New bridge over the mainstem Sandy Downstream of the Clear Creek confluence with associated road approaches.	• River right abutment will be on Old Maid lahar deposits, river left abutment will be on alluvial terrace • Within CMZ	• Abutment sour • Channel migration into of high terrace • Channel migration within alluvial terrace	• Locate crossing downstream of confluence. • Locate river left abutment as high on the terrace as possible. • Provide scour mitigation for both abutments.	Crossing location is at a narrow section of the valley and is comparable to other alternatives. Channel susceptible to systemic widening in this reach.
Existing E. Barlow Trail Rd Alignment (common to both options)	Road modifications to increase level of service of existing road.	• Old Maid lahar deposits • Moving north increasing influence of steep (~60% slope) hillside mapped as Tertiary volcaniclastic. • Within CMZ	• Channel migration into high lahar terrace • Hillslope failures	• May require geotechnical stabilization of hillslope • May require scour protection along Clear Creek bank	Reduces exposure to channel migration by staying on terrace, but increases exposure to hillslope processes.

ALIGNMENT SEGMENT	DESCRIPTION	GEOMORPHIC SETTING	GEOMORPHIC RISK ELEMENTS	DESIGN CONSIDERATIONS	SUMMARY
New Road Alignment on toeslope	Extend road north along toeslope west of Clear Creek.	• Old Maid lahar deposits • Moving north increasing influence of steep (~60% slope) hillside mapped as Tertiary volcaniclastic. • Active channel of Clear Creek • Within CMZ	• Channel migration into lahar terrace • Hillslope failures • Very limited lateral distance between toeslope and Clear Creek Channel	• May require geotechnical stabilization of hillslope • May require moving Clear Creek to provide sufficient room for road. • Provide scour mitigation for both abutments.	This section of road presents significant geomorphic challenges. If a road alignment higher on the slope can be identified, potentially blasted into bedrock, it would substantially increase feasibility.
New Bridge Over Clear Creek	Bridge over Clear Creek between valley toe slope and high lahar terrace. Includes Realignment of Lolo Pass Road on Lahar Terrace.	• Old Maid lahar deposits • Steep (~60% slope) hillside mapped as Tertiary volcaniclastic. • Within CMZ	• Channel migration into high lahar terrace • Hillslope failures	• May require geotechnical stabilization of hillslope • Locate river left abutment as high on the terrace as possible. • Provide scour mitigation for river right abutment	Bridge landing to the east avoids the lower alluvial deposits, reducing risk
New Road Alignment – Lahar Terrace (common to both options)	Move Lolo Pass Road generally NW to higher alluvial terrace and up to lahar terrace	• Old Maid lahar deposits • Within CMZ	• Channel migration into lahar terrace	• Set back from edge of terrace where possible.	This section of road will reduce risk over existing conditions by relocating higher, but will still be on a terrace.

SUMMARY AND COMPARISON TO PAST ALTERNATIVES

The E. Barlow Trail alternative to re-align Lolo Pass Road uses two bridges to cross Clear Creek then the Sandy River. The road alignment along E. Barlow Trail Road has advantages from a channel migration perspective as it maximizes the road distance on the higher terrace and potentially on bedrock. Aligning Lolo Pass Road at the toeslope increases exposure to hillslope processes from the steep, tall, valley wall. Geomorphic risk from the hillside appears to generally increase with distance to the north. The two options reviewed for the Barlow Trail alignment have different risk exposures, generally trading off exposure to hillslope processes and channel migration.

Option 1 uses the current alignment of E. Barlow Trail Road, and reduces exposure to hillslope processes in this alignment. Lolo Pass Road would be aligned to higher ground to approach the new Clear Creek crossing. The re-aligned portion of Lolo Pass Road would have reduced exposure to channel migration over existing conditions, but would still require design consideration of bank protection in portions of the Sandy River adjacent to the higher alluvial terrace.

Option 2 extends the road alignment along E. Barlow Trail road further to the northeast, requiring a new road alignment between Clear Creek and the toe slope. The proposed bridge over Clear Creek could be aligned to have the eastern landing on the higher terrace, avoiding a section of Lolo Pass road on the alluvial terrace between Clear Creek and the Sandy River. The new section of road will be increasing exposed to hillslope processes to the north. The Option 2 new road alignment would also need to traverse a location where Clear Creek has meandered against the valley wall. Therefore, while Option 2 reduces the distance of road on the lower terrace, it substantially increases exposure to hillslope processes.

From a geomorphic perspective, both Barlow Trail alignment options are comparable in terms of overall risk to the two previously analyzed alternatives. The primary geomorphic advantages for Barlow Trail are: (1) the main channel crossing that can span between higher terraces, (2) the Clear Creek crossing is over a much smaller stream with less potential for lateral migration, and (3) longer portions of Lolo Pass Road are moved away from the mainstem Sandy River. Geomorphic risks for the Barlow Trail alternative focus on: (1) increased exposure to hillslope processes, (2) the need to protect bridge abutments from scour, and (3) the Sandy River mainstem crossing location included in this alternative may hold more long term geomorphic risk as it is in a narrow portion of the valley that may be poised to widen, as with the upstream reach there.

Our review indicates that the Barlow Trail road alternative presents more geomorphic risk than the new upstream road alignment and longer bridge span discussed in our previous report. The Barlow Trail alternative is comparable to replacement along the existing alignment

alternative, but likely presents less overall risk as a longer portion of Lolo Pass Road is relocated away from proximate lateral channel migration hazards.

REFERENCES

DOGAMI, in prep. Sandy River HEC-RAS Hydraulic Model.

NSD, 2015. *Geomorphic and Hydraulic Assessment of the Sandy River for the Lolo Pass Road Access Alternatives Study.* Prepared for David Evans and Associates September 23, 2015