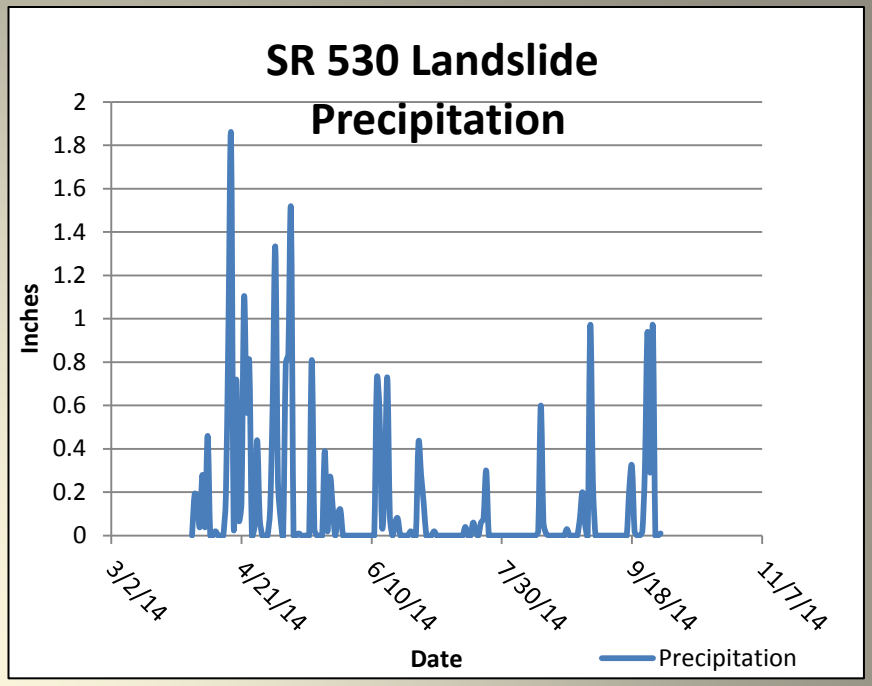
Resources and opportunities to better manage landslide risk

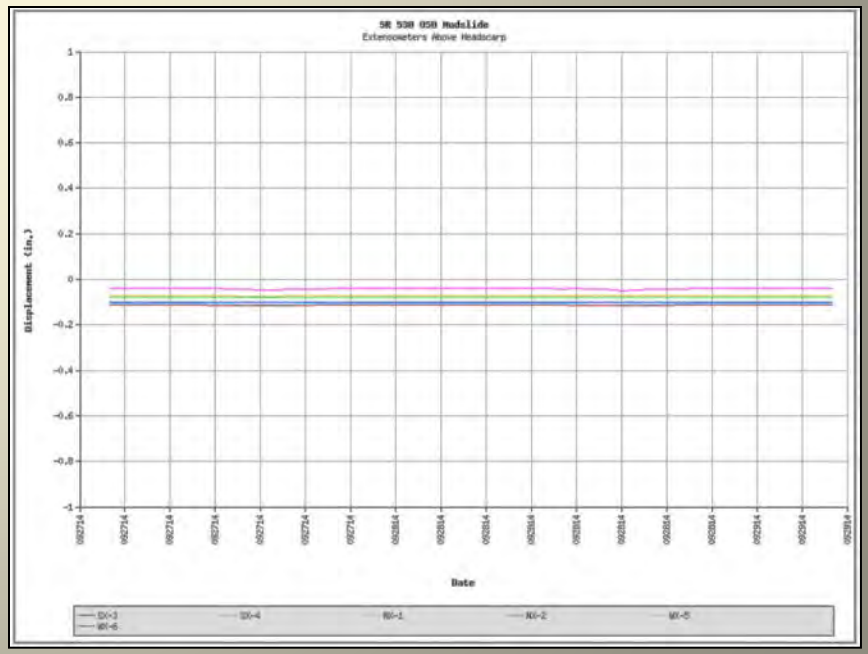
Tom Badger

WSDOT's Initial Response Efforts

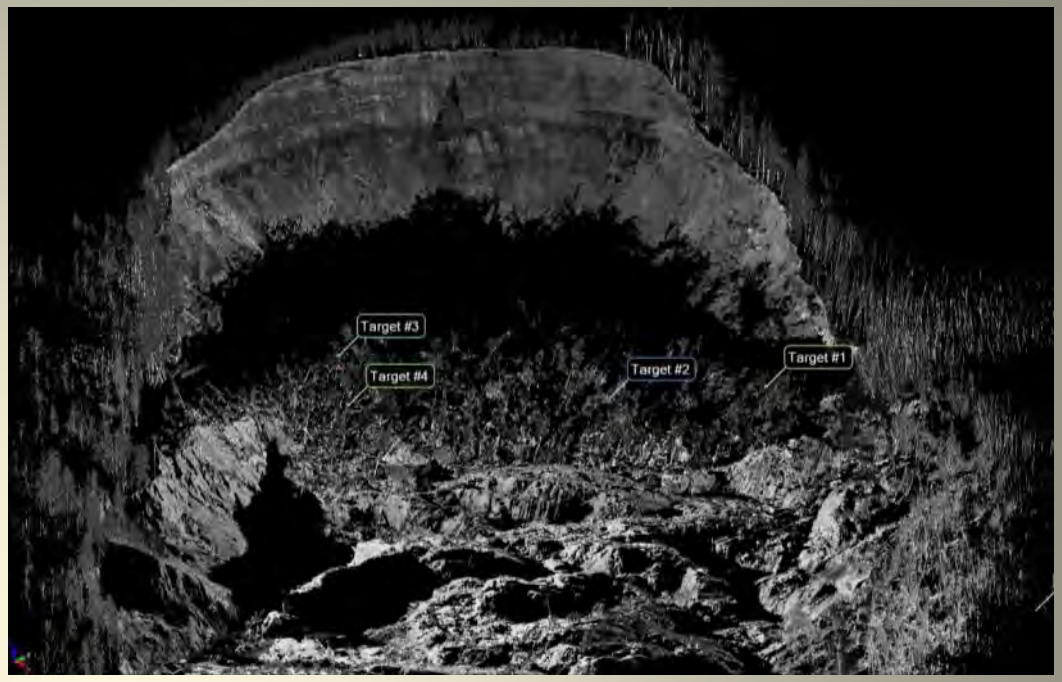
- ESF1-Transportation lead
- Science teams support

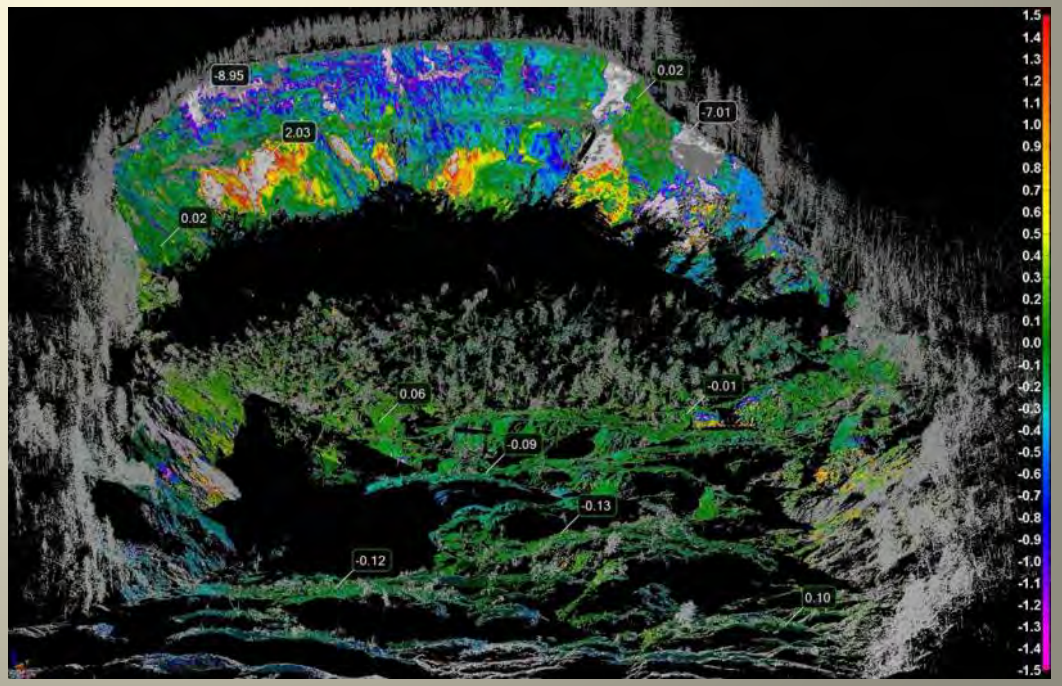
Landslide Monitoring


SR 530 Landslide
Precipitation
Inches
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
3/2/14
4/21/14
6/10/14
7/30/14
9/18/14
11/7/14
Date
Precipitation

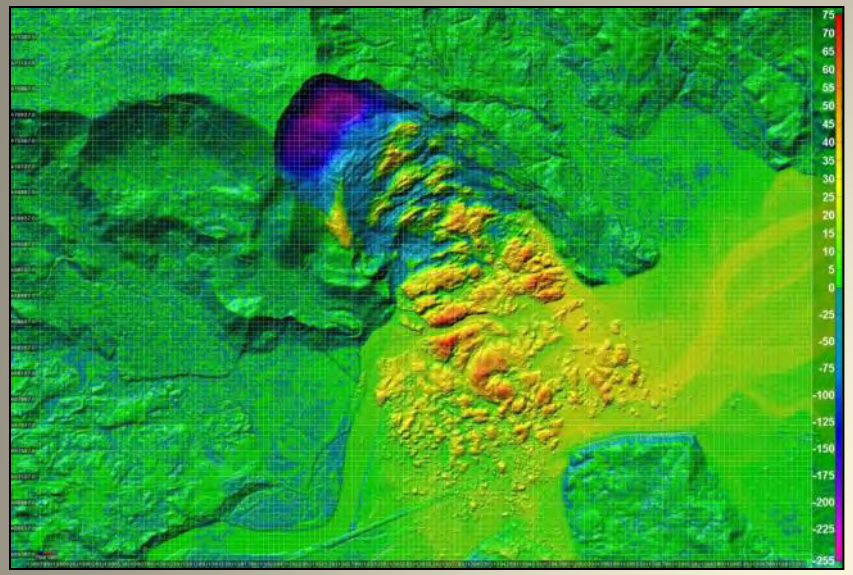

SR 530 OSO Mudslide
Extensometers Above Headscarp
Displacement (in.)
Date

Landslide Monitoring Laser Scanning

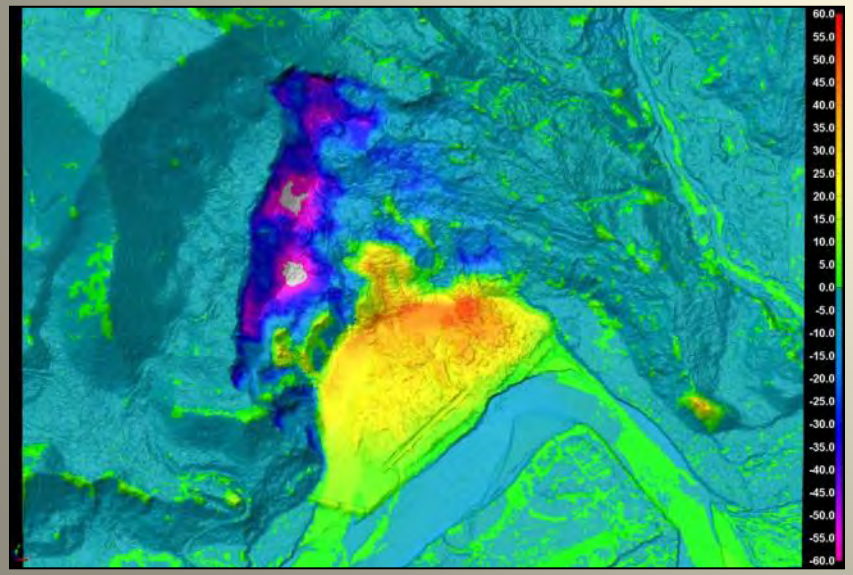




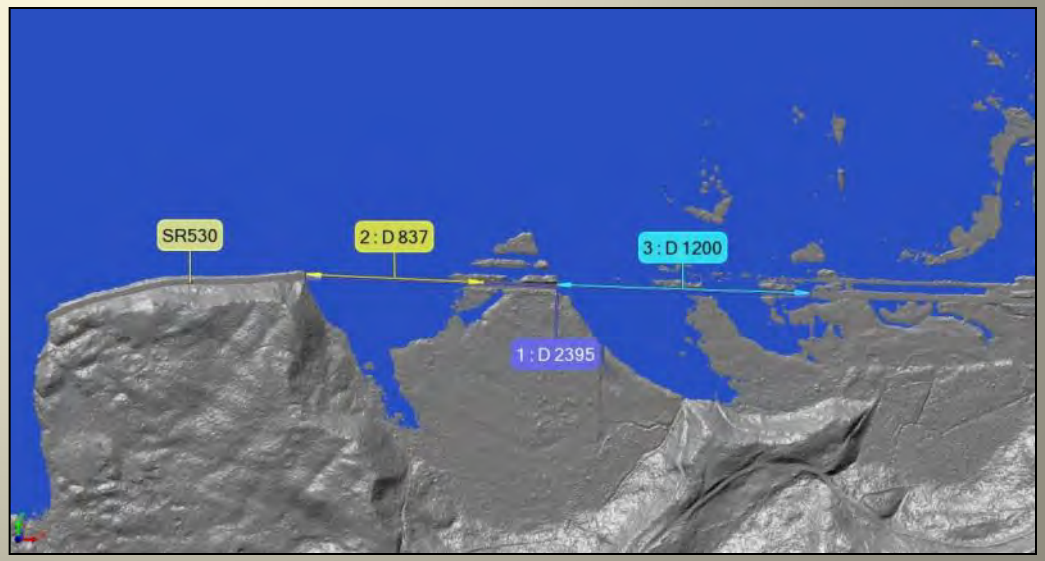
Mapping Products



Change Analysis 2013 to 2014



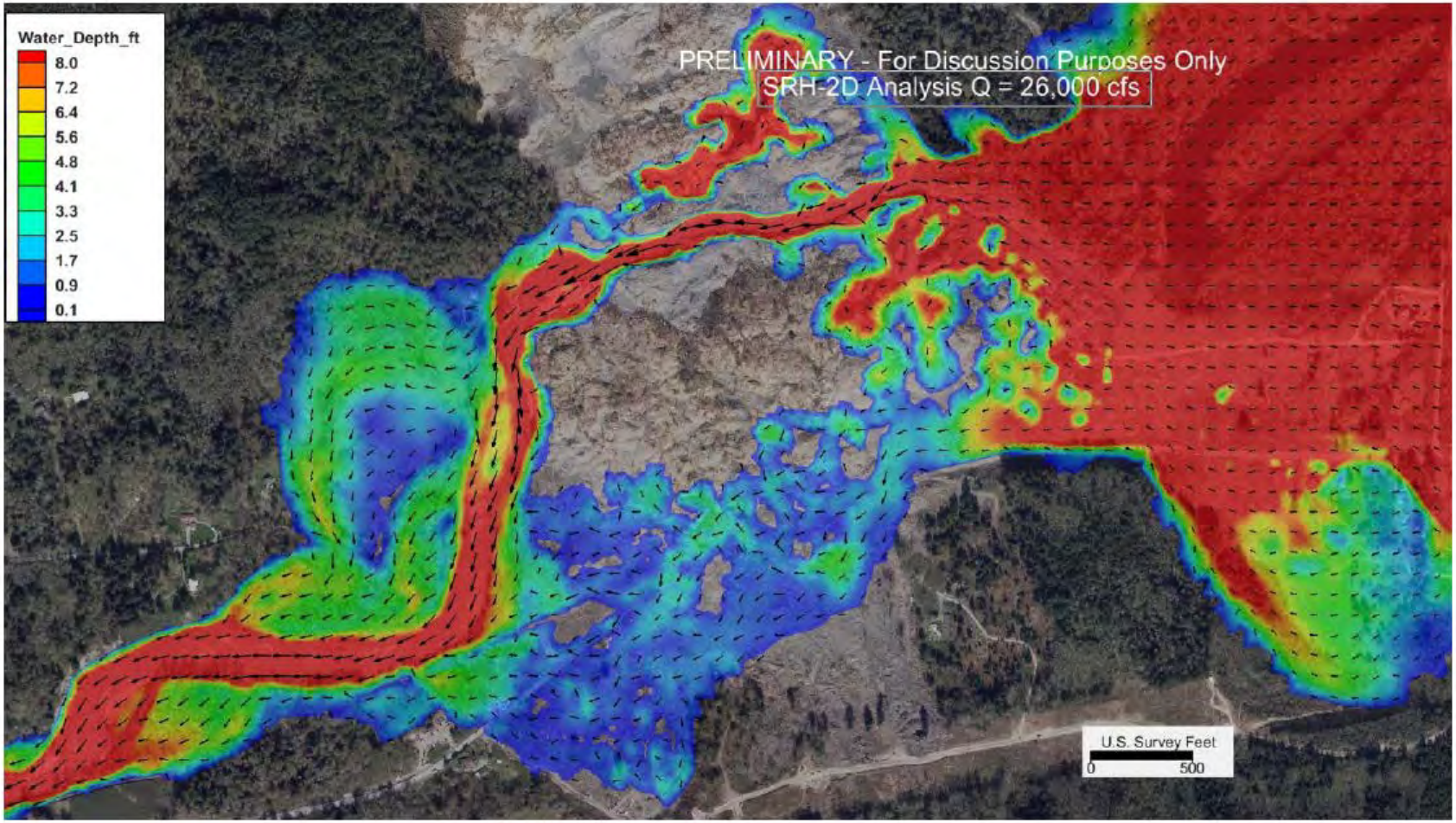
Change Analysis 2003 to 2013



Mapping Products

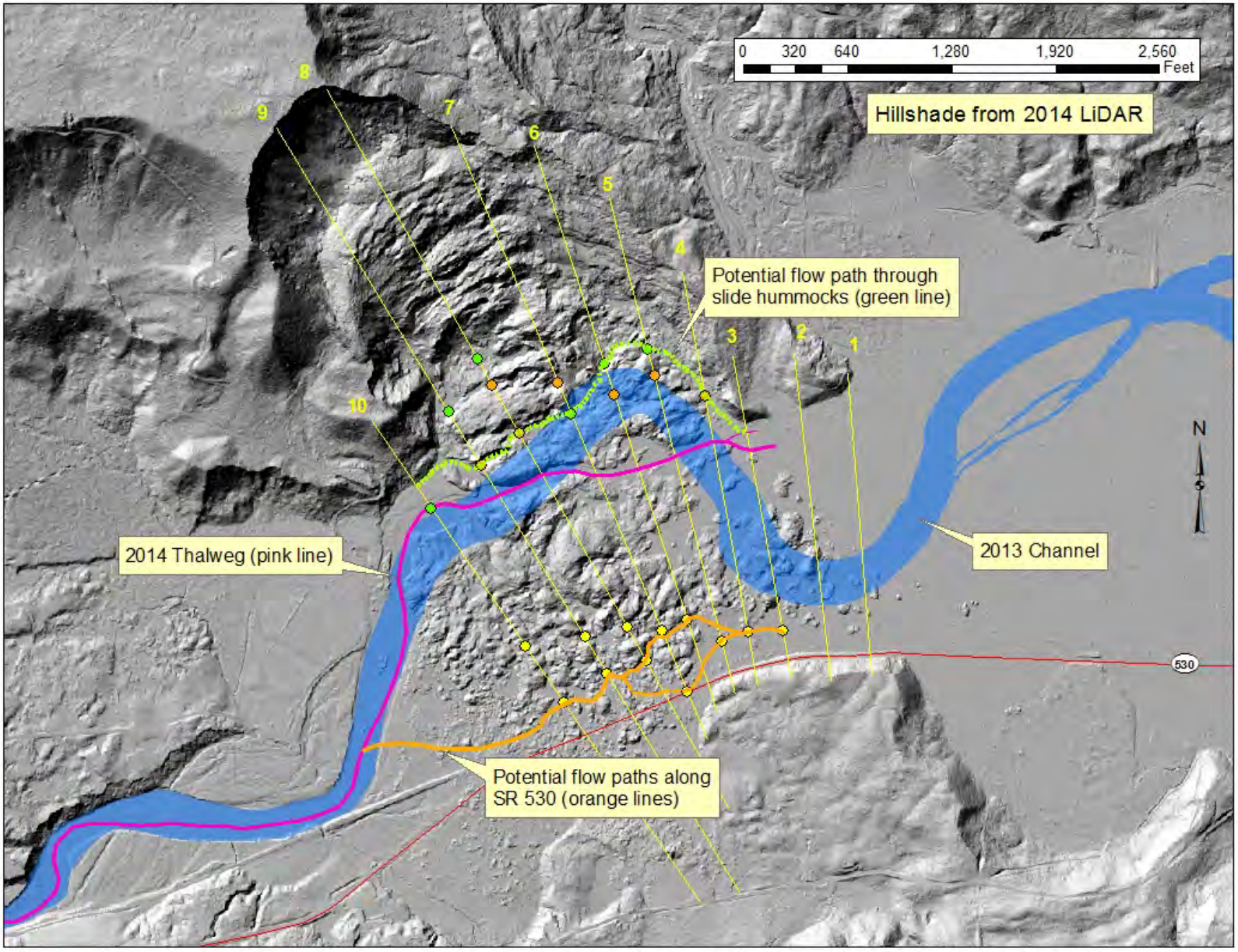
Hydraulic Analyses

Q = 26,000 cfs (~10-YR)– Depth

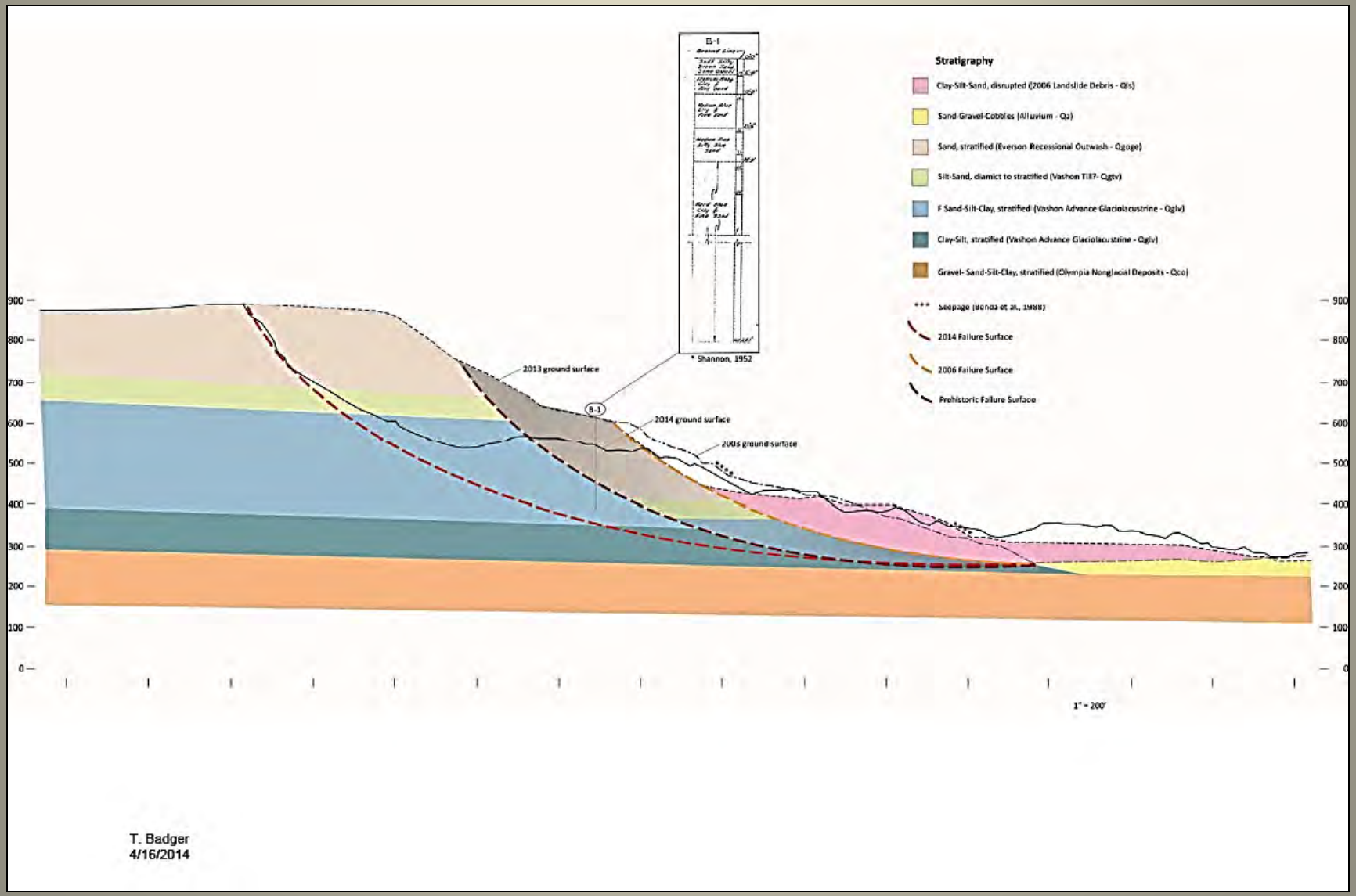


PRELIMINARY - FOR DISCUSSION PURPOSES ONLY

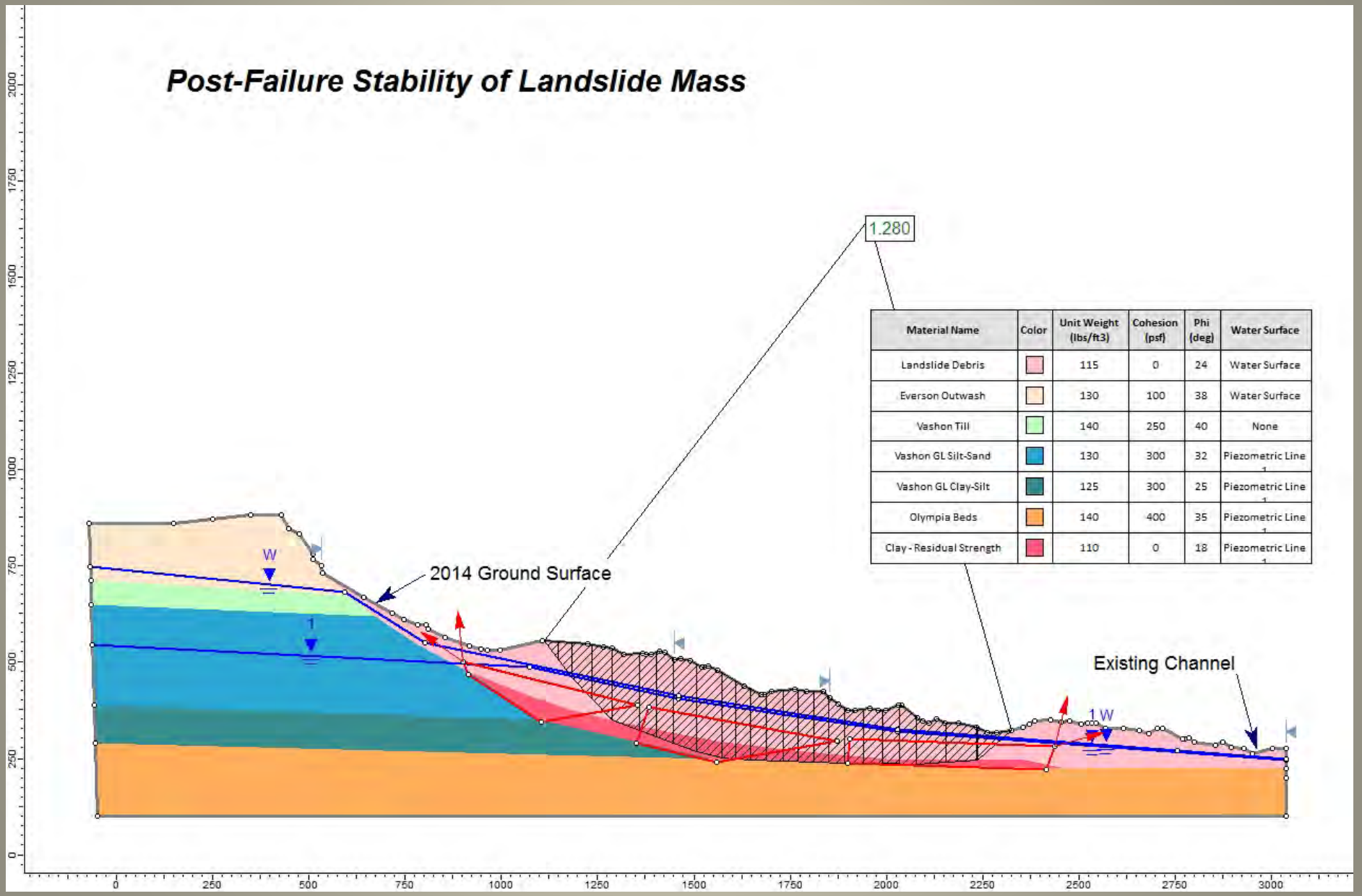
Potential Flow Paths



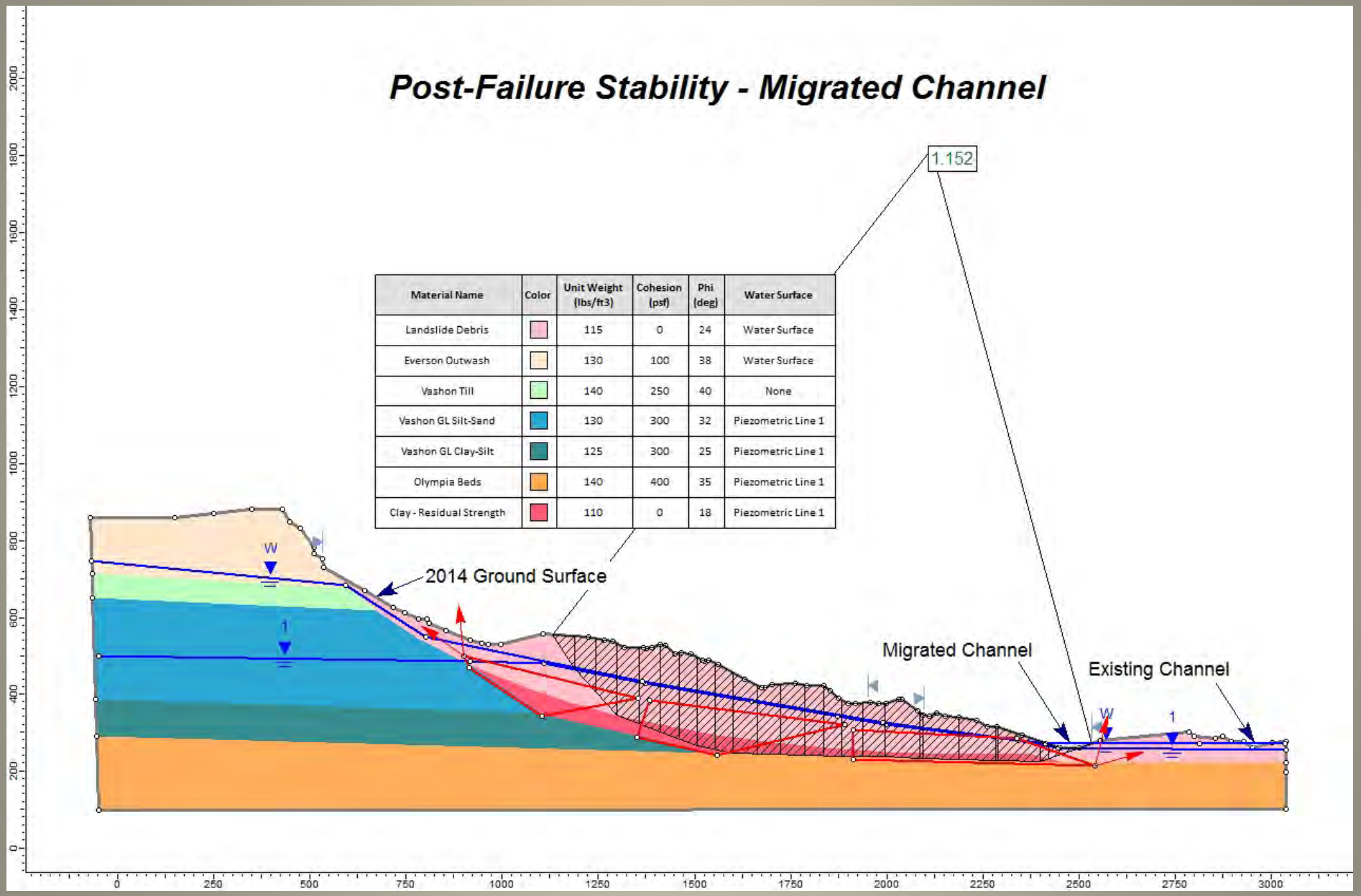
Conceptual Geologic Section



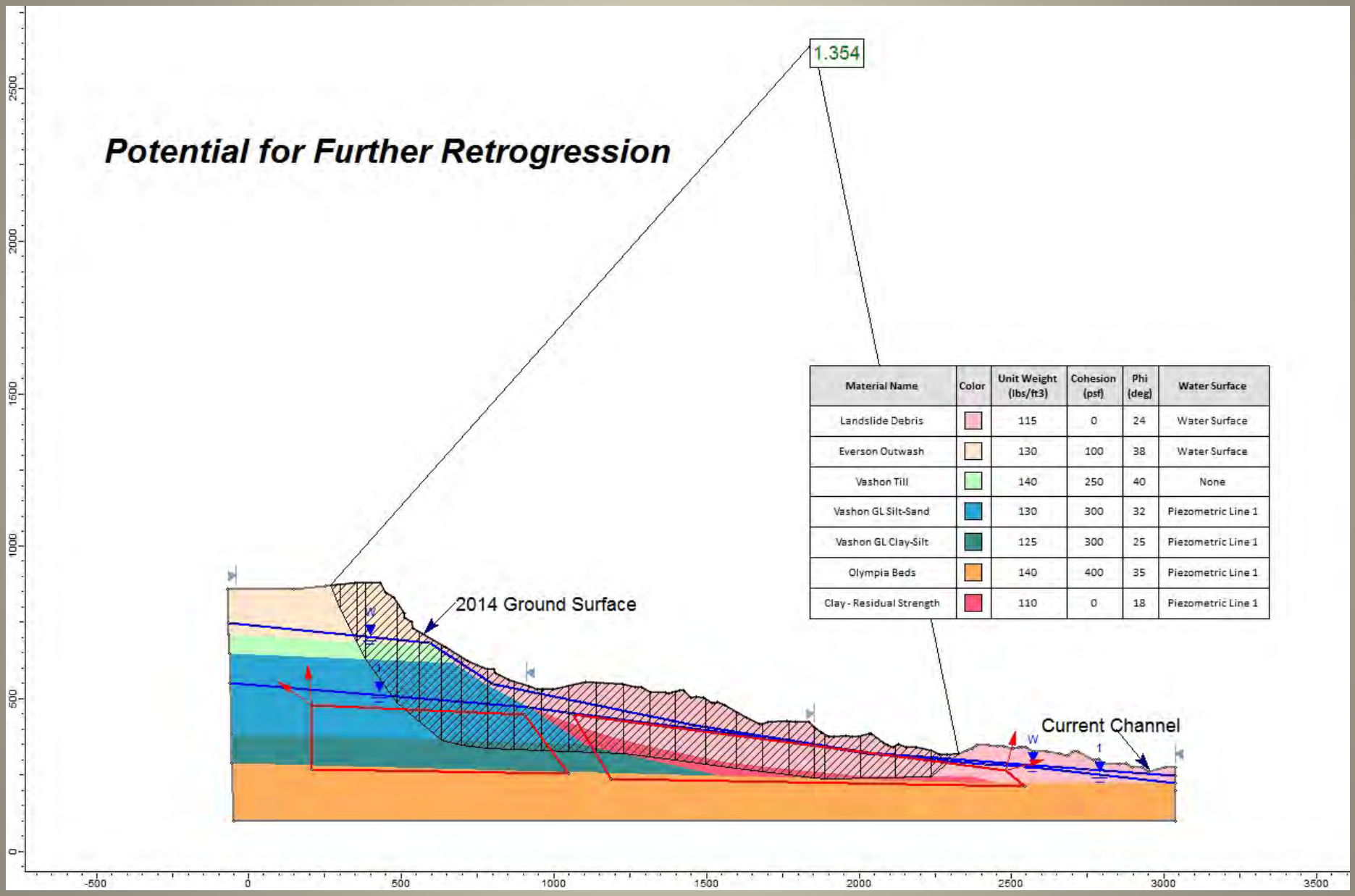
Post-Failure Stability of Landslide Mass



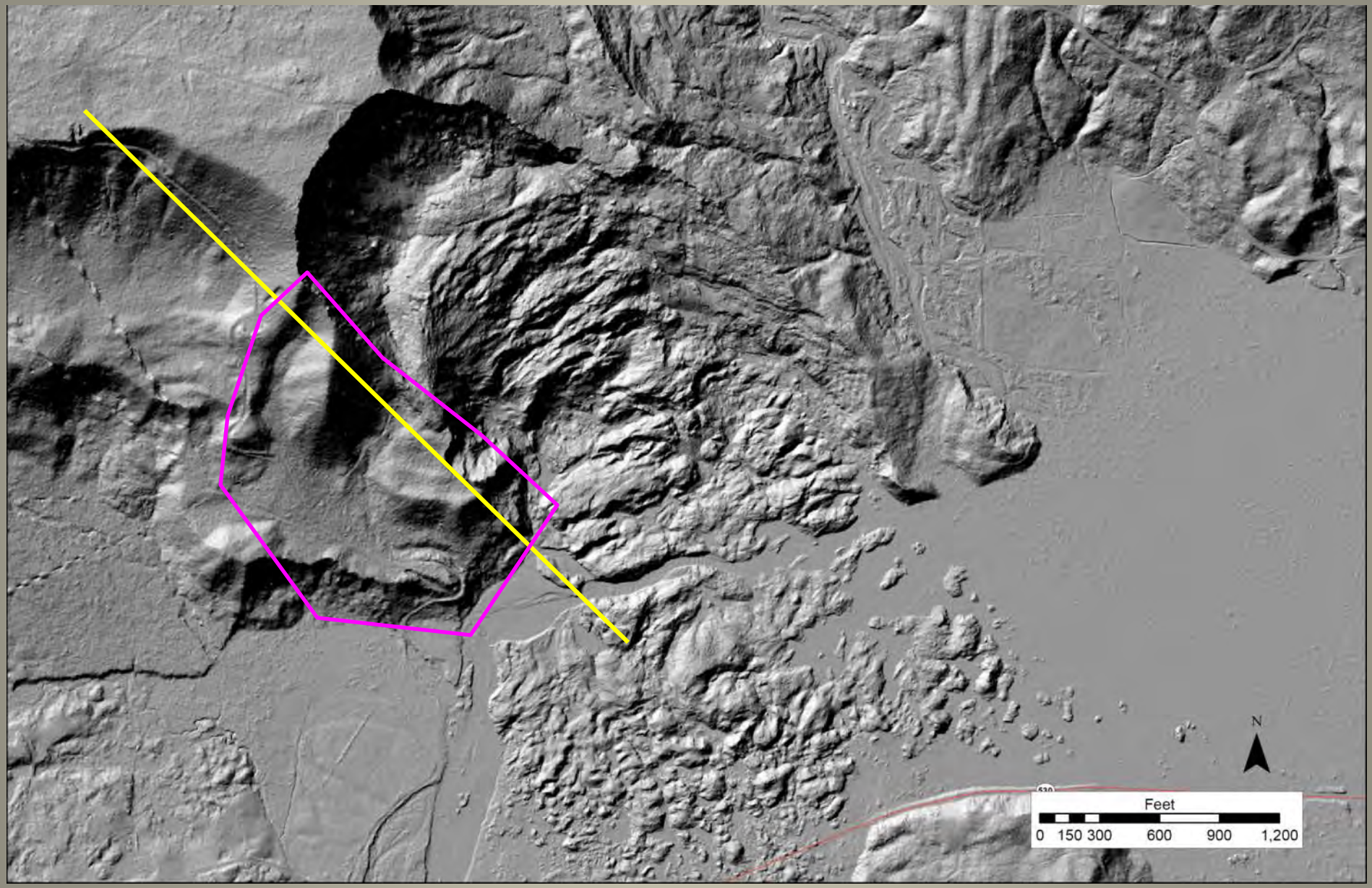
Post-Failure Stability - Migrated Channel



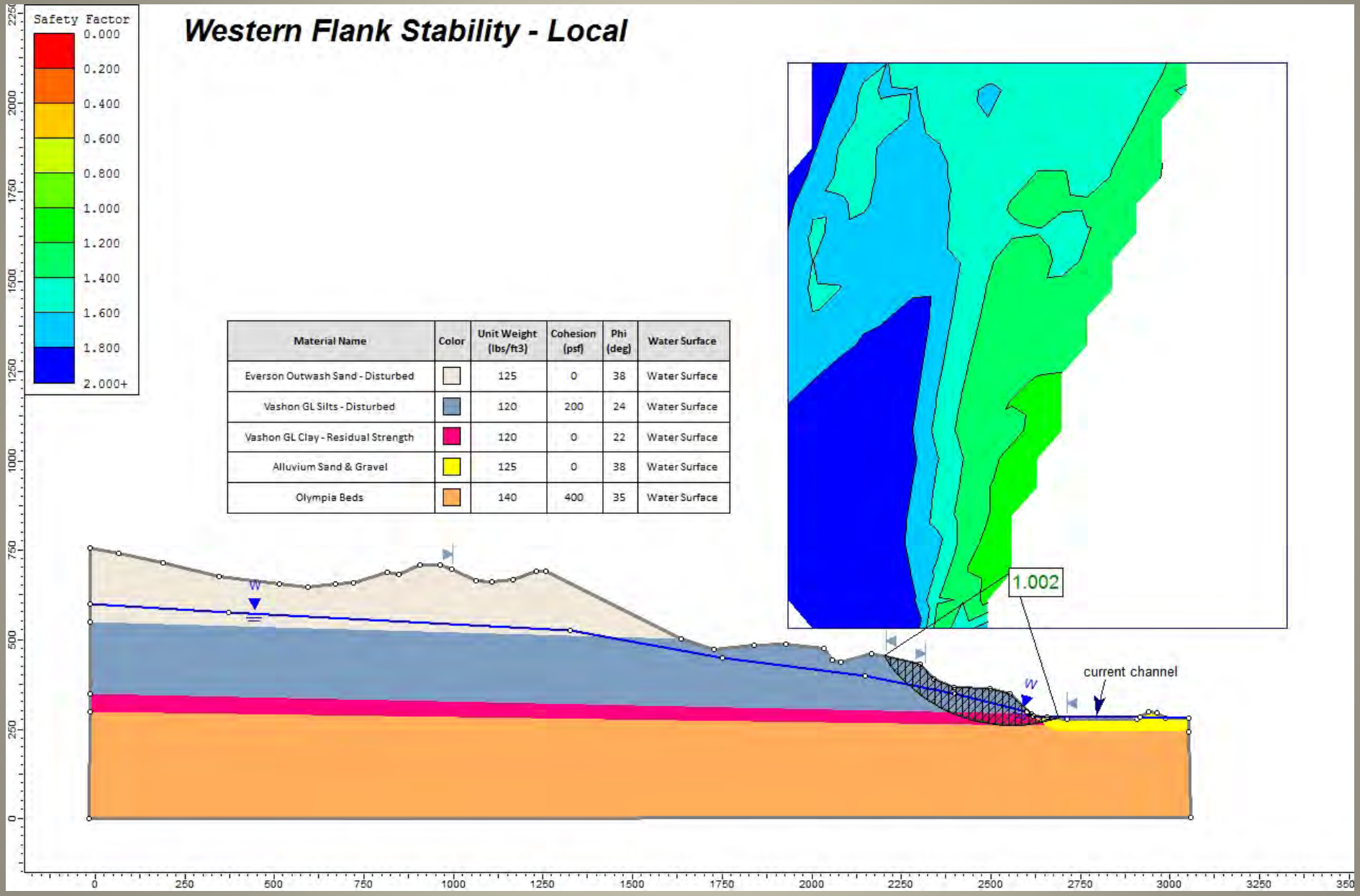
Potential for Further Retrogression



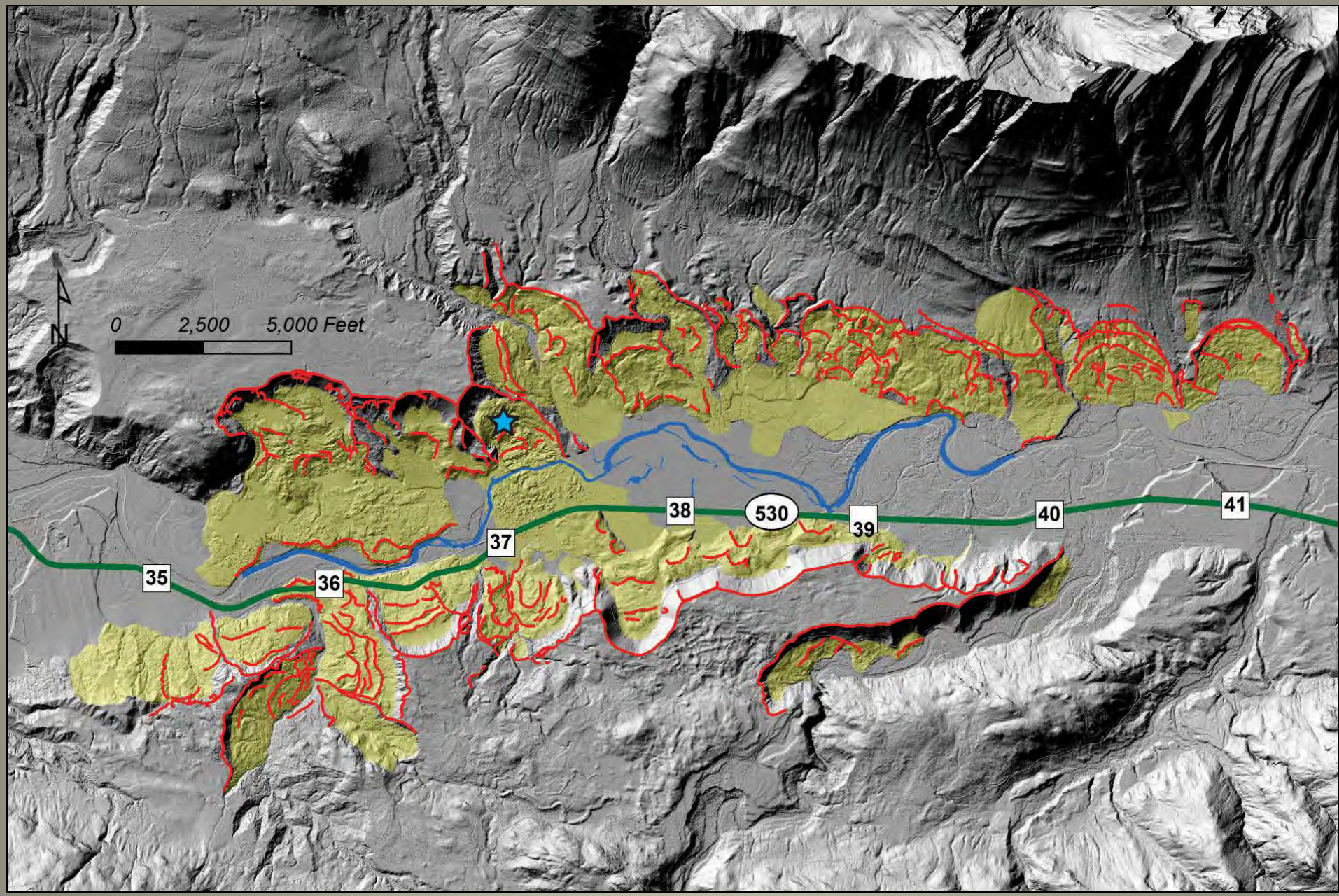
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)	Water Surface
Landslide Debris		115	0	24	Water Surface
Everson Outwash		130	100	38	Water Surface
Vashon Till		140	250	40	None
Vashon GL Silt-Sand		130	300	32	Piezometric Line 1
Vashon GL Clay-Silt		125	300	25	Piezometric Line 1
Olympia Beds		140	400	35	Piezometric Line 1
Clay - Residual Strength		110	0	18	Piezometric Line 1


N
Feet
0 150 300 600 900 1,200

Western Flank Stability - Local

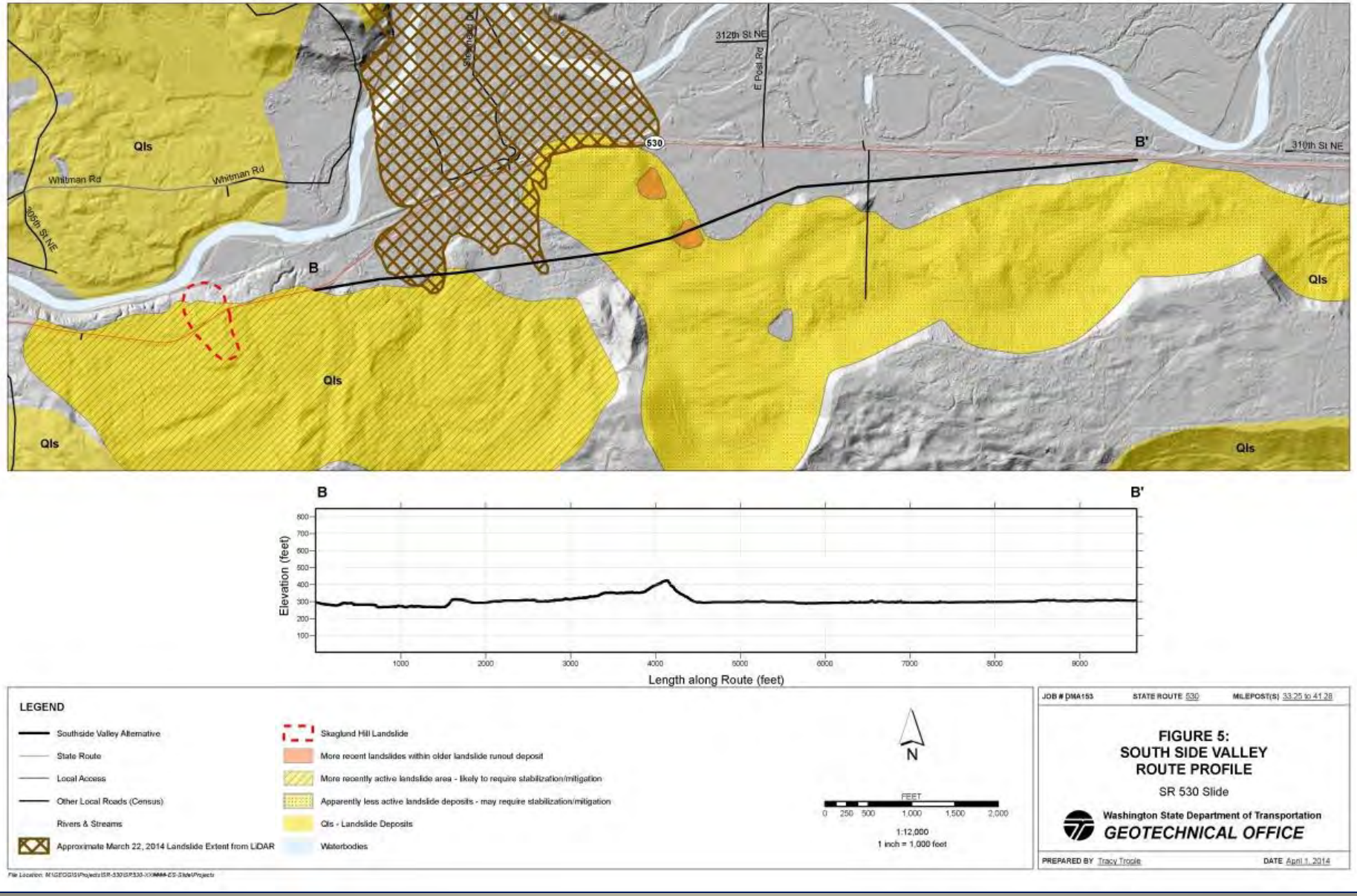


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)	Water Surface
Everson Outwash Sand - Disturbed		125	0	38	Water Surface
Vashon GL Silts - Disturbed		120	200	24	Water Surface
Vashon GL Clay - Residual Strength		120	0	22	Water Surface
Alluvium Sand & Gravel		125	0	38	Water Surface
Olympia Beds		140	400	35	Water Surface

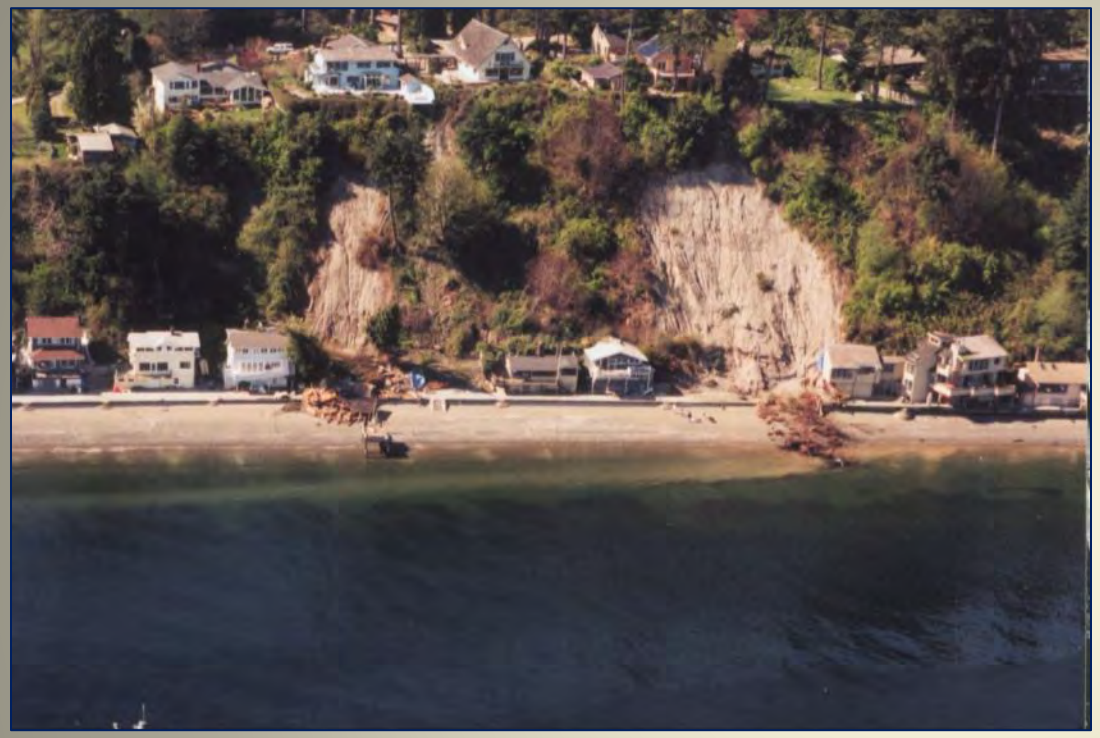


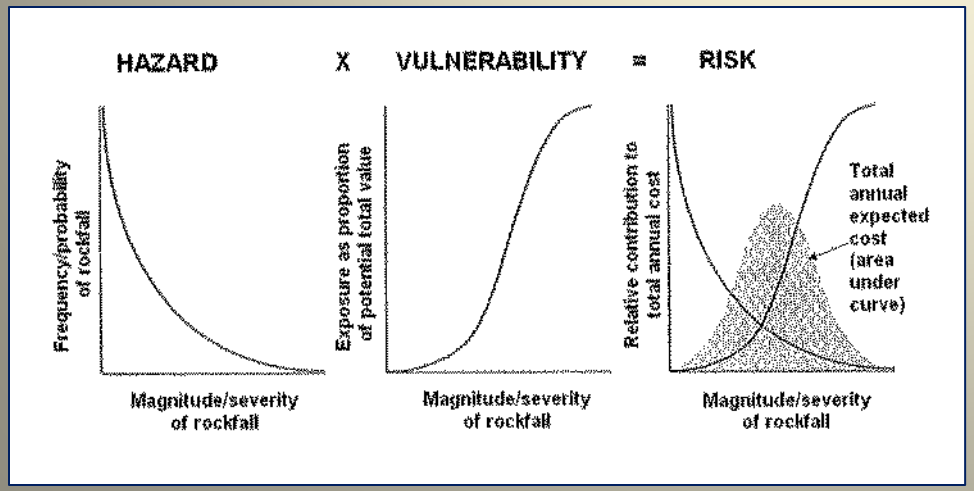
Gerstel and Badger, 2014

SR-530 Realignment Alternatives



Risk Exposure



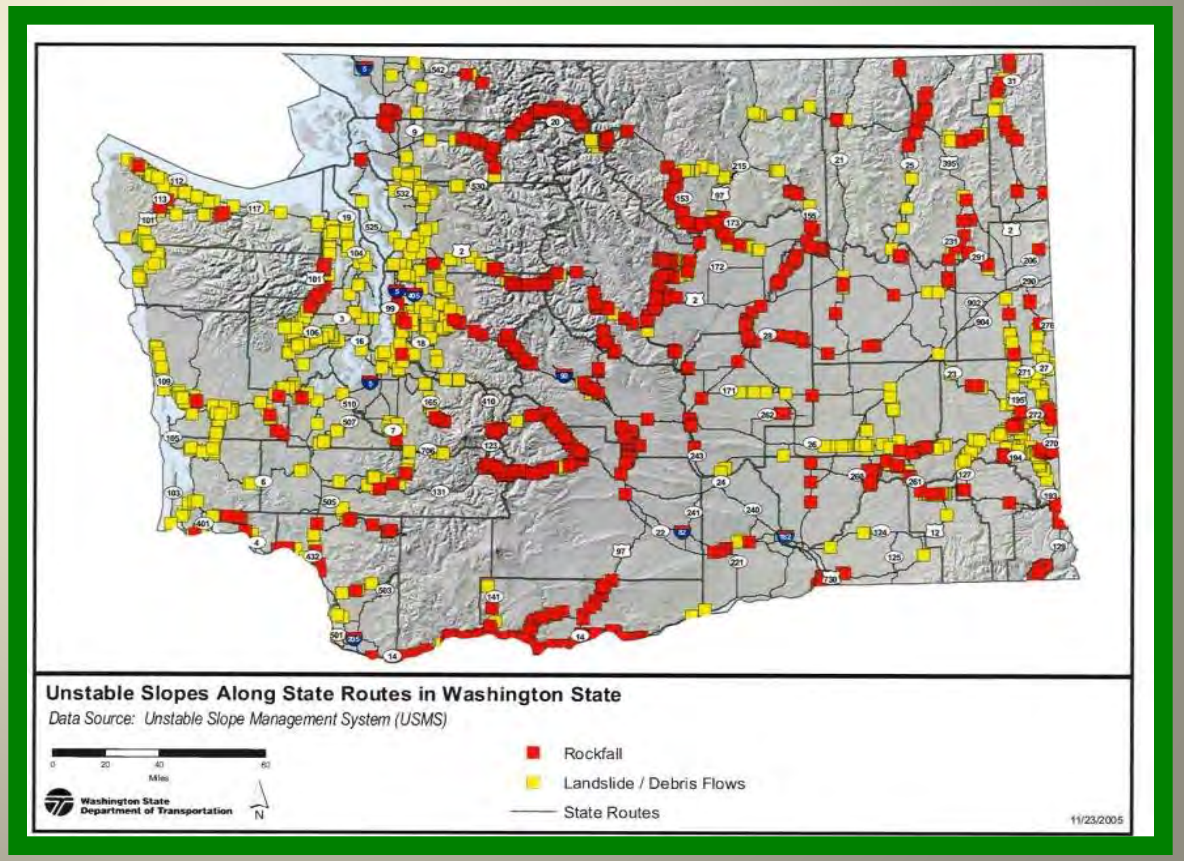


Hazard Mitigation

- Avoid
- Protect
- Stabilize
- Monitor-Warn

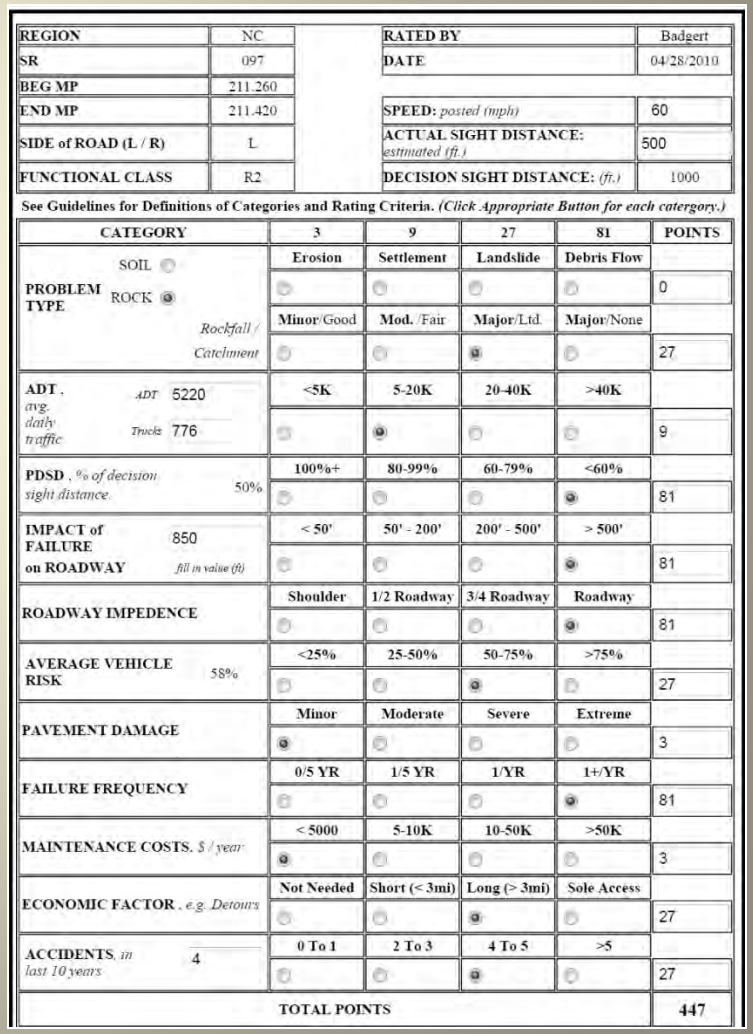
In support of priority programming, WSDOT launched the USMS in 1993, which includes four asset management activities:

- *Inventory development*



In support of priority programming, WSDOT launched the USMS in 1993, which includes four asset management activities:

- *Inventory development*
- *Slope ranking*



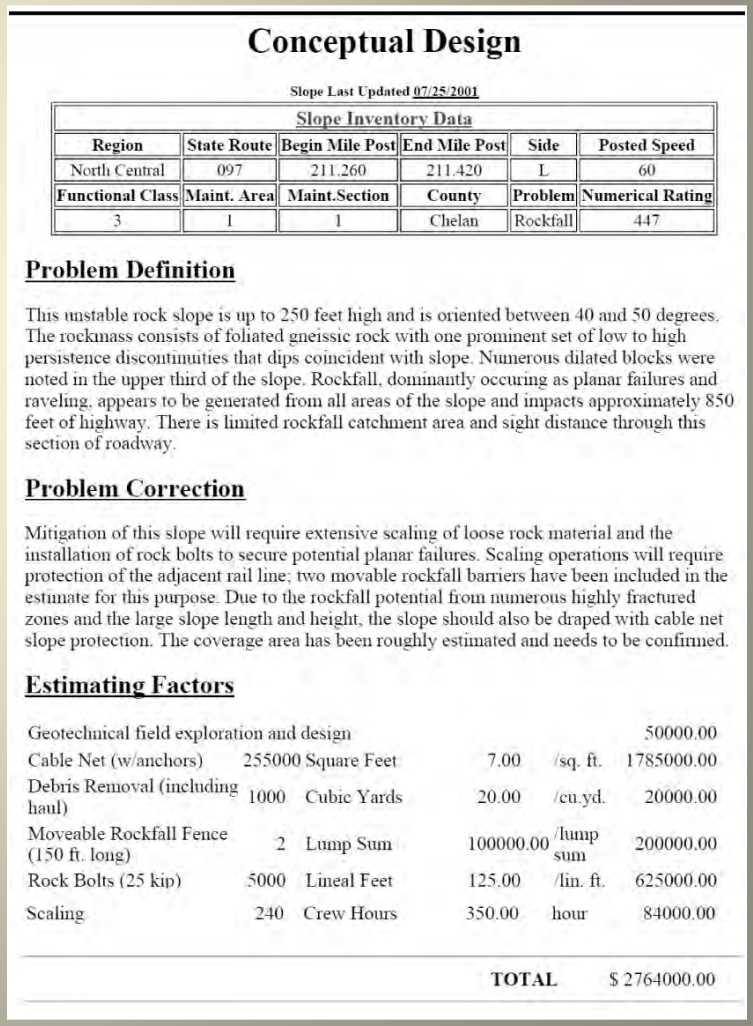
REGION	NC	RATED BY	Badgert
SR	097	DATE	04/28/2010
BEG MP	211.260		
END MP	211.420	SPEED: *posted (mph)*	60
SIDE of ROAD (L / R)	L	ACTUAL SIGHT DISTANCE: *estimated (ft.)*	500
FUNCTIONAL CLASS	R2	DECISION SIGHT DISTANCE: *(ft.)*	1000

See Guidelines for Definitions of Categories and Rating Criteria. *(Click Appropriate Button for each catergory.)*

CATEGORY	3	9	27	81	POINTS
PROBLEM TYPE — SOIL	Erosion	Settlement	Landslide	Debris Flow	
PROBLEM TYPE — ROCK	○	○	○	○	0
	Minor/Good	Mod. /Fair	Major/Ltd.	Major/None	
Rockfall / Catchment	○	○	●	○	27
ADT, *avg. daily traffic* — ADT 5220	<5K	5-20K	20-40K	>40K	
Trucks 776	○	●	○	○	9
PDSD, *% of decision sight distance* — 50%	100%+	80-99%	60-79%	<60%	
	○	○	○	●	81
IMPACT of FAILURE on ROADWAY — 850 *fill in value (ft)*	< 50'	50' - 200'	200' - 500'	> 500'	
	○	○	○	●	81
ROADWAY IMPEDENCE	Shoulder	1/2 Roadway	3/4 Roadway	Roadway	
	○	○	○	●	81
AVERAGE VEHICLE RISK — 58%	<25%	25-50%	50-75%	>75%	
	○	○	●	○	27
PAVEMENT DAMAGE	Minor	Moderate	Severe	Extreme	
	●	○	○	○	3
FAILURE FREQUENCY	0/5 YR	1/5 YR	1/YR	1+/YR	
	○	○	○	●	81
MAINTENANCE COSTS, *$ / year*	< 5000	5-10K	10-50K	>50K	
	●	○	○	○	3
ECONOMIC FACTOR, *e.g. Detours*	Not Needed	Short (< 3mi)	Long (> 3mi)	Sole Access	
	○	○	●	○	27
ACCIDENTS, *in last 10 years* — 4	0 To 1	2 To 3	4 To 5	>5	
	○	○	●	○	27
TOTAL POINTS					447

In support of priority programming, WSDOT launched the USMS in 1993, which includes four asset management activities:

- *Inventory development*
- *Slope ranking*
- *Project scoping*



Conceptual Design

Slope Last Updated 07/25/2001

Slope Inventory Data					
Region	**State Route**	**Begin Mile Post**	**End Mile Post**	**Side**	**Posted Speed**
North Central	097	211.260	211.420	L	60
Functional Class	**Maint. Area**	**Maint.Section**	**County**	**Problem**	**Numerical Rating**
3	1	1	Chelan	Rockfall	447

Problem Definition

This unstable rock slope is up to 250 feet high and is oriented between 40 and 50 degrees. The rockmass consists of foliated gneissic rock with one prominent set of low to high persistence discontinuities that dips coincident with slope. Numerous dilated blocks were noted in the upper third of the slope. Rockfall, dominantly occuring as planar failures and raveling, appears to be generated from all areas of the slope and impacts approximately 850 feet of highway. There is limited rockfall catchment area and sight distance through this section of roadway.

Problem Correction

Mitigation of this slope will require extensive scaling of loose rock material and the installation of rock bolts to secure potential planar failures. Scaling operations will require protection of the adjacent rail line; two movable rockfall barriers have been included in the estimate for this purpose. Due to the rockfall potential from numerous highly fractured zones and the large slope length and height, the slope should also be draped with cable net slope protection. The coverage area has been roughly estimated and needs to be confirmed.

Estimating Factors

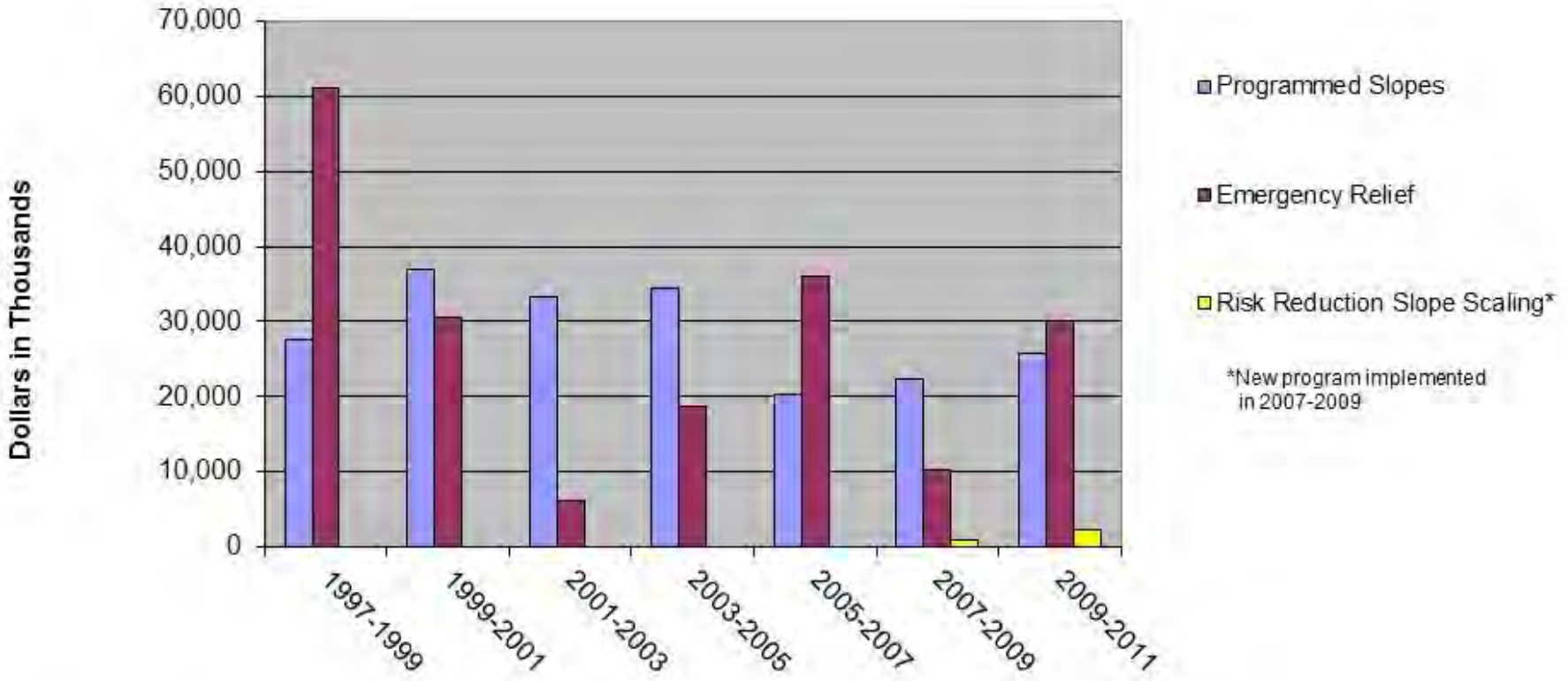
Geotechnical field exploration and design					50000.00
Cable Net (w/anchors)	255000	Square Feet	7.00	/sq. ft.	1785000.00
Debris Removal (including haul)	1000	Cubic Yards	20.00	/cu.yd.	20000.00
Moveable Rockfall Fence (150 ft. long)	2	Lump Sum	100000.00	/lump sum	200000.00
Rock Bolts (25 kip)	5000	Lineal Feet	125.00	/lin. ft.	625000.00
Scaling	240	Crew Hours	350.00	hour	84000.00
			TOTAL		$ 2764000.00

In support of priority programming, WSDOT launched the USMS in 1993, which includes four asset management activities:

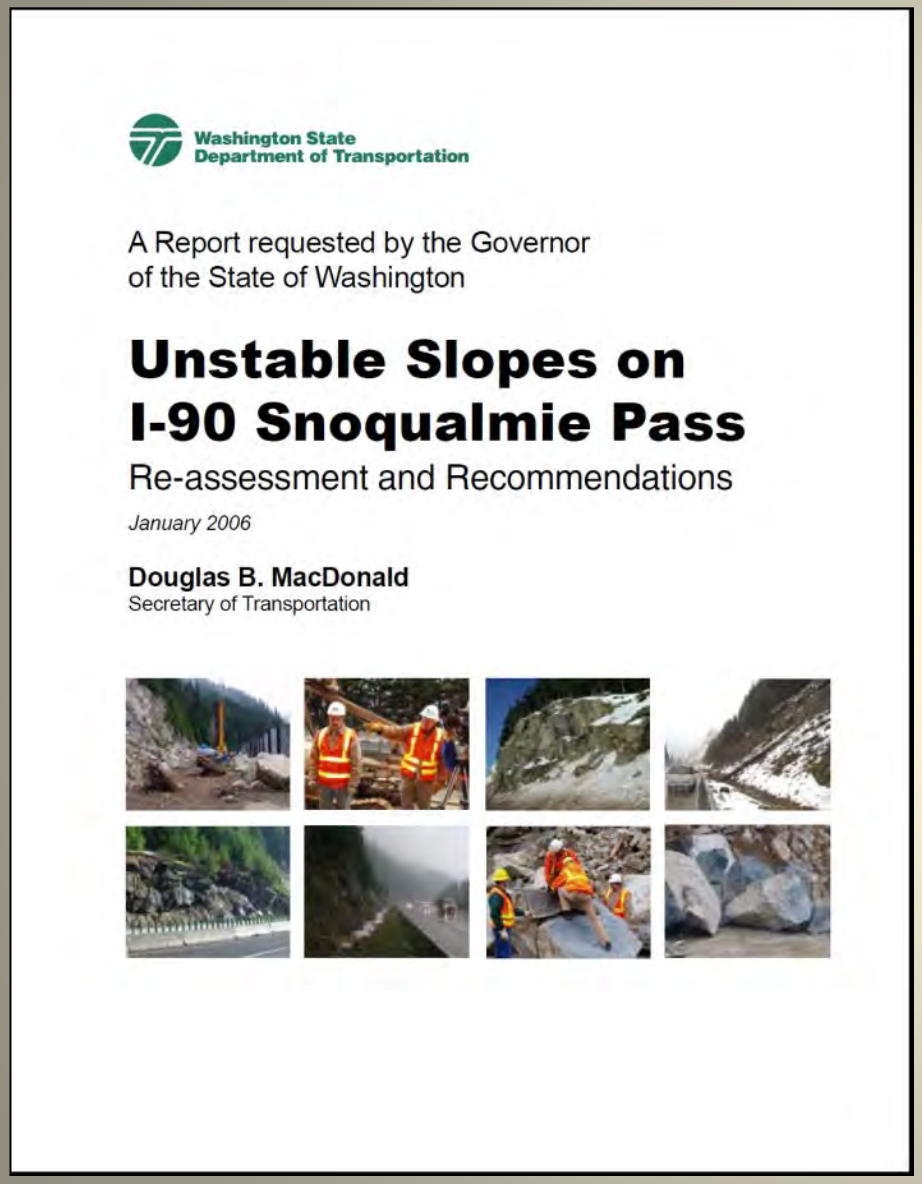
- *Inventory development*
- *Slope ranking*
- *Project scoping*
- *Prioritization*
  - *Benefit-Cost Analysis*
  - *Programming Criteria*

Performance Measurement

Expenditures



Note: 2005-2007 Emergency Relief includes landslide mitigation as a result of severe rain and 500 year flooding events in November of 2006 and December of 2007.
2009-2011 Emergency Relief includes $18,860 for the SR 410 Nile Valley Landslide investigation and temporary SR 410 detour.



"…after three decades of stabilization work, the opinion of the geotechnical specialist involved since inception is that only now are the benefits clearly recognizable".

Golder Associates (2005 WSDOT program evaluation) cited the experience of a comparable rockfall maintenance program for a railroad in British Columbia involving about 750 sites

2 May 2014 Badakhshan Landslide

Opportunities

Emergency Response

- Rapid response geohazards team
- Interagency cooperation/responsibilities
- Discretionary immunity for betterments??

Intermediate/Long Term

- LS inventory-susceptibility-hazard maps
- Avoidance & monitor-warn strategies
- Timber harvest effects on GW recharge??
- Cumulative effects from development??
- Public engagement