# Resources and opportunities to better manage landslide risk

Tom Badger

# WSDOT's Initial Response Efforts

- ESF1-Transportation lead
- Science teams support





#### Landslide Monitoring

Aerial imagery flown 04/02/2014







- Extensometer
- Engineering lookout
- Lake level gage
- Scarp ponitoring point
- Terrestrial lidar station
- USGS Spider

SR530 Slide Landslide monitoring sites updated 4/14/2014 - 0930 - SLS

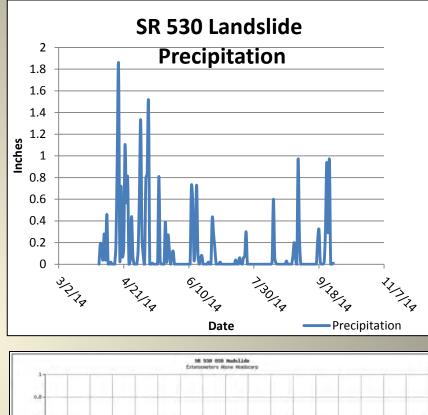
Meters

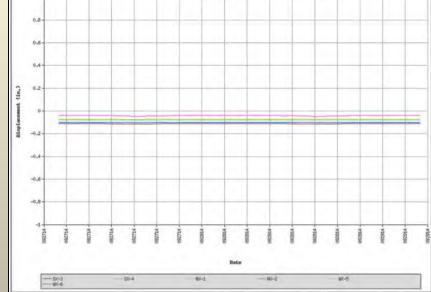
100

Feet

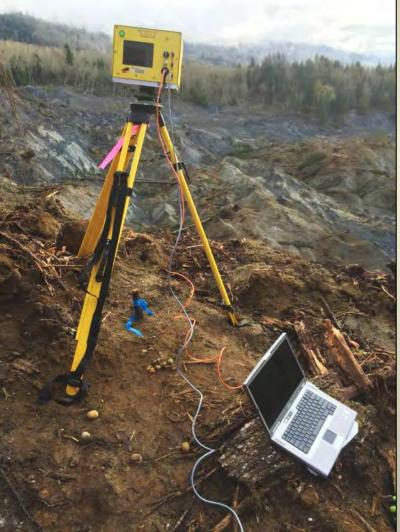
- d 4/14/2014 0930 SLS 50
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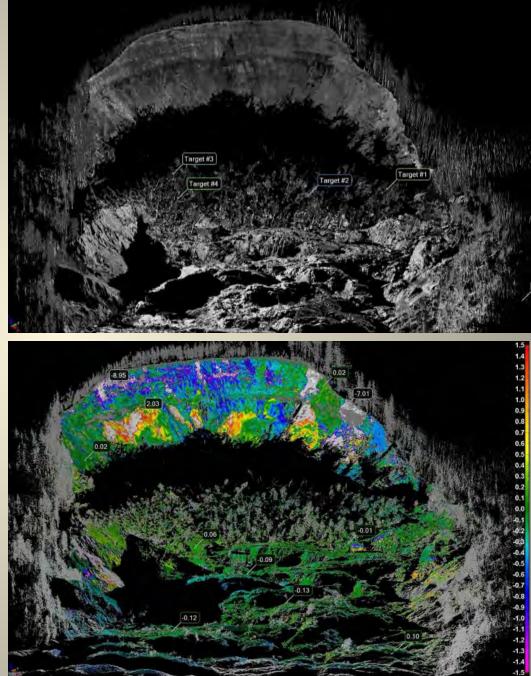




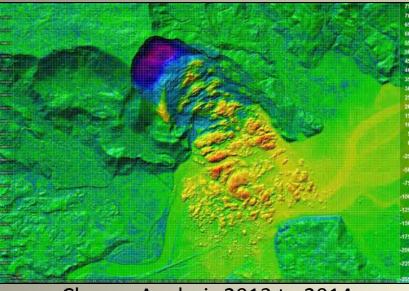


#### Landslide Monitoring Laser Scanning

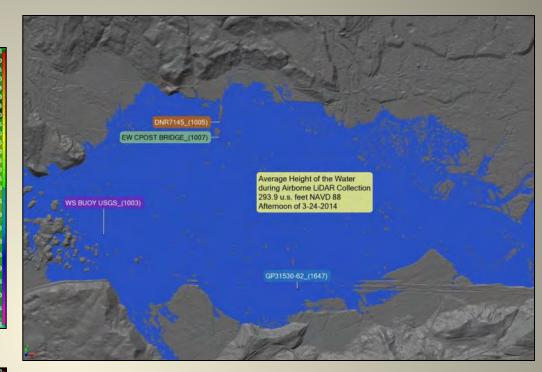


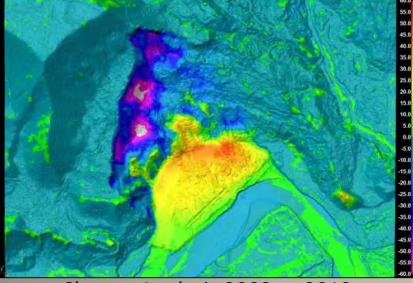


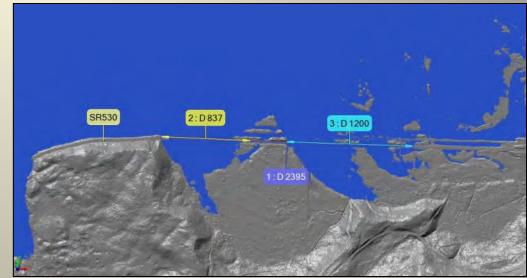
### **Mapping Products**



Change Analysis 2013 to 2014



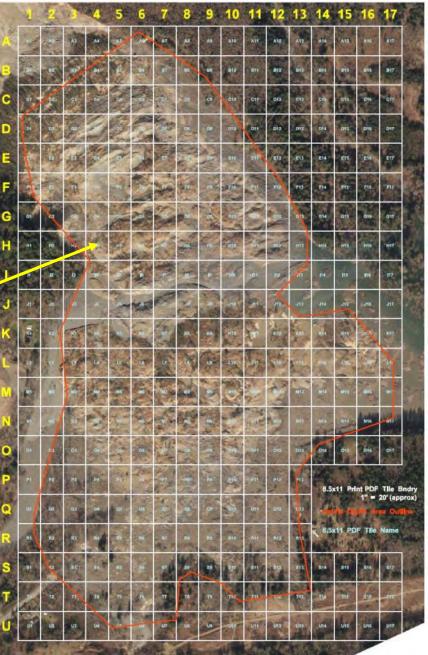




Change Analysis 2003 to 2013

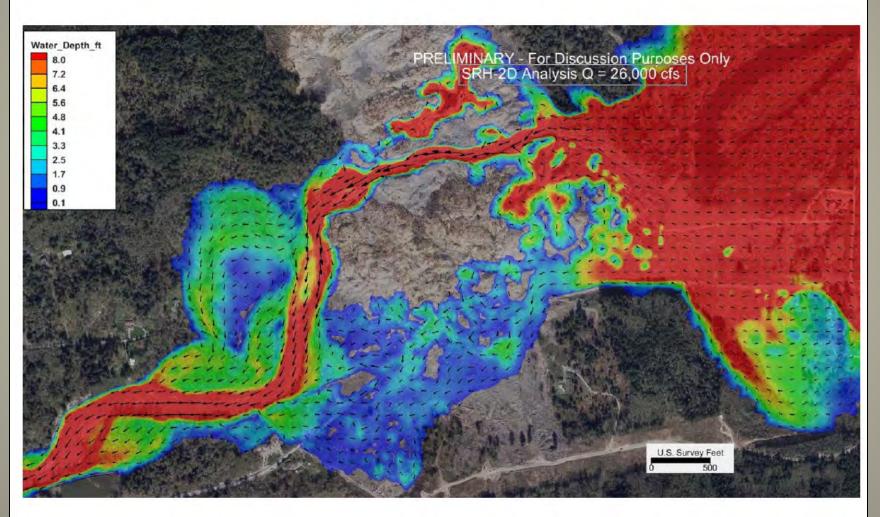
# **Mapping Products**





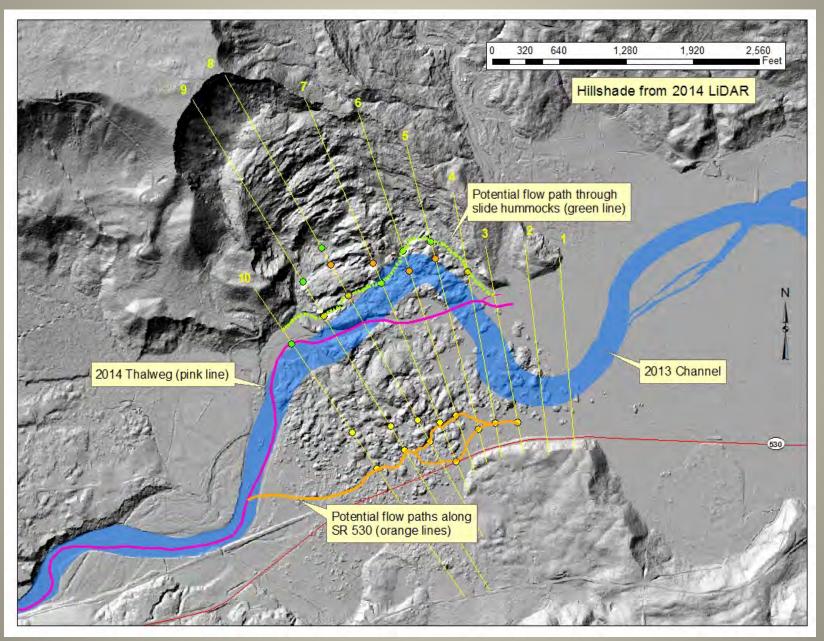
#### Hydraulic Analyses

#### Q = 26,000 cfs (~10-YR)- Depth

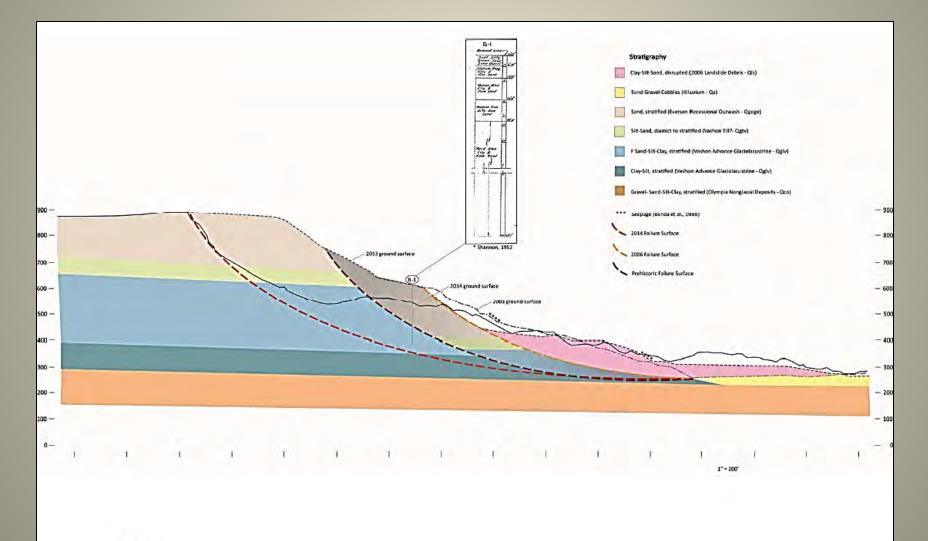


PRELIMINARY - FOR DISCUSSION PURPOSES ONLY

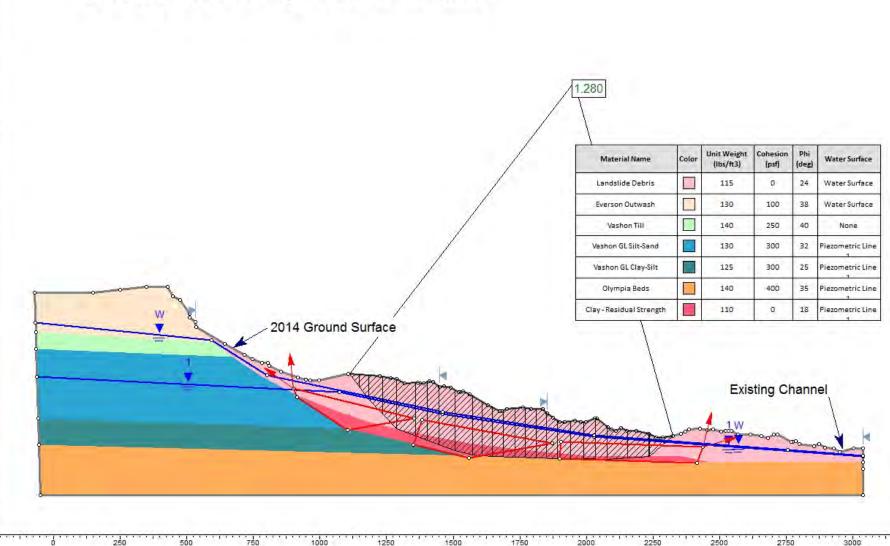
### **Potential Flow Paths**



### **Conceptual Geologic Section**



T. Badger 4/16/2014



#### Post-Failure Stability of Landslide Mass

#### **Post-Failure Stability - Migrated Channel**

2000

1800

1.1.1

1600

1400

1200

1000

14.1

800

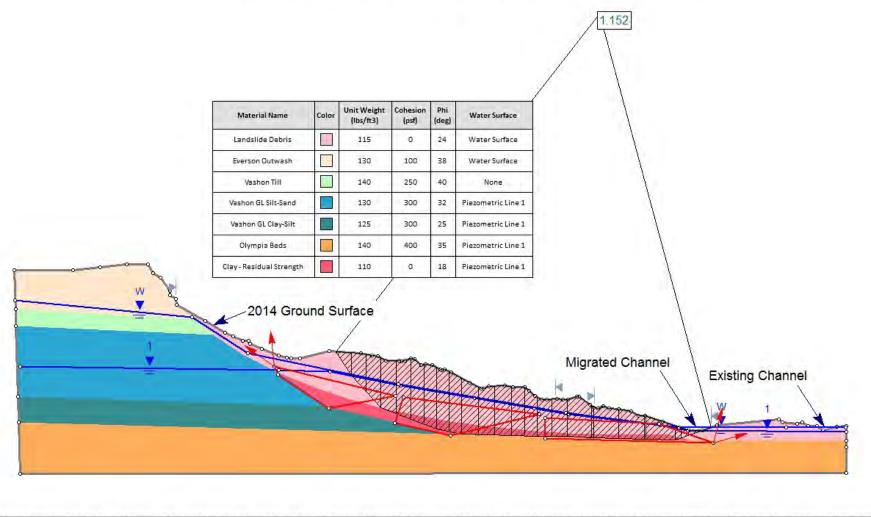
800

÷

40

200

0-



0 250 500 750 1000 1250 1500 1750 2000 2250 2500 2750 3000



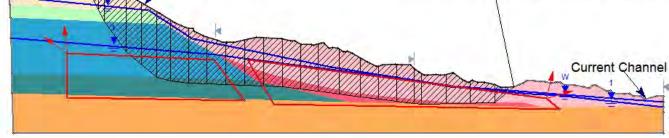
200

000

200

-500

Material Name	Color	Unit Weight (Ibs/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 :	
Vashon GL Clay-Silt		125	300	25	Piezometric Line :	
Olympia Beds		140	400	35	Piezometric Line :	
Clay - Residual Strength		110	0	18	Piezometric Line	

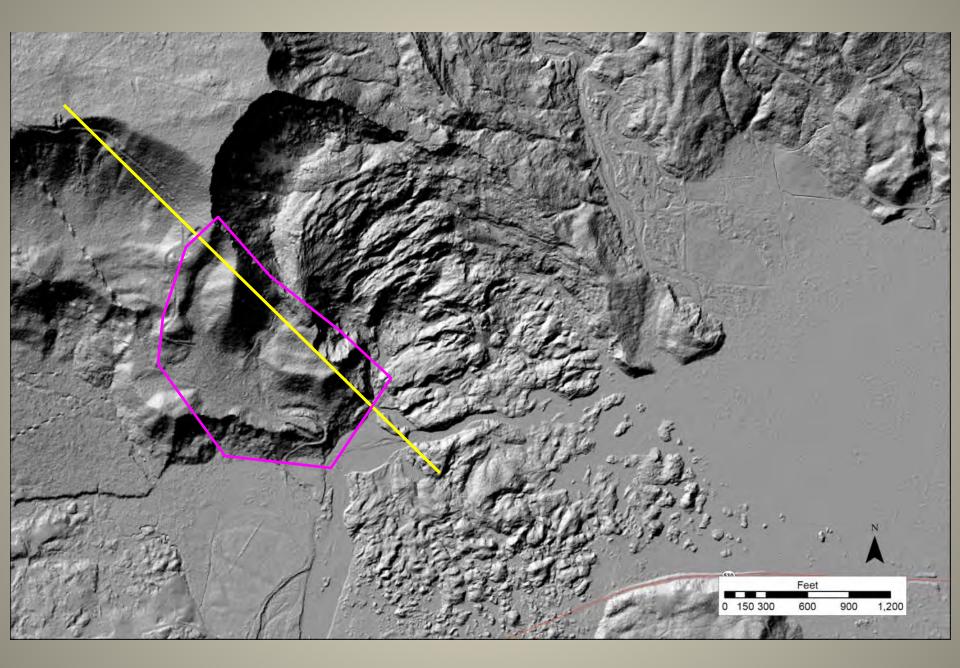


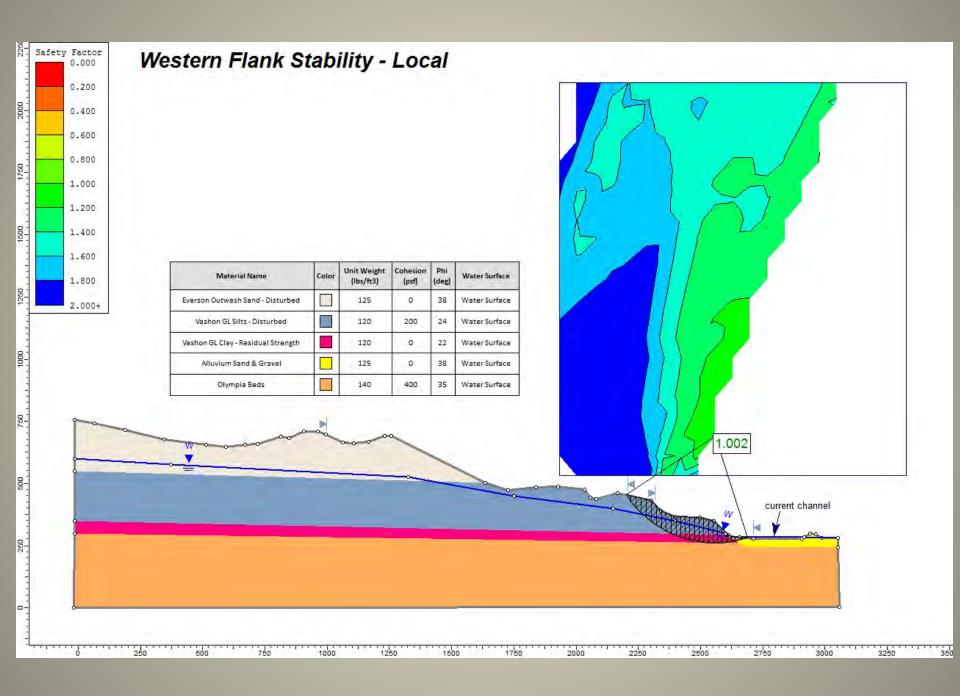
2014 Ground Surface

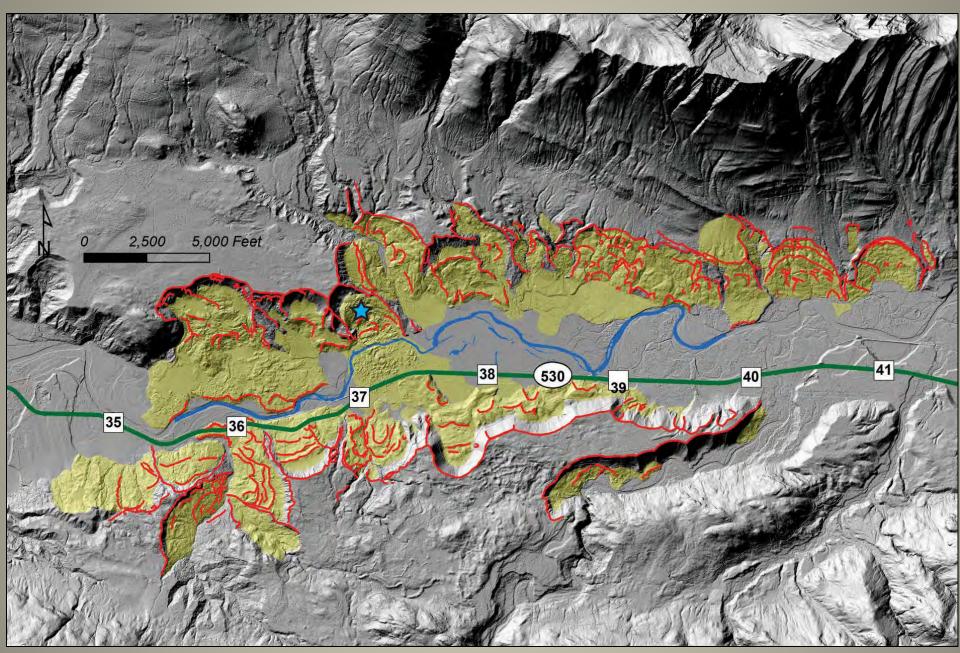
0 500 1000 1500 2000 2500 3000 3500

1.354



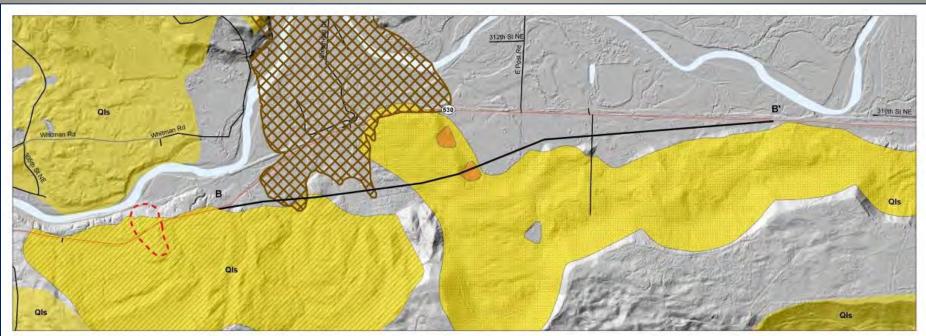


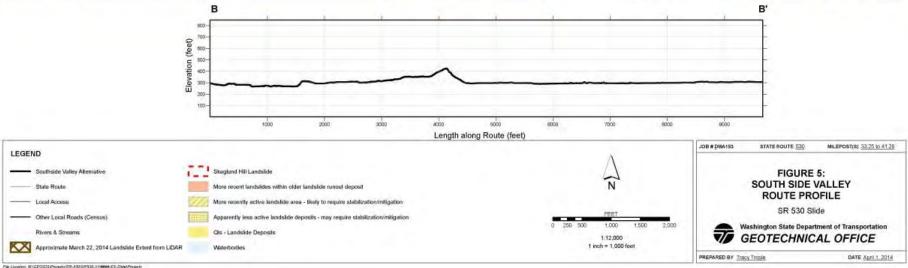




Gerstel and Badger, 2014

### SR-530 Realignment Alternatives

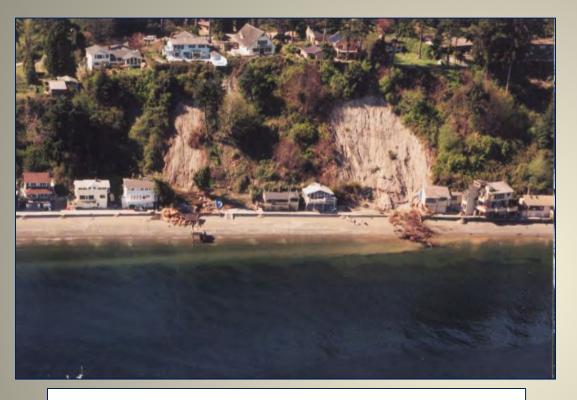


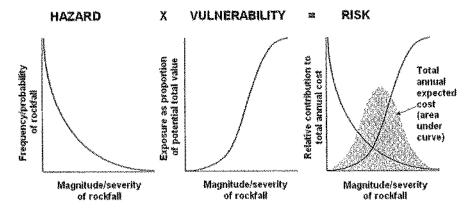


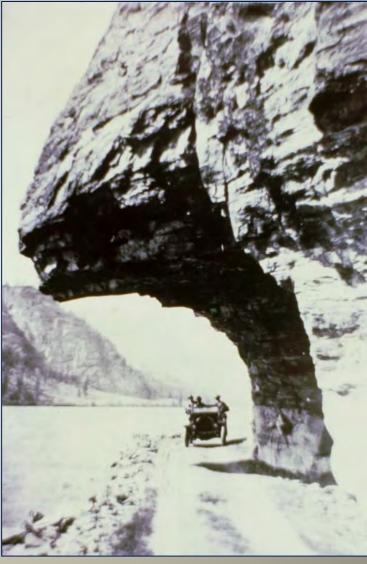




### **Risk Exposure**



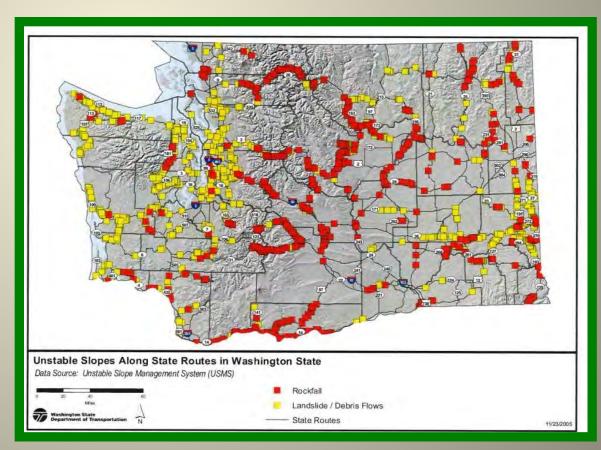




# Hazard Mitigation

- Avoid
- Protect
- Stabilize
- Monitor-Warn

Inventory development



Inventory developmentSlope ranking

SIDE of ROAD (L / R) L ACTUAL S	RATED BY			
END MP       211.420       SPEED: pool         SIDE of ROAD (L / R)       L       ACTUAL S         SIDE of ROAD (L / R)       L       ACTUAL S         FUNCTIONAL CLASS       R2       DECISION         See Guidelines for Definitions of Categories and Rating Criteria. (Cl       CATEGORY       3       9         SOIL       CATEGORY       3       9       0       0       0         PROBLEM ROCK       Erosion       Settlement       0       0       0       0       0         ADT       ADT 5220       <5K				
SIDE of ROAD (L / R) L ACTUAL S SIDE of ROAD (L / R) L FUNCTIONAL CLASS R2 See Guidelines for Definitions of Categories and Rating Criteria. (Cl CATEGORY SOIL CATEGORY SO			1.1.1	
SIDE of ROAD (L / R) FUNCTIONAL CLASS R2 See Guidelines for Definitions of Categories and Rating Criteria. (Cl CATEGORY 3 9 SOIL PROBLEM ROCK TYPE Rockfall / Minor/Good Mod./Fair Catelment Catelment Criteria. (Cl Minor/Good Mod./Fair Catelment Catelment Catelment Criteria. (Cl Minor/Good Mod./Fair Catelment Catelment Catelment Criteria. (Cl Minor/Good Mod./Fair Catelment Catelment Catelmen	SPEED: posted (mph)			
See Guidelines for Definitions of Categories and Rating Criteria. (Cl CATEGORY 3 9 SOIL SOIL CATEGORY 3 9 FORBLEM ROCK MAINTENANCE COSTS. S / year Rockfall / Minor/Good Mod. / Fair Rockfall / Minor/Good Mod. / Fair Catchinent Mainer Soil Settlement Rockfall / Minor/Good Mod. / Fair Catchinent Soil Settlement Minor/Good Mod. / Fair Catchinent Soil Settlement Minor/Good Mod. / Fair Soil Settlement Mod. / Fair Soil Settlement Soil Settlement Minor/Good Mod. / Fair Minor/Good Mod. / Fair Soil Settlement Soil Settlement Soil Settlement Soil Settlement Soil Settlement Soil Soil Settlement Shoulder 1/2 Roadway Shoulder 1/2 Roadway Shoulde	ACTUAL SIGHT DISTANCE: estimated (fi.)			
CATEGORY         3         9           SOIL         Erosion         Settlement           PROBLEM TYPE         ROCK         Immor/Good         Mod./Fair           Rockfall/ Catchment         Minor/Good         Mod./Fair           ADT         ADT         5220           avg. darby         ADT         5220           darby         Tracks         776           mark         100%+         80-99%           gath         fill markar (b)         Immor/Good           PDSD.% of decision         50%         Soll           sight filstance         50%         Soll           MARCT of FAILURE         850         <50'	SIGHT DISTA	NCE: (fi.)	1000	
SOIL     Erosion     Settlement       PROBLEM TYPE     ROCK     Minor Good     Mod. / Fair       Rockfall/ Catchment     Minor Good     Mod. / Fair       ADT.     ADT 5220     <5K	ick Appropriate	Button for ea	ch catergory	
SOIL         Minor Good         Mod. / Fair           Rockfall / Catciment         Minor Good         Mod. / Fair           Rockfall / Catciment         Minor Good         Mod. / Fair           ADT         S220         <5K	27	81	POINTS	
PROBLEM TYPE         Rockfall         Immediate         Minor/Good         Mod. / Fair           Rockfall         Catchmen         Immediate         Mod. / Fair           ADT         ADT         5220 <sk< td="">         5-20K           arg. dathy         Tracks         776         Immediate         Immediate           PDSD         % of decision         50%         Immediate         Immediate           prostly         fill in value (b)         Immediate         Immediate         Immediate           PDSD         % of decision         Stonuler         1/2 Roadway           prostly         fill in value (b)         Immediate         Immediate           RACADWAY         fill in value (b)         Immediate         Immediate           RACADWAY IMPEDENCE         Shoulder         1/2 Roadway           RISK         SS%         Immediate         Immediate           AVERAGE VEHICLE         S8%         Immediate         Immediate           FAILURE FREQUENCY</sk<>	Landslide	Debris Flow	¢ _	
Rockfall Catchment     Minor/Good     Mod./Fair       Catchment     Image: Catchment     Image: Catchment       ADT.     ADT     5220       (1)     ADT     5220       (1)     Truck:     776       (1)     Image: Catchment     Image: Catchment       PDSD.     % of decision     100%+       sight distance     50%     Image: Catchment       IMPACT of fair     850     <50°	0	Ø	0	
Catchment     Image: Catchment       ADT.     ADT       (TY2)     (SK)       (ADT)     5220       (TY2)     (SK)       (ADT)     Trucks       (ADT)     (ADT)       <	Major/Ltd.	Major/Non	e	
arg.     An OLLO       daily     Tracks 776       pDSD., % of decision     100%+       sight distance     50%       MPACT of 850     < 50°	8	0	27	
datty traffic     Tracks     776     Image: Constraint of the second s	20-40K	>40K		
FDSD, 's of acction'     50%       sight distance.     50%       IMPACT of FAILURE on ROADWAY     850       on ROADWAY     fill in value (f)       ROADWAY IMPEDENCE     Shoulder       AVERAGE VEHICLE RISK     225%       PAVEMENT DAMAGE     Minor       FAILURE FREQUENCY     0/5 YR       MAINTENANCE COSTS. 5 / year     0       Shout Comparison     50%       Shout Comparison     50%	0	Ó	9	
sight distance. 50% Sight distance. 50% 50° - 200° FAILURE 850 50° - 200° FAILURE 850 50° - 200° FAILURE 850 50° - 200° FAILURE 850 50° - 200° Shoulder 1/2 Roadway Shoulder 1/2 Roadway Shou	60-79%	<60%		
FAILURE 850 on ROADWAY fill in value (f) ROADWAY IMPEDENCE 58% AVERAGE VEHICLE 58% RISK 225% 25-50% RISK 0 PAVEMENT DAMAGE 0 FAILURE FREQUENCY 0 MINOR MODERATE FAILURE FREQUENCY 0 Source 510K MAINTENANCE COSTS. 5 / year 0 Source 510K 0 MINOR 510K 0 Source 510K 0 MON Needed Short (< 3mi)	0	9	81	
ou ROADWAY fill m value (f) ROADWAY IMPEDENCE AVERAGE VEHICLE 58% AVERAGE VEHICLE 58% PAVEMENT DAMAGE FAILURE FREQUENCY Minor Moderate 0/5 YR 1/5 YR 0/5 YR 1/5 YR 0/5 -10K 0/5 YR 0/5 -10K 0/5 YR 0/5 YR 0/5 YR 0/5 -10K 0/5 YR 0/5 YR 0/5 YR 0/5 YR 0/5 YR 0/5 YR 0/5 YR 0/5 YR 0/5 YR 0/5 -10K 0/5 -10K 0/5 -10K 0/5 -10K 0/5 YR 0/5 -10K 0/5 -10K	200' - 500'	> 500'		
ROADWAY IMPEDENCE	0		81	
AVERAGE VEHICLE 58% 25.50% 25.50% RISK 58% 25.50% 25.50% PAVEMENT DAMAGE 0 FAILURE FREQUENCY 0 MAINTENANCE COSTS. \$/year 0 CONSTR 1/5 YR 1/5 YR 0 CONSTR	3/4 Roadway	Roadway		
AVERAGE VEHICLE 58% RISK 58% PAVEMENT DAMAGE FAILURE FREQUENCY MAINTENANCE COSTS. 5 / year: COST S	0	Roadway Roadway @ 81		
RISK 58% Minor Moderate PAVEMENT DAMAGE 0 FAILURE FREQUENCY MAINTENANCE COSTS. \$/year CONOMIC FACTOR, e.g. Derowy Not Needed Short (< 3mi)	50-75%	>75%		
PAVEMENT DAMAGE PAILURE FREQUENCY MAINTENANCE COSTS. 5 / year CONSTRUCTION. e.g. Deromy Not Needed Short (< 3mi)	0	<ul> <li>&lt;60%</li> <li></li> <li>&lt;500'</li> <li></li> <li></li> <li>81</li> <li></li> <li>81</li> <li>Roadway</li> <li></li> <li></li></ul> <li></li> <li> <li></li> <li></li> <li></li> <li></li> <li></li> <li>     &lt;</li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li></li>	27	
Image: Second state	Severe	300           ANCE: (f, l)         100           Button for each cater,         81           POI         0           Major/None         0           Major/None         27,           >40K         9           <60%		
FAILURE FREQUENCY     Image: Constraint of the second	0		3	
MAINTENANCE COSTS, 5 / year CONOMIC FACTOR, e.g. Detours Not Needed Short (< 3mi)	1/YR	1+/YR	1	
MAINTENANCE COSTS. \$ / year Not Needed Short (< 3mi) ECONOMIC FACTOR . e.g. Derours	0	0	81	
CONOMIC FACTOR . e.e. Detours	10-50K	>50K		
ECONOMIC FACTOR . e.g. Detours	0	Ø	3	
ECONOMIC FACTOR , e.g. Detonrs	Long (> 3mi)	Sole Access		
	a	0	27	
ACCIDENTS. in 4 0 To 1 2 To 3	4 To 5	>5		
last 10 years	â	0	27	

- Inventory development
- Slope ranking
- Project scoping

#### **Conceptual Design**

		Slope Last Updat	ed <u>07/25/2001</u>				
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 explorat	ion and	design			50000.00
Cable Net (w/anchors)	25500	) 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

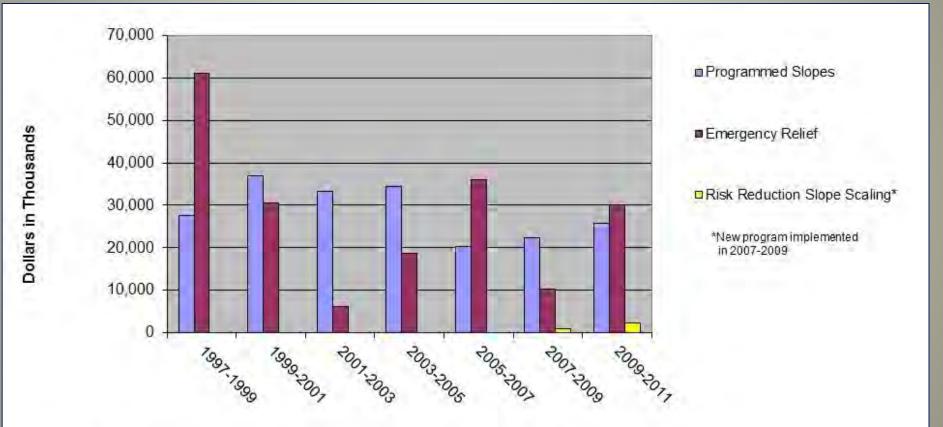
TOTAL

\$ 2764000.00

- 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.



A Report requested by the Governor of the State of Washington

#### Unstable Slopes on I-90 Snoqualmie Pass

Re-assessment and Recommendations

January 2006

Douglas B. MacDonald Secretary of Transportation



"...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