Figure 11. Photo. Site of historical road deformation along Interstate-82 near Benton City.

Geotechnical Background

There has been no long-term history of deformation at the MP 90.6 site. The 2002 report was the first to note the vertical uplift and deformation of the concrete panels in the eastbound lanes. Two boreholes were drilled and SIs installed as part of the 2002/03 geotechnical investigation. Large landslides exist upslope of this road deformation site as well, but to-date this upslope area has not been visibly active.

In the mid- to late-1980's, during excavation around MP 91.9 for the realignment of Interstate-82 near Benton City, WA, an approximately 1000-foot section of the eastbound lanes and the slope above began to deform. Construction was halted and a geotechnical investigation ensued. A number of borings with instrumentation were installed. The conclusion of this investigation was that the excavation had undercut a large, prehistoric landslide and reactivated it. A shear-key rock buttress was constructed to mitigate the upslope landslide movement.

In the early 1990's, tension cracks in the upslope county road and significant vertical movement of the road surface were observed. As a result of these observations, WS-DOT investigated the nature of this new distress and four additional borings were installed in 1993 and 1994. Three were placed upslope of the buttress section and one was located in front of the buttress section at its east end. The three upslope borings experienced significant lateral movement while the boring located in front of the buttress lacked any conclusive evidence of landslide-related movement. A geotechnical summary memorandum was submitted in 1995, concluding that the landslide movement continues upslope of the buttress, but no significant movement was identified in the slope inclinometer (SI) between the buttress face and the deforming eastbound lanes. It was noted that vertical movement of the highway pavement slabs may be due to the presence of a layer of expansive clays in this vicinity.

Vertical displacement continued to be observed in the concrete panels in the eastbound lanes. Since 1992, WS-DOT has removed some of the concrete panels in the MP 91.9 section to reduce the traffic hazard and improve maintenance of this problematic section. Maintenance alternates between grinding and paving to re-level this section of highway.

To reassess the extent of the movement problems at MP 91.9, further work was conducted from 2002 to 2003. The work included borings and SI measurements at several times over approximately one year.

Suitability for InSAR

To determine the suitability of this site for InSAR monitoring, the five characteristics for site selection, listed previously in the section on the Summary of InSAR Suitability of Chapter 2, were reviewed.

- Slope Alignment: The Prosser slope generally dips to the North, although it is thought that the movement is in a northwesterly direction. Therefore, the alignment of this slope can be considered fair to poor for InSAR monitoring.

- Slope Grade: The overall grade of the Prosser slide and surrounding slopes are well within recommended limit for InSAR monitoring. Shadow and layover are not a problem in the main region of interest and in the surrounding regions.

- Image Coherence: The Prosser slide and surrounding hills are characterized by dry grasses and sparse shrubs. The region is considered semi-arid, with slow growing vegetation on the slopes to be monitored. There are a number of agricultural regions in the area, in particular to the south and northwest of the Prosser slide. This may introduce some challenges to phase unwrapping. In spite of this, the site is considered to be an ideal candidate for producing high InSAR coherence over the regions of interest. This was confirmed by examining a test InSAR pair, which, as shown in Figure 12, produced relatively high coherence over the entire region of interest for the 24-day revisit time. Note that in Figure 12 the landslide area of immediate concern is outlined by the black polygon, with the two larger prehistoric landslide areas given by the red and orange polygons, and the roads denoted by the white lines.

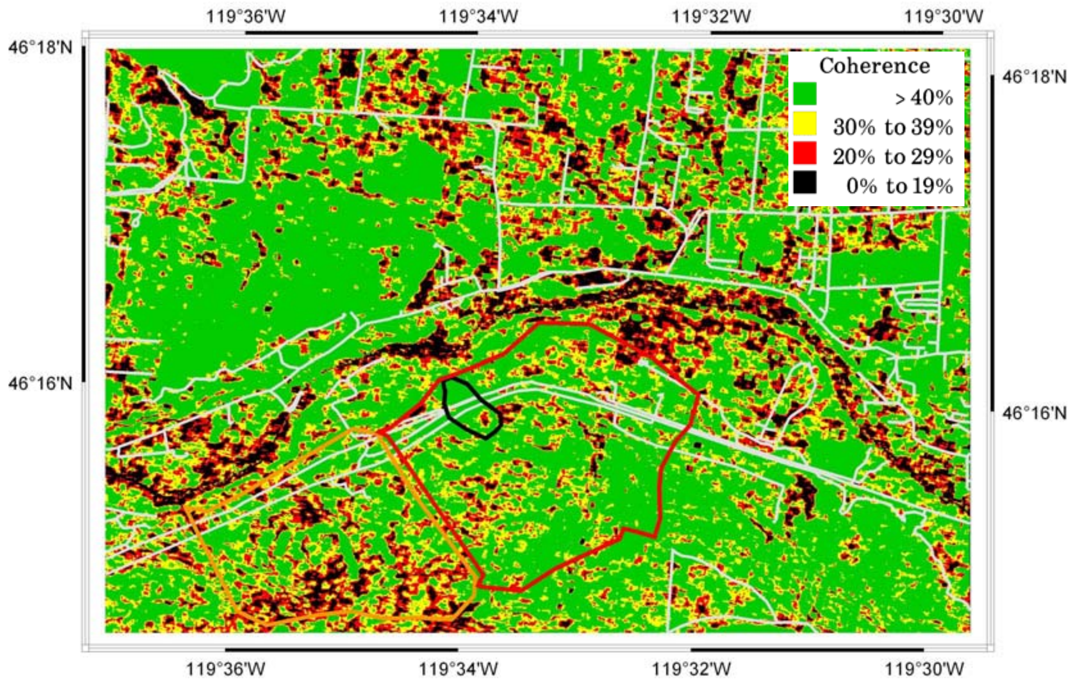

Figure 12. Graph. Coherence of Prosser site for January 15 – February 8, 2003.

- Existing Site Data: Benton County has 61 cm (2.0 ft) resolution color orthophotography that was acquired in 1998. These data are referenced to NAD-83 in a Washington State Plane (South) coordinates. Although there was no site survey meta data available at WS-DOT, survey control is believed to be well established for the site. An evaluation of the digital orthophotography revealed that it lined up well with other sources of data for the region, which confirms the accuracy of the established control in the absence of the survey meta data.

- Data availability: There is a large quantity of ERS data available over the site, comprising 20 scenes from 1998 to 2000. In addition, there is a quantity of RADARSAT-1 data starting in November 2002.

The slope alignment for this site is poor; however, the other site factors are excellent. There is generally good InSAR coherence and the orthophotography will be an excellent source of SAR GCPs to establish good geo-referencing of the SAR data. Therefore, the suitability of this site to InSAR monitoring is considered good in spite of the poor slope alignment.

CIMARRON

The following section is a summary from a paper presented at Geo-Denver 2000.[16] The Cimarron Valley is south of U.S. route 50 and east of U.S. route 550, near the town of Montrose, in southwest Colorado. A topographic map of the Cimarron Valley is given in Figure 13. There are numerous historic and prehistoric landslides in the valley. A pre-existing earth flow had been exhibiting slow creep for years. The earth flow has had an unlined irrigation ditch crossing its upper half since the early 1900's and, prior to 1996, maintenance efforts of this ditch and the nearby highway (Forest Highway 78) were minor. By 1996, however, the ditch width had reached about 50m (164 ft), probably through gradual movement and erosion. In 1996, the ditch was reconstructed to its narrower section and a depression that had developed in Forest Highway 78 was filled where it crossed the earth flow below the ditch. No other actions were taken in 1996 and no unusual movement was observed.

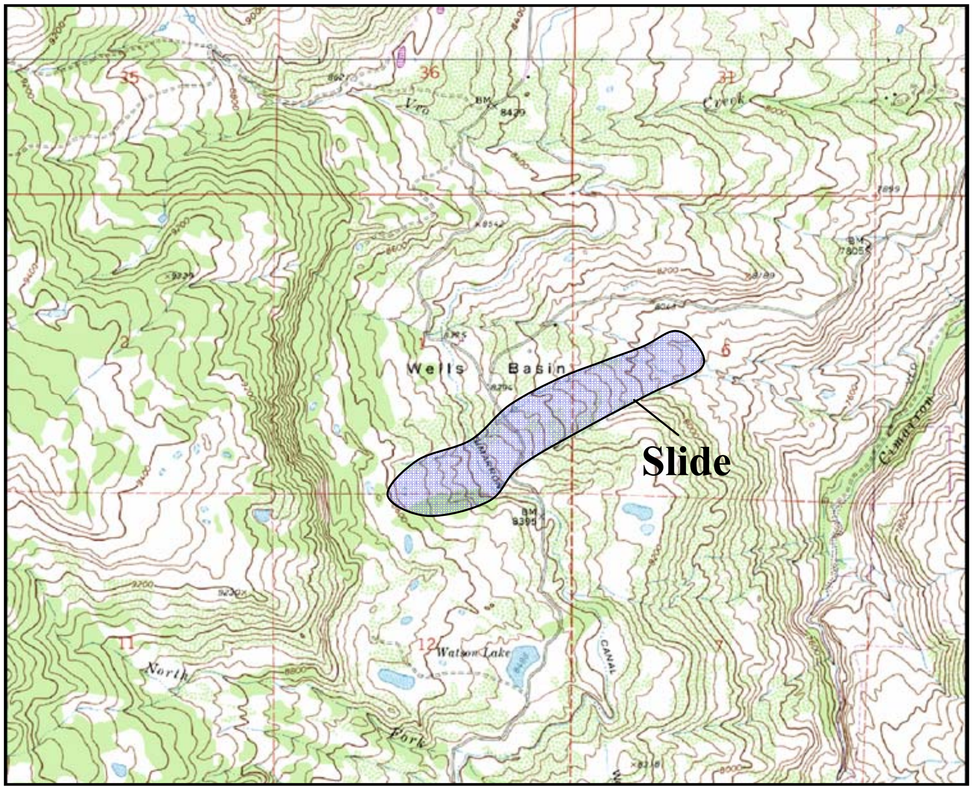

Figure 13. Map. Topographic map showing a portion of Cimarron Valley and the Cimarron Slide.

The spring of 1997 was wetter than average and in June 1997 part of the earth flow started to move rapidly, reaching rates of up to a few meters per day. More than 150 m (490 ft) of horizontal movement accumulated during the summer and the rapid movement stopped by November.

Geotechnical Background

A geotechnical investigation conducted by FLH on this problem indicated that failure occurred by sliding along a basal clay layer just above the shale bedrock and that shear failure in this clay layer was triggered by excessive pore fluid pressures most likely resulting from the unusually high precipitation. Available geotechnical data includes surface site inspections throughout the period of major sliding from June to November 1997, subsurface soil profiles from a borehole program from November 1997 to February 1998, and SI measurements from November 1997 to May 1998. Descriptive reports of similar land sliding in the valley more than 100 years previous were discovered during the investigation of this slide, which aided in the understanding of slope failures generally within the valley.

The Cimarron River valley elevation is between about 2,100 m (6,930 ft) and 2,800 m (9,240 ft) above sea level. The lower valley slopes are vegetated with grass and sagebrush, and other limited woody vegetation. The upper slopes contain aspen and conifer trees. The lower valley slopes are gently sloped and undulating, and the upper slopes are notably steeper, in many places consisting of bedrock outcrop. A recent photo of the slide is provided in Figure 14, with the slide location indicated by the yellow arrow.

Figure 14. Photo. Cimarron Slide, Owl Creek, CO.

Suitability for InSAR

To determine the suitability of this site for InSAR monitoring, the five characteristics for site selection, listed previously in the section on the Summary of InSAR Suitability of Chapter 2, were reviewed.

- Slope Alignment: The Cimarron slide is generally facing towards the East-Northeast direction, which is generally favourable for InSAR.

- Slope Grade: The overall grade of the Cimarron slide and surrounding slopes are well within the recommended limit for InSAR monitoring. Shadow and layover are not a problem in the main region of interest, however there is some layover and shadow present along the river valley to the east of Cimarron. This will not present a problem for monitoring the Cimarron slide.

- Image Coherence: The Cimarron slide is similar to Prosser in that the slope face is characterized by dry grasses and sparse shrubs. Unlike Prosser however, the Cimarron area also contains some stands of conifers and deciduous trees (mostly aspen and scrub oak as seen in the upper left of Figure 14). These forested regions will make phase unwrapping challenging for summer SAR acquisitions because it will create patches of low coherence. This problem should be reduced in the fall and spring when leaves are absent from the deciduous trees. Based on the above, the site is considered a reasonable candidate for producing good coherence of large portions of the SAR image from spring to summer to fall. However, due to snow cover in the winter, monitoring during these months will not be possible. A test InSAR pair captured at a 24-day interval early in this monitoring program revealed good coherence over much of the image, with low coherence patches, as shown in Figure 15. The slide area of interest is outlined by the black polygon in the figure, with the roads shown as red lines. Since this pair was captured in the fall, this coherence represents the best-case scenario, and lower coherence should be expected for summer intervals.

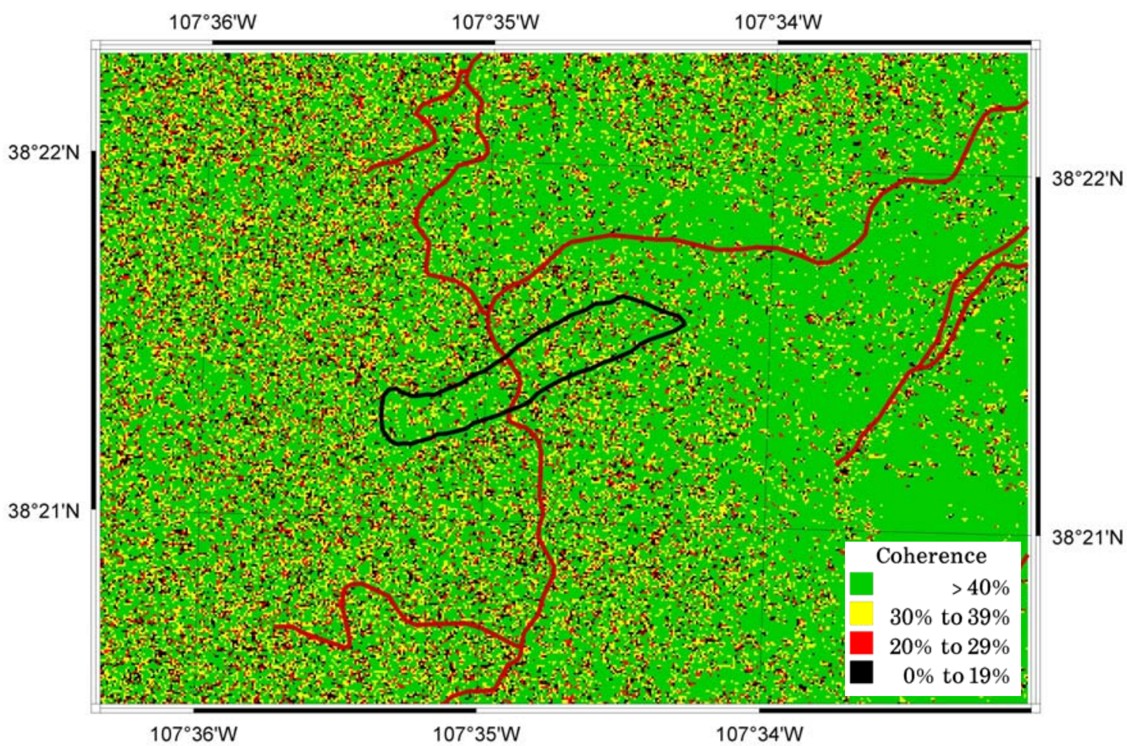

Figure 15. Graph. Coherence of Cimarron site (slide outlined) for September 3-27, 2003.

- Existing Site Data: Of the three sites, the Cimarron site has the most survey control information available. Aerial photography, digitized to 1 m (3.3 ft) resolution, was captured in support of the 1998 realignment of Forest Highway 78. The coverage of the air photo is 4.7 × 3.3 km (2.9 × 2 mi), and includes the main region of interest, i.e., the Cimarron slide, and surrounding region. The photogrammetry work conducted in 1998 included the generation of 5 m (16 ft) contours over a small section of the captured air photo. Wilson & Company performed the primary control network in 1997 for the

ground control supporting the aerial mapping. The final coordinates for the primary control and panel points were published in:
  - NAD 83 Geodetic, Meter
  - State plane Lambert, Colorado Central, Meter
  - Ground Coordinate System by modified state plane, Meter

  The positional accuracies of the published points are within centimeters.

- Data availability: In the timeframe from 1993 to 2003, there is a quantity of ERS SAR data that was available in the summer of 1997 during the time of the main slide event. In addition, there is a quantity of SAR data captured over the region during the summer of 2000.

Given the above favorable site characteristics, this area is considered to be a good candidate for InSAR monitoring.

MESA VERDE

Public access to Mesa Verde National Park and the cliff dwellings it contains is only from the north on the Main Access Road, as shown in the topographic map of Figure 16. This road crosses slopes comprised of the Mancos shale and other problematic sedimentary formations to reach the cliff forming Mesa Verde sandstone and the historic sites. The road has been continuously impacted by landslides and has been realigned several times in an effort to find more stable ground, safer and more dependable access, and lower maintenance requirements.

Geotechnical Background

Major realignments to the Main Access Road started in 1927 when the road was removed from the slope northwest of Lone Cone and located on the east-facing slope east of Point Lookout, which is its current location. Figure 17 shows a topographical map circa 1926 with the original alignment of this road. Once in Morfield Canyon however, the road continued back to the northwest and around the north and west of the Knife Edge to the Montezuma Valley Overlook. This continued to be the alignment until approximately 1950, when the existing tunnel was built to connect Morfield and Prater Canyons. Several years later, another realignment was made between Montezuma Valley Overlook and Moccasin Overlook, to the south. This alignment reduced the grade on the road and added several new cuts and fills. Subsequent to these realignments, slope stability has been an ongoing issue, especially in the Point Lookout area (Point Lookout Slide), north of the Mancos Valley Overlook and in the cuts and fills in the vicinity of Moccasin Overlook (for example, MP 8.3, MP 8.6, MP 8.9, and MP 9.3 slides as indicated in Figure 16). Further details of this are provided below.