UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

Sierra National Forest
1600 Tollhouse Road
Clovis. CA. 93667

Ferguson Rock Slide
Geology Report

June 20, 2006

By

Alan J. Gallegos and Jerry DeGraff

Ferguson Rock Slide
Geology Report

June 20, 2006

By:

Alan J. Gallegos
Southern Sierra Province
Assistant Geologist

Jerome V. DeGraff
Southern Sierra Province
Geologist

TABLE OF CONTENTS

Ferguson Rock Slide

Sierra National Forest - Bass Lake Ranger District

6/16/06

Executive Summary

The Ferguson Rock Slide is an active, complex rock slide that consists of a deep-seated rock slide that toes out 150-200 feet above the Merced River. A rock fall/rock slide is located below the toe of the deep-seated rock slide and is depositing predominately rock into the Merced River. The landslide deposit has encroached on the Merced River by about 30 feet. The deep-seated rock slide is probably creeping and is expected to be active for years and possibly decades. The rock fall/rock slide is currently active and is expected to be active until the rock slide stabilizes and the steep canyon slope has stabilized to a natural angle of repose. There is a low likelihood that the rock slide will fail catastrophically and dam the Merced River. If the landslide fails catastrophically, most likely the landslide material will deposit and partially dam the Merced River and constrict the flow of the river. A potential dam height of 100 feet has been evaluated for flooding above the potential rock slide deposition area.

A contingency plan should be developed in the event of a catastrophic landslide that dams the Merced River. The contingency plan should include an early warning system and evacuation plan for any people in the flood prone area of a potential 100 feet dam and immediately downstream of the potential dam.

Monitoring of the landslide should be conducted using a complement of the GPS/Geophone/Tilt meter system, stream gauging stations and high resolution digital cameras. All of these systems should be set up to radio telemeter data to a central location. The GPS/Geophone/Tilt meter system and stream gauging stations should be set up to sound an alarm if movement exceeds a threshold level that indicates increased movement of the rock slide.

An analysis of the rock slide should be implemented to make a more precise determination of the volume of the rock slide and the potential volume that could fail catastrophically. This analysis should include accurate mapping of landslide features and a projection of the failure plane from the toe of the landslide projected to where it intersects the head scarp. If the rock slide is deemed safe to access in the next few months, a field developed cross section should be constructed with accurate locations of landslide features. In addition, a quantitative analysis should be done to model movement and deposition of landslide material into the Merced River. This quantitative analysis should be the basis for a potential landslide dam in the Merced River.

Introduction

On June 1, 2006 Ed Cole, Forest Supervisor of the Sierra National Forest requested that Alan Gallegos attend a multi-agency meeting that was scheduled on June 2nd in Mariposa, CA. The purpose of the multi-agency meeting was to discuss the Ferguson Rock Slide and start a dialog between the agencies that might be involved in evaluating the emergency that the Ferguson Rock Slide had created. Ed Cole related that he was concerned about the potential catastrophic failure of the landslide and what agencies the Forest Service could work with in the event of a catastrophic failure and the potential damming of the Merced River. As a result of the multi-agency meeting a Type II Multi-Agency Incident Team was formed and Alan Gallegos and Jerry DeGraff acted as resource advisors to the team. Several agencies have contributed to the current knowledge of the landslide and have made recommendations for a contingency plan of a potential catastrophic failure and potential damming of the Merced River. These agencies include: California Department of Transportation (CalTrans), Army Corp of Engineers (ACOE), United States Geologic Survey (USGS), Yosemite National Park, Forest Service (FS) and California Division of Water Resources (DWR). The following is a summary of the current knowledge of the landslide and recommendations for a contingency plan of a potential catastrophic failure and potential damming of the Merced River.

Geologic Reconnaissance Methods

The landslide was reviewed between June 12 and June 13, by Alan Gallegos (FS), Jerry DeGraff (FS) Kellen Takanaka (FS), Ed Harp (USGS), Jonathan Godt (USGS) and Mark Reid (USGS). Ground-based field evaluation consisted of viewing the slide from Highway 140 on the west side of the slide, from the east side of the slide on the Incline Road, and from about 300 feet up the slope above the Incline Road. The rock slide was also reviewed from a helicopter and photographs were taken for later examination.

The Ferguson Rock Slide was initially examined by Duncan Willey at the request of CalTrans. Willey documented the results of his aerial and field reconnaissance in a report dated June 6, 2006 (Willey, 2006). Cotton, Shires and Associates, Inc. compiled their interpretation of the rock slide based on aerial photo interpretation and published information on June 5, 2006 and documented the results of their review and analysis in a report dated June 8, 2006 (Cotton and Associates, 2006).

Physiography and Geomorphology

The Ferguson Rock Slide is located approximately 6 miles west of El Portal on the west side of the Merced River and State Highway 140 (see Map insert at end of text). The rock slide was originally estimated to be 600 feet wide by CalTrans geologists (personal communication) and 800 feet long x 600 feet wide along Highway 140 by Duncan Wyllie. Wyllie estimated that the volume of the slide is about 2 to 3 million cubic yards. Cotton and Associates estimate the rock slide to be 1200 feet long x 800 feet wide x over 100 feet deep.

During the analysis of the Ferguson Rock Slide, 1:24,000 scale aerial photos were reviewed and the rock slide was mapped on the aerial photos. The lines from the aerial photos were later transferred to a topographic map and landslide dimensions were measured. The rock slide has a total of 560 feet vertical relief from the top of the head scarp to the bottom of the toe and a vertical relief of 720 feet from the top of the head scarp to the edge of the highway. The actual length of the rock slide is approximately 800 feet long from the top of the head scarp to the bottom of the toe. The length of the rock slide/rock fall/rock slide complex, to the edge of the highway is 1,012 feet from the top of the head scarp to the edge of State Highway 140. The width of the rock slide is approximately 485 feet at its widest, in the toe area of the rock slide. The rock slide is located on steep, canyon inner gorge slopes of the Merced River, where natural slopes have gradients that range from cliffs to 90% (42º).

Landslide Description

The Ferguson Rock Slide is a rock block slide-rock fall complex that is approximately 9 acres in size (see Map Insert). The rock slide toes out on the steep canyon wall where rock fall and rock slide material is deposited on the slope to the river. The rock slide consists of highly fractured phyllite, slate and chert from the Phyllite and Chert of Hite Cove (Bateman, 1997).

The landslide consists of a reactivated deep-seated rock block slide that toes out on a steep canyon slope, approximately 150-200 feet above the Merced River (Fig. 1). A smaller lobe of the slide is located on the west side of slide, where the head scarp, main block and several tension cracks were reviewed during the field review. The main scarp of the rock block slide was observed on the west side of the slide during the field review, where displacement along the head scarp was measured between 4 and 6 feet. This displacement is only a small proportion of the total scarp height. Most of the scarp was exposed in an earlier pre-historic movement. The surface of the slide is severely broken up with scarps and tension cracks throughout the slide mass. Field observations suggest movement of the slide is translational in nature. It is estimated, based on aerial photography and topographic maps that the maximum displacement of the slide at the head scarp is 30 feet. At the time of the field review the landslide did not appear to be moving, but we could not exclude the possibility that the slide was slowly creeping. The slip surface of the rock block slide is visible in the steep canyon face above the rock fall deposit. The slip surface is obvious on the east side of the slide where it is located above outcropping bedrock. The slip surface continues to the west, where it is buried by the landslide deposit and then it is visible again where it surfaces and undulates under the western lobe of the landslide. There is also the possibility that there could be multiple slip surfaces above the lower failure plane (Fig. 2). Another interpretation of a lower landslide slip surface was given by Ed Harp of the USGS. This lower slip surface could be where the lower dashed line is located on Figure 2. The location of the lower failure plane is significant in the determination of the volume of the rock slide. The depth and the volume of the rock slide will be determined by the location of the failure plane.

A rock fall/rock slide area is located below the rock block slide and has formed a deposit with a 38º slope. This material has deposited into the Merced River and has reduced the width of the Merced River by approximately 30 feet (Fig. 3)). This landslide deposit consists of somewhat elongated, highly fractured blocks that range from small car size boulders to 6-inch diameter rocks. The flow of the Merced River has not moved a significant amount of the rock fall/rock slide material downstream.

Rock falls and rock slides are very active on the steep canyon face. Several weeks ago, rock fall and rock slide activity was occurring at a rate of once every 5 seconds and as of June 16th rock fall and rock slide activity is occurring once every 5 to 10 minutes. The activity of rock fall and rock slides could be in response to the larger block slide moving material to the edge of the slope where it falls down the steep slope or could be in response to initial movement of the rock slide and the formation of a new slope that is trying to adjust itself. The depth of the rock slide can only be estimated at this time, whereas the length and width of the rock slide are based on map measurements. The volume of the rock slide is based on a 100 to 150 feet depth and ranges from 2 million yds^3 to 3 million yds^3. The volume will be revised when the rock slide depth is verified or based on additional empirical data.

Figure 1 – View of rock block slide and landslide deposit below toe of rock slide. Toe of landslide is 200 feet above the Merced River.

Figure 2 – Photo of rock slide toe taken from slope above the Incline Road showing interpretation of failure planes (solid lines). Lower line with ?...?...? is a possible lower failure plane covered with landslide deposit.

Figure 3 – View of landslide deposit below toe of landslide. Landslide material has encroached approximately 30 feet into Merced River.

Very little ground water was observed on the rock slide mass. A small seepage area was observed along the east margin of the slide above the rock slide failure plane (Fig. 2). This wet area does not appear to have very much water flowing and is more of a seep then anything else. Vegetation on the slide mass is drying out and turning brown as a result of the root systems being disrupted and shallow soil water draining through fractured rock.

Slope Stability

Slope stability of the landslide can be described for the large deep-seated rock slide and for the steep rock fall/rock slide slope. Active movement of the deep-seated rock slide and rock fall/rock slide activity are related, with rock fall/rock slide activity responding to movement of the deep-seated rock slide. As the rock slide is moving down slope along the failure plane and over the steep canyon slopes, rock falls and rock slides will increase. Rock falls and rock slides could also be occurring as the slope stabilizes to a more stable angle of repose. Rock fall activity will continue over the summer, next winter and probably into the next several years and possibly decades, as the slope attempts to stabilize and reach a natural angle of repose or in response to additional deep-seated movement of the rock slide. As rock fall/rock slides continue, the material will deposit on the slope below and could further narrow the width of the Merced River. Activity of the rock fall/rock slide area could also be a hazard to the Incline Road corridor across the canyon,

Movement of the deep-seated rock slide probably will continue to occur for years and possibly for decades to come. It is not known if the slide is currently moving, but it should be assumed that the slide is probably creeping. Movement of the slide mass needs to be determined in order to determine short and long term stability of the rock slide. Based on the current activity of the landslide there is a low likelihood that the rock slide will fail catastrophically and dam the Merced River. However, there is a still the possibility that a landslide dam could form in the future with renewed movement. There is also a possibility, that in the event of a partial failure of the block slide, the width of the Merced River could become narrower and flow could become constrained.

Landslide Dam Potential

Natural dams created by landslide deposits blocking water courses are found worldwide as documented by Costa and Schuster (1988). Many have caused extensive damage upstream by impounding stream flow and downstream when breaching released water to flood downstream. Based on 63 cases, Schuster and Costa found that 59 percent of natural dams lasted only 1 month or less before impounded water breached these barriers and 22 percent lasted only 1 day or less (Schuster and Costa, 1986). Overtopping with subsequent down cutting of water into the dam is the most common mode for breaching.

No standard methodology exists for predicting the likelihood of a natural dam forming from a landslide. It is highly dependant on the triggering mechanism and dynamics of the landslide. In the case of the Ferguson Rockslide, it is concluded to have a low likelihood of occurrence. There are several reasons for this conclusion. First, the current movement is a reactivation of an existing rockslide feature. The head scarp associated with the earlier movement suggests that past movement was much greater. Field work did not identify any remnants of earlier landslide dams that might reasonably be expected from an earlier and larger movement. Second, it would require a rapid movement of much of the Ferguson Rockslide to move enough material into the river channel to form a landslide dam. The record for current movement on this feature does not suggest that such a rapid failure is likely without very unusual circumstances to trigger it. What can be expected is constricting of the Merced River channel through this area as the toe of the rock fall deposit extends down slope into the channel. This will affect the size and quantity of rock material transported immediately downstream, alter some localized bank erosion, and potentially influence the scour pattern for any structures founded in or next to the channel immediately downstream.

Despite the low likelihood of a landslide dam occurring, it is prudent to evaluate the potential impacts to guide any response planning for such an emergency. This can best be evaluated by assuming the possible maximum volume of landslide debris available to form a landslide dam. The potential impact of a natural dam can then be estimated from the dam height assuming either the entire landslide volume or some portion of it. For the Ferguson rockslide, the maximum volume is estimated at 3 million cubic yards. Mr. Larry Bergmooser led a U.S. Army Corps of Engineers team that determined that the maximum landslide dam volume would form a 100-foot high natural dam. To evaluate the scenario where less than the maximum volume formed a natural dam, it was assumed to be 50-foot high. The potential rock slide dam of 100-foot was determined using a qualitative analysis and needs to be refined using a more quantitative approach. Ed Harp from the USGS proposes to determine how the rock slide would deposit in the Merced River forming a potential dam, using 3-dimensional modeling that the USGS has done for other areas (personal communication).

The immediate effect of either landslide dam scenario is the impoundment of water flow up the Merced River (Fig. 4). This would include both the main stem of the Merced and the South Fork which enters about 0.5 mile upstream from the Ferguson Rockslide. The impounded waters would transform part of the Merced River into a temporary lake. The upstream limit and downstream of the impounded waters within the canyon are important to analyze the safety of evacuation routes and identify people and structures at risk from flooding water.

When filled to overtopping, the 100-foot landslide dam would impound 3,800 acre-feet of water. The 50-foot landslide dam would impound 540 acre-feet. The time between formation of the landslide dam and being full to overtopping depends on the discharge of the Merced River at that time. At the current discharge of about 8,000 cubic feet per second (cfs), the entire inundation area behind the 100-foot dam would be filled in 6 hours. For the 50-foot dam, filling to overtopping would take only 1 hour. Because there are recording stream gauges on the Merced River at Pohono Bridge above the community of El Portal and at Briceberg a few mile below the Ferguson Rockslide, it is possible to adjust the time of infilling with current discharge rates in the future (see Appendix C).

Knowing the time for complete filling of the impounded water behind the landslide dam is needed for planning effective evacuation and safety closure. The times of 6 hours and 1 hour represent the quickest time for filling the impoundment area behind these potential landslide dams. Lower flows commonly experienced during the summer and early fall on the Merced River would provide more time. Historical flow data can help forecast the likely fill times for the future. These can be updated with real-time information when critical dates are defined.

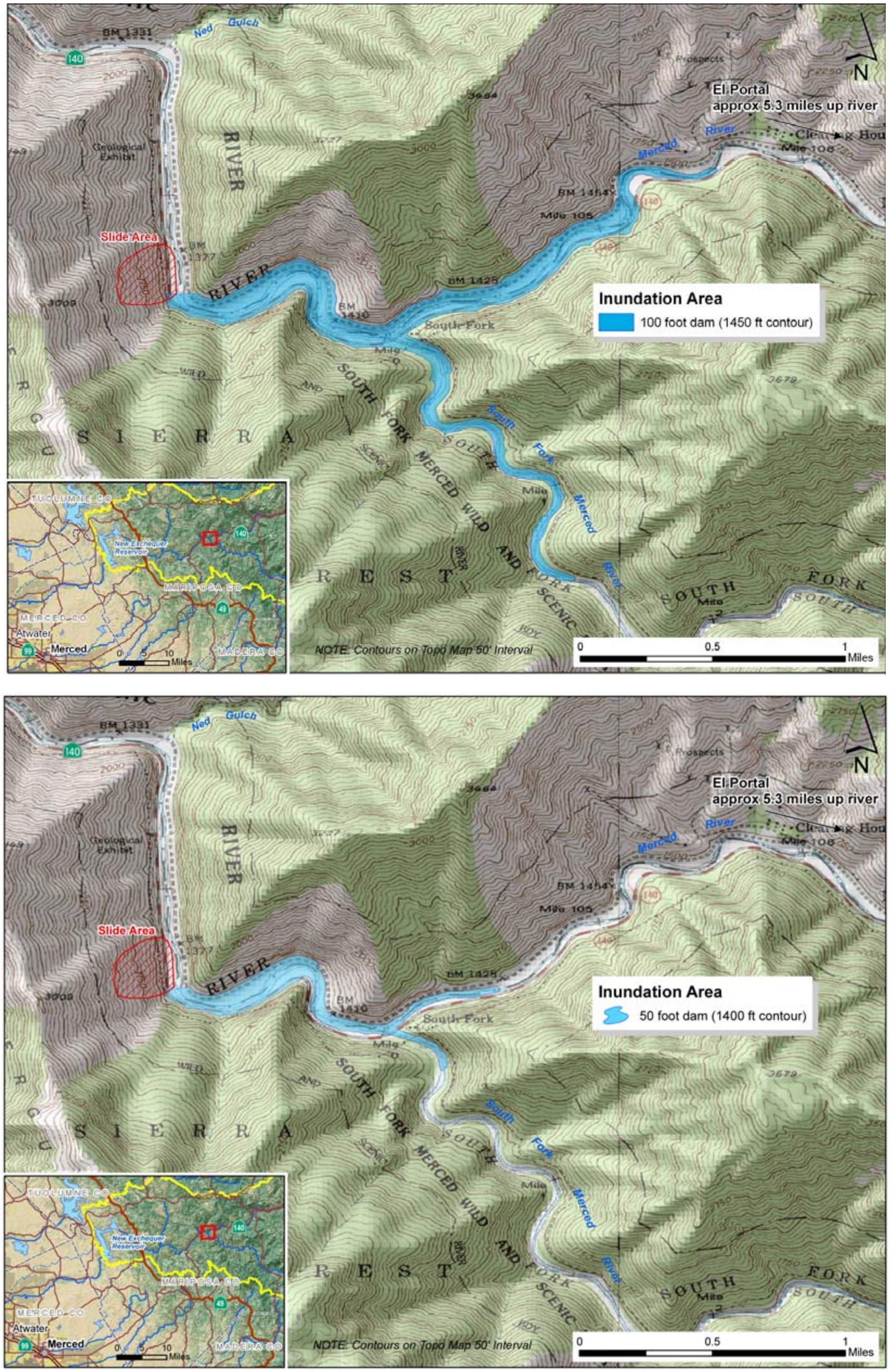


Figure 4. 100-ft (upper map) and 50-ft (lower map) landslide dam inundation areas.

The 100-foot landslide dam would impound the most water creating the greatest impact upstream. While it is not possible to be exact, it would appear that some low-lying buildings around Savage's Trading Post at the junction of the main stem of the Merced River and the South Fork could be partially flooded. Also, California Highway 140 and Incline Road would be under water for most of their length until a point just downstream from the Clearinghouse Mine. Under the 50-foot landslide dam scenario, the principal difference is the strong possibility that no structures at Savage's Trading Post would be impacted and both California Highway 140 and Incline Road would be above water upstream from the junction of the Merced and South Fork. Under no current scenarios is inundation forecast to affect Cedar Lodge or any other residential or commercial structures farther upstream from the Ferguson Rockslide area. An earlier emergency map exercise by the Mariposa County Sheriff's Office found that such an extensive impoundment would require a landslide dam at least 350 feet high. Such a large landslide dam currently is inconsistent with the highest landslide deposit volume estimates.

As noted earlier, it is unlikely that any natural dam formed by the Ferguson Rockslide would not be breached naturally within a matter of days. The material forming the landslide dam is expected to consist of both rock and soil. With the source being a rockslide, the proportion of rock is expected to be great. The material forming the natural dam is one of the characteristics strongly affecting the time it remains in existence (Schuster and Costa, 1986). Finer grained material like that in debris flows would be likely to fail in a matter of hours rather than weeks. The Sourgrass debris flow on the Stanislaus River in 1996 is an example of how brief landslide dams formed from this material can be (DeGraff, 2001).

The high proportion of rock expected in a landslide dam also suggests that some seepage may move through the dam as it fills (L. Bergmooser, Pers. Comm, June 15, 2003). This may lengthen the time between its emplacement and filling to overtopping, but is not expected to differ greatly from the time estimated by comparing impoundment volume to current river discharge. While rock is a significant component of natural dams that have survived longer than a year, they remain intact more from the shear bulk of the blockages (Schuster and Costa, 1986).

Once the landslide dam is overtopped, erosion across this threshold intensifies and leads to greater erosional effectiveness. Consequently, the impounded water is released rapidly. This can cause flooding downstream for a significant distance. Such flooding has been a major impact for many landslide dam breaches in the world. Therefore, the U.S. Army Corps of Engineers also examined that potential for both a 100-foot and 50-foot landslide dam. Their modeling assumption was that the entire dam was removed completely and nearly instantaneously to demonstrate the worst impact possible from landslide dam breaching. The river channel affected by this release of impounded water would be from the landslide dam location to Lake McClure roughly 19 miles downstream.

Appendix A contains the six maps showing the area underwater from the flood flows from breaching of the 100-foot and 50-foot landslide dam scenarios. It is important to remember that the river channel prior to any breaching the landslide dam would be virtually dry. If seepage does occur before overtopping, it would support a very low discharge. Consequently, the water surface inundation displayed on the maps would be the maximum occurring starting with the channel virtually empty, rising to this level, and then dropping rapidly to a water level that is sustainable by the normal river discharge at the time of the landslide dam breach.

Obviously, the release of nearly 3,800 acre-feet of water impounded by the 100-foot landslide dam affects a greater area adjacent to the channel that the 540 acre-feet associated with the 50-foot landslide dam. The water also moves faster for the larger release associated with the 100-foot landslide dam. It arrives upstream of McClure Lake (16.3 miles down stream from the landslide dam location) in 2.1 hours. This compares to 4.1 hours for the release of water impounded by the 50-foot landslide dam.

It is important to note that the water level indicated for McClure Lake in either scenario is virtually identical. This is because McClure Lake capacity is 1,024,000 acre-feet. The 3,800 acre-feet impounded behind the possible 100-foot landslide dam represents 0.4% of the capacity of McClure Lake. So this inflow would barely cause a ripple across the lake and the inflow from the 450 acre-feet associated with the 50-foot landslide dam may be difficult to even detect when it arrived. It is expected that capacity would exist for this added water to Lake McClure because flow from the Merced River would be cut off by the landslide dam in the period prior to breaching. Emergency planning should evaluate whether this situation would also require some precautionary release prior to breaching of a landslide dam to provide an additional margin of safety. This may be appropriate if the situation developed at a time when McClure Lake is near capacity.

Monitoring

Monitoring of the landslide is critical to determine movement of the deep-seated block slide and to determine the activity of the rock fall/rock slide area at the toe of the rock slide. Cal Tran’s objectives for monitoring the rock slide are to determine the activity level of the deep-seated rock slide and the rock fall/rockslide area for the purpose of protecting the public, contractors and Cal Trans employees during the construction phase of an alternative route around the rock slide. CalTrans has proposed to monitor the slide using several methods including Live Stream Web Based Video (LSWBV), Digital Terrain Modeling (DTM) Surveys, Light Detection and Ranging (LIDAR), and Slope Stability Radar (SSR). In addition, CalTrans is planning on having a contract geologist observe the rock slide for 8-hours/day for up to one year. The Forest Service objectives for monitoring the rock slide are to determine the activity level of the deep-seated rock slide for the purpose of determining the potential for a catastrophic rock slide that could dam and block the Merced River. In addition, the Forest Service intends on setting up an early warning system in the event of a catastrophic rock slide. The Forest Service is considering monitoring the rock slide, with assistance from the US Geological Survey, using an integrated system that includes: three to four GPS/Geophone/Tilt meter spider units; stream gauges, upstream and downstream of the rock slide; and high resolution digital terrestrial photography. See Appendix B for a description of each monitoring system.

On June 16, a conference call was conducted between Dave Martin (District Ranger, Bass Lake Ranger District), Ed Harp (USGS), Jonathan Godt (USGS), Rick LaHussen (USGS), Mark Reid (USGS), Tim Beck (CalTrans), and Alan Gallegos (USFS). The purpose of the conference call was to discuss each agency (CalTrans and Forest Service) objectives for monitoring the rock slide, options for monitoring the rock slide and to get a consensus how the rock slide should be monitored. During the conference call, each monitoring technique was discussed including strengths and weaknesses and cost to implement and maintain the systems. The consensus of the conference call was a recommendation that an integrated monitoring system with radio telemetry be installed and would include: GPS/Geophone/Tilt meter system; stream gauges upstream and downstream of the rock slide; and high resolution digital terrestrial photography.

The monitoring system should be designed to designate the activity level of the rock slide into levels of activity and hazard to life and property in the canyon. For example, landslide alert status could be designated similar to fire danger status using color codes of green, yellow, and red. Green Landslide Hazard status could indicate no landslide to very little landslide activity. Yellow status could indicate minor creeping of the deep-seated rock slide and 1 to 10 episodes of minor (1-10 yds3) rock fall/rock slide activity per day. Red status could indicate an acceleration of the deep-seated rock slide and episodes of major rock fall/rock slide activity per day. When the landslide hazard status is green, work could continue as planned and rock slide monitoring could be relied on with the radio telemetry. When the landslide hazard status is yellow, work could continue with caution and a geologist should be requested to investigate the nature of the movement and the stability of the slope. The rock slide should be observed around the clock until the landslide hazard status goes back down to green. When the landslide hazard is red, work should be stopped and preparations should be made to evacuate everyone that could be affected by the rock slide include upstream and downstream residences.

Conclusions and Recommendations

The Ferguson Rock Slide is an active, complex rock slide that is probably creeping and will continue to move for years to come, possible decades. The toe of the rock slide is exposed or "day lighted" approximately 150-200 feet above the Merced River where it generates rock falls and rock slides. The rock fall material moving down and depositing on the steep inner gorge slopes is encroaching into the Merced River by approximately 30 feet. Active rock falls and rock slides will continue as the deep-seated rock slide moves and or as the slope stabilizes to a more stable slope (natural angle of repose). There is a low likelihood that the rock slide will fail catastrophically and form a dam across the Merced River. It is more likely that if a large portion of the slide failed, that it would deposit in the river and constrict the flow of the river, but not completely block the river. However, it would be prudent for emergency planning to include provisions for a catastrophic failure that could result in a landslide dam up to 100 feet high. A contingency plan should be developed that includes an early warning system and evacuation plan for any people in the flood prone area of the 100 feet dam and immediately downstream of the potential dam.

Monitoring of the landslide should be conducted using a complement of the GPS/Geophone/Tilt meter system, stream gauging stations and high resolution digital cameras. All of these systems should be set up to radio telemeter data to a central location. The GPS/Geophone/Tilt meter system and stream gauging stations should be set up to sound an alarm if movement exceeds a threshold level that indicates increased movement of the rock slide.

An analysis of the rock slide should be implemented to make a more precise determination of the volume of the rock slide and the potential volume that could fail catastrophically. This analysis should include accurate mapping of landslide features and a projection of the failure plane from the toe of the landslide projected to where it intersects the head scarp. If the rock slide is deemed safe to access in the next few months, a field developed cross section should be constructed with accurate locations of landslide features. In addition, a quantitative analysis should be done to model movement and deposition of landslide material into the Merced River. This quantitative analysis should be the basis for a potential landslide dam in the Merced River.

Alan J. Gallegos
Southern Sierra Province Asst. Geologist

Jerome V. DeGraff
Southern Sierra Province Geologist

References

Bateman, Paul C. and Krauskopf, Konrad B., 1987. Geologic map of the El Portal Quadrangle, West-Central Sierra Nevada, California. United States Geologic Survey Miscellaneous Field Studies Map MF-1998. Scale 1:62500.

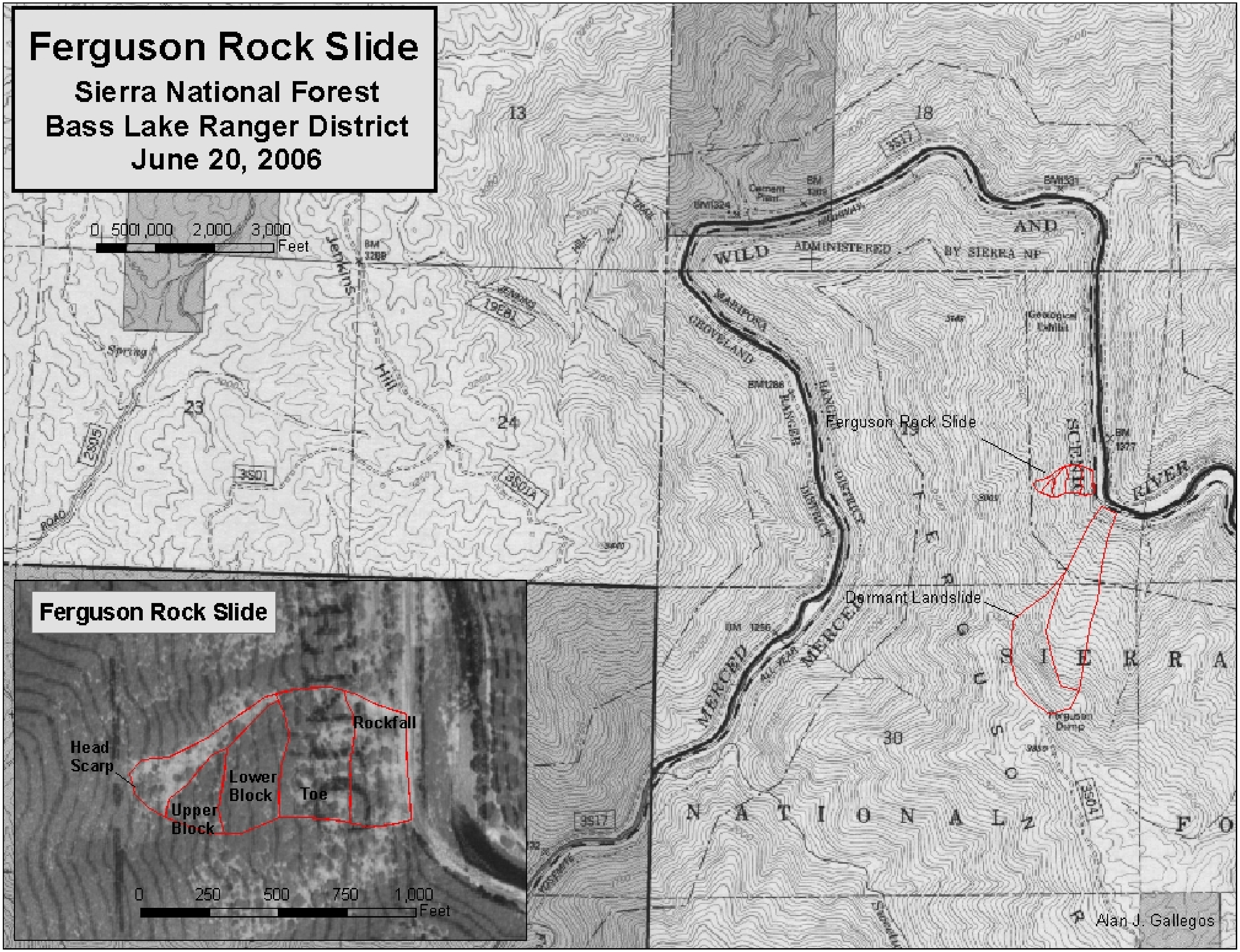
Costa, John E. and Schuster, Robert L., 1988. Formation and failure of natural dams: Geological Society of America Bulletin v. 100; no. 7; p. 1054-1068.

Cotton, Shires and Associates, 2006. Preliminary Thoughts About the Highway 140 Rockslide. Los Gatos, CA. http://www.cottonshires.com/ p.1-5.

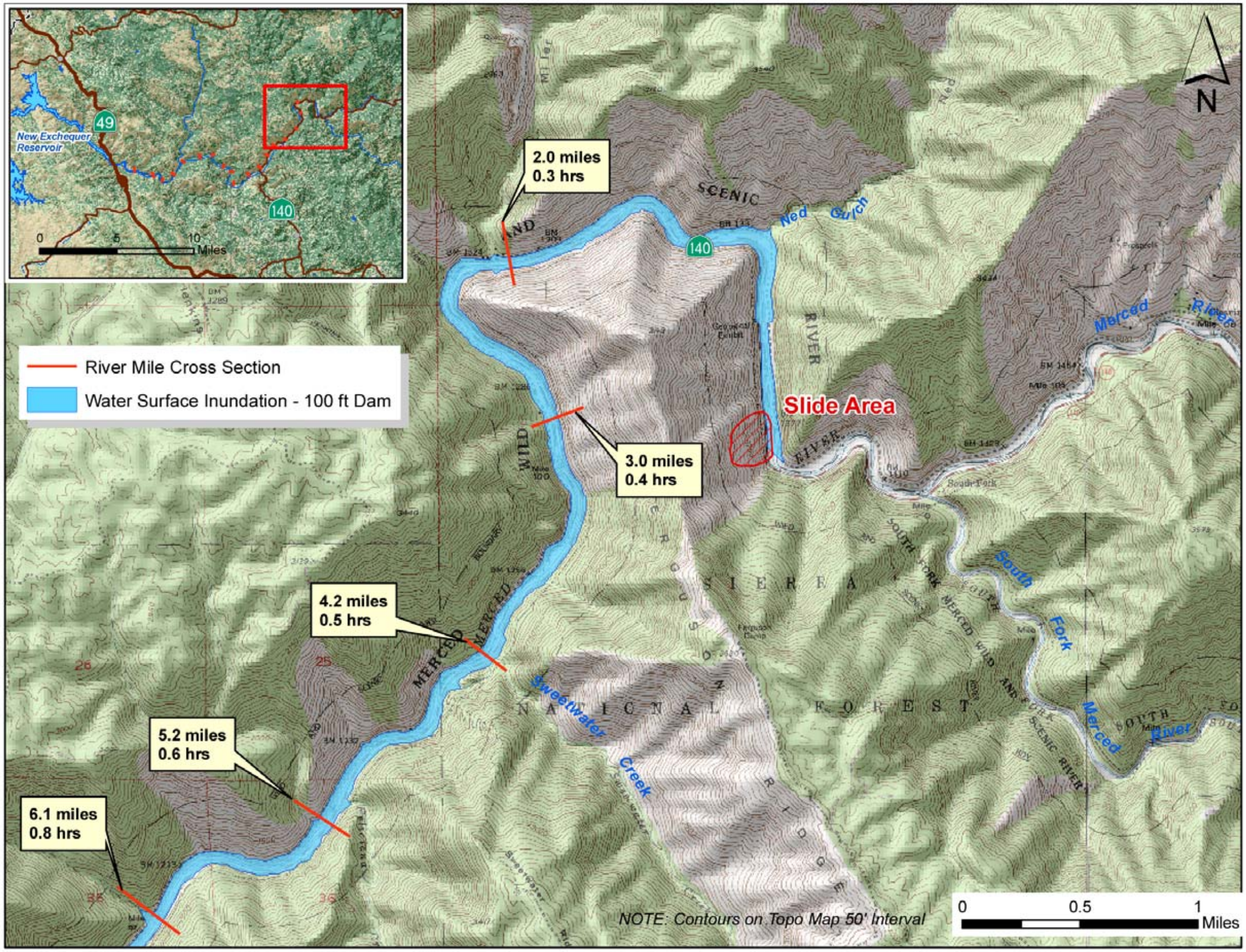
DeGraff, Jerome V., 2001. Sourgrass debris flow: a landslide triggered in the Sierra Nevada by the January 1997 New Year Storm, In Ferriz, H. and Anderson, R. (eds.), Engineering Geology Practice in Northern California, California Division of Mines and Geology Bulletin 210, p. 69-76.

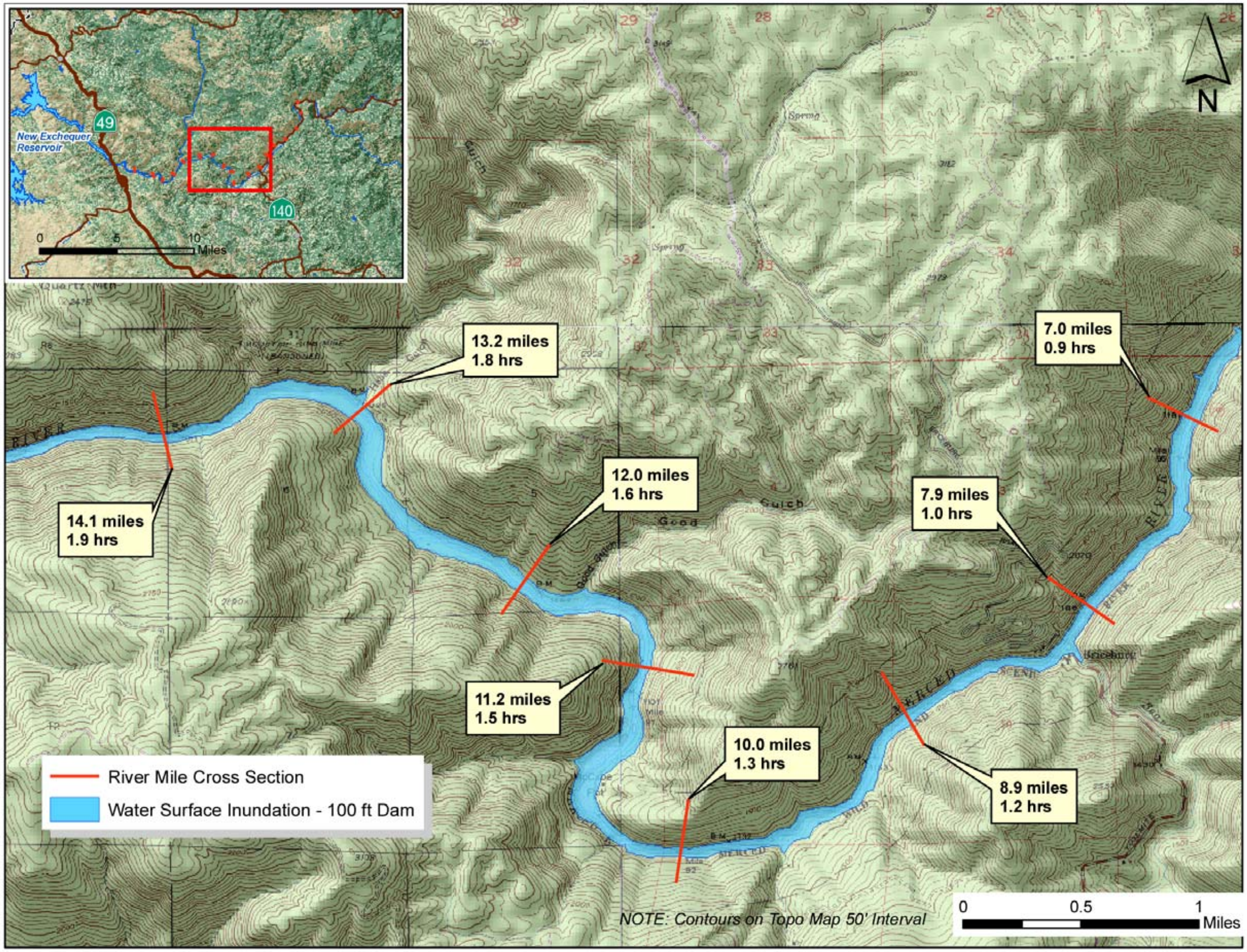
Schuster, Robert L. and Costa, John E., 1986. A perspective on landslide dams, in Schuster, R.L. (ed.), Landslide Dams: Processes, Risk and Mitigation, Geotechnical Special Publication n. 3, American Society of Civil Engineers, New York, p. 1-20.

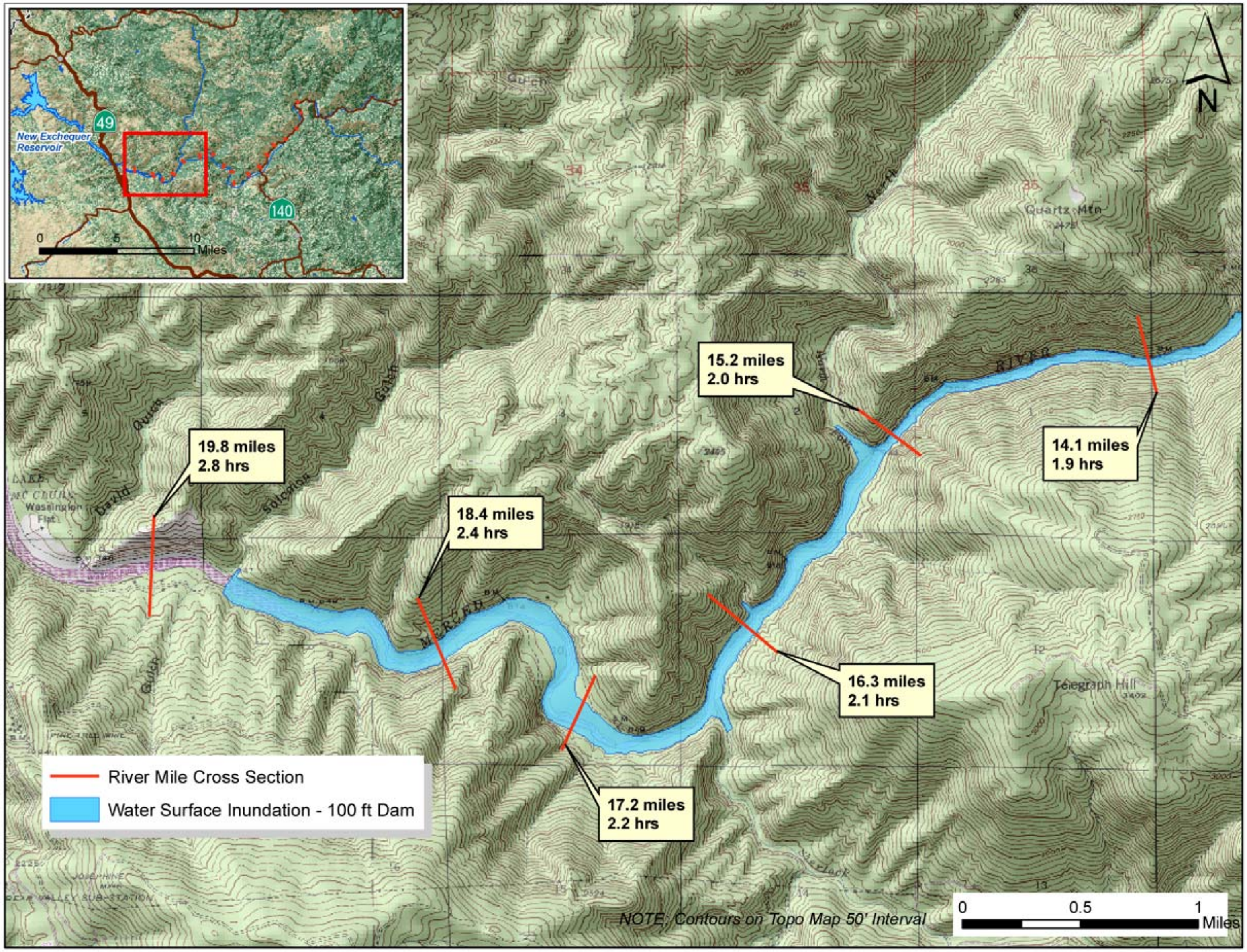
Wyllie, Duncan C., 2006. Ferguson Rockslide, Highway 140, Mariposa to El Portal Stability Evaluation. California Department of Transportation, Division of Engineering Services, Geotechnical Services, Sacramento, CA. p. 1-6.

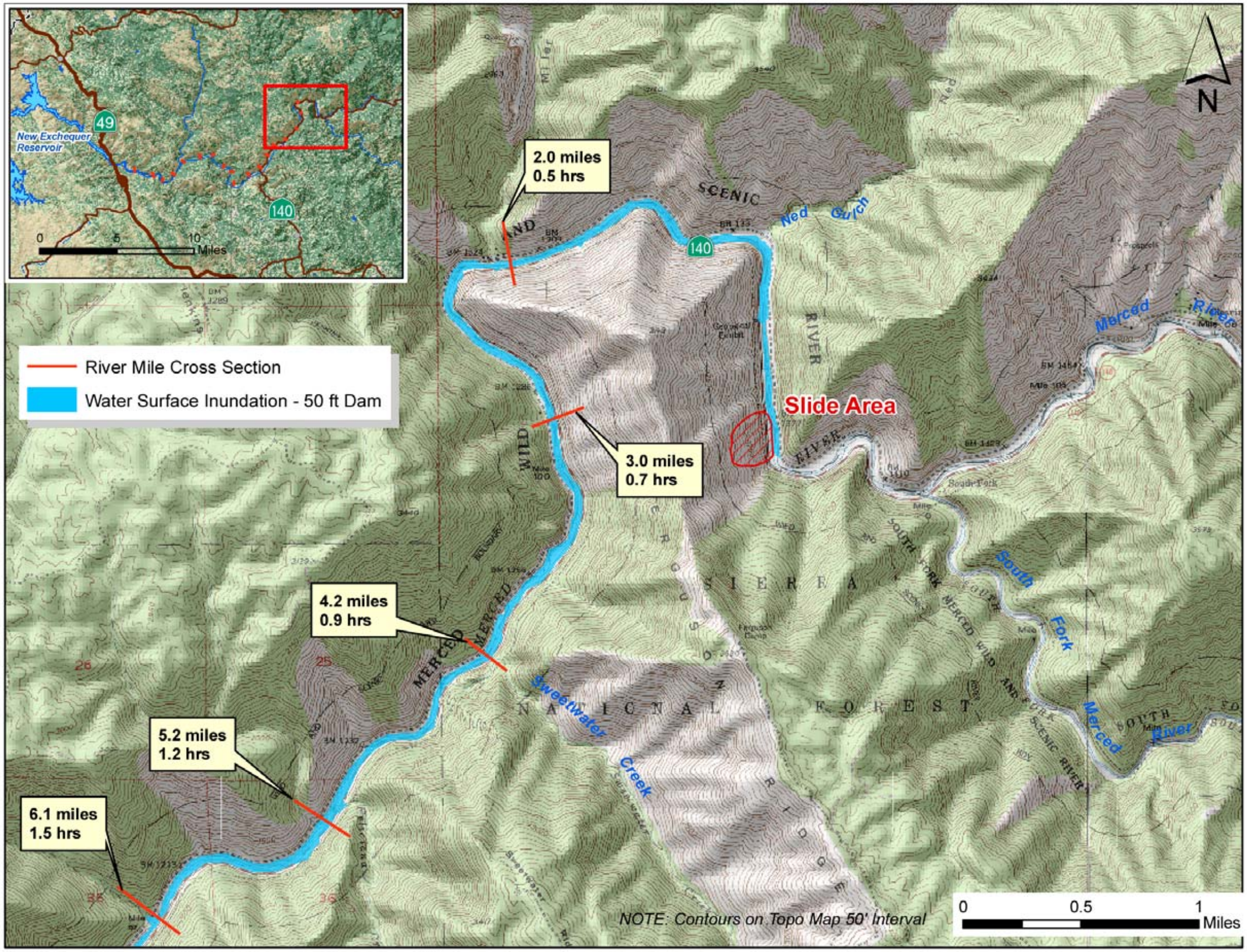

Ferguson Rock Slide
Sierra National Forest
Bass Lake Ranger District
June 20, 2006
0 500 1,000 2,000 3,000
Feet
Ferguson Rock Slide
Dormant Landslide
Ferguson Rock Slide
Head Scarp
Upper Block
Lower Block
Toe
Rockfall
0 250 500 750 1,000
Feet
Alan J. Gallegos

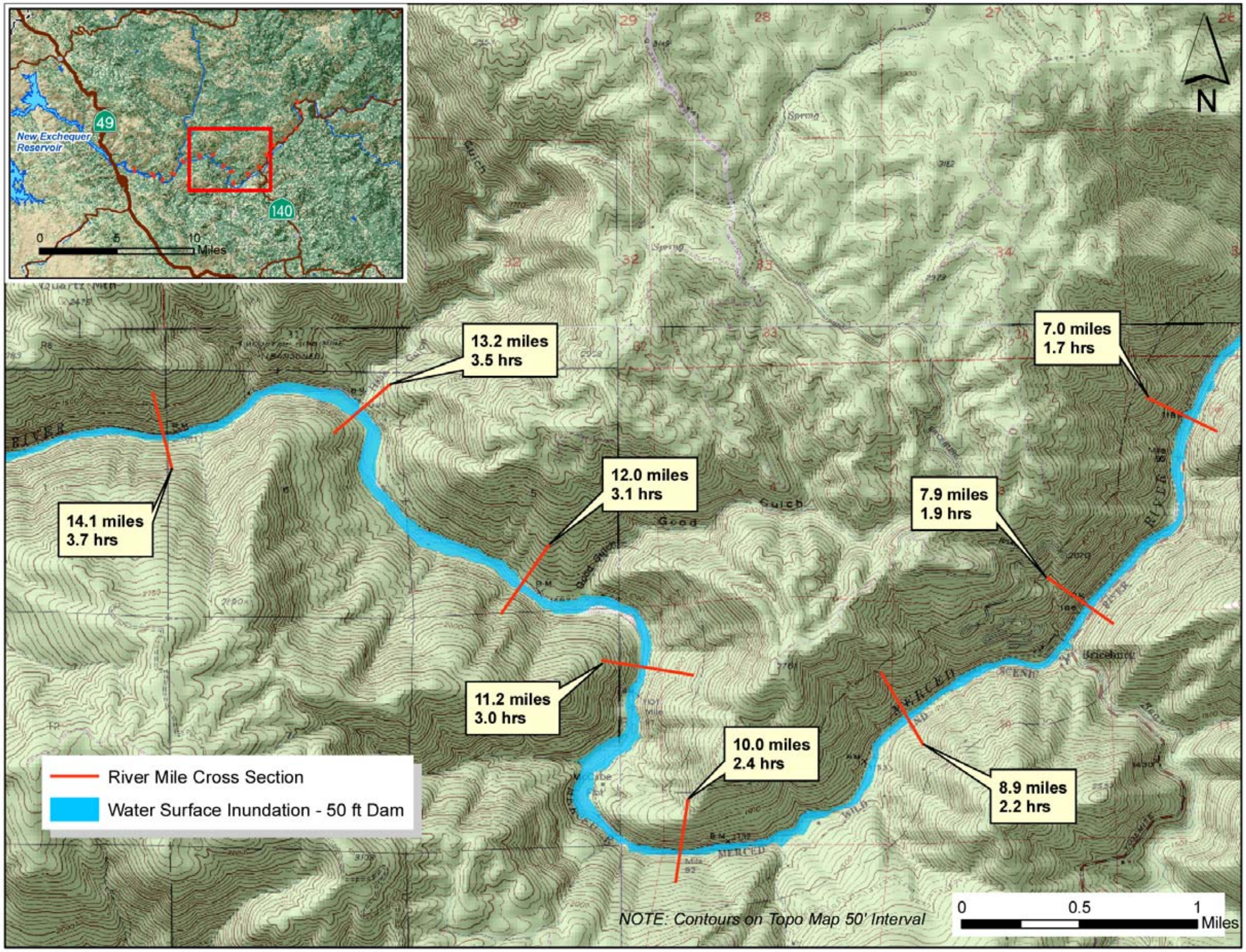
Appendix A – Flood Inundation Maps Downstream of Potential Rock Slide Dam

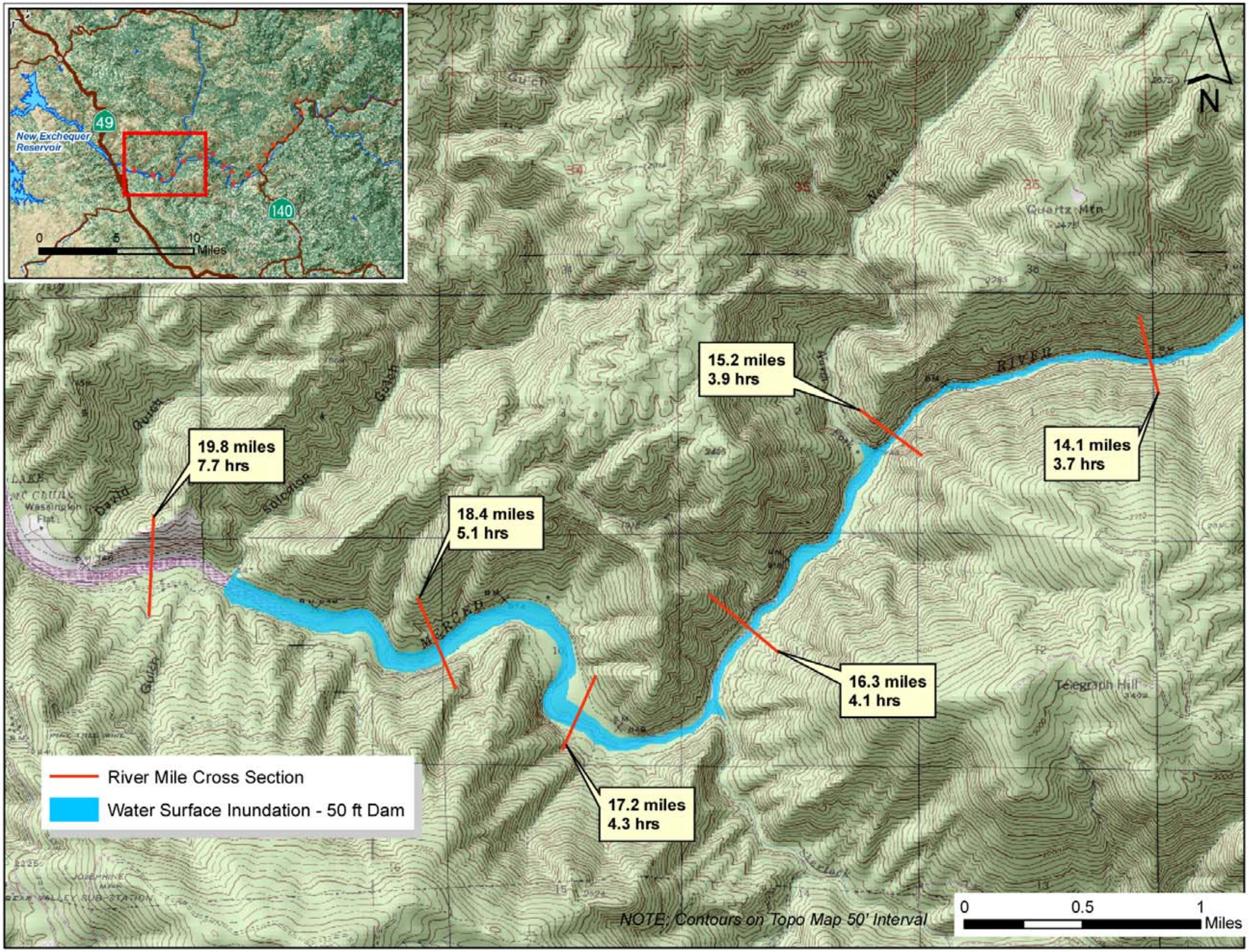



New Exchequer Reservoir
49
140
0 5 10 Miles
13.2 miles
1.8 hrs
14.1 miles
1.9 hrs
12.0 miles
1.6 hrs
11.2 miles
1.5 hrs
10.0 miles
1.3 hrs
8.9 miles
1.2 hrs
7.9 miles
1.0 hrs
7.0 miles
0.9 hrs
N
River Mile Cross Section
Water Surface Inundation - 100 ft Dam
NOTE: Contours on Topo Map 50' Interval
0 0.5 1 Miles


New Exchequer Reservoir
49
140
0 5 10 Miles
15.2 miles
2.0 hrs
14.1 miles
1.9 hrs
19.8 miles
2.8 hrs
18.4 miles
2.4 hrs
16.3 miles
2.1 hrs
17.2 miles
2.2 hrs
River Mile Cross Section
Water Surface Inundation - 100 ft Dam
NOTE: Contours on Topo Map 50' Interval
0 0.5 1 Miles
N
Quartz Mtn
Telegraph Hill


New Exchequer Reservoir
49
140
0
5
10
Miles
River Mile Cross Section
Water Surface Inundation - 50 ft Dam
2.0 miles
0.5 hrs
3.0 miles
0.7 hrs
4.2 miles
0.9 hrs
5.2 miles
1.2 hrs
6.1 miles
1.5 hrs
Slide Area
Ned Gulch
Merced River
South Fork
Merced River
Sweetwater Creek
N
0
0.5
1
Miles
NOTE: Contours on Topo Map 50' Interval


New Exchequer Reservoir
49
140
0
5
10
Miles
N
13.2 miles
3.5 hrs
14.1 miles
3.7 hrs
12.0 miles
3.1 hrs
11.2 miles
3.0 hrs
10.0 miles
2.4 hrs
7.0 miles
1.7 hrs
7.9 miles
1.9 hrs
8.9 miles
2.2 hrs
River Mile Cross Section
Water Surface Inundation - 50 ft Dam
NOTE: Contours on Topo Map 50' Interval
0
0.5
1
Miles


New Exchequer Reservoir
49
140
0
5
10
Miles
19.8 miles
7.7 hrs
18.4 miles
5.1 hrs
17.2 miles
4.3 hrs
16.3 miles
4.1 hrs
15.2 miles
3.9 hrs
14.1 miles
3.7 hrs
N
River Mile Cross Section
Water Surface Inundation - 50 ft Dam
NOTE: Contours on Topo Map 50' Interval
0
0.5
1
Miles

Appendix B – Landslide Monitoring

Live Stream Web Based Video (LSWBV) is in operation by CalTrans during daylight hours and not during inclement weather. This system is staffed during operational hours by CalTrans Highway staff. This system is close to real time (4 sec. delay) and requires that a person review the video for indications of slope failure. Currently the camera is located on the opposite side of the rock slide on the Incline Road and focused on the rock fall/rock slide portion of the rock slide. The camera and other equipment are located in the deposition zone of a potential catastrophic rock slide. This system is not dependable during the most critical times when monitoring of the rock slide is most important when people are asleep or slope stability conditions could be at their lowest when it is raining.

The Digital Terrain Model (DTM) survey is being collected by CalTrans every 3 days. The data collected from this survey system is 3-demensional and a topographical map and slope cross-sections can be constructed from this data. Comparison of the most recent DTM survey with previous surveys determines if the slope has changed with reference to slope deformation. This data requires a survey crew to collect the data from the instrument. The DTM survey does not require targets or reflectors on the slide surface and is able to reflect the survey instruments laser electrodes off of hard surfaces back to the instrument. There is a limitation on the distance the DTM survey is capable of surveying and the farthest points of the rock slide may be at the outside limitations of the survey instrument.

LIDAR uses the same principle as RADAR. The LIDAR instrument transmits light out to a target. The transmitted light interacts with and is changed by the target. Some of this light is reflected / scattered back to the instrument where it is analyzed. The change in the properties of the light enables some property of the target to be determined. The time for the light to travel out to the target and back to the LIDAR is used to determine the range to the target. The LIDAR data can be used to construct a high resolution topographic map that can be used to map the features of the rock slide and determine a more accurate estimate of the volume of the rock slide.

Slope Stability Radar (SSR) is Australian technology that uses radar technology to monitor movement of open pit mining walls. The technology has been used to monitor movement of other slopes including landslides. The device can measure slope displacement to within .1 mm and can be set up to transfer data via telemetry to a central location. CalTrans is proposing to monitor the landslide for three months at a cost of $100,000 per month for a total of three months.

GPS, Geophones, Tiltmeters are three sensors that monitor horizontal and vertical movement, slope deformation, and ground shaking. The sensors are attached to a spider like device complete with batteries and solar panels to recharge the batteries. The device is designed to install on land surfaces with a helicopter. The unit is also set up to record and transfer data via telemetry to a central location. The Yosemite National Park headquarters in El Portal is an ideal location for this central location because the site not only is connected to the world wide web it also houses the Information Technology center for Yosemite National Park. The data collected and transferred to the central location is real time data and can be set up to set off an alarm at pre-designated threshold levels. USGS has proposed to install and maintain this system for a cost of $60,000 to $70,000 for one year.

High Resolution Digital Photography are simple digital cameras set up with microprocessor technology to take photos at pre-designated intervals for the purpose of recording the target using digital photographic images. The image data can be set up to record and transfer data via telemetry to a central location. The cost to install and maintain this system is $2,000 for one year.

Stream Gauges are proposed upstream and downstream of the rock slide. The purpose of the stream gauges are to monitor stream flow between the two gauges. The stream gauges are especially critical to determine whether a failure of the rock slide has resulted in a landslide dam that has blocked flow of the Merced River. The DWR currently has two stream gauges at Pahona Bridge in Yosemite National Park and at Briceburg. The downstream Briceburg stream gauge is too far downstream to be affective in monitoring the stoppage of flow as a result of the rock slide. Stream gauge data can be set up to record and transfer data via telemetry to a central location. DWR estimates that cost for them to install and maintain the stream gauges at approximately $44,000 for one year.

Appendix C – Rock Slide Dam Impoundment Rates

	Dam Height (feet)				
	25	50	100	150	200
	Impound Volume (acre-feet)				
		541	3809		
River Discharge Rate (cfs)	Time to Fill in hours				
8000		0.82	5.76		
7500		0.87	6.15		
7000		0.94	6.58		
6500		**1.01**	**7.09**		
6000		**1.09**	**7.68**		
5500		1.19	8.38		
5000		1.31	9.22		
4500		1.45	10.24		
4000		1.64	11.52		
3500		1.87	13.17		
3000		**2.18**	**15.36**		
2500		2.62	18.44		
2000		3.27	23.04		
1500		4.36	30.73		
1000		6.55	46.09		
500		**13.09**	**92.18**		
250		26.18	184.36		
200		32.73	230.44		
100		65.46	460.89		

Bold Red *Highest recorded monthly flows, Jun-Jul-Aug, at USGS Merced River near Briceburg gage*

Green Shade *June monthly average flow based on COMBINED Merced River near Briceburg gage records*
Orange Shade *July monthly average flow based on COMBINED Merced River near Briceburg gage records*
Purple Shade *August monthly average flow based on COMBINED Merced River near Briceburg gage records*

Bold Purple *Approximate current discharge at slide site based on CDEC real-time Briceburg gage MBB, 6/12/2006 0900 - 6,229 cfs*