ShakeOut Scenario Appendix G: Preliminary Liquefaction Deformation Analysis at Lifeline Crossings

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USGS Open File Report 2008-1150, Appendix G
CGS Preliminary Report 25G

2008

U.S. Department of the Interior
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Suggested citation:
Real, Charles R., Pridmore, Cynthia L., and Loyd, Ralph C., 2008, ShakeOut Scenario Appendix G; Preliminary liquefaction deformation analysis at lifeline crossings, Appendix G *of* Jones, L.M., and others, The ShakeOut Scenario: U.S. Geological Survey Open-File Report 2008-1150 and California Geological Survey Preliminary Report 25G, 33 p. [http://pubs.usgs.gov/of/2008/1150/appendixes/of2008-1150_appendix_g.pdf].

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The ShakeOut Scenario
Appendix G: Preliminary Liquefaction Deformation Analysis at Lifeline Crossings for the M7.8 Southern San Andreas Earthquake Scenario

by Charles R. Real, Cynthia L. Pridmore, Ralph C. Loyd
California Geological Survey

Introduction

The California Geological Survey (CGS) has made estimates of ground deformation related to liquefaction in three "focus areas" as part of the Multi-Hazard Demonstration Project sponsored by the U.S. Geological Survey. Part of the demonstration project includes preparation of a credible M 7.8 earthquake scenario that entails rupture of the San Andreas Fault from Bombay Beach in Imperial County to Lake Hughes in Los Angeles County. A principal objective of the scenario includes a detailed assessment of the impact to critical lifelines that are concentrated in four fault-rupture focus areas in southern California: 1) Cajon Pass, 2) San Gorgonio Pass, 3) Coachella, and 4) Palmdale (Figure 1). A detailed evaluation was not performed in the Palmdale focus area as part of this study because liquefaction potential in the region was recently assessed (Pridmore, 2005; Mattison and Barrows, 2003) and zones of required investigation for liquefaction were delineated under California's Seismic Hazards Mapping Act (Sec 2690 et seq. Public Resources Code).

Lifelines include petroleum, water, fiber optic, truck and rail freight traffic, and power lines among others, which provide goods and services to and from southern California. They present a particular vulnerability because of their geographic extent, co-location in the focus areas, and inherent susceptibility to physical distress. Lifelines are generally linear structures that because of their geographic extent have a greater opportunity for impact by ground failure. Failure of any component along the lifeline extent can result in failure to deliver service over a large region. Once broken, transmission of the commodity through the lifeline ceases, which can have catastrophic repercussions down the line: loss of power to critical facilities such as hospitals, impaired disposal of sewage, contamination of water supplies, disruption of all forms of transportation, release of inflammable fuels, and so on. Therefore the overall impact of lifeline failures, including secondary failure of systems that depend on lifelines, can be much greater than that of individual buildings or residential dwellings.

The objective of this report is to evaluate the exposure of lifelines passing through the prescribed focus areas to liquefaction-induced ground failure. In addition to ground shaking, the extension, torsion, compression, settlement and fissuring associated with permanent ground deformation can break and disrupt lifelines for long periods causing

serious economic impact. Fault rupture and earthquake-triggered landslides and are another cause of hazardous ground failure, and are addressed separately in companion reports. Conservative estimates of liquefaction deformation are made that provide a range of maximum lateral ground displacement at a few selected sites where several lifelines are co-located. Inferences are made from these analyses as to the magnitude and pervasiveness of the hazard throughout each of the focus areas. This information is passed along to help engineers assess the impact and overall performance of the various lifelines, and the potential economic impacts can be better quantified so appropriate mitigation can be given informed consideration.

Methodology

General Approach

Assessment of earthquake-induced ground failures typically involves site-specific geotechnical investigations that characterize the sediment composition and physical properties of ground materials. More detailed quantitative measurements of these properties drive the more complex models that lead to better estimates of hazard. The scope of this analysis is reconnaissance, however, which precludes acquiring measurements of such data. Furthermore, only limited existing data are available for the identified focus areas, which limits the level of sophistication in the analysis and necessitates making assumptions for use of those models that are appropriate under these conditions.

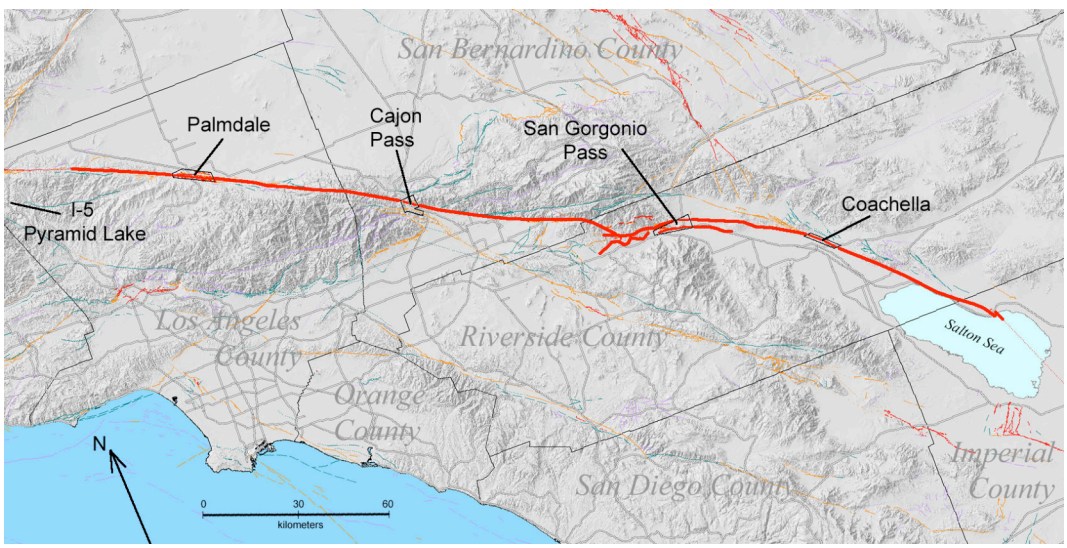


Figure 1. Location of MHDP Focus Areas evaluated for liquefaction hazards in southern California.

When considering the greatest potential hazard within each focus area, specific targets were selected for analysis based on the proximity of co-located lifelines to active fluvial systems, where liquefaction is most prevalent and the largest displacements that are caused by lateral spreading are most likely to occur. These areas were identified from analysis of available geologic/topographic maps and aerial photographs. Field visits were

then made to each of the sites selected within each focus area in order to make the final selection.

Model

We estimate maximum horizontal ground displacement due to lateral spreading using the empirical 4-parameter regression model of Bardet and others (2002). This model was selected over the Youd and others (2002) model because the latter requires an estimate of median grain size of the sediments, which is not known for the area. The Bardet and others model was explicitly developed without that parameter because it is not commonly found in available boring logs. The model can be applied to free-face or ground slope conditions and small displacements, when appropriate adjustments to parameter coefficients are made. The model is based on over 400 measurements of lateral spread from case histories that include the large magnitude earthquakes that occurred in Niigata, Japan, Alaska, and California. Because the maximum observed displacements in the database used to derive the model range from less than a meter to about 10 m, estimates made in the current project that exceed this value are truncated beyond that limit.

Cajon Pass Focus Area

Cajon Pass follows a canyon that separates the San Gabriel Mountains to the west from the San Bernardino Mountains to the east, and is traversed by the San Andreas Fault rupture prescribed for this scenario. Cajon Creek flows southward through the canyon, and is a major component of the Santa Ana River watershed. Numerous lifelines carrying commodities to and from the southern California region share right-of-ways through the pass, and are vulnerable to fault rupture along the San Andreas Fault, triggered landslides, and liquefaction deformation along drainages (FEMA, 1992a; 1992b). Because of abundant river channel deposits along Cajon Creek and its tributaries, seasonally high water table, and proximity to the San Andreas Fault, liquefaction is likely to accompany the scenario earthquake during the winter months when groundwater levels are high.

Eight sites were identified on aerial imagery as potential liquefaction sites near co-located lifelines (Figure 2). Of the eight sites, field inspection revealed four that have a high potential for liquefaction lateral spread. Estimates of horizontal displacement were made for these four sites, and are summarized in Table 1 and Figure 2. Sites 3 and 4 located on the tributary creek in Lone Pine Canyon were eliminated as a hazard because the creek is deeply incised, youthful, and carries a body of sediments too thin to be of liquefaction concern. Site 2, along a narrow stretch where Cajon Creek has incised to bedrock, is also not of liquefaction concern (note: there is no site 7).

The current channel of Cajon Creek is flanked by a series of four elevated terraces formed as the mountain range has continued to uplift as Cajon Creek continues to erode downward (Photo 1). Without site specific geotechnical investigation, including drilling and soil testing, determination of terrace liquefaction potential is problematic. The key questions are 1) depth to shallowest sediment saturation, which is known to dramatically fluctuate seasonally, and 2) the thickness of liquefiable sediments. Surface sediments, and those visible in terrace cut-banks, are loose and highly heterogeneous, consisting of cobbles and boulders in a matrix of silts, sand and gravel. These sediments do not have fine-grained layers, which in some localities can confine groundwater leading to greater build-up of pore pressures, and therefore, greater potential for liquefaction. Despite the lack of a significant “fines cap”, coarse material can liquefy under very high levels of ground shaking. Because all sites at Cajon Pass are less than 2 km from the primary rupture

scenario of a M7.8 event, it is assumed that the high amplitude and long duration of shaking will build pore pressures so rapidly that liquefaction will occur in the heterogeneous channel and terrace deposits.

Although field conditions were dry during the summer visit, it is expected that channel deposits become completely saturated during winter and spring runoff. Groundwater monitoring wells near the intersection of Interstate 15 and Interstate 210 indicate seasonal fluctuations of more than 20m at times of heavy winter rain. Erosion scars that are evidence of ephemeral springs suggest that subsurface water flow down mountain slopes flanking Cajon Wash during winter months can be significant, giving rise to the possibility that terrace sediments may become saturated and susceptible to liquefaction. As terrace elevation and age increases, the deposits are less susceptible to liquefaction because depth to saturation increases and the deposits become more indurated with age. Therefore, the lowest terrace, which lies in the Cajon Wash, is considered the most susceptible, while the highest terraces are considered unlikely to liquefy. It is assumed for purposes of the scenario that the lower 2 terraces are susceptible to liquefaction lateral spreading, so our deformation analysis is focused there.

Borings near the bend in Cajon Wash indicate sediment thickness in excess of 30m, increasing southward toward the Santa Ana River basin. Because actual sediment thickness at the sites is unknown, ground deformation estimates are based on assumptions of two thicknesses of liquefied material. Lateral spread displacements are estimated assuming fully saturated liquefiable sediment thicknesses of 5 and 15 meters at each site evaluated. Setbacks (distance from the lifeline to the free-face) for specific lifelines at each of the four sites are considered in the calculations. Displacement is rounded to whole meters, and the 16th and 84th percentiles can be approximated by halving and doubling respectively the displacement values provided.

Results

Horizontal displacement estimates from potential liquefaction lateral spreading at 4 sites in the Cajon Pass Focus Area are summarized in Table 1 and Figure 2. Displacement estimates have been made assuming thickness of liquefied sediments of 5m and 15m. Ranges for 16th and 84th percentile can be approximated by halving and doubling respectively the median values shown. The following sections provide details of the estimates.

Table 1. Summary of Estimated Displacements

Site	DISPLACEMENTS (meters)	
	5m liquefies	15m liquefies
LQ-1 (8):		
5-Meter Setback	7	10
10-Meter Setback	5	10
LQ-5*:		
Profile 1:		
Lower track	4	7
Upper track	1	2
Profile 2:		
Lower track	4	7
Upper track	1	3
LQ-6:		
Lower track	3	5
Upper track	2	4
LQ-9:		
Petroleum lines:	8	10
High-pressure gas:	6	10
Highway/fiber optic:	4	6

* 36” high-pressure gas line between tracks.

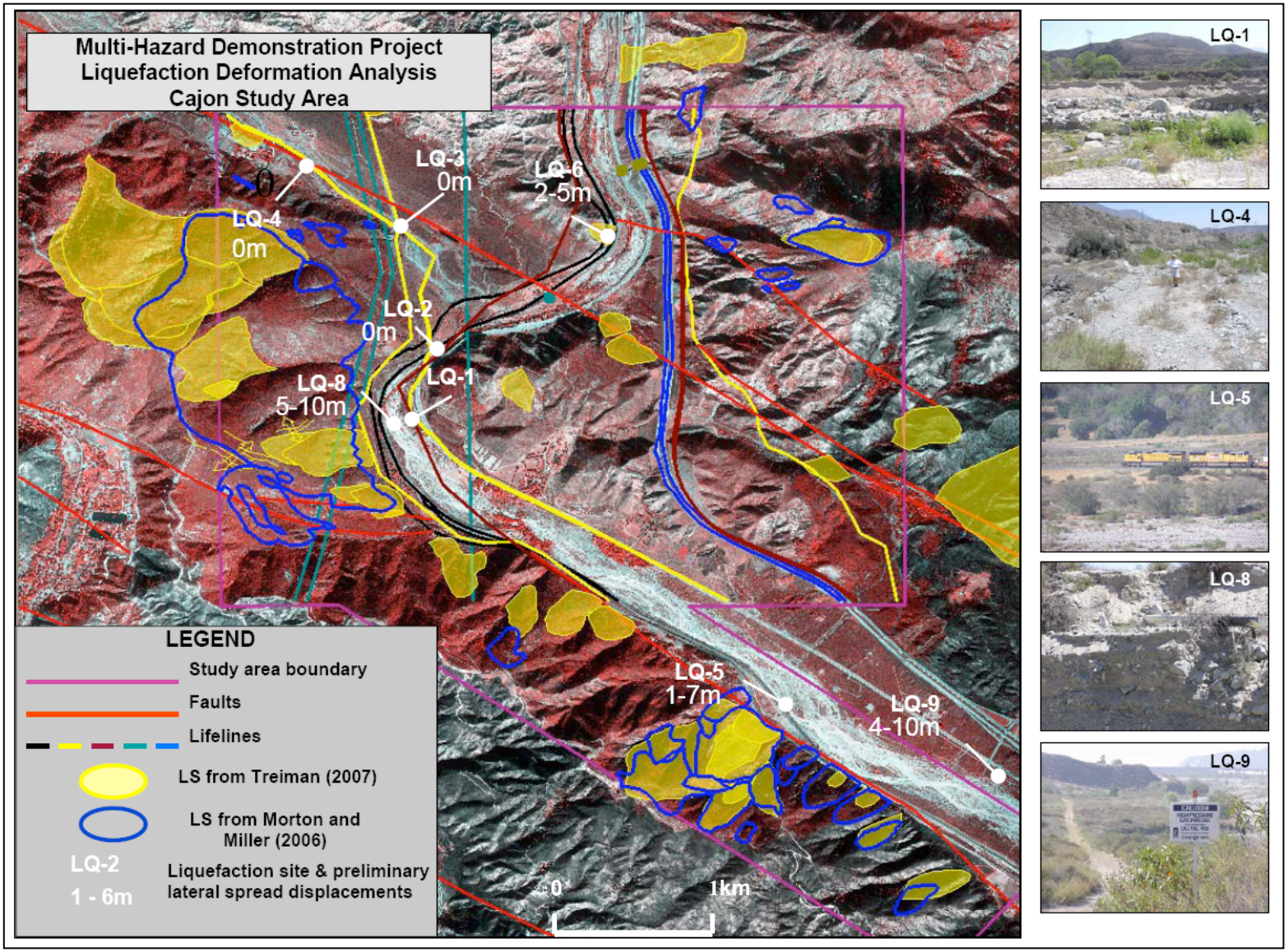


Figure 2. Summary of Lateral Spreading Displacement Estimates

Sites LQ-1,LQ- 8

This site is located on the inside of the major bend in Cajon Creek (Figures 1,2), where large point bars and terraces have formed over time (Photo 1). Displacement estimates were made on the lower terrace where a gas line crosses through the channel (Photo 2). A surface profile and calculated displacements are provided. Two estimates are made measured from where the pipeline enters the free-face: setback at 5m and 10m as shown in the diagram of Figure 3 and Figure 4.

Photo 1. Looking east from Cajon Creek across a series of four terraces. The youngest (lowest) terraces are probably the most susceptible to liquefaction lateral spreading due to their young age and close proximity to the water table.

Photo 2. Cutbank on terrace 2 in Cajon Creek Channel, where gas pipeline is exposed by recent channel erosion. Free face is about 3m high.

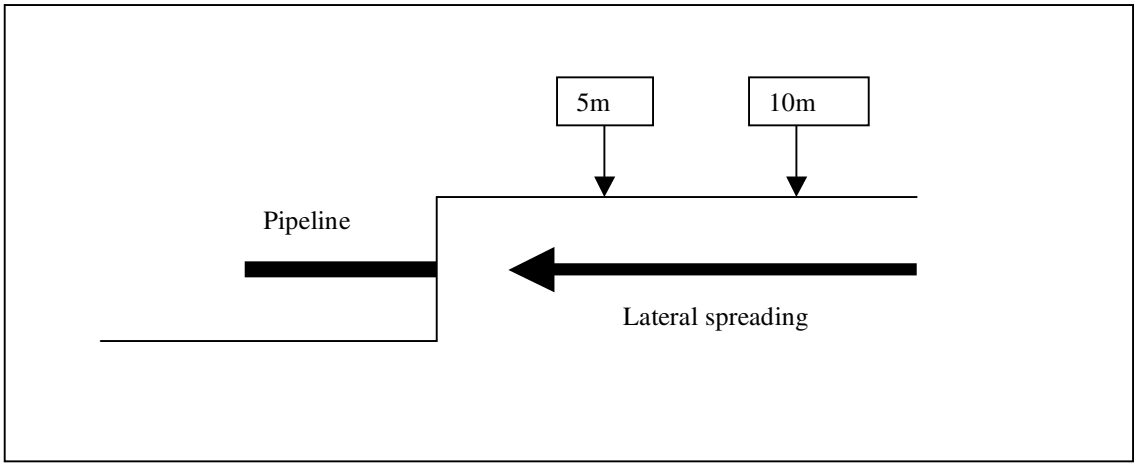
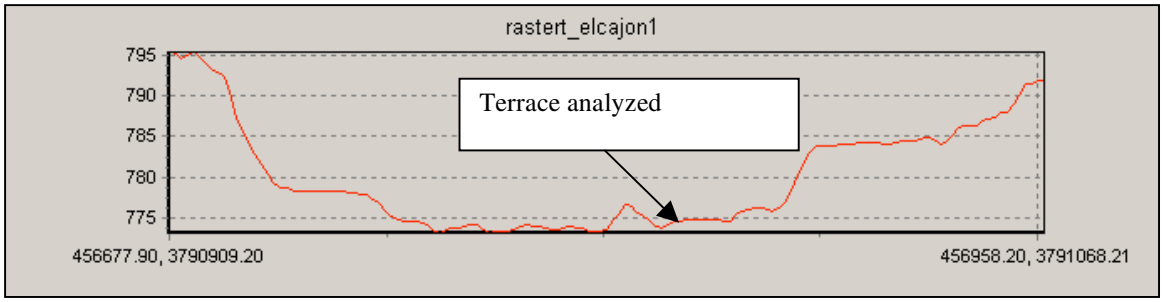


Figure 3. Diagram showing location of setback points for calculation of horizontal displacement.

Figure 4. Lateral Spread Displacement Estimates at Site LQ-1/LQ-8



Setback 5 m:

SUMMARYTABLE 15m liquefies	
Mw:	7.8
R:	1.4km
L:	5m
H:	3m
T15:	15m
D:	10m

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	1.4km
L:	5m
H:	3m
T15:	5m
D:	7m

Setback 10m:

SUMMARYTABLE 15m liquefies	
Mw:	7.8
R:	1.4km
L:	10m
H:	3m
T15:	15m
D:	10m

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	1.4km
L:	10m
H:	3m
T15:	5m
D:	5m

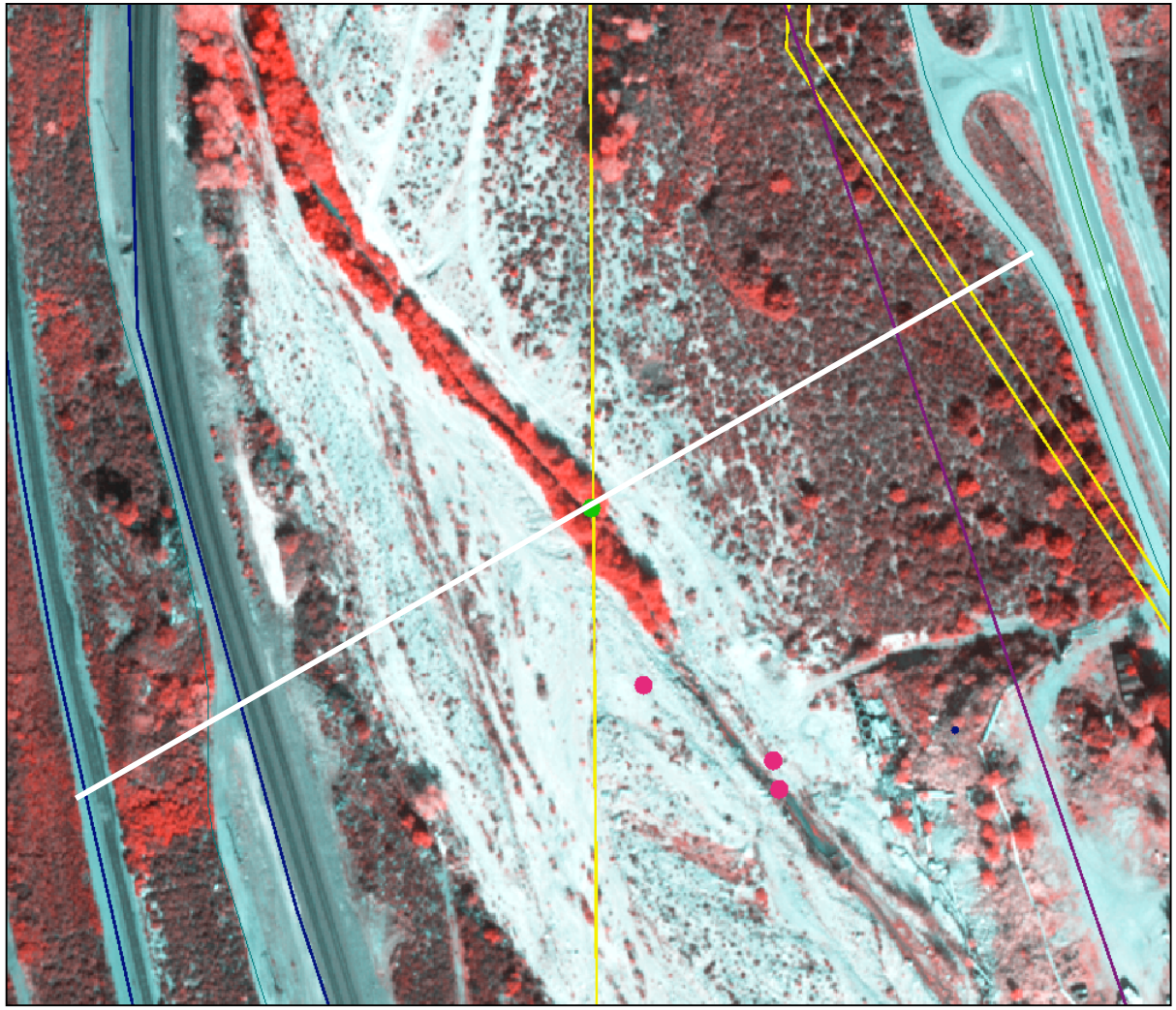


Figure 5. Aerial view of site LQ-8 showing profile line extending from the rail lines on the left to Cajon Road on the right.

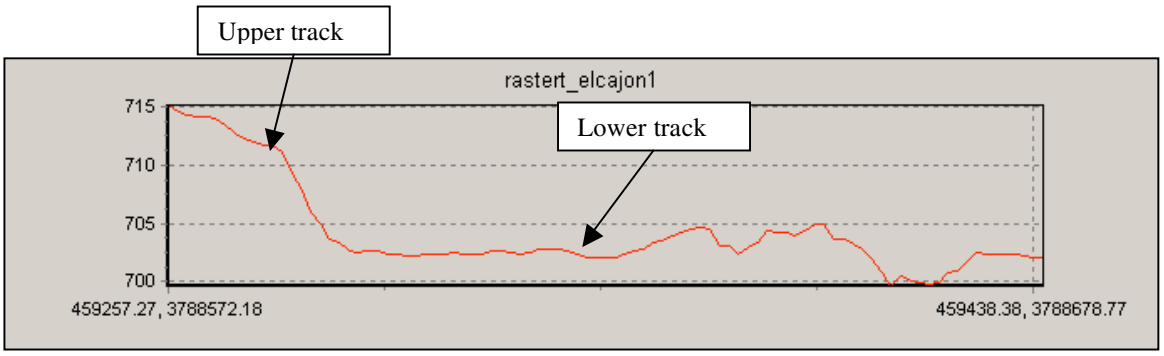
Site LQ-5

This site lies on the west side of Cajon Wash, and is adjacent to a very young, active landslide that has been evaluated by Wilson et al (2008)(Figure 2, Photo 3). Inspection of the landslide revealed subsurface water exiting near the foot of the slide, just above the upper rail line. The lower rail line rests upon a stream terrace and is adjacent to Cajon Wash channel. Ballast for the rail line forms part of the channel banks that are about 4 m high. Heavy steel debris fences line the channel banks here, indicative of high river levels during heavy winter floods. During such conditions, much of the surrounding sediments are saturated at channel level and most likely within the lower portions of the terraces.

Photo 3. Site LQ-5 looking west from Cajon Wash toward the rail lines. A 36 inch high-pressure gas line lies between the two tracks. All lifelines at this site have high exposure to potential earthquake-triggered landslides and lateral spreading.

Figures 6a, 6b, and 7 show the profile location and results of the displacement estimates at site LQ-5.

Figure 6a. Lateral Spread Displacement Estimates at Site LQ-5.



Profile 1

a) Lower Track

SUMMARYTABLE 15m liquefies	
Mw:	7.8
R:	2km
L:	20m
H:	4m
T15:	15m
D:	7m

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	2km
L:	20m
H:	4m
T15:	5m
D:	4m

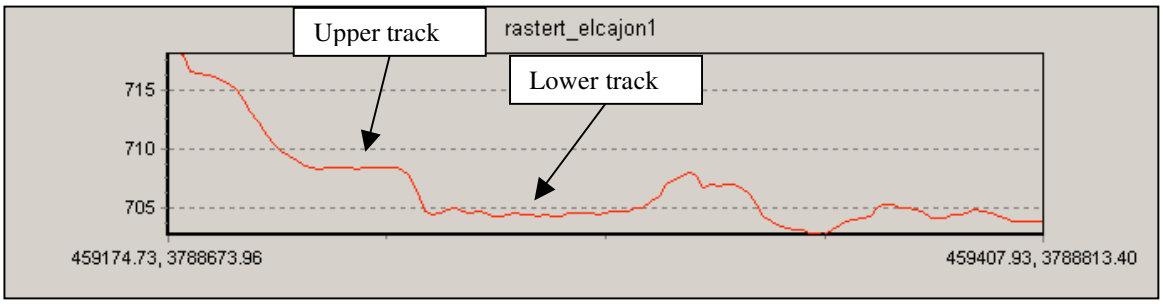
b) Upper Track

SUMMARYTABLE 15m liquefies	
Mw:	7.8
R:	2km
L:	180m
H:	4m
T15:	15m
D:	2m

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	2km
L:	180m
H:	4m
T15:	5m
D:	1m

Figure 6b. Lateral Spread Displacement Estimates at Site LQ-5

Profile 2



c) Lower Track

SUMMARYTABLE 15m liquefies	
Mw:	7.8
R:	2km
L:	20m
H:	4m
T15:	15m
D:	7m

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	2km
L:	20m
H:	4m
T15:	5m
D:	4m

d) Upper Track

SUMMARYTABLE 15m liquefies	
Mw:	7.8
R:	2km
L:	150m
H:	4m
T15:	15m
D:	3m

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	2km
L:	150m
H:	4m
T15:	5m
D:	1m

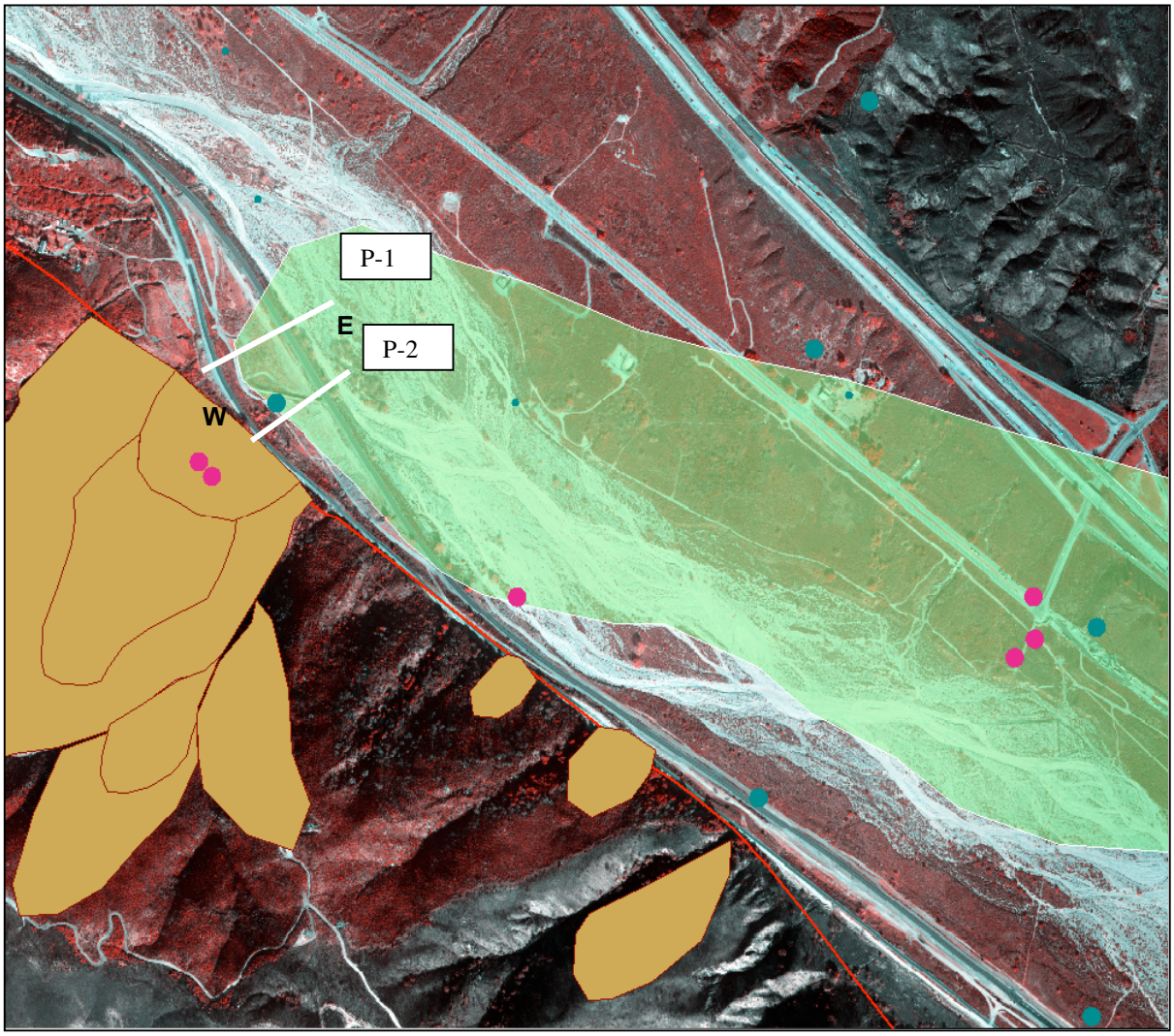


Figure 7. Aerial view of site LQ-5 showing two profile lines (white). Green area is identified as shallow groundwater and colored dots indicate location of field photos (red), water borings (small blue) and co-located lifelines (large blue). Brown patches are mapped landslides.

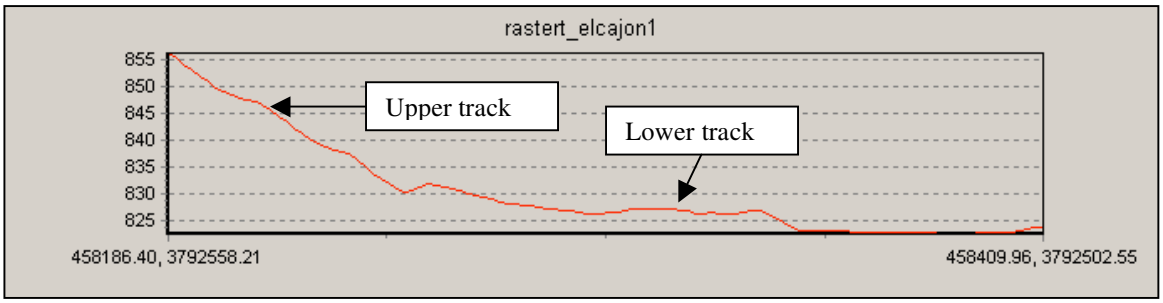
Site LQ-6

This site lies north of Sites LQ-1 and LQ-8, on the west side of Cajon Wash where the eastward meander has formed a broad point bar (Figure 2, Photo 4). Two major rail lines are co-located atop a landslide (see Site LS-3 in the landslide report) along the flank of Cajon Wash near the western edge of the point bar. The lower rail line is situated about 5m, and the upper rail line about 20m, above the channel bottom. The free-face height of the point bar is about 5m and lies about 110m from the lower rail line.

Photo 4. Site LQ-6 (and landslide site LS-3) showing large landslide on hillside, upper and lower rail lines, and point bar just visible above the foreground trees.

The presence of both landslide and liquefaction lateral spread hazard makes this site particularly hazardous. Figures 8 and 9 show the profile location and results of the displacement estimates at site LQ-6.

Figure 8. Lateral Spread Displacement Estimates at Site LQ-6.



e) Lower Track

SUMMARYTABLE 15m liquefies	
Mw:	7.8
R:	0.7km
L:	110m
H:	5m
T15:	15m
D:	5m

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	0.7km
L:	110m
H:	5m
T15:	5m
D:	3m

Mw:	7.8
R:	0.7km
L:	174m
H:	5m
T15:	15m
D:	4m

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	0.7km
L:	174m
H:	5m
T15:	5m
D:	2m

f) Upper Track

SUMMARYTABLE 15m liquefies

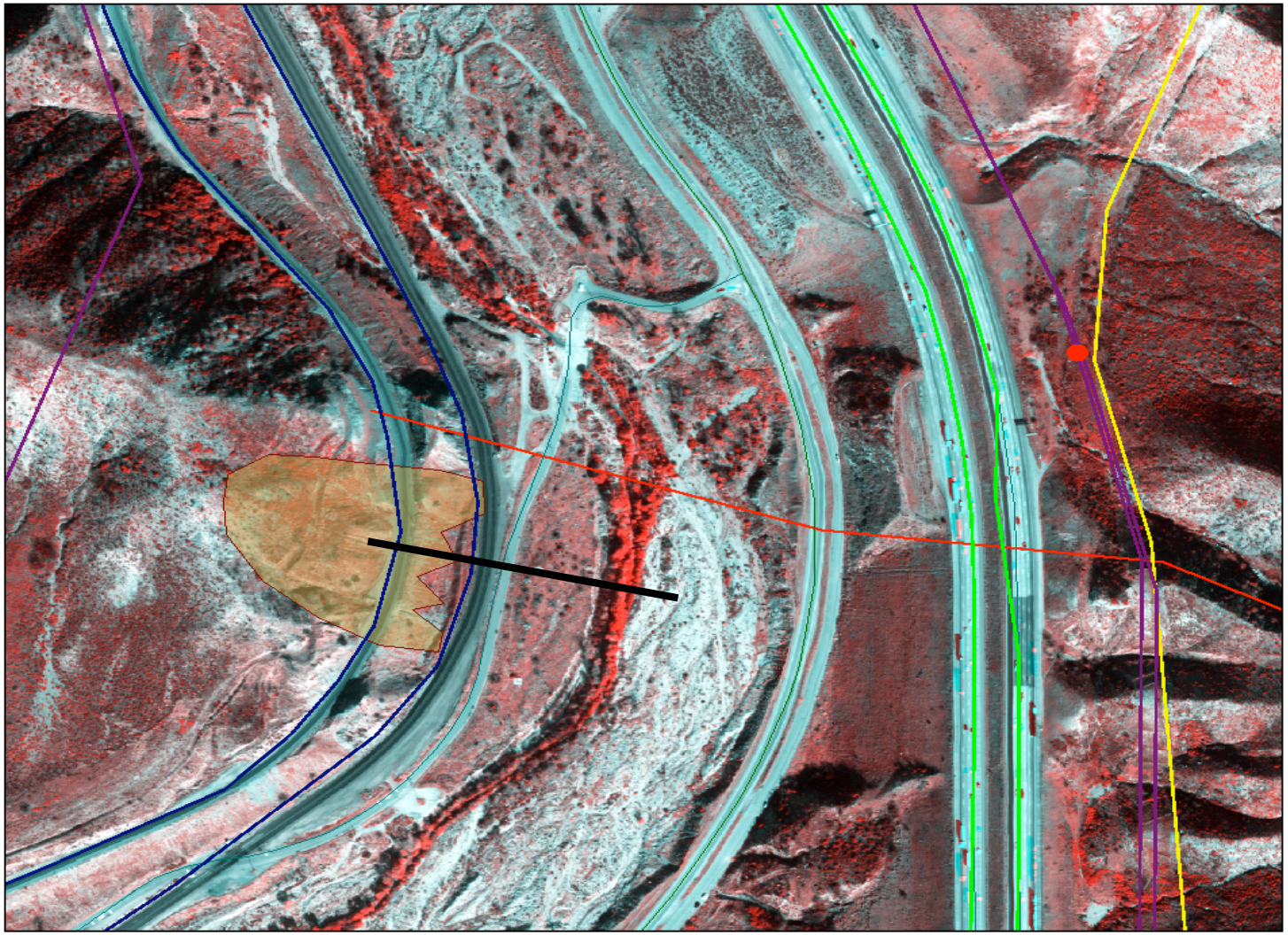


Figure 9. Aerial view of Site LQ-6 showing landslide (site LS-3 in landslide report), rail lines, and profile across point bar.

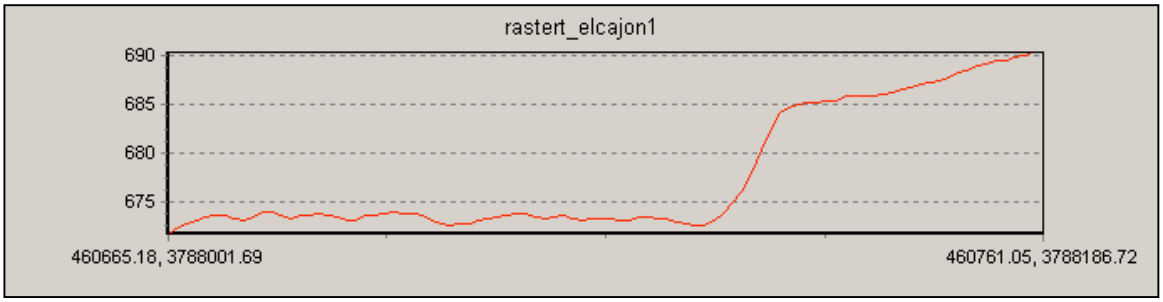
Site LQ-9

This site is located about 1.5 km southeast of site LQ-5, on the east side of Cajon Wash (Figure 2, Photo 5). At this location there are 4 fiber optic lines, 1 high-pressure gas line, 2 petroleum lines and a highway. The free-face height from the floodplain to the first terrace is 13m, and shows relic scars of bank collapse at this location (Figure 11).

Photo 5. Site LQ-9 which has several co-located lifelines passing through the site. Evidence of a bank failure scarp can be seen immediately behind the caution sign.

Figures 10 and 11 show the profile location and results of the displacement estimates at site LQ-9.

Figure 10. Lateral Spread Displacement Estimates at Site LQ-9



15m liquefiable soil:

Petroleum Lines:

SUMMARYTABLE 15m liquefies	
Mw:	7.8
R:	1.6km
L:	18m
H:	13m
T15:	15m
D:	10m

High Pressure Gas Line:

SUMMARYTABLE 15m liquefies	
Mw:	7.8
R:	1.6km
L:	35m
H:	13m
T15:	15m
D:	10m

Old Highway:

SUMMARYTABLE 15m liquefies	
Mw:	7.8
R:	1.6km
L:	86m
H:	13m
T15:	15m
D:	6m

Petroleum Lines:

5 m liquefiable soil:

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	1.6km
L:	18m
H:	13m
T15:	5m
D:	8m

High Pressure Gas Line:

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	1.6km
L:	35m
H:	13m
T15:	5m
D:	6m

Old Highway:

SUMMARYTABLE 5m liquefies	
Mw:	7.8
R:	1.6km
L:	86m
H:	13m
T15:	5m
D:	4m

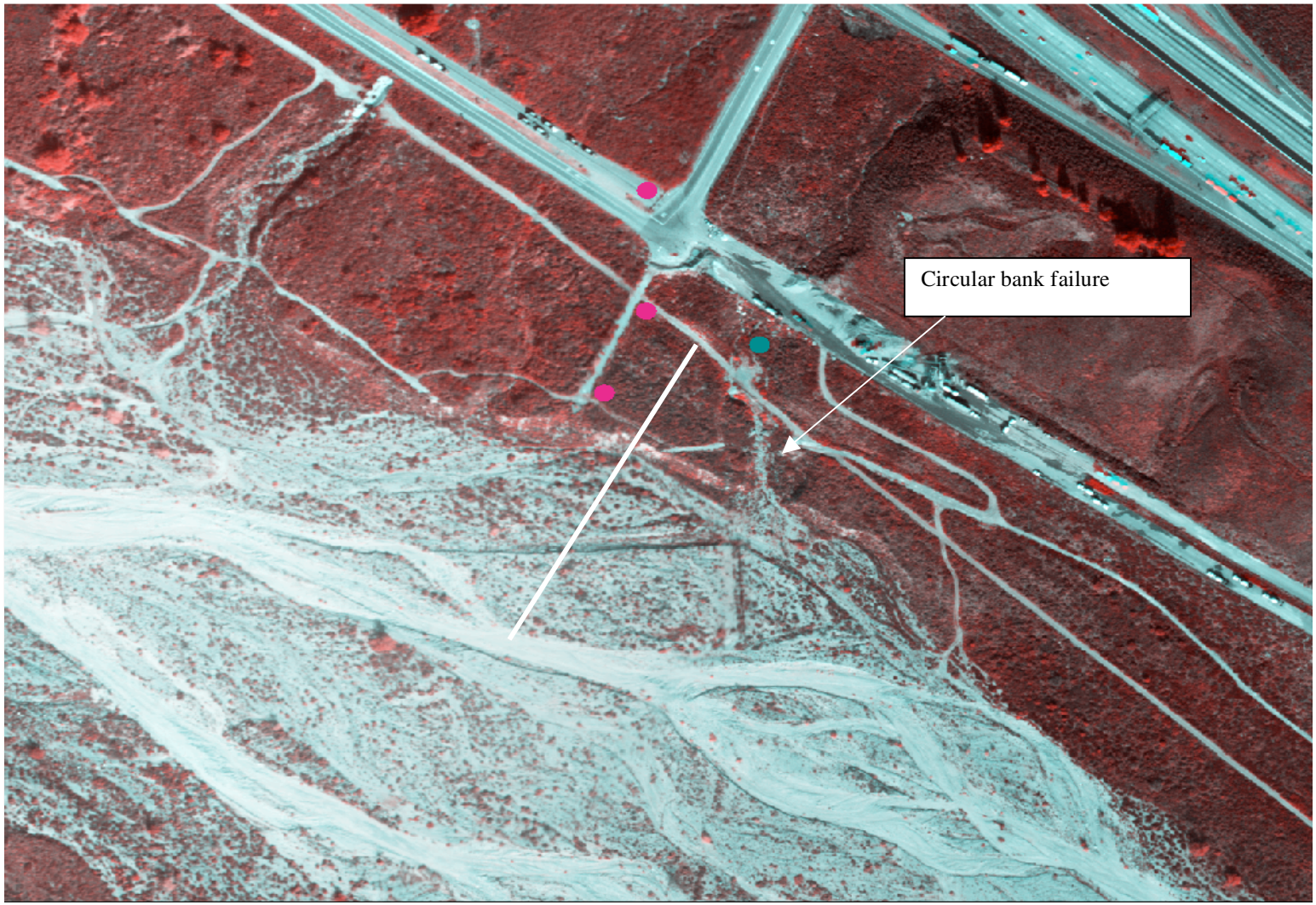


Figure 11. Aerial view of site LQ-9 showing line of profile across free-face formed by floodplain and adjacent terrace. Circular bank collapse is visible, as well as lineation of vegetation across floodplain, which are indicative of buried pipelines.

San Gorgonio Pass Focus Area

The San Gorgonio Pass Focus Area encompasses a broad valley that separates the San Jacinto Mountains to the south from the San Bernardino Mountains to the north. Several strands of the San Andreas Fault flank the northern slopes of the valley (Figure 12). The Whitewater River flows southward into the valley, crosses strands of the San Andreas, and is a major source of groundwater recharge for this region. Several lifelines transmitting services or carrying commodities to and from the southern California region cross through this region, and are vulnerable to fault rupture, triggered landslides, and liquefaction deformation. Due to the combination of river/alluvial fan deposits, localized surface water from the Whitewater River, and the proximity to the San Andreas Fault, liquefaction is likely to accompany the scenario earthquake during months when the river is flowing. Water was flowing in the Whitewater River channel at Interstate 10 at the time of the CGS field visit in June 2007.

Five sites were evaluated as potential liquefaction sites near co-located lifelines (Figure 13). Two of the sites are along Interstate 10 where fiber optic cables and the interstate highway share right-of-way (sites 1 and 5). The three other sites evaluated are located further out in the valley where high pressure gas pipelines (site 2), and rail lines (sites 3 and 4) are located. Site 4 is located on the San Gorgonio River, and site 5 located on and Cottonwood Creek; geotechnical data from both sites were used for comparison to the other nearby sites .

Photo 6. San Gorgonio Pass overlooking I-10 and White Water Road bridge crossings of White Water River. View looking south. Hwy 111 extends along tree line at base of mountains in background. Confluence of San Gorgonio River and White Water Wash is at base of mountains on right side of photo where wind-blown sand from the channel has been redeposited on slope of an alluvial fan (see photo 10).

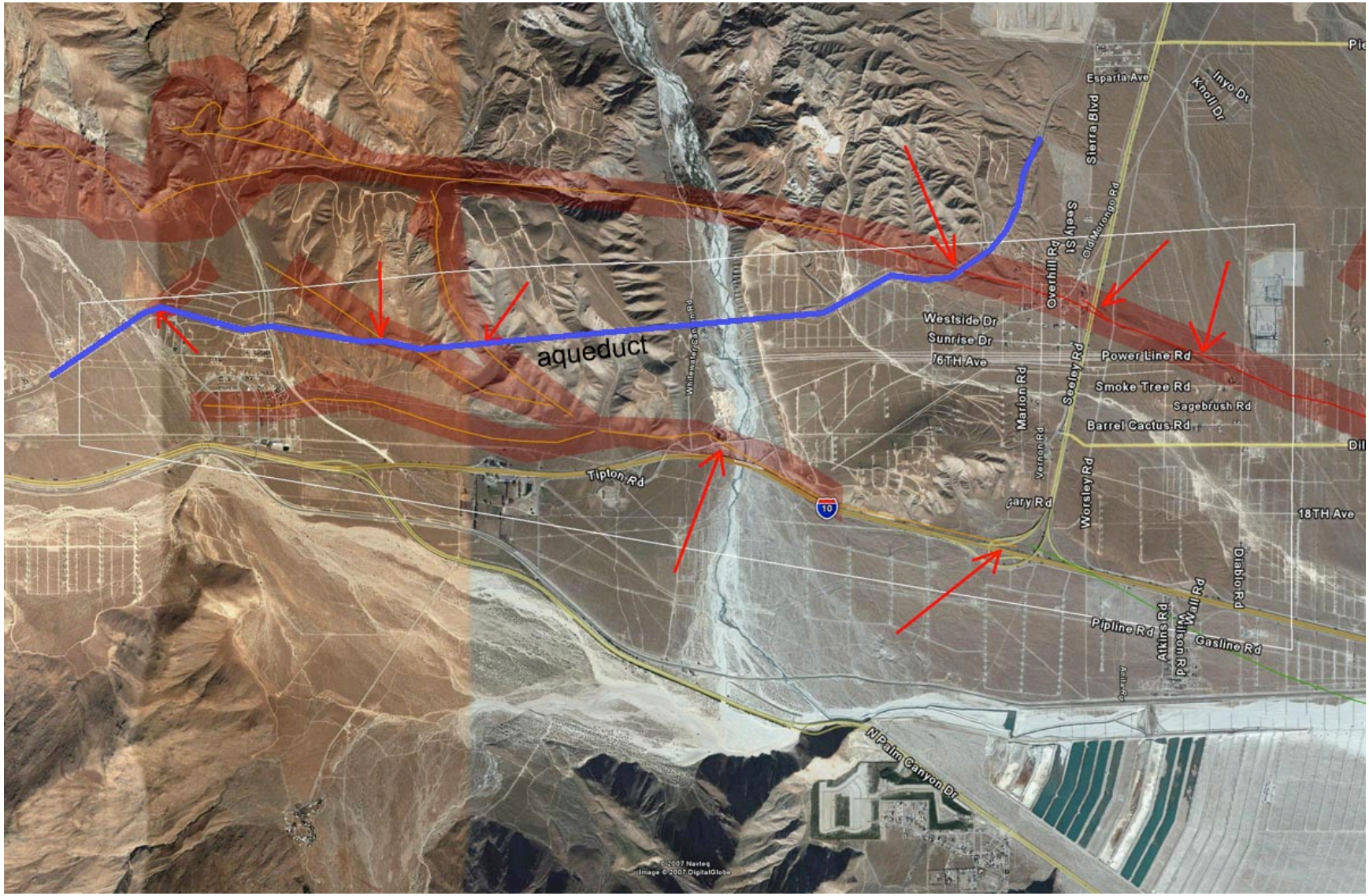


Figure 12. Air photo of San Gorgonio Pass / White Water area showing life lines and Earthquake Fault Zones designated along faults traces in the San Andreas Fault Zone. Arrows point to crossings of life lines by branches of the San Andreas Fault.

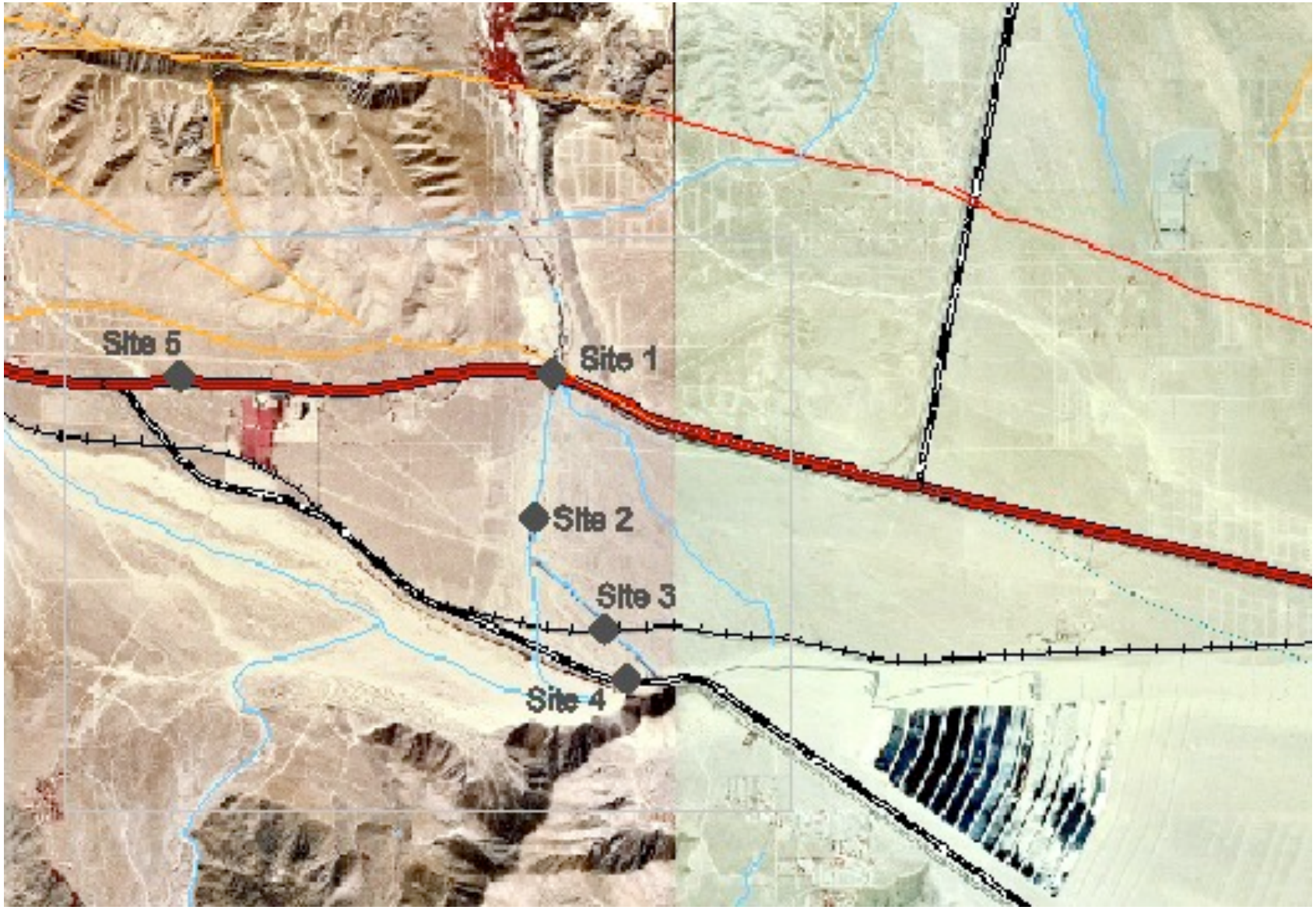


Figure 13. Locations of Sites 1-5, San Gorgonio Pass Focus Area

Photo 7. Site 1: View looking southeast. Northerly trending buried fiber optic lines extend beneath west side of I-10 bridge crossing of White Water River. Note signs on wooden posts marking trace of the buried lines.

Photo 8. Site 2: Easterly trending, buried high-pressure gas line markers in the channel of the White Water Wash about 1.4 km south of I-10 bridge crossing. Note standing water in active channel portion of the wash, indicating saturated subsurface conditions.

Photo 9. Site 3. Railroad tracks and bridge within channel of White Water River. Several trains per hour were observed hauling freight on this rail line.

Photo 10. Site 4. View looking north from Hwy 111 at the confluence of the San Gorgonio River (sandy channel) and the White Water Wash (sand and cobbles).

Results

A summary of horizontal displacement estimates for potential liquefaction sites for the San Gorgonio Pass Focus area is shown in Table 1. Lateral spreading due to liquefaction was evaluated at these sites using the ground slope parameters of the Bardet *et al*. (2002) model. The Garnet Hill strand of the San Andreas Fault was used to calculate distance from site to source. The modeling assumes groundwater to be at near-surface conditions.

Because the actual thickness of liquefiable sediment at each site is unknown, ground deformation estimates are based on assumptions of potential minimum and maximum thicknesses of liquefied material. These thicknesses were established by reviewing geotechnical data from nearby borehole data and using geologic inferences. Displacement is rounded to whole meters; the 16th and 84th percentiles can be approximated by halving and doubling, respectively, the displacement values provided.

Table SG-1 Summary of Estimated Displacements San Gorgonio Pass Focus Area (Fault Source: Garnet Hill strand of the San Andreas Fault)

Site	Thickness of liquefiable sediment * (meters)	**Horizontal Displacement** (meters)
Site 1 I-10 and Fiber Optic conduits at Whitewater River	0.5	4
	2	8
Site 2 High Pressure Pipeline(s) at Whitewater River	2	4
	5	6
Site 3 Rail Lines at Whitewater River	2	3
	5	5
Site 4 Hwy 111 at San Gorgonio River	2	3
	5	5
Site 5 I-10 and Fiber Optic conduits at Cottonwood Creek	2	4
	5	7

* Assumes near-surface sediments to be saturated

Coachella Focus Area

The Coachella Valley lies within the low lying region bounded by the San Andreas Fault to the east, the Little San Bernardino Mountains to the north and the San Jacinto Mountains to the west. Surface elevations in the town of Indio near the point where Interstate 10 (I-10) crosses the San Andreas Fault, are at or below sea level. The Whitewater River is channelized through this region, a flood control measure, where to the south it eventually meets the Salton Sea. At the time of CGS field visit in June 2007, the river bed was dry, but supported phreatophytes. Shallow ground-water levels associated with semi-perched conditions make this portion of the Coachella area susceptible to liquefaction hazards. Lifelines in the Coachella focus area that would be affected by liquefaction include Interstate 10, fiber-optic cables, and rail lines.

Six sites were evaluated for liquefaction displacements (Figure 13). Five of these (sites 1-5) are along Interstate 10 where fiber optic cables and the interstate highway share right-of-way. Site 6 evaluated the rail lines near Avenue 46 and Highway 111/86.

Photo 11. Site 1. I-10 over-crossing of Dillon Road, Indio, California. Ground water level during test drilling for the construction of this bridge over-crossing was recorded at 2.1 meters. Soils penetrated during drilling consisted mainly of loose sand and silt. Life Line Hazard within focus area: Potential for liquefaction along entire length of freeway.

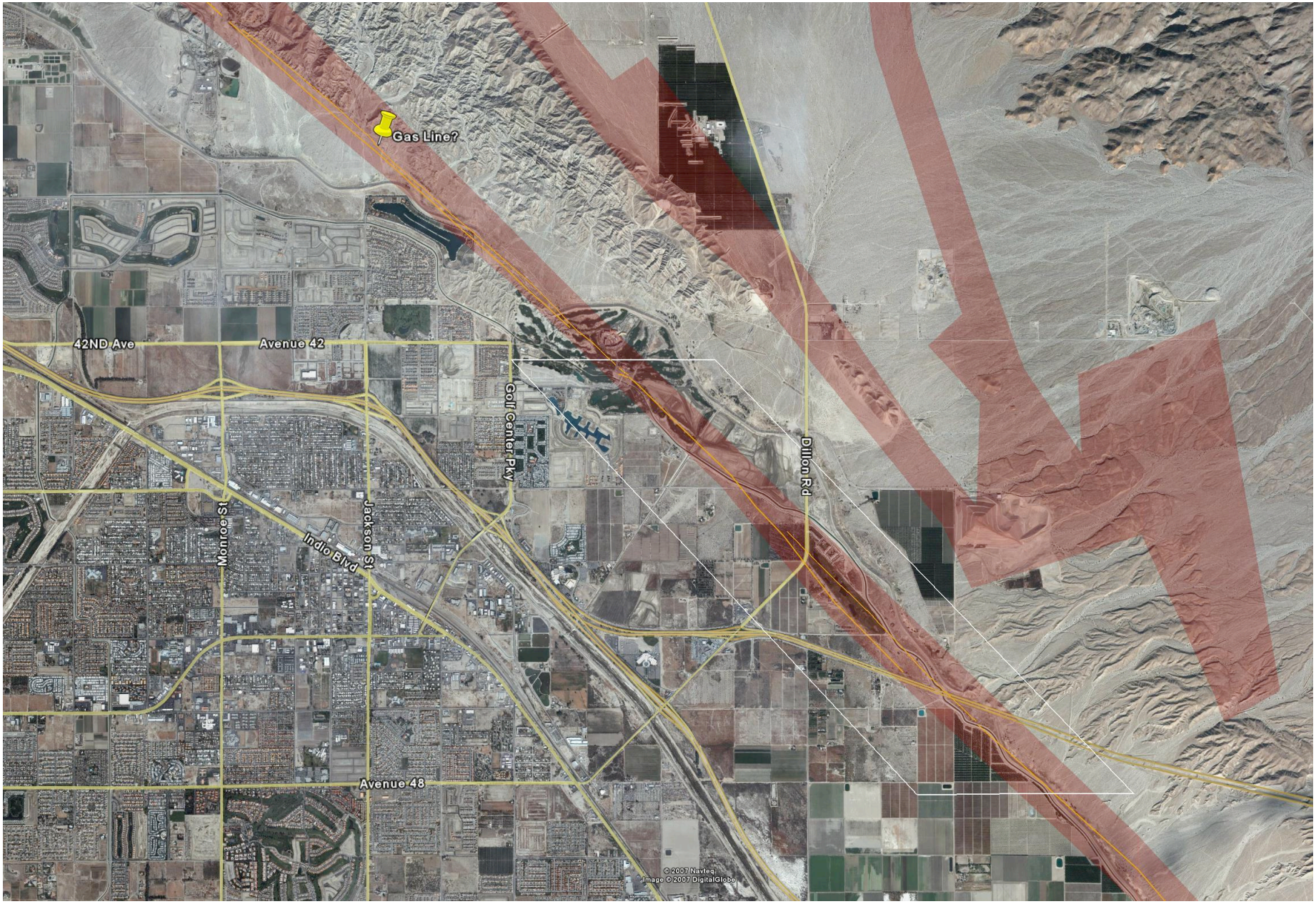


Figure 14. Air photo of Coachella Focus Area showing City of Indio and Earthquake Fault Zones designated along fault traces within the San Andreas Fault Zone.

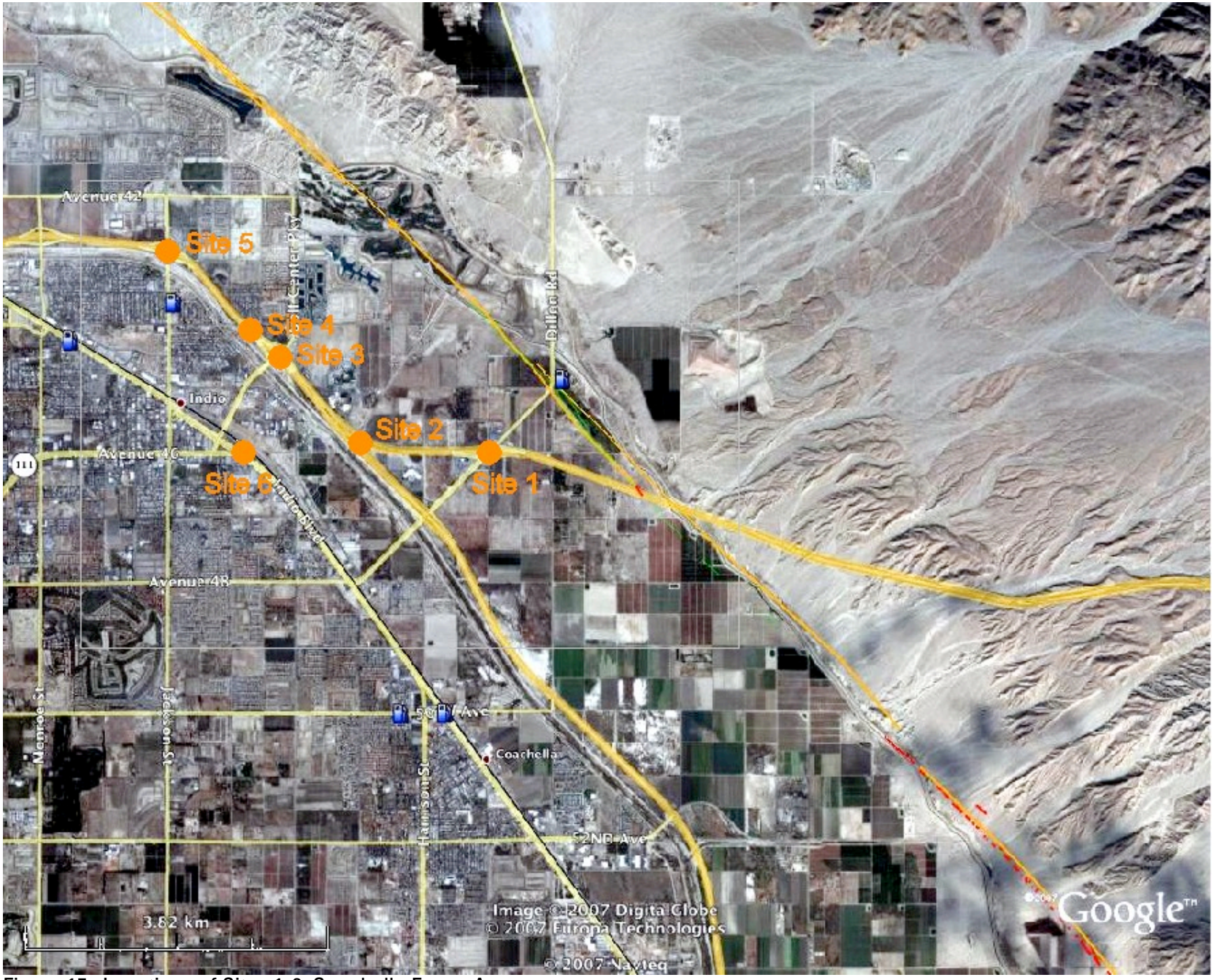


Figure 15. Locations of Sites 1-6, Coachella Focus Area.

Photo 12. Sites 2 - 6. View west from Dillon Road over-crossing of White Water River Beginning 1.2 km south of this point, I-10 parallels the deeply channelized White Water River at a distance measuring between 20 and 100 meters along a 5.5 kilometer-long segment on the north and northeast margins of the city. Life line Hazard: Potential for lateral spreading.

Results

A summary of horizontal displacement estimates for potential liquefaction sites is shown in **Table C-1**. Lateral spreading was evaluated using the Bardet *et al* (2002) model. Among the six sites, sites 2 to 5 were evaluated for lateral spread deformation with respect to the free face of the nearby channelized Whitewater River. The thicknesses of liquefiable materials use for the evaluation were inferred directly from geotechnical boring logs drilled at the time the interstate bridges were emplaced in the late 1960's.

Two other sites (sites 1 and 6) were evaluated for lateral spreading using the ground slope parameters of the Bardet *et al* (2002) model. As with the other sites, Site 1 utilized geotechnical data from the bridge overpass at that site. For Site 6, no geotechnical data were available; therefore two estimates of liquefiable thicknesses were inferred from other sites. All of the sites were evaluated at groundwater levels that were present at the time of drilling (late 1960's). Displacement is rounded to whole meters; the 16th and 84th percentiles can be approximated by halving and doubling, respectively, the displacement values provided.

Table C1. Summary of Estimated Displacements Coachella Focus Area (Fault Source: San Andreas Fault)

i. Site	Thickness of liquefiable sediment * (meters)	**Horizontal Displacement** (meters)
Site 1 Interstate 10 and Fiber Optics at Dillon Road *(slope model)*	4	3
Site 2 Interstate 10 and Hwy 86 Interchange *(lateral spread model)*	5	2
Site 3 Interstate 10 and Golf Center Pkwy *(lateral spread model)*	4	2
Site 4 Interstate 10 and 44th Avenue *(lateral spread model)*	5	2
Site 5 Interstate 10 and Jackson Street *(lateral spread model)*	6	2
Site 6 Rail Lines near Avenue 46 and Hwy 111 *(slope model)*	3	1
	5	1

* Assumes near-surface sediments to be saturated

Palmdale Focus Area

Several lifelines in the Palmdale area could be affected by liquefaction-induced lateral spreading caused by severe ground shaking during the scenario earthquake. These include State Highway 14, buried fiber-optic cables, petroleum pipelines, railway lines, and the California Aqueduct (Figure 16). The liquefaction potential for the Palmdale area was assessed in earlier studies by CGS for the delineation of Seismic Hazard Zones (Mattison and Barrows, 2003; Pridmore, 2003). The current focus area represents a restricted area specific to the San Andreas Fault along which much of the area is identified as potentially liquefiable and is included in the Seismic Hazard Zone maps for the area. Presence of estimated peak ground accelerations in excess of 75%g, high historical ground-water levels, and the occurrence of loose sandy materials within the upper 12 meters (40 feet) of sediment contribute to the high liquefaction potential for this area. Due to the close proximity of the San Andreas Fault the overriding damage to lifelines will result from surface faulting during the scenario earthquake; however, ground deformation will be complex and will potentially include components of differential settlement and lateral spreading related to liquefaction that may cause further distress to lifelines.

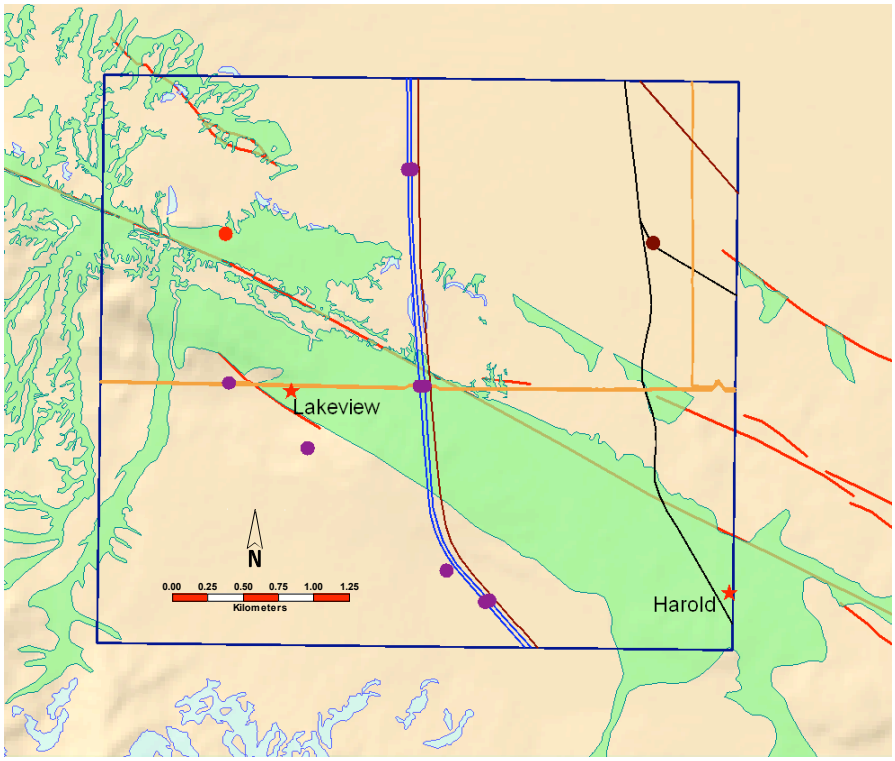


Figure 16. Palmdale focus area showing lifeline exposure for major highways (blue lines), fiber optics (brown lines), natural gas (orange lines), power stations (red dots), and bridges (brown dots), to potential liquefaction (green area) and landslides (blue areas). Red lines are surface traces of the San Andreas Fault system.

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