ShakeOut Scenario Appendix E: Fault Rupture Impacts at Areas of Lifeline Concentration

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ShakeOut Scenario
Appendix E. Fault Rupture Impacts at Areas of Lifeline Concentration

by Jerome A. Treiman, Charles R. Real, Rick I. Wilson, Michael A. Silva, Cynthia L. Pridmore, Timothy P. McCrink, Ralph C. Loyd, and Michael S Reichle
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The California Geological Survey (**CGS**) is participating in the preparation of a scenario for a M_w 7.8 earthquake on the southern San Andreas fault, as part of the USGS-sponsored Multi-Hazards Demonstration Project (MHDP). The earthquake is modeled to rupture unilaterally from Bombay Beach (along the east shore of the Salton Sea) northwestward to near Lake Hughes in the southwestern Mojave Desert. One of our tasks is to assess the potential for geologic disruption of lifelines where they are concentrated at several "choke points" crossed by the scenario ground rupture. Lifelines are part of the linear infrastructure that provide vital transportation and communication avenues and include highways, railroads, aqueducts, power lines, pipelines (oil and gas) and fiber-optic lines. Principal lifelines converge in the natural passes of the Transverse Ranges. **CGS** has evaluated the potential impact to lifelines from surface fault rupture in four focus areas: Palmdale, Cajon Pass, San Gorgonio Pass and Coachella (Figure 1).

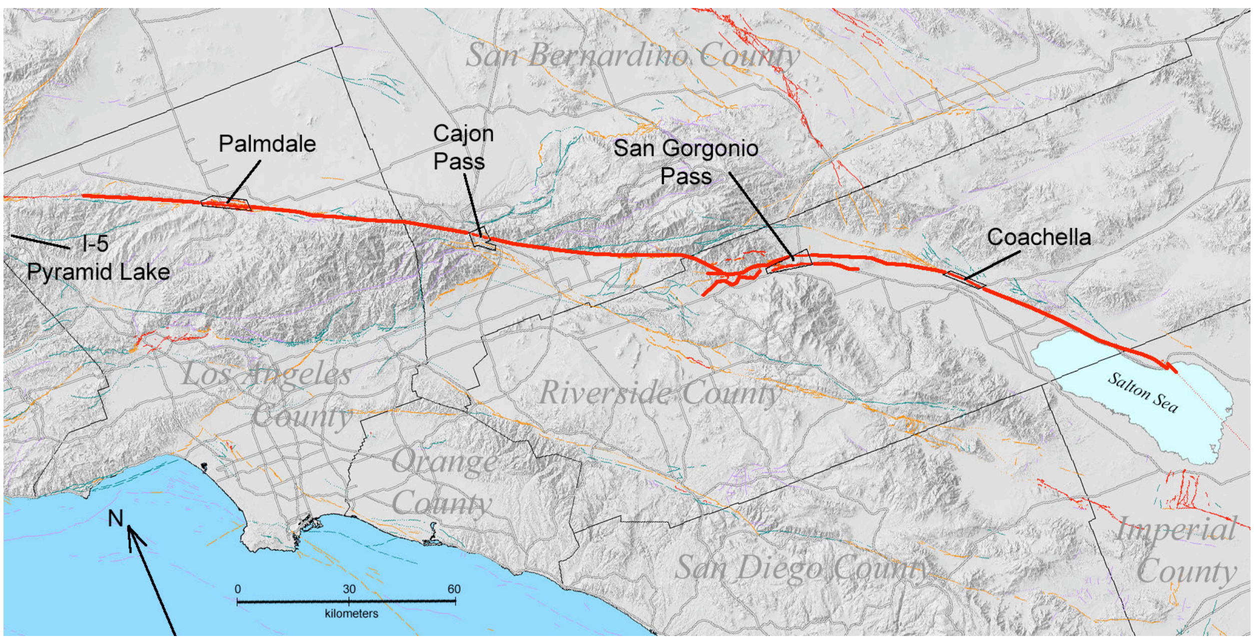

Figure 1 - Location of scenario fault rupture (heavy red line) and four focus areas.

The modeled slip for the scenario rises quickly to a maximum of 13 meters adjacent to the Salton Sea and then drops off generally to the northwest, but also reaches local maximums of 7.5 m northwest of Cajon Pass and 7.7 m northwest of Palmdale. Lifeline locations for this analysis were initially extracted from the HSIP Gold database provided by the National Geospatial Intelligence Agency (K. Hudnut, USGS, personal communication). Selected highway and aqueduct crossings were added, as were other lifelines that were observed in the field or in aerial imagery. Some lifeline locations, especially railroads, were corrected to match USGS orthophoto quadrangle imagery. Effects on powerlines will vary, depending on whether the ground displacement underlies towers (rarely) or whether it puts the overhead lines in tension or relaxation.

The slip model (v.1.2.0), developed by others (Hudnut *et al*, 2008) for ground motion calculations, was not suitable for determining precisely where surface rupture would occur. We used best-available mapping of the San Andreas Fault Zone to develop a likely surface rupture map and, within the four focus study areas, translated the modeled slip values (yellow dots in subsequent figures) to the expected surface rupture traces, apportioning the slip as needed where there are several fault traces. The assigned slip values, and slip distribution among the various fault strands, should be considered reasonable values for one particular event rather than a prediction or a necessarily maximum value. Fault crossing points for individual lifelines (or for closely spaced lifelines in some areas) were identified and slip values established for each point of potential disruption (Table 1). The criteria and methodology used to select fault rupture traces in each focus area are discussed in the following sections, as well as the reasoning used in the apportionment of slip at various crossing points.

In addition to fault rupture impact, potential landslide displacement is identified where it would affect critical infrastructure in Cajon and San Gorgonio passes. Landslides are more thoroughly assessed in Wilson and others (2008).

Palmdale Focus Area

Surface Fault Rupture

Surface displacement within the Palmdale Focus Area is proposed to occur on the principal strand of the San Andreas Fault as well as several adjacent parallel fault strands, namely the Littlerock, Cemetery and Nadeau faults (Figure 2a). Fault slip at lifeline crossings (Figure 2b) is taken directly from the rupture model slip, as designated for each 500 m section, and translated orthogonally to the several fault traces in proportions as described above. Fault trace locations are based on detailed field mapping and aerial photo interpretation by Barrows and others (1985) who accurately plotted the fault traces on orthophoto base maps at a scale of 1:12,000. The detail of the original mapping also allowed anticipation of some of the broader local zones of deformation (Figures 2c-e). Due to the accuracy of the original mapping methodology, as well as time constraints for this evaluation, aerial photos were not re-evaluated.

For the scenario earthquake, 8% of the model displacement (yellow dots on Figure 2a) was assigned to the Nadeau Fault, 10% to the strands of the Littlerock Fault, 2% to the Cemetery Fault and the remainder of the displacement was assigned to the adjacent part of the San Andreas Fault. For instance, at the western end of the focus area, 8% of the slip is on the Nadeau Fault and 92% is on the San Andreas Fault; a little to the east an additional 10% is taken from the San Andreas Fault for the Littlerock Fault strands; still farther east a full 20% of the slip is assigned to secondary fault strands. These slip distributions are a judgment call based on experience and familiarity with the San Andreas fault and observation of slip distribution in strike-slip earthquakes on other faults; the slip distributions selected are not quantitatively controlled by paleoseismic studies.

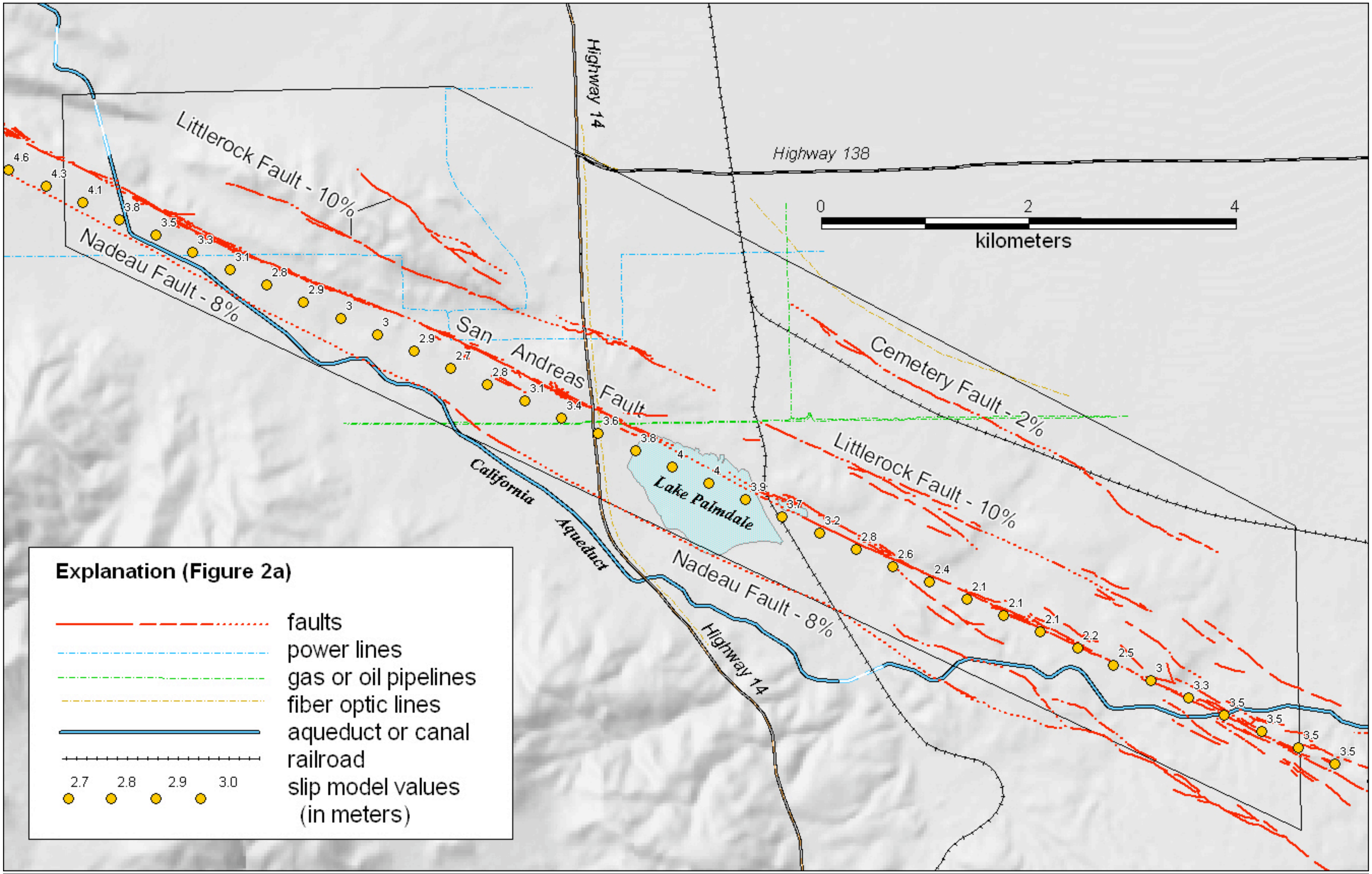

Figure 2a - Palmdale focus area with fault traces, modeled slip, and lifelines plotted.

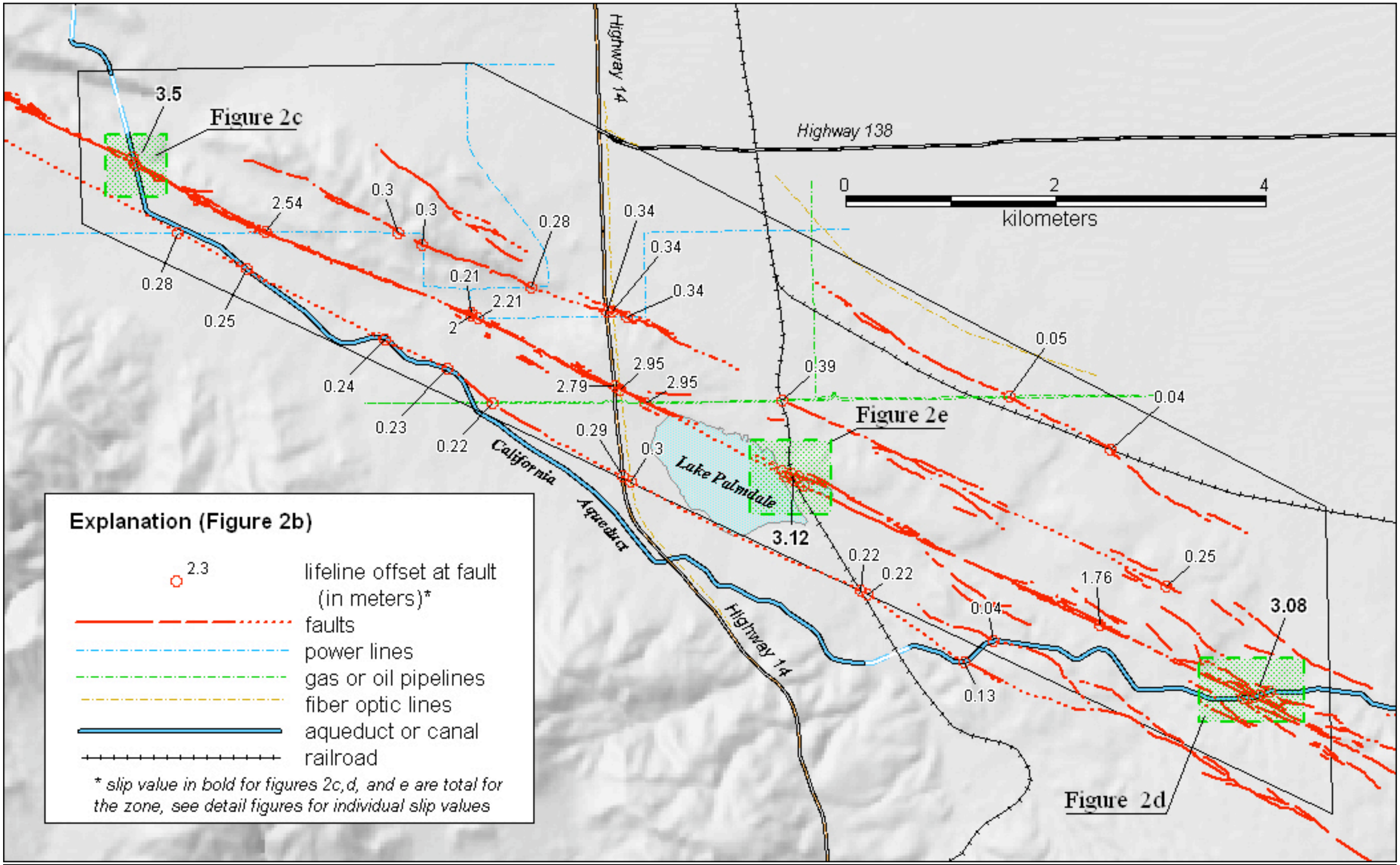

Figure 2b – right-lateral displacement of lifelines at fault crossings within Palmdale focus area. See detail areas (Figures 2c, 2d and 2e) for multiple offset lifelines and structures.

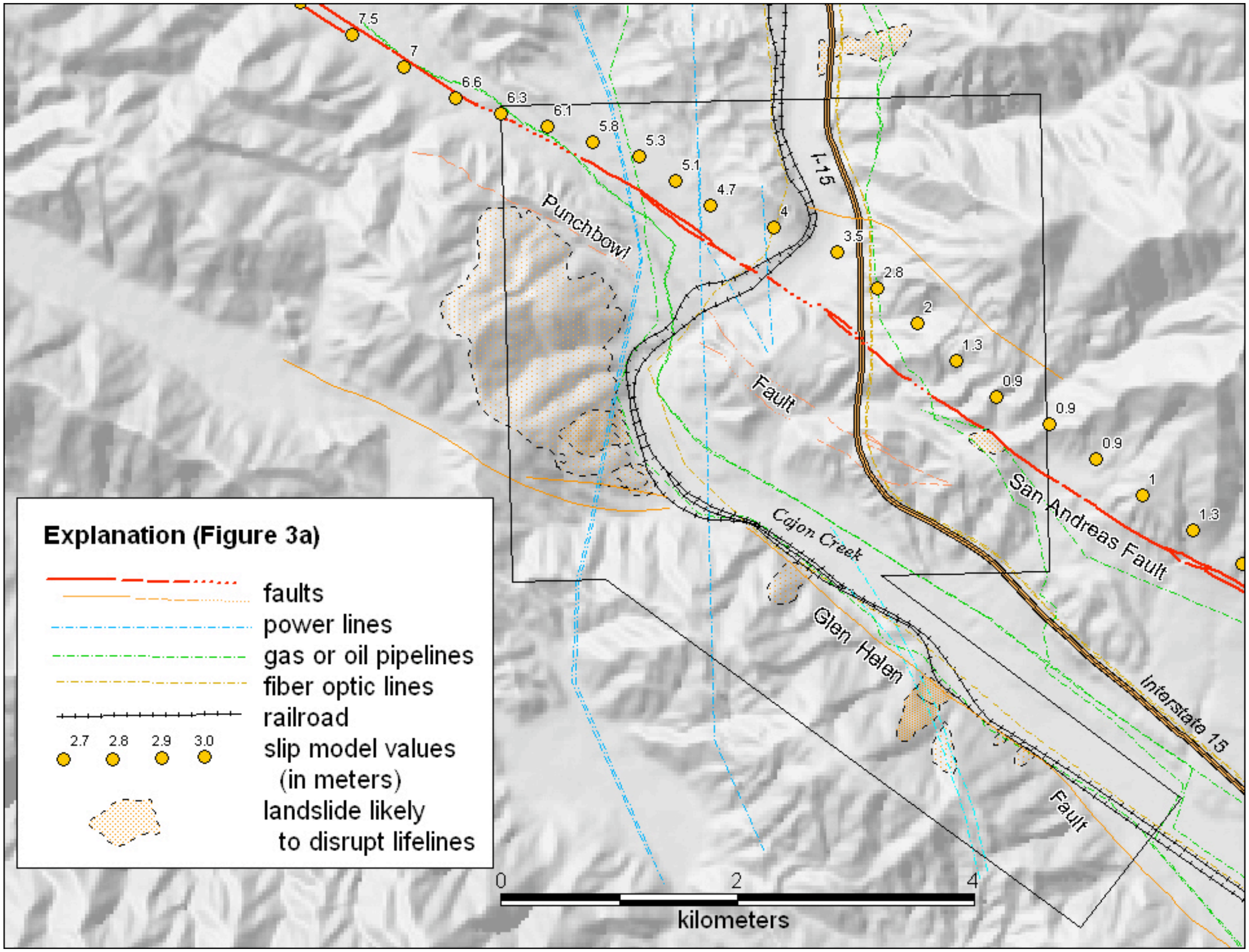

Figure 3a - Cajon Pass focus area, showing rupture trace and other faults, modeled slip, landslides and affected lifelines.

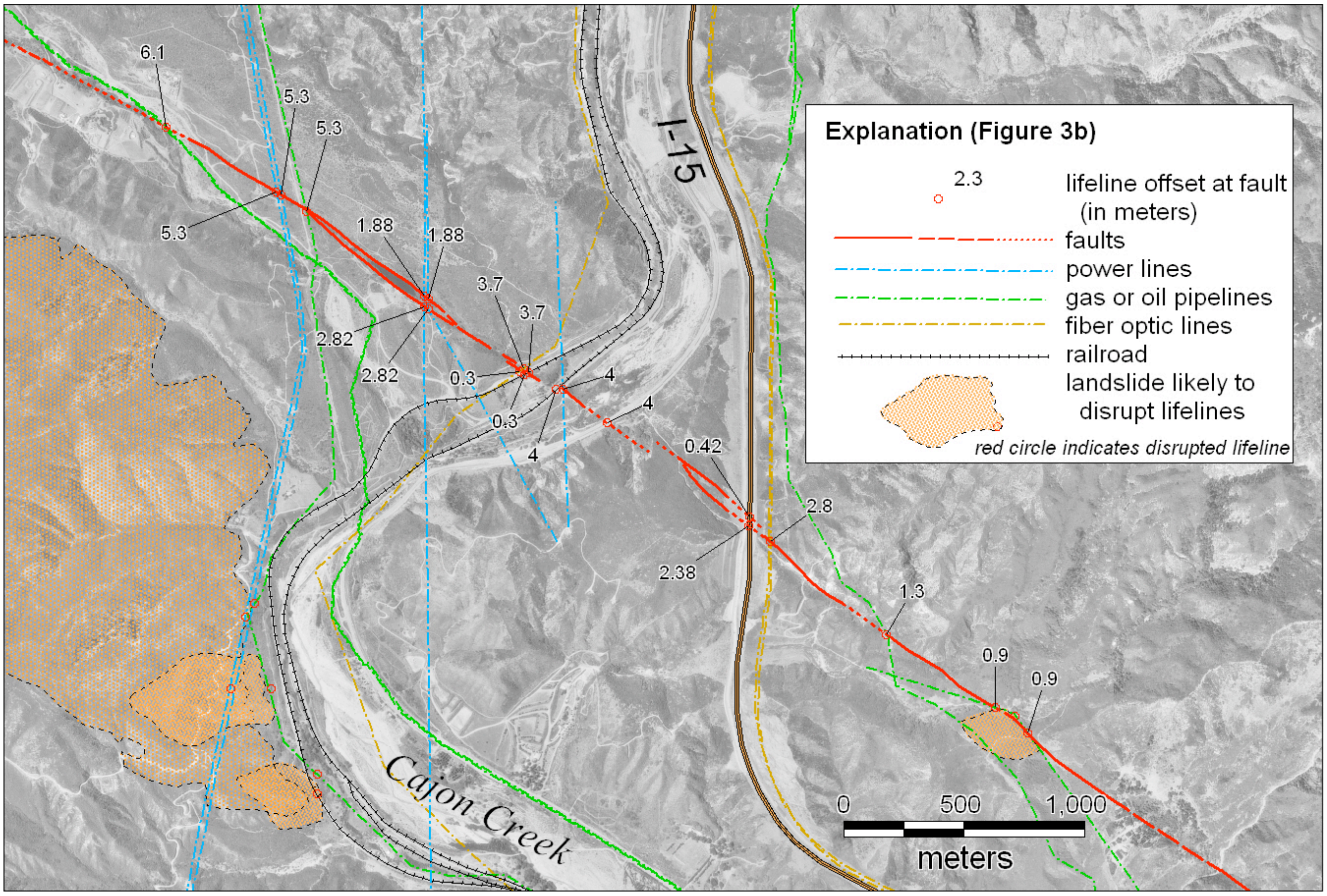

Figure 3b - lifeline offsets in Cajon Pass focus area. Base from USGS Cajon orthophoto quadrangle.

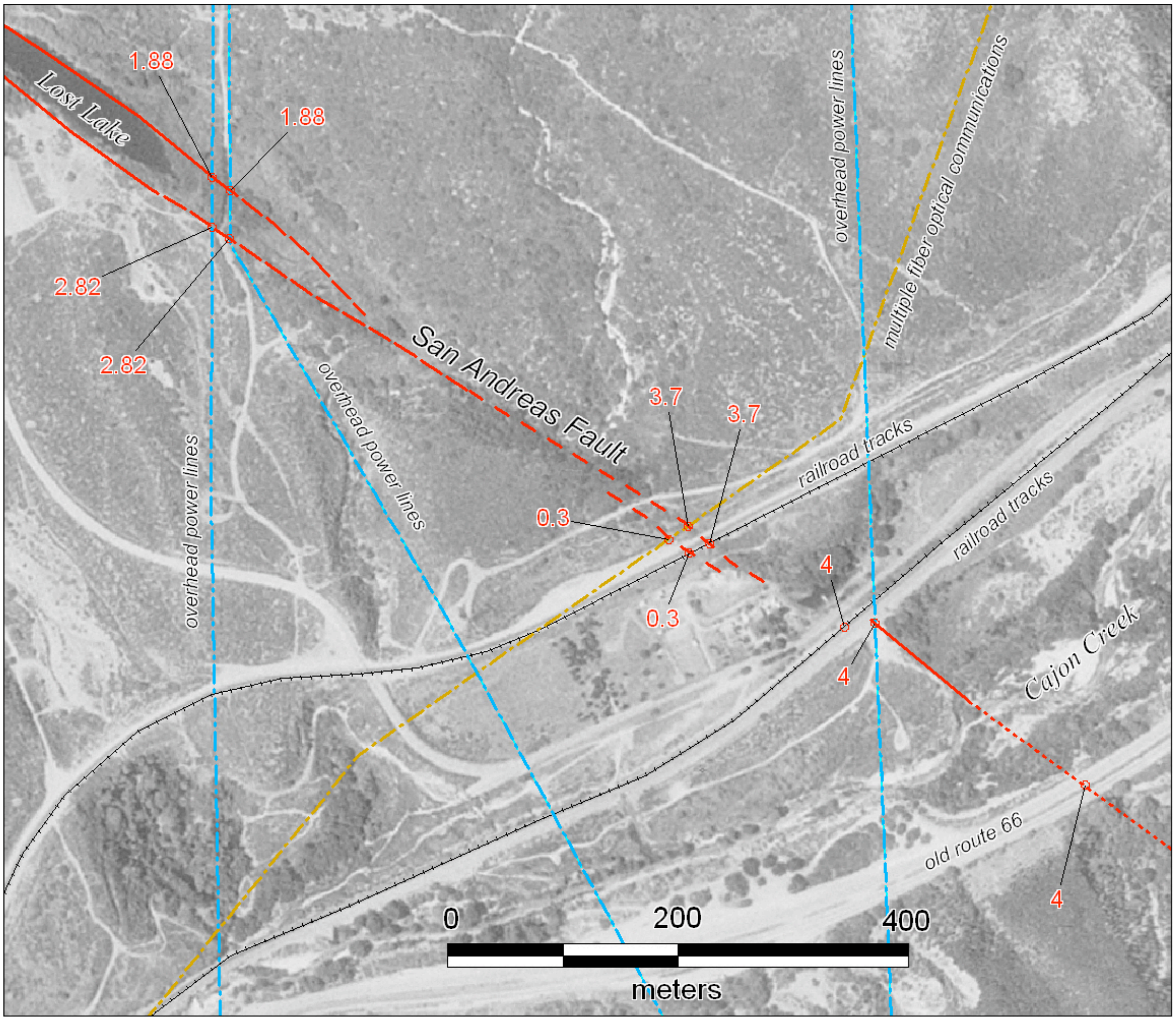

Figure 3c – detail of lifeline offsets, west of Cajon Creek. Base from USGS Cajon orthophoto quadrangle.

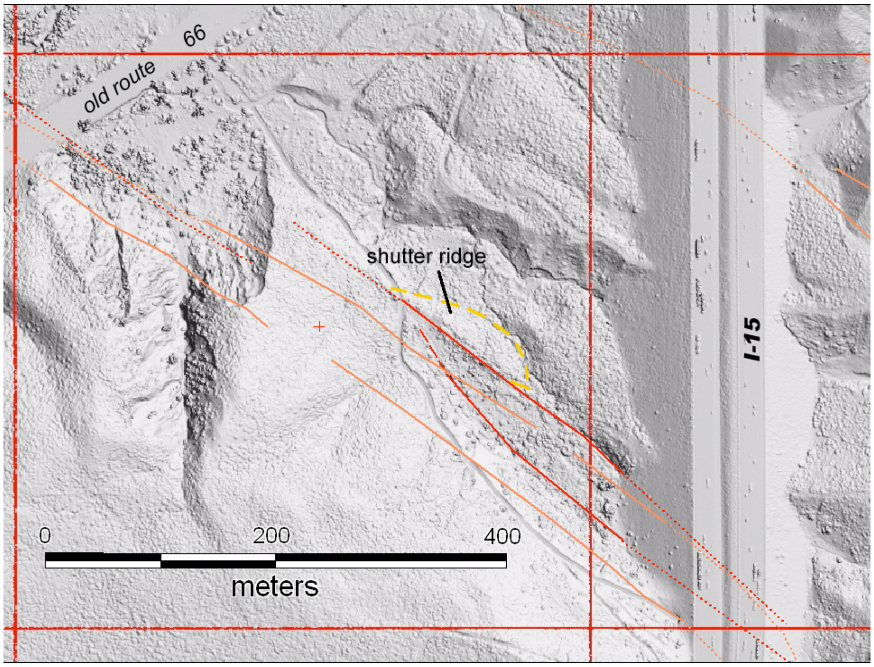

Figure 3d – ALSM image from the B4 survey. Fault traces from Weldon (1986) are shown in orange and relocated traces are in red. Interstate Highway I-15 is on the right side of the image and old Route 66 is in the upper left.

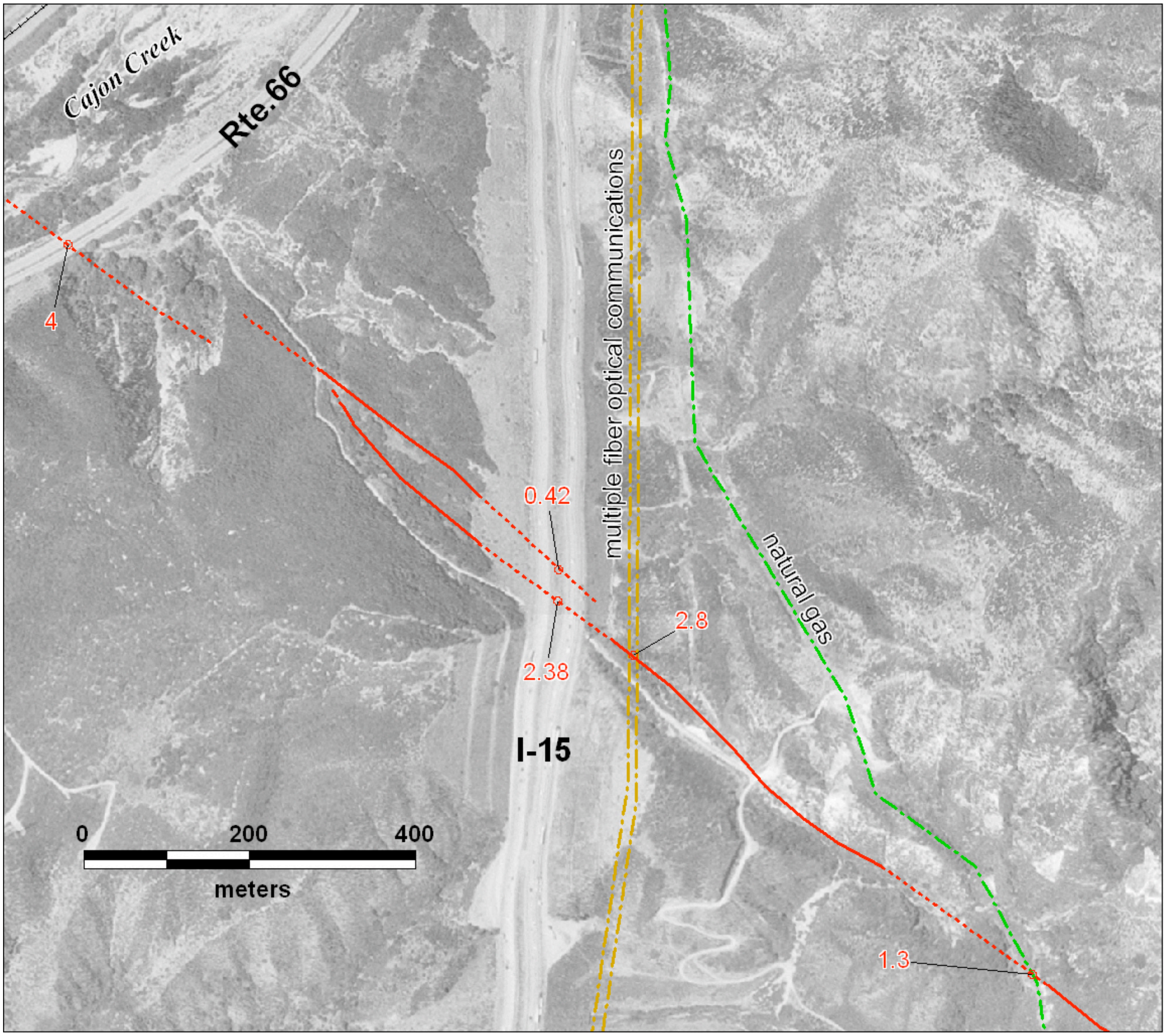

Figure 3e – relocated fault traces at I-15 in Cajon Pass showing detailed distribution of right-lateral slip across the stepover at highway and utility crossings. Base from USGS Cajon orthophoto quadrangle.

San Gorgonio Pass Focus Area

Surface Fault Rupture

The San Gorgonio Pass focus area includes a broad stepover from the Banning Fault to the Garnet Hill Fault. For the scenario and determination of ground motions, fault slip values were modeled along a single line, as shown at the yellow dots on Figure 4a. To anticipate surface rupture impacts on lifelines it was necessary to distribute this slip to the principal surface traces – the Banning, Garnet Hill and San Gorgonio Pass faults.

Intense shearing and deformation adjacent to the main trace will be expected to cause some broader zones (200+ m) of distributed shear, most importantly at the two aqueduct crossings and at Lake Palmdale dam. These three areas are shown in more detail on Figures 2c, 2d & 2e, with total slip distributed across the zone and slip at individual shears indicated. The broadest zones may be expected to distribute minor slip between identified shears so that total displacement on individual faults may be slightly less than the total scenario displacement.

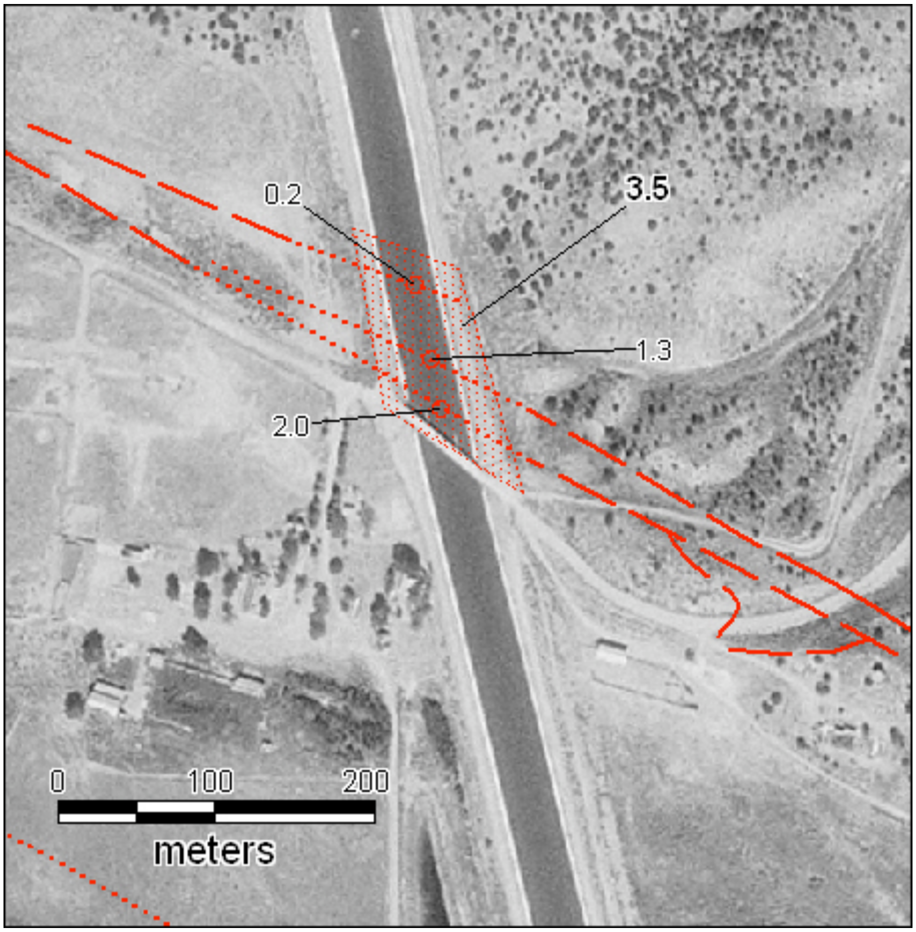

Figure 2c – aqueduct crossing at west end of Palmdale focus area showing multiple breaks. Slip value in **bold** font is total right-lateral slip for the boxed area. Base from USGS Ritter Ridge orthophoto quadrangle.

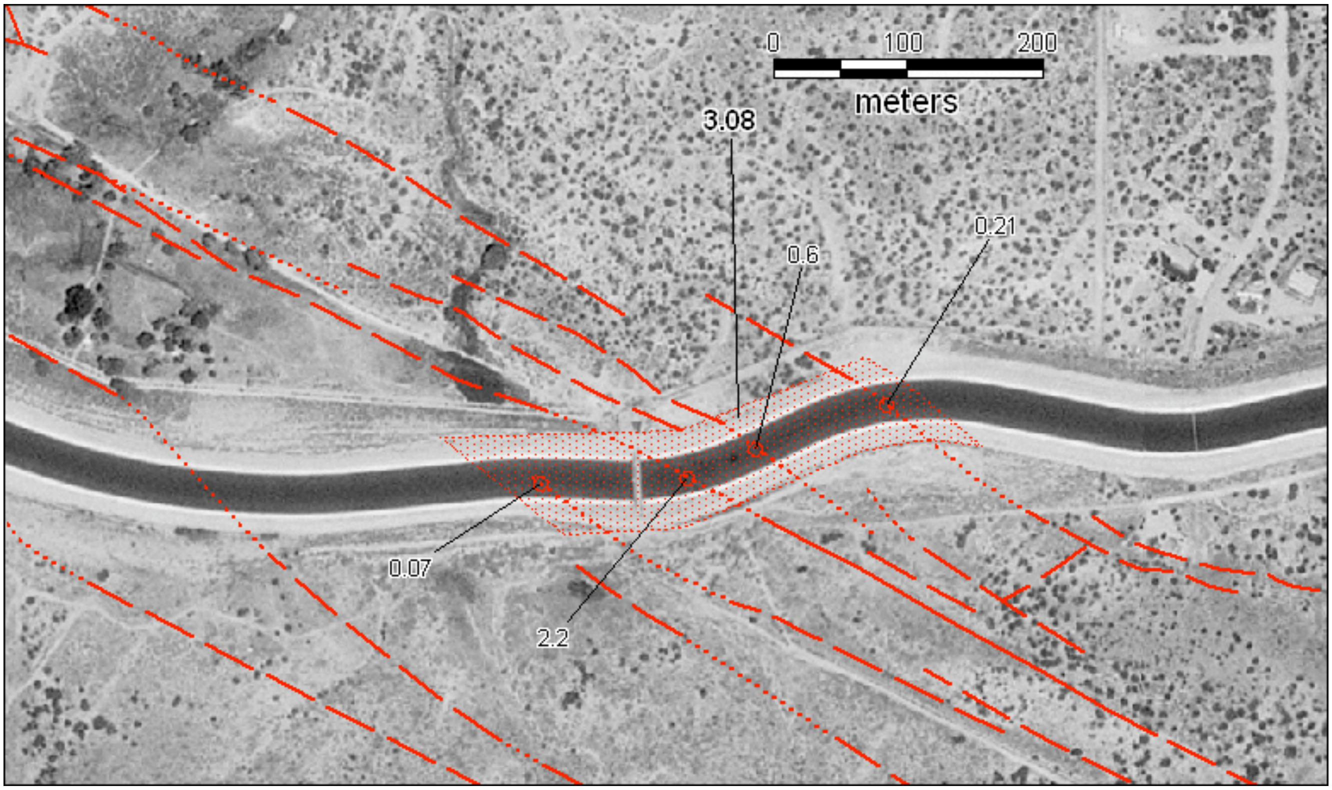

Figure 2d – aqueduct crossing at east end of Palmdale focus area showing multiple breaks. Slip value in bold font is total right-lateral slip for the boxed area. Base from USGS Palmdale orthophoto quadrangle.

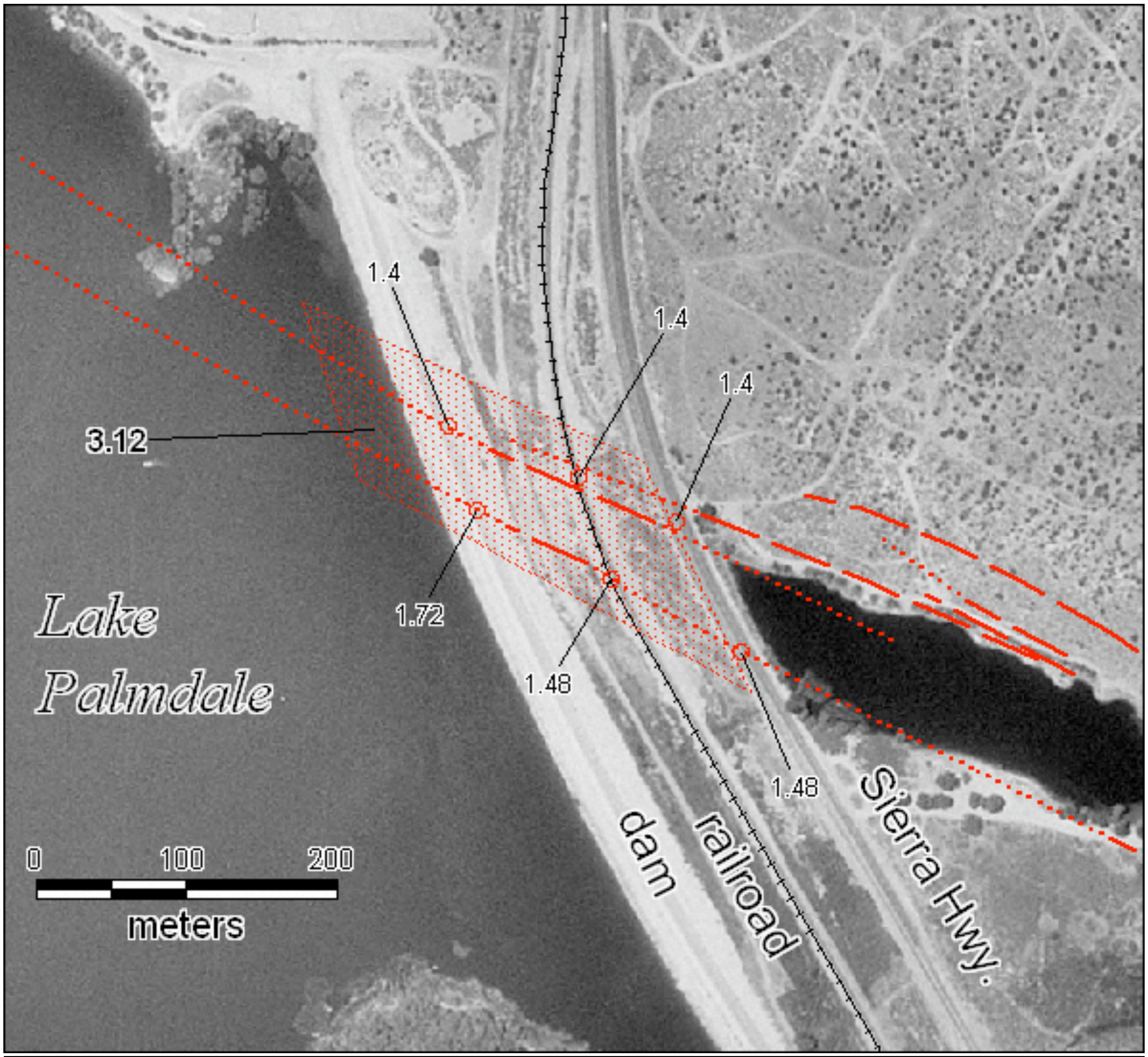

Figure 2e – Right-lateral slip along fault strands at Lake Palmdale are indicated for the dam, highway and railroad. Slip value in bold font is total right-lateral slip for the boxed area. Displacement is likely to be distributed through the earth-fill dam across a zone as much as 130 m wide or more. Similarly, values shown for highway and railroad displacement may be distributed across broader zones than suggested by the individual fault traces. Base from USGS Palmdale orthophoto quadrangle.

Cajon Pass Focus Area

Surface Fault Rupture

Surface displacement within the Cajon Pass Focus Area is modeled to occur only along the principal trace of the San Andreas Fault (Figure 3a). Fault trace locations are initially based on 1:24,000-scale mapping by Weldon (1986), but are locally modified by adjusting the principal fault trace locations to geomorphic features observed in aerial imagery[1] and LiDAR data from the B4 project (Bevis et al, 2005).

[1] see references at end of report for aerial imagery used in each focus area

Slip was not modeled, southwest of the San Andreas Fault, on the Glen Helen or Punchbowl faults for this scenario (Figure 3a). The Glen Helen fault was excluded because the north-directed rupture was considered to be less likely to trigger slip on this strand of the San Jacinto Fault Zone. The Punchbowl Fault shows little or no indication of Quaternary activity here and to the northwest (Barrows and others, 1985; Weldon and Sieh, 1985). Other fault strands north of the main trace were judged to have not moved as recently as the main trace (based on lesser degree of geomorphic expression) and thus were also not included in this scenario.

Fault slip at lifeline crossings (Figure 3b) is taken directly from the rupture model slip, as designated for each 500 m section, and translated orthogonally to the fault trace. Where more than one fault trace is mapped (for example, the stepover at Lost Lake – Figure 3c) the slip is divided between the traces with a relatively even transfer of slip across the step.

An example of where fault traces were relocated is where the San Andreas Fault crosses I-15. The fault traces from Weldon (1986) were re-interpreted from pre-highway imagery and then accurately located based on topography in ALSM imagery (Figure 3d). Slip was then modeled to transfer across the fault stepover (Figure 3e).

Landslides

Within the Cajon Pass Focus Area some critical infrastructure will be affected by landslides in addition to fault rupture (Wilson and others, 2008 and this study) and a southeasterly extension was made to the focus area to include those landslide impacts (Figure 3a). The most active-appearing portions of existing landslides were modeled to displace and impact infrastructure (e.g., Figure 3b). These are more generalized points than the specific fault crossings and displacement estimates are not provided in this evaluation but are further discussed in Wilson and others (2008). Landslide damage is anticipated along the railroad rights-of-way and will also affect adjacent lifelines.

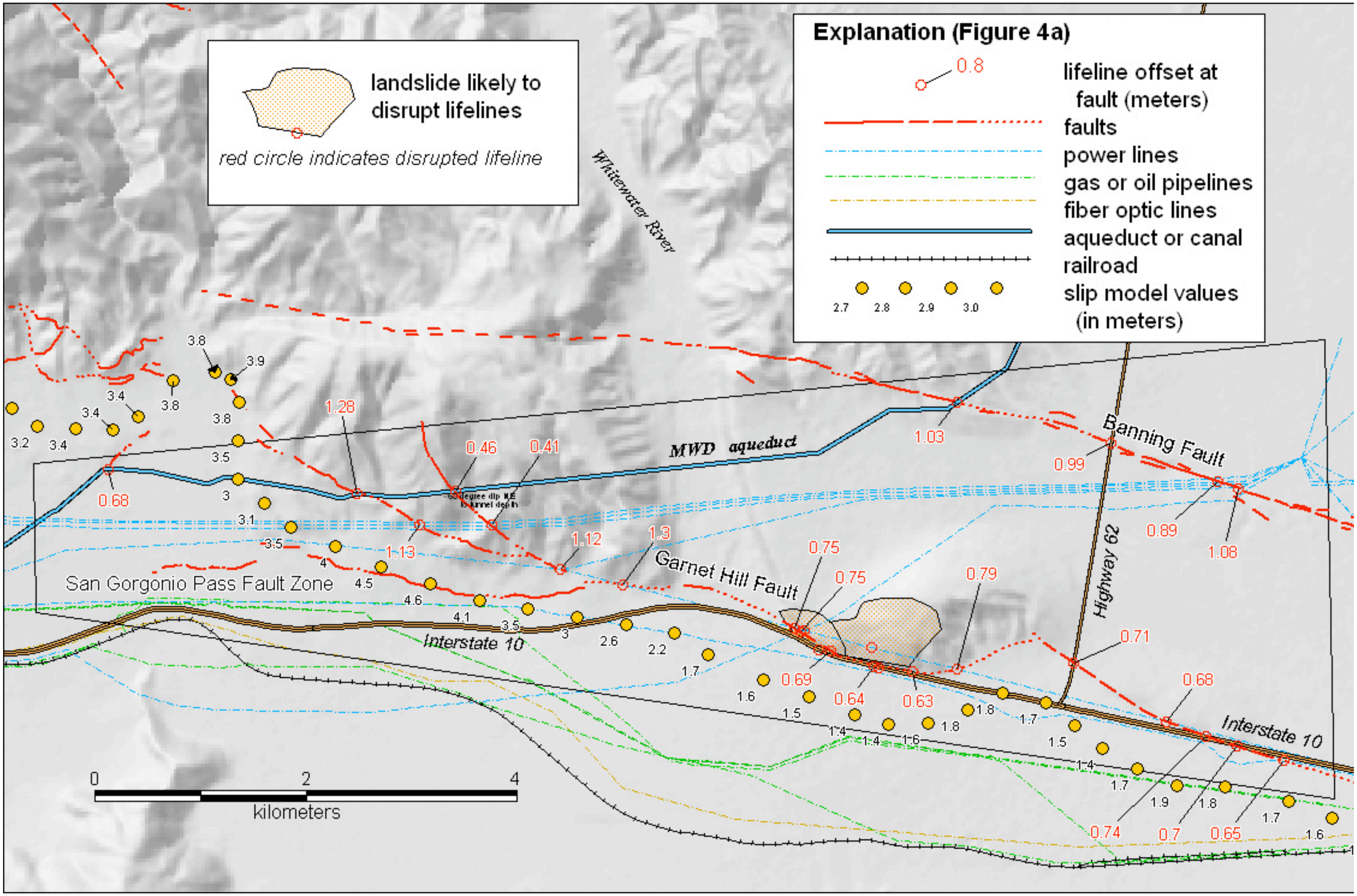

Figure 4a - San Gorgonio Pass focus area, showing rupture traces, modeled slip, landslides, and displacement at lifeline crossings.

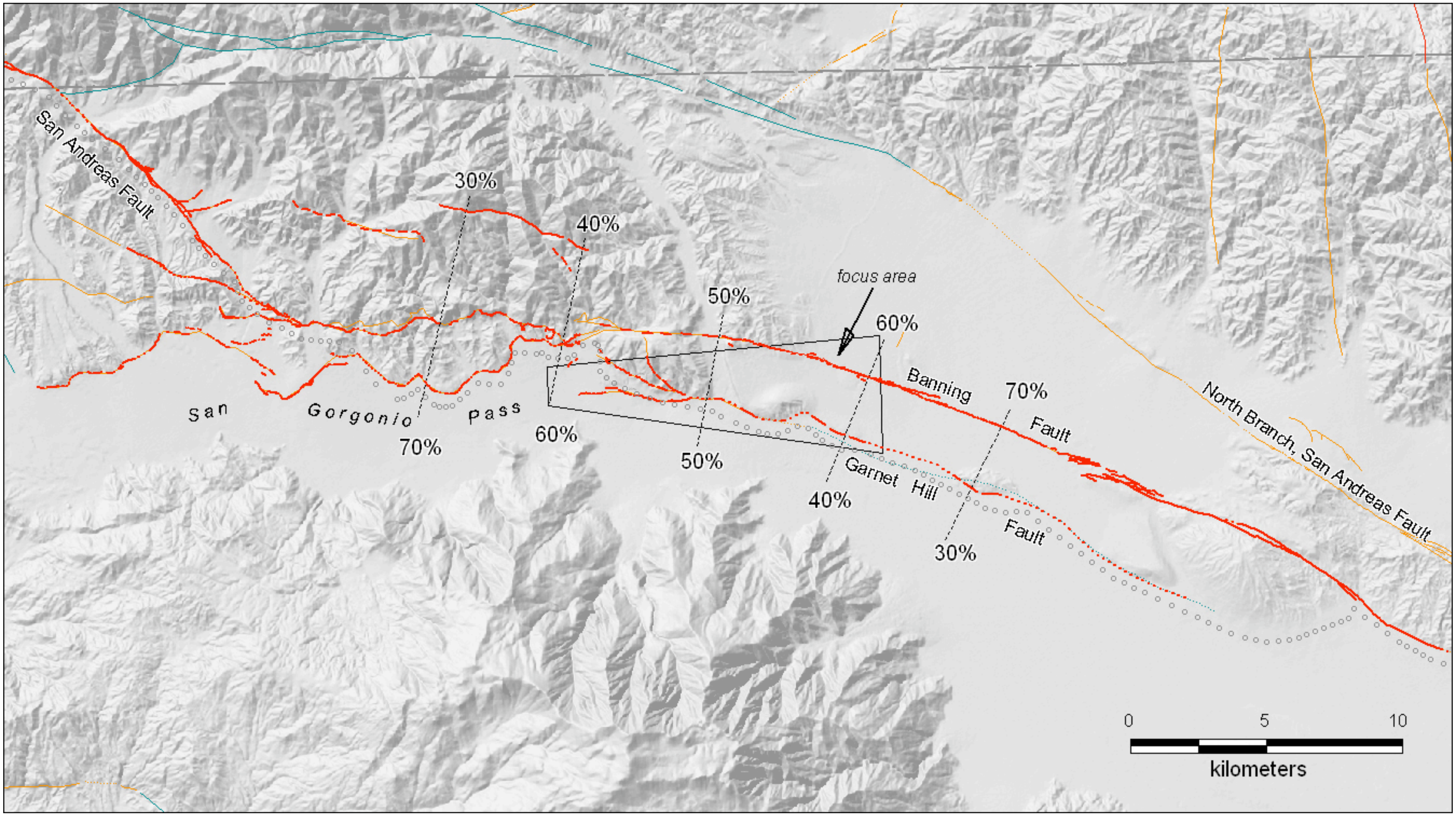

Figure 4b – map shows the stepover between the Banning Fault and the Garnet Hill-San Gorgonio Pass Fault Zone. Apportionment of the modeled scenario slip between the two fault zones is based on the percentages shown. Slip distribution west of the focus area is more complex.

Based on geomorphic expression, the Banning Fault is the primary fault trace to the east but slip appears to diminish westward into the Pass. Meanwhile, the Garnet Hill Fault, poorly expressed to the east, becomes prominent to the west and merges into the active San Gorgonio Pass Fault Zone. Surface slip (1.4-4.6 m) is modeled to transfer gradually between the Banning Fault and the Garnet Hill-San Gorgonio Pass faults. To estimate the slip transfer a simple model is proposed with percentages of slip apportioned as suggested on Figure 4b. Actual slip would probably be more complex, involve more fault traces, and include a significant compressional component. Slip values from the scenario model, as designated for each 500 m section, are translated orthogonally to the individual lifeline crossing points (Figure 4a). Fault trace locations are based on aerial photo interpretation[1] and field mapping (refer to Fault Evaluation Reports by Smith, 1979 and Treiman, 1994 and sources therein). It is anticipated that in the scenario event the MWD aqueduct will be disrupted by strike slip displacement at several points, including the tunnel section in the west-central part of the focus area.

Landslides

Slope failures have occurred in the past on the southwestern flank of Whitewater Hill, a low anticlinal hill just east of the mouth of Whitewater Canyon (Figure 4c). Seismically-triggered slope failure is anticipated to recur and may affect I-10 and lifelines, as shown. Displacement estimates for landslide disruption are not provided in this evaluation but are discussed in Wilson and others (2008).

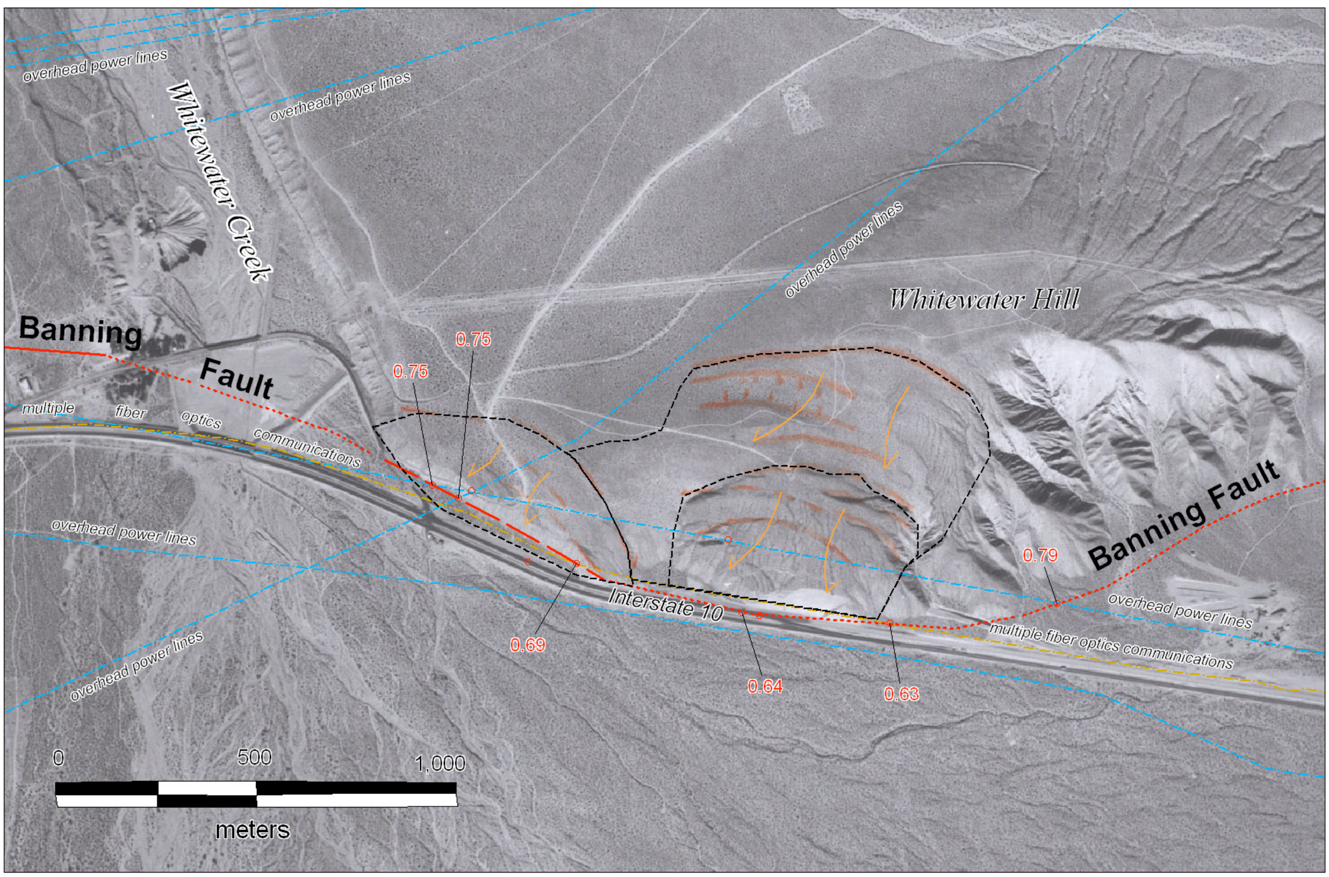

Figure 4c - ancient landslides near the mouth of Whitewater Creek. Displacement values are shown for fault crossings. Unnumbered circles indicate general disruption by landsliding. Base image is from USDA, frame AXM-13K-171 (1953).

Coachella Focus Area

Surface Fault Rupture

The Coachella focus area is characterized by a single fault trace with some minor extensional stepovers. Anticipated surface displacement at individual lifeline crossings is translated orthogonally, from each 500 m section along the scenario rupture (yellow dots). These values represent the total slip at depth; co-seismic slip at the surface is projected to be 60% of these values with afterslip continuing for weeks to months as strain propagates through the deep alluvium in this area.

Previous fault trace mapping on 1:24,000-scale topographic maps (Clark, 1984) has been relocated based on interpretation of vintage aerial photos[2] and careful registration of the images within a GIS database utilizing persistent creosote bushes and cultural features. Additional photo interpretation and mapping by consultants was used to identify and relocate the fault in some areas (Miles Kenney, pers.comm., 2007).

Several lifelines, including Interstate 10 and the Coachella Canal, may be affected immediately by 2.2 m to 4.0 meters of offset along this rupture segment. The scenario should anticipate afterslip amounting to an additional 1.8-2.7 meters along this section of the fault, which may interfere with recovery efforts. Total cumulative slip is shown on Figure 5.

[2] see references at end of report for aerial imagery used in each focus area

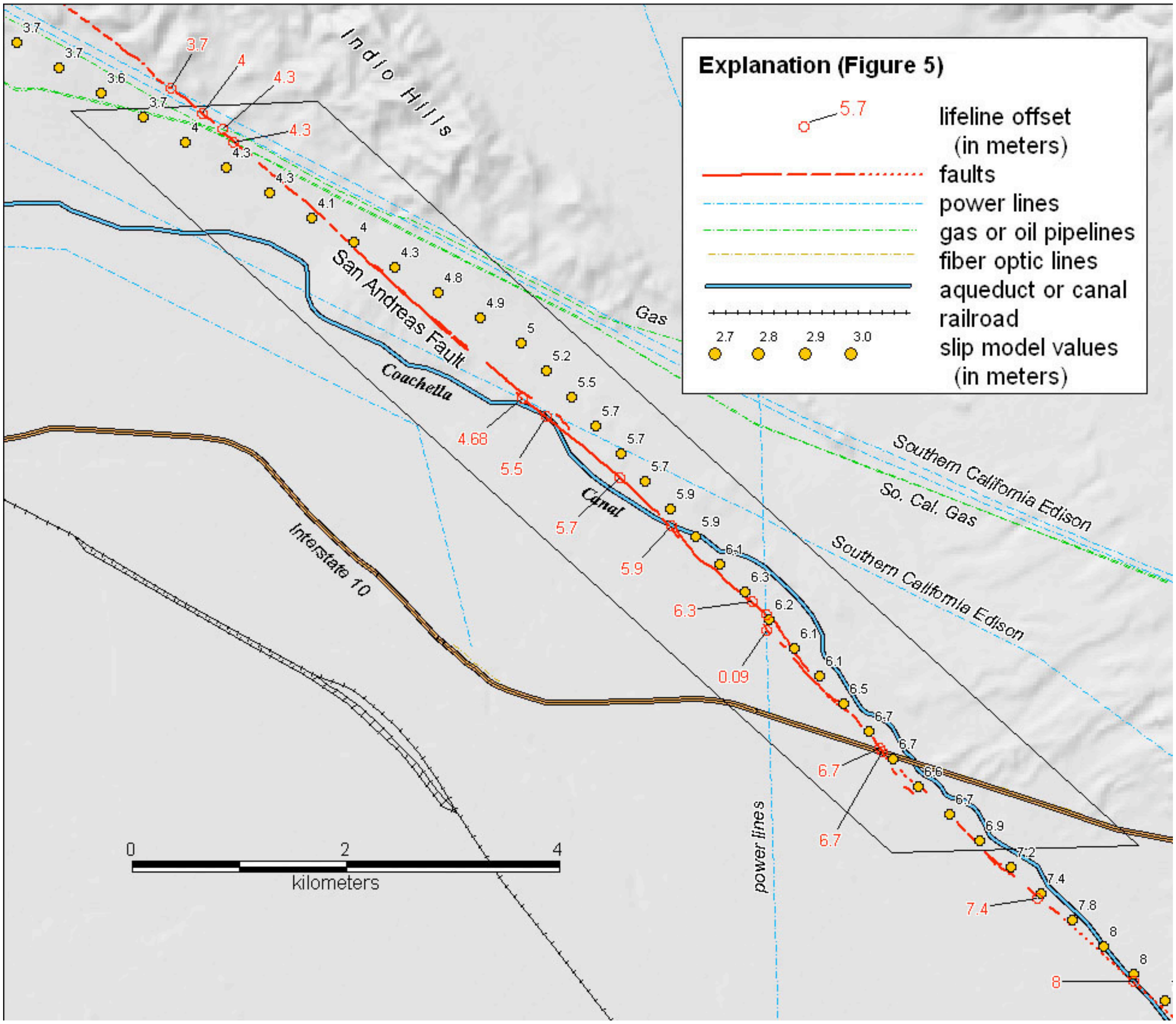

Figure 5 - Coachella focus area, showing rupture trace, modeled slip and displacement at lifeline crossings.

Conclusions

A reasonable representation of ground surface rupture that might accompany the MHDP M7.8 scenario earthquake has been developed for four study areas selected for their concentration of critical lifelines. The dynamic fault rupture model was translated to surface faults based on best-available mapping and distributed between several splays where faulting is more complex. Each focus area presented unique opportunities and challenges to this task. The Palmdale area presented us with several parallel active fault strands, and multiple smaller-scale fault splays that could create zones of shearing more than 200 meters across. Cajon Pass has a single trace with several small fault steps but has some locational accuracy issues that were resolved with new, high-precision LiDAR imagery. The assessment of faulting in the San Gorgonio Pass required interpretation of the possible mechanics of a broad stepover between two primary strands of the San Andreas Fault. The Coachella focus area had different issues relative to accuracy of fault location that required several types of data to resolve. The Coachella area also presents the complication of an extended period of continued "afterslip", potentially complicating some repair efforts.

Overlaying of the various lifelines across the fault rupture map allowed us to propose displacement values at specific lifeline-fault intersections. The figures in this report show six railroad offsets (4 meters maximum), at least nine highway offsets (6.7 meters maximum), twelve pipeline (oil/gas) offsets (6.1 meters maximum), nine fiber-optic cable offsets (6.7 meters maximum), nineteen aqueduct offsets (8 meters maximum) and twenty-nine overhead power transmission tower alignment offsets (5.3 meters maximum). The pipeline, fiber-optic and power line numbers may not reflect all lines in one right-of-way. These and other infrastructure displacements are presented more thoroughly in Table 1. Fault rupture represents just one part of the total ground failure impact to lifelines that are addressed in other reports (Real et al, 2008; Wilson et al, 2008; Treiman et al, 2008).

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Weldon, R.J., and Sieh, K.E., 1985, Holocene rate of slip and tentative recurrence interval for large earthquakes on the San Andreas fault, Cajon Pass, southern California: Geological Society of America Bulletin, v.96, p.793-812.

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Table 1 – This table presents coordinates (UTM - WGS84) and offset amounts (meters) for each identified lifeline-fault intersection. The letters in the "cause" column indicate whether the offset is from faulting (F-) or landsliding (L-). Location of utilities is from the HSIP Gold database (K. Hudnut, USGS, personal communication). Queried features are identified from field or aerial photo observation and not corroborated in that database.

cause	offset	feature	longitude	latitude
F-	0.28	overhead power lines	391960.2	3826296
F-	2.54	overhead power lines	392799.5	3826286
F-	0.3	overhead power lines	394069.5	3826252
F-	0.3	overhead power lines	394296.6	3826135
F-	0.28	overhead power lines	395326.1	3825709
F-	2	overhead power lines	394748.3	3825450
F-	0.22	natural gas (x2)	394938.5	3824610
F-	2.95	natural gas (x2)	396397.3	3824583
F-	0.34	fiber optic	396092	3825455
F-	0.34	overhead power lines	396234.2	3825406
F-	0.3	fiber optic	396239	3823833
F-	0.22	Sierra Hwy	398475.5	3822708
F-	1.48	Sierra Hwy	397881.8	3823758
F-	2.95	fiber optic	396159.2	3824713
F-	0.05	natural gas (x2)	399871.7	3824567
F-	0.04	railroad tracks	400832.5	3824040
L-		railroad tracks	458098.6	3789621
L-		fiber optic	458128.2	3789611
L-		natural gas	458121.4	3789650
L-		railroad tracks	458162.7	3789641
L-		railroad tracks	459229.9	3788614
L-		natural gas	459279.7	3788599
L-		natural gas	459993.7	3788018
L-		railroad tracks	459957.9	3788022
L-		overhead power lines	459154.5	3788383
F-	6.1	petroleum product	456197.1	3793167
F-	5.3	overhead power lines	456656.5	3792897
F-	5.3	natural gas	456782	3792817
F-	2.82	overhead power lines	457274.3	3792420
F-	3.7	fiber optic	457686.8	3792161
F-	3.7	railroad tracks	457705.1	3792146
F-	4	railroad tracks	457822.1	3792075
F-	2.8	fiber optic	458713.5	3791441

F-	1.3	natural gas	459195.1	3791056
L-		overhead power lines	456468.5	3790829
L-		natural gas	456634.9	3790829

cause	offset	feature	longitude	latitude
L-		fiber optic	458517.7	3794025
L-		natural gas	458850.4	3794025
L-		pipeline ?	458942.4	3794038
L-		overhead power lines	456529.8	3791127
L-		natural gas	456826.5	3790475
F-	4	Hwy 66	458031.4	3791938
F-	0.42	I-15	458624	3791545
F-	2.38	I-15	458622.7	3791507
F-	0.34	Hwy 14	396047.1	3825464
F-	0.29	Hwy 14	396162.7	3823879
F-	1.03	aqueduct /canal	535757.8	3755642
F-	0.99	Hwy 62	537205.7	3755215
F-	0.89	overhead power lines	538216	3754836
F-	0.71	10/62 overpass	536804.6	3753143
F-	0.46	aqueduct /tunnel	530980.1	3754904
F-	1.28	aqueduct, buried	530049.5	3754901
F-	0.68	aqueduct, buried	527685.1	3755188
F-	1.3	overhead power lines	532548.2	3753979
F-	0.41	overhead power lines	531313.7	3754573
F-	1.13	overhead power lines	530635.7	3754588
F-	4.3	natural gas	572687.8	3736192
F-	4.3	natural gas	572581.9	3736310
F-	4.68	overhead power lines	575331.4	3733724
F-	5.9	aqueduct/canal	576702	3732501
F-	6.7	I-10 hwy	578626.6	3730333
F-	8	aqueduct/canal	580935.7	3728122
F-	5.5	aqueduct/canal	575555	3733548
F-	4	overhead power lines	572397.9	3736464
F-	3.7	overhead power lines	572106.4	3736711
F-	2	aqueduct/canal	391561.9	3826949
F-	0.25	aqueduct/canal	392611.3	3825936
F-	0.24	aqueduct/canal	393918.3	3825239
F-	0.23	aqueduct/canal	394501.8	3824952
F-	0.07	aqueduct/canal	402042.6	3821641
F-	0.13	aqueduct/canal	399384.4	3822041
F-	0.22	railroad tracks	398410.2	3822744
F-	0.25	Pearblossom Hwy	401332.2	3822724
F-	1.48	railroad tracks	397796	3823806
F-	1.72	Lake Palmdale dam	397706.9	3823852
F-	2.21	overhead power lines	394808.3	3825420
F-	5.7	flood channel	576225.6	3732963
F-	6.3	Dillon Rd.	577442	3731770

cause	offset	feature	longitude	latitude
F-	7.4	canal ?	580054.1	3728923
F-	1.08	overhead power lines	538408.4	3754755
F-	0.75	overhead power lines	534228.6	3753493
F-	0.65	overhead power lines	538778.6	3752167
F-	0.74	fiber optic	538051	3752421
F-	0.7	I-10	538341.7	3752318
L-		railroad tracks	459768.4	3788161
L-		natural gas	459799.3	3788152
L-		overhead power lines	459288.1	3788006
L-		I-10	534389.4	3753320
L-		overhead power lines	534892.9	3753335
L-		I-10	534956.1	3753137
F-	0.9	pipeline ?	459648.7	3790750
F-	0.9	pipeline ?	459781.4	3790646
L-		pipeline ?	459731.2	3790713
L-		natural gas	456567.3	3791183
L-		railroad tracks	456829.6	3790393
L-		I-15	458413.7	3793969
L-		Hwy 66	458300.3	3793960
F-	5.3	overhead power lines	456678.1	3792886
F-	1.88	overhead power lines	457274.3	3792463
F-	1.88	overhead power lines	457289.9	3792452
F-	2.82	overhead power lines	457288.6	3792411
F-	4	overhead power lines	457849	3792078
F-	1.12	overhead power lines	531959.7	3754138
F-	1.3	aqueduct/canal	391556.5	3826981
F-	0.2	aqueduct/canal	391545.8	3827027
F-	0.04	aqueduct/canal	399670.6	3822236
F-	0.39	natural gas (x2)	397706.3	3824575
F-	0.21	overhead power lines	394746.7	3825469
F-	1.4	Sierra Hwy	397839	3823844
F-	1.4	railroad tracks	397774.8	3823873
F-	1.76	Pearblossom Hwy	400688.1	3822372
F-	0.6	aqueduct/canal	402202	3821667
F-	0.21	aqueduct/canal	402300.4	3821700
F-	2.2	aqueduct/canal	402151.7	3821646
F-	6.2	overhead power lines	577574.1	3731640
F-	0.09	overhead power lines	577576.2	3731499
F-	6.7	fiber optic	578603.4	3730367
F-	0.68	overhead power lines	537677.4	3752566
F-	0.79	overhead power lines	535702.2	3753107
F-	0.64	I-10	534913.1	3753149

cause	offset	feature	longitude	latitude
F-	0.63	fiber optic	535280	3753092
F-	0.3	fiber optic	457669.7	3792150
F-	0.3	railroad tracks	457688	3792138
F-	0.75	overhead power lines	534166	3753532
L-		overhead power lines (2)	534261.4	3753510
F-	0.69	fiber optic	534510.2	3753305
F-	2.79	Hwy 14	396098.5	3824744
F-	1.4	Lake Palmdale dam	397687.9	3823908

Aerial Imagery

Cajon Pass Focus Area

USDA

AXL-34K-34 to 38		1/31/53	1:20:000	B/W
AXL-34K-72 to 75		1/31/53	1:20,000	B/W
AXL-35K-80 to 84		1/31/53	1:20,000	B/W

CalTrans

VIII-SBd-31-B,C	fr. 1-5 to 1-7	2/3/62	1:18,000	B/W
VIII-SBd-31-B,C	fr. 1-14 to 1-17	2/3/62	1:18,000	B/W
VIII-SBd-31-B	fr. 1-16 to 1-20	10/10/63	1:6,000	B/W
08-SBD-15	fr. 12E-146 to -149	5/12/00	1:5,000	B/W

Airborne Laser Swath Mapping (ALSM)

B4 LiDAR survey of the San Andreas fault	May 2005	digital

Coachella Focus Area

USDA

AXM-10K-62 to 66	10/27/53	1:20,000	B/W
AXM-10K-114 to 117	10/27/53	1:20,000	B/W
AXM-14K-125 to 132	12/13/53	1:20,000	B/W

Spence Airplane Photos

Negatives 183-191	4/16/30	1:18,000	B/W

San Gorgonio Pass Focus Area

CalTrans

VIII-SBD-RIV, fr. 5-89 to94	8/23/56	1:15,000?	B/W
08-RIV, fr. 1-165 to 167	3/17/69	1:24,000	B/W

Spence Airplane Photos

Negatives 155-158	4/16/30	1:18,000	B/W

USDA

AXM-1K-38 to 41	8/19/53	1:20,000	B/W
AXM-12K-55 to 58	11/25/53	1:20,000	B/W
AXM-12K-128 to 130	11/25/53	1:20,000	B/W
AXM-12K-144 to 146	11/25/53	1:20,000	B/W
AXM-13K-170 to 173	12/6/53	1:20,000	B/W
AXM-13K-183			